Chapter 19. Emergent Risks and Key Vulnerabilities

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Contents

Executive Summary

This chapter assesses climate-related risks in the context of Article 2 of the UN Framework Convention on Climate Change [Box 19.1]. Such risks arise from the interaction of the evolving exposure and vulnerability of human, socioeconomic and biological systems with changing physical characteristics of the climate system [19.2]. Alternative development paths influence risk by changing the likelihood of climatic events and trends (through their effects on greenhouse gases and other emissions) and by altering vulnerability and exposure [19.2.4, Figure 19-1, Box 19-2].

Interactions of climate change impacts on one sector with changes in exposure and vulnerability, as well as adaptation and mitigation actions affecting the same or a different sector are generally not included or well integrated into projections of risk. However, their consideration leads to the identification of a variety of *emergent risks* [Box 19-2] that were not previously assessed or recognized [19.3, *high confidence*]**.** This chapter identifies several such complex-system interactions that increase vulnerability and risk synergistically. For example:

- **The risk of climate change to human systems (e.g., agriculture and water supply) is increased by the loss of ecosystem services which are supported by biodiversity** (e.g. water purification, protection from extreme weather events, preservation of soils, recycling of nutrients, and pollination of crops) [*high confidence*]. Studies since AR4 broadly confirm that a large proportion of species are at increased risk of extinction at all but the lowest levels of warming. [19.3.2.1, 19.5.1, 19.6.3.5]
- **Risks result from the management of water, land, and energy in the context of climate change.** For example, in some water stressed regions, as groundwater stores that have historically acted as buffers against impacts of climate variations and change are depleted, adverse consequences arise for human systems and ecosystems simultaneously undergoing alteration of regional groundwater resources due to climate change. The production of bioenergy crops to mitigate climate change leads to land conversion (e.g., from food crops and unmanaged ecosystems to energy crops; [*high confidence*]) and in some scenarios, reduced food security as well as additional greenhouse gas emissions over the course of decades or centuries. [19.3.2.2]
- **Climate change has the potential to adversely affect human health by increasing exposure and vulnerability to a variety of stresses.** For example the interaction of climate change with food security can exacerbate malnutrition, increasing vulnerability of individuals to a range of diseases [19.3.2.3, *high confidence*].
- **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** (*high confidence*). These areas, many characterized by increasing populations, are exposed to multiple hazards and potential failures of critical infrastructure, generating new systemic risks. Cities in Asian megadeltas, where populations are subject to sea level rise, storm surge, coastal erosion, saline intrusion, and flooding, provide an example [19.2.3, 19.3.2.4, 19.4.2.1, 19.6.1.3.1, 19.6.2.1, 19.7.5, Table 19-4].
- **Spatial convergence of impacts in different sectors creates compound risk in many areas** (*medium confidence*). Examples include the Arctic (where thawing and sea ice loss disrupt land transportation, buildings, other infrastructure, and are projected to disrupt indigenous culture); and 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) [19.3.2.4].

Emergent risks also arise from indirect, trans-boundary, and long-distance impacts of climate change. Adaptive responses and mitigation measures sometimes increase such risks [19.4, *high confidence*]. Human or ecological responses to local impacts of climate change can generate harm at distant places.

- Increasing prices of food commodities on the global market due to local climate impacts, in conjunction with other stressors, decrease food security and exacerbate food insecurity at distant locations [19.4.1].
- Climate change will bear significant consequences for human migration flows at particular times and places, creating risks as well as benefits for migrants and for sending and receiving regions and states (*high confidence*) [19.4.2.1].
- The effect of climate change on conflict and insecurity is an emergent risk because factors such as poverty and economic shocks that are associated with a higher risk of violent conflict are themselves sensitive to climate change. In numerous statistical studies, the influence of climate variability on violent conflict is large in magnitude [*medium confidence*, 19.4.2.2].
- Many species shift their ranges in response to climate change, adversely affecting ecosystem function and services while presenting new challenges to conservation efforts [19.4.2.3*; medium confidence*].
- Mitigation measures taken in one location can have long-distance or indirect impacts on biodiversity and/or human systems. For example, the development of biofuels as energy sources can increase food prices [*high confidence*] and affect distant land use practices [19.4.1, 19.4.3].

Additional risks related to particular biophysical impacts of climate change have arisen recently in the literature in sufficient detail to permit assessment [19.5, *high confidence*].

- **Risks associated with global temperature rise in excess of 4°C relative to preindustrial levels[1]** arise from the potential for adverse impacts on agricultural production worldwide, extensive loss of ecosystem functioning, extinction of a substantial proportion of the earth's species *(high confidence)*, and traversing thresholds that lead to disproportionately large earth systems responses [19.5.1].
- **Ocean acidification poses risks to marine ecosystems and the societies that depend on them.** For example, ocean acidification is *very likely* to lead to changes in coral calcification rates. Reduced coral calcification is projected to have impacts of medium to high magnitude on some ecosystem services, including tourism and the provisioning of fishing [19.5.2].
- **There is increasing evidence in the literature that high ambient CO_2 concentrations in the atmosphere will affect human health by increasing the production and allergenicity of pollen and allergenic compounds and by decreasing nutritional quality of important food crops [19.5.3].**
- **In addition to providing potential climate change abatement benefits, geoengineering poses widespread risks to society and ecosystems.** For example, in some model experiments the implementation of Solar Radiation Management [SRM] for the purpose of limiting global warming leads to ozone depletion and reduces precipitation. In addition, the failure or abrupt halting of SRM risks rapid climate change [19.5.4].

[FOOTNOTE 1: Levels of global mean temperature change are variously presented in the literature with respect to “pre-industrial” temperatures in a specified year or period, e.g., 1850-1900. Alternatively, the average temperature within a recent period, e.g., 1986-2005, is used as a baseline. In this chapter, we use both, depending on the literature being assessed. The increase above pre-industrial (1850-1900) levels for the period 1986-2005 is estimated at 0.61°C (AR5 WGI Section 11.3.6.3). For example, using these baselines, a 2°C increase above pre-industrial levels corresponds to a 1.39°C increase above 1986-2005 levels. We use other baselines on occasion depending on the literature cited and explicitly indicate where this is the case. Climate impact studies often report outcomes as a function of regional temperature change, which can differ significantly from changes in global mean temperature. In most land areas, regional warming is larger than global warming (AR5 WGI Section 10.3.1.1.2). However, given the many conventions in the literature for baseline periods, the reader is advised to check carefully and to adjust baseline levels for consistency when comparing outcomes.]

Global, regional, and local socio-economic, environmental and governance trends indicate that vulnerability and exposure of communities or social-ecological systems to climatic hazards related to extreme events are dynamic and thus vary across temporal and spatial scales [*high confidence*]. 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, ethnic composition, age structure and governance had a significant influence on the outcome of past crises associated with climatic hazards [19.6.1.].

Challenges for vulnerability reduction and adaptation actions are particularly high in regions that have shown severe difficulties in governance. Studies confirm that countries that are classified as failed states and afflicted by violence are often not able to effectively reduce vulnerability. Unless governance improves in countries with severe governance failure, risk will increase as a result of climate changes interacting with increased human vulnerability [*high confidence*, 19.6.1.3.3.].

***Key risks* inform evaluation of “dangerous anthropogenic interference with the climate system,” in the terminology of UNFCCC Article 2. These are potentially severe adverse consequences for humans and social-ecological systems resulting from the interaction of hazards linked to climate change and the vulnerability of exposed societies and systems. Key risks were identified in this assessment based on expert judgments made by authors of the various chapters of this report in light of criteria described here [19.2.2.2] and consolidated into the following representative list (*high confidence*).** [CC-KR; 19.2.2.2, 19.6.2.1, Table 19-4, Box 19-2; Roman numerals indicate corresponding entries in Table 19-4; Notation at end of each entry indicates corresponding Reasons for Concern, discussed below.]

(i) **Risk of death, injury, and disruption to livelihoods, food supplies, and drinking water, in addition to loss of common-pool resources, sense of place, and identity due to sea level rise,** coastal flooding and storm surges affecting high concentrations of people, economic activity, biodiversity, and critical infrastructure in low-lying coastal zones and small island developing states. [*RFC 1, 2, 3, 4, and 5*]
(ii) **Risk of food insecurity and the breakdown of food systems** linked to warming, drought and precipitation variability particularly in regions that are characterized by poorer populations in urban and rural settings. [*RFC 2, 3 and 4*]
(iii) **Risk of severe harm due to inland flooding** and the limited coping and adaptive capacities of large urban populations. [*RFC 2 and 3*]
(iv) **Risk of loss of rural livelihoods and income of rural residents due to insufficient access to drinking and irrigation water,** and reduced agricultural productivity, as well as risk of food insecurity, particularly for farmers and pastoralists with minimal capital in semi-arid regions. [*RFC 2 and 3*]
(v) **Systemic risks due to multiple interacting hazards affecting infrastructure in combination with a high dependency of people on critical services** (electricity, water supply, health and emergency services) which may break down during extreme events. [*RFC 2, 3, and 4*]
(vi) **Risk of loss of marine ecosystems and the services they provide for coastal livelihoods.** Biodiversity and coastal ecosystem services important for fishing communities in the tropics and the Arctic are especially at risk due to rising water temperature and the increase of stratification and ocean acidification. [*RFC 1, 2, 3, 4, and 5*]
(vii) **Risk of loss of terrestrial ecosystems and the services they provide for terrestrial livelihoods.** Biodiversity and terrestrial ecosystem services are important for rural and urban communities globally. These services are at risk due to rising temperatures, changes in precipitation patterns, and extreme weather events. Risks are high for communities whose livelihoods depend on provisioning services [*RFC 1, 3, and 4*].
(viii) **Risk of mortality, morbidity, and other harms during periods of extreme heat, particularly for urban populations of the elderly, infants, people with chronic diseases or compromised immune systems, and expectant mothers**. Increasing frequency and intensity of extreme heat (including exposure to the urban heat island effect and air pollution) interacts with an inability of some local organizations that provide health, emergency, and social services to adapt to new risk levels for vulnerable groups. [*RFC 2 and 3*]

Climate change risks vary substantially across plausible alternative development pathways and the relative importance of development and climate change varies by sector, region and time period; both are important to understanding possible outcomes [*high confidence*]. In some cases, there is substantial potential for adaptation to reduce risks, with development pathways playing a key role in determining challenges to adaptation, including through their effects on ecosystems and ecosystem services. [19.6.2.2]

Assessment of the Reasons for Concern framework pertinent to Article 2 of the UNFCCC has led to evaluations of risk being updated in light of the advances since the AR4. [19.6.3] (All temperature changes are relative to 1986-2005, i.e.,“recent”; Numbers are indicative of RFC designation in key risk enumeration, above.)

(1) Some **unique and threatened systems** are at risk from climate change at recent temperatures, with increasing numbers at risk of severe consequences at global mean warming of 1°C, and many species and systems with limited ability to adapt subject to very high risk at warming of 2°C, particularly Arctic sea ice and coral reef systems (*high confidence*) [19.6.3.2].
(2) Risk associated with **extreme events** accompanying climate change is moderate at recent temperatures based on the attribution of heat extremes to anthropogenic climate change, the attribution to climate change of impacts of extremes on a unique and threatened system, coral reefs (*high confidence*), and the current vulnerability of other exposed systems. Risk is high at 1°C warming based on the *magnitude* and *likelihood* and *timing* of the change in hazard from extreme events (*medium confidence*) [19.6.3.3].
(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. Risk is moderate at recent temperatures because regionally differentiated impacts generally related to food production have been attributed to climate change *with medium to high confidence*. Based on risk to regional crop production and water resources in some countries, risk becomes high for warming above 2°C (*medium confidence*). [19.6.3.4]

(4) Risk associated with **global aggregate impacts** is determined by both economic and noneconomic metrics. For instance, the evidence for a link between increasing risk of long-term species extinction, a noneconomic metric, and increasing temperature is *robust*. Overall, global aggregate impacts become moderate between 1-2°C of warming based on model assessment that the global aggregate economic impact of climate change will become negative and significant in magnitude (*medium confidence*). Risk becomes high around 3°C, reflecting an increase in the *magnitude* and *likelihood* of both aggregate economic risks (*low confidence*) and risk of extensive loss of biodiversity with concomitant loss of ecosystem services (*high confidence*; 19.3.2.1; 19.5.1; 19.6.3.5).

(5) Risk associated with **large-scale singular events** becomes moderate between 0-1°C due to early warning signs that both coral reef and Arctic systems are experiencing irreversible regime shifts. Risk becomes high between 1-4°C with a disproportionate increase in risk as temperature increases between 1°C and 2°C due to the potential for commitment to a large and irreversible sea level rise from ice sheet loss (*medium confidence*). [19.6.3.6]

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 [19.7.1, *high confidence*]. Among the impacts assessed here, benefits from mitigation are most immediate for surface 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 increases the time available for adaptation to a particular level of climate change, potentially by several decades.

Only mitigation scenarios in the most stringent category (i.e. with 2100 CO_2e concentrations of 430-480ppm) maintain moderately healthy coral reefs (*medium confidence*). With respect to the Reasons for Concern, these scenarios constrain overall risks to Unique and Threatened Systems, and those associated with Extreme Weather Events to a moderate level for some stringent scenarios and to the lower end of the high range of risk for others. Such scenarios constrain the level of risk associated with all other Reasons for Concern to the moderate or neutral level *(high confidence)* [19.6.3.2, 19.6.3.3, 19.7.1].

The higher part of the range of greenhouse gas emission scenarios in the literature, i.e. those with 2100 CO_2e concentrations above 720 ppm create risks in the high range for all Reasons for Concern and in the very high range (reflecting inability to adapt) for Unique and Threatened Systems. Risks for Distribution of Impacts also approach the very high range *(high confidence)* [19.6.3.2, 19.6.3.4, 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, very few integrated assessment model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5°C with at least 50% likelihood [19.7.1, 19.7.2.].

The risk of crossing tipping points (critical thresholds) in the Earth system or socio-ecological systems is projected to decrease with reduced greenhouse gas emissions [19.7.3], and the risk of crossing tipping points in socio-ecological systems can also be reduced by reducing human vulnerability or by preserving ecosystem services, or both (*medium confidence*) [19.7.4]. The risk of crossing tipping points is reduced by limiting the level of climate change and/or removing concomitant stresses such as overgrazing, overfishing, and pollution, but there is *low confidence* in the level of climate change associated with such tipping points and measures to avoid them.

19.1. Purpose, Scope, and Structure of the Chapter

The objective of this chapter is to assess new literature published since the Fourth Assessment Report on emergent risks and key vulnerabilities to climate change from the perspective of the distribution of risk over geographic location, economic sector, time period, and socioeconomic characteristics of individuals and societies. Frameworks used in previous IPCC reports to assess risk in the context of Article 2 of the UN Framework Convention on Climate Change (UNFCCC) are updated and extended in light of new literature; and additional frameworks arising in recent literature are examined. A focal point of this chapter is the interaction of the changing physical characteristics of the climate system with evolving characteristics of socioeconomic and biological systems (exposure and vulnerability) to produce risk (see Figure 19-1). Given the centrality of Article 2 to this chapter, the greater emphasis is on harmful outcomes of climate change rather than potential benefits.

[INSERT FIGURE 19-1 HERE
Figure 19-1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. The figure visualizes the different terms and concepts discussed in this chapter. It underscores that 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 Box 19-2 and the Glossary. Vulnerability and exposure are, as the figure shows, largely the result of socio-economic development pathways and societal conditions (although changing hazard patterns also play a role, see 19.6.1.1). Changes in both the climate system (left side) and development processes (right side) are key drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk (modified version of Figure 1, IPCC 2012a).]

19.1.1. Historical Development of this Chapter

The Third and Fourth Assessment Reports (TAR and AR4, respectively) each devoted chapters to evaluating the state of knowledge relevant to Article 2 of the UNFCCC (Smith *et al.*, 2001; Schneider *et al.*, 2007; see Box 19-1). The TAR sorted and aggregated impacts discussed in the literature according to a framework called *Reasons for Concern* (RFCs), and assessed the level of risk associated with individual impacts of climate change as well as each category or “reason” as a whole, generally as a function of global mean warming. This assessment took account of the distribution of vulnerability across particular regions, countries, and sectors. AR4 furthered the discussion relevant to Article 2 by assessing new literature and developing criteria potentially useful for policy makers in the determination of *key* impacts and vulnerabilities, i.e, those meriting particular attention in respect to Article 2 (see Box 19-2 for definitions of Reasons for Concern, Key Vulnerabilities (KVs) and related terms. Some definitions go beyond those in the Glossary to provide details especially pertinent to this chapter). AR4 emphasized the differences in vulnerability between developed and developing countries but also assessed new literature describing vulnerability pertaining to various aggregations of people (such as by ethnic, cultural, age, gender, or income status) and response strategies for avoiding key impacts. The Reasons for Concern were updated and the Synthesis Report (IPCC, 2007) noted that they “remain a viable framework to consider key vulnerabilities” (AR4 WGII Section 5.2). However, their utility was limited by several factors: the lack of a time dimension (i.e., representation of impacts arising from timing and rates of climate change and climate forcing), the focus on risk only as a function of global mean temperature, lack of a clear distinction between impacts and vulnerability, and importantly, incomplete incorporation of the evolving socioeconomic context, particularly adaptation capacity, in representing impacts and vulnerability.

19.1.2. The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

SREX (IPCC, 2012a) provides additional insights with respect to two RFC (risks associated with extreme weather events and the distribution of impacts) and particularly the distribution of capacities to adapt to extreme events across countries, communities, and other groups, and the limitations on implementation of these capacities. SREX emphasized the role of the socioeconomic setting and development pathway (expressed through exposure and vulnerability) in determining, on the one hand, the circumstances where extreme events do or do not result in extreme impacts and disasters, and on the other hand, when non-extreme events may also result in extreme impacts and disasters.

19.1.3. New Developments in this Chapter

With these frameworks already established, and a long list of impacts and key vulnerabilities enumerated and categorized in previous assessments, the current chapter has three goals: first, to recognize and assess risks which arise out of complex interactions involving climate and socioecological systems, called *emergent risks* (see Box 19-2, Table 19-4, CC-KR). In many cases, scientific literature sufficient to permit assessment of such risks has become available largely since AR4. In this chapter, we consider only those emergent risks which are relevant to interpreting Article 2 or have the potential to become relevant (see criteria in 19.2.2) as additional understanding accumulates. For example, since AR4, sufficient literature has emerged to allow initial assessment of the potential relationship between climate change and conflict. The second goal is to reassess and reorganize the existing frameworks (based on Reasons for Concern and Key Vulnerabilities) for evaluating the literature pertinent to Article 2 of the UNFCCC in order to address the deficiencies cited in section 19.1.1, particularly in light of the advances in SREX and the current report's discussions of vulnerability and human security (see Chapters 12 and 13) and adaptation (see Chapters 14-17 and 20). From this perspective, the objective stated in Article 2 may be viewed as aiming in part to ensure human security in the face of climate change. Thirdly, this chapter will assess recent literature pertinent to additional frameworks for categorizing risk and vulnerability, particularly focusing on indirect impacts and interaction and concatenation of risk, including geographic areas of compound risk (see Section 19.3).

In order to clarify the relative roles of characteristics of the physical climate system, like increases in temperature, precipitation, or storm frequency, and characteristics of the socioeconomic and biological systems with which these interact (vulnerability and exposure) to produce risks of particular consequences (the latter term used interchangeably here with "impacts" and "outcomes"), we rely heavily on a concept used sparingly in the TAR and AR4, *key risks* (see Box 19-2). Furthermore, we emphasize recent literature pointing to the *dynamic* character of vulnerability and exposure based on their intimate relationship to development.

Section 19.2 describes the framework used here for identifying key vulnerabilities, key risks, and emergent risks. We consider a variety of types of emergent risks, including in 19.3 those arising from multiple interacting systems and stresses, and in 19.4, those arising from indirect impacts, trans-boundary impacts, and impacts occurring at a long distance from the location of the climate change which causes them. One example which illustrates all of these properties is the extent to which climate change impacts on agriculture, water resources, and sea level affect human migration flows. These shifts entail both risks of harm and potential benefits for the migrants, for the regions where they originate, and for the destination regions (see 19.4.2.1 and 12.4). Associated risks include indirect impacts, like the effect of land use changes on ecosystems occurring at the new locations of settlement, which may be near the location of the original climate impact or quite distant. Such distant, indirect effects would compound the direct consequences of climate change at the locations receiving the incoming migrants. In 19.5, we discuss other risks newly assessed here, including those arising from ocean acidification. Section 19.6 assesses key risks and vulnerabilities in light of the criteria discussed here [19.2.2] and in the context of the Reasons for Concern, and section 19.7 assesses response strategies aimed at avoiding key risks.

_____ START BOX 19-1 HERE ____

Box 19-1. Article 2 of the UNFCCC

<u>Article 2</u>

OBJECTIVE
The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

_____ END BOX 19-1 HERE ____

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Box 19-2. Definitions

Exposure - The presence of people, livelihoods, species or ecosystems, 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. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

A broad set of factors such as wealth, social status, and gender determine vulnerability and exposure to climate-related risk.

Impacts (Consequences, Outcomes) - Effects on natural and human systems. In this report, the term *impacts* is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health status, ecosystems, economic, social, and cultural assets, services (including environmental), and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as *consequences* and *outcomes*. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

Hazard - The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. In this report, the term *hazard* usually refers to climate-related physical events or trends or their physical impacts.

Stressors - Events and trends, often not climate-related, which have an important effect on the system exposed and can increase vulnerability to climate-related risk.

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 hazardous events or trends multiplied by the consequences if these events occur.

Risk = (Probability of Events or Trends) X Consequences

This report assesses climate-related risks.

Key vulnerability, key risk, key impact – A vulnerability, risk, or impact relevant to the definition and elaboration of “dangerous anthropogenic interference (DAI) with the climate system,” in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2, meriting particular attention by policymakers in that context.

Key risks are potentially severe adverse consequences for humans and social-ecological systems due to the interaction of climate-related hazards with vulnerabilities of societies and systems exposed. Risks are considered “key” due to high hazard or high vulnerability of societies and systems exposed, or both.

Vulnerabilities are considered “key” if they have the potential to combine with hazardous events or trends to result in key risks. Vulnerabilities that have little influence on climate-related risk, for instance, due to lack of exposure to hazards, would not be considered key.

Key impacts are severe consequences for humans and social-ecological systems.

Extract from Chapter 19, WGII, AR4:

Many impacts, vulnerabilities and risks merit particular attention by policy-makers due to characteristics that might make them 'key'. The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with 'dangerous anthropogenic interference' (DAI) with the climate system, in the terminology of United Nations Framework Convention on Climate Change (UNFCCC) Article 2 (see Box 19-1). Ultimately, the definition of DAI cannot be based on scientific arguments alone, but involves other judgments informed by the state of scientific knowledge.

Emergent Risk: A risk that arises from the interaction of phenomena in a complex system, for example the risk caused when geographic shifts in human population in response to climate change lead to increased vulnerability and exposure of populations in the receiving region. Many of the emergent risks discussed in this report have only recently been analyzed in the scientific literature in sufficient detail to permit assessment. In this chapter, the only emergent risks discussed are those which have the potential to become key risks once sufficient understanding accumulates.

Reasons for Concern – Elements of a classification framework, first developed in the IPCC Third Assessment Report, which aims to facilitate judgments about what level of climate change may be "dangerous" (in the language of Article 2 of the UNFCCC) by aggregating impacts, risks, and vulnerabilities.

Summary of Reasons for Concern (revised from TAR, WGII, Chapter 19; see also Chapter 1.2.3. and Chapter 18.6.4.):

"Reasons for Concern" may aid readers in making their own determination about what is a "dangerous" climate change. Each Reason for Concern is consistent with a paradigm that can be used by itself or in combination with other paradigms to help determine what level of climate change is dangerous. The reasons for concern are the relations between global mean temperature increase and:

1. Risks to unique and threatened systems
2. Risks associated with extreme weather events
3. Risks associated with the distribution of impacts
4. Risks associated with aggregate impacts
5. Risks associated with large-scale singular events

_____ END BOX 19-2 HERE _____

19.2. Framework for Identifying Key Vulnerabilities, Key Risks, and Emergent Risks

19.2.1. Risk and Vulnerability

Definitions and frameworks that systematize hazards, exposure, vulnerability, risk and adaptation in the context of climate change are multiple, overlapping, and often contested (see e.g. Burton *et al.*, 1983; Blaikie *et al.*, 1994; Twigg, 2001; Turner *et al.*, 2003a; Turner *et al.*, 2003b; UNISDR, 2004; Schröter, 2005; Füssel and Klein, 2006; Adger, 2006; Villagrán de León, 2006; Thomalla *et al.*, 2006; Tol and Yohe, 2006; Birkmann, 2006b; IPCC, 2007; Cutter *et al.*, 2008; Cutter and Finch, 2008; ICSU - LAC, 2010a; ICSU - LAC, 2010b; Cardona, 2011; Kienberger, 2012; IPCC, 2012a; Costa and Kropp, 2012; DEFRA, 2012; Birkmann *et al.*, 2013a). Today, key reports and most authors differentiate between hazards, vulnerability, risk and impacts (see e.g. Hutton *et al.*, 2011; IPCC, 2012a; Birkmann *et al.*, 2013a). The recent literature underscores that risks from climate change are not solely externally generated circumstances or changes in the climate system to which societies respond, but rather, the result of complex interactions among societies or communities, ecosystems, and hazards arising from climate change (Susman *et al.*, 1983; Comfort *et al.*, 1999; Birkmann *et al.*, 2011a; UNISDR, 2011; IPCC, 2012a; Birkmann *et al.*, 2013a). The differentiation of the various aspects of these interactions is an important improvement since AR4 because it exhibits the social construction of risk through the concept of vulnerability (IPCC, 2012a). This new framework, growing out of SREX, translates information more easily into a risk management approach that facilitates policy making (de Sherbinin, 2013). The following section advances this framework in the context of Article 2 of the UNFCCC.

We refer to the characteristics of climate change and its effects on geophysical systems, such as floods, droughts, deglaciation, sea level rise, increasing temperature and frequency of heat waves, as *hazards*. In contrast, *vulnerability* refers primarily to characteristics of human or social-ecological systems exposed to hazardous climatic (droughts, floods etc.) or non-climatic events and trends (increasing temperature, sea-level rise) (UNDRO, 1980; Cardona, 1986; Liverman, 1990; Cannon, 1994; Blaikie *et al.*, 1996; UNISDR, 2004; Cannon, 2006; Birkmann, 2006a; Thywissen, 2006; Füssel and Klein, 2006; UNISDR, 2009; IPCC, 2012a). Ecosystems or geographic areas can be classified as vulnerable, which is of particular concern if human vulnerability increases as a result of potential impairment of the related ecosystem services. The Millennium Ecosystem Assessment (MEA) for example identified ecosystem services that affect the vulnerability of societies and communities, such as provision of fresh water resources and air quality (Millenium Ecosystem Assessment, 2005). Examples in this chapter and other chapters in this report include the vulnerability of warm water coral reefs and respective ecosystem services for coastal communities (see Table 19-4 and CC-KR).

The new framework used here also underscores that the development process of a society has significant implications for exposure, vulnerability and risk. Climate change is not a risk per se; rather climate changes and related hazards interact with the evolving vulnerability and exposure of systems and therewith determine the changing level of risk (see Figure 19-1 and Table 19-4). Identifying key vulnerabilities facilitates estimating key risks when coupled with information about evolving hazards associated with climate change. This approach provides the basis for criteria developed in the following sections.

19.2.2. Criteria for Identifying Key Vulnerabilities and Key Risks

Vulnerability is dynamic and context specific, determined by human behavior and societal organization, which influences for example the susceptibility of people (e.g. by marginalization) and their coping and adaptive capacities to hazards (see IPCC, 2012a). In this regard coping mainly refers to capacities that allow a system to protect itself in the face of adverse consequences, while adaptation – by contrast – denotes a longer-term process that also involves adjustments in the system itself and refers to learning, experimentation and change (Yohe and Tol, 2002; Pelling, 2010; Birkmann *et al.*, 2013a). Perceptions and cognitive constructs about risks and adaptation options as well as cultural contexts influence adaptive capacities and thus vulnerability (Grothmann and Patt 2005; Rhomberg, 2009; Kuruppu and Liverman 2011; see section 19.6.1.4). SREX stressed that the consideration of multiple dimensions (e.g., social, economic, environmental, institutional, cultural), as well as different causal factors of vulnerability can improve strategies to reduce risks to climate change (see IPCC 2012c, p.17 and Cardona *et al*., 2012, p. 17, 67-106).

Key vulnerability and key risk are defined in Box 19-2. Vulnerabilities that have little influence on overall risk are not considered key. Similarly, the magnitude or other characteristics of climate change related hazards, such as glacier melting, sea level rise or heat waves, are not by themselves adequate to determine key risks, since the consequences of climate change also will be determined by the vulnerability of the exposed society or social-ecological system. Key vulnerabilities and key risks embody a normative component because different societies might rank the various vulnerability and risk factors and actual or potential types of loss and damage differently (see Lavell *et al*., 2012, p. 45; Schneider *et al*., 2007, p. 785). Generally, vulnerability merits particular attention when the survival of societies, communities, or ecosystems is threatened (see UNISDR 2011, 2013; Birkmann *et al.*, 2011a). Climate change will influence the nature of the climatic hazards people and ecosystems are exposed to and also contribute to deterioration or improvement of coping and adaptive capacities of those exposed to these changes. Consequently, many studies (Wisner *et al.*, 2004; Cardona, 2010; Birkmann *et al.*, 2011a) focus with a priority on the vulnerability of humans and societies as a central feature, rather than solely on the level of climatic change and respective hazards.

19.2.2.1. Criteria for Identifying Key Vulnerabilities

We reorganize and further develop criteria for identifying vulnerabilities as "key" used in AR4 based on the literature (Blaikie *et al.*, 1994; Bohle, 2001; Turner *et al.*, 2003a; Turner *et al.*, 2003b; Birkmann, 2006a; Villagrán de León, 2006; Cutter *et al.*, 2008; Cutter and Finch, 2008; ICSU - LAC, 2010a; ICSU - LAC, 2010b; UNISDR, 2011; Cardona, 2011; Birkmann, 2011a; IPCC, 2012a; Birkmann *et al.*, 2013a) and the differentiation of hazard, exposure, and vulnerability presented here. The criteria in this and succeeding sections were used to identify key vulnerabilities, key risks, and emergent risks in 19.6.2 and Table 19-4. Not all of the criteria need to be fulfilled to characterize a vulnerability or risk as key but the characterization of a phenomenon as a key vulnerability or key risk is usually supported by more than one criterion.

The following five criteria are used to judge whether vulnerabilities are key:

1) *Exposure of a society, community, or social-ecological system to climatic stressors.* While exposure is distinct from vulnerability, exposure is an important precondition for considering a specific vulnerability as key. If a system is not at present nor in the future exposed to hazardous climatic trends or events, its vulnerability to such hazards is not relevant in the current context. Exposure can be assessed based on spatial and temporal dimensions.
2) *Importance of the vulnerable system(s). Views on the importance of different aspects of societies or ecosystems can vary across regions and cultures* (see Kienberger, 2012). However, the identification of key vulnerabilities is less subjective when it involves characteristics that are crucial for the survival of societies or communities or social-ecological systems exposed to climatic hazards. Defining key vulnerabilities in the context of particular societal groups or ecosystem services also takes into account the conditions that make these population groups or ecosystems highly vulnerable, such as processes of social marginalization or the degradation of ecosystems (Leichenko and O'Brien, 2008; O'Brien *et al.*, 2008; IPCC, 2012a).
3) *Limited ability of societies, communities or social-ecological systems to cope with and to build adaptive capacities to reduce or limit the adverse consequences of climate-related hazard.* Coping and adaptive capacities are part of the formula that determines vulnerability (see IPCC, 2012a; Birkmann *et al*., 2013a). While coping describes actions taken within existing constraints to protect the current system and institutional settings, adaptation is a continuous process which encompasses learning and change of the system exposed – including changes of rule systems or modes of governance (Smithers and Smit, 1997; Pielke Jr, 1998; Smit *et al.*, 1999; Frankhauser *et al.*, 1999; Adger *et al.*, 2005; Smit and Wandel, 2006; Pelling, 2010; Kelly and Adger, 2000; Yohe, 2002; IPCC, 2012a; Pelling *et al.*, 2008; Garschagen, 2013; Tschakert and Dietrich; 2010; Birkmann *et al.*, 2013a). Severe limits of coping and adaptation provide criteria for defining a vulnerability as key, since they are core factors that increase vulnerability to climatic hazards (see e.g. Warner *et al*., 2012).
4) *Persistence of vulnerable conditions and degree of irreversibility of consequences.* Vulnerabilities are considered key when they are persistent and difficult to alter. This is particularly the case when the susceptibility is high and coping and adaptive capacities are very low due to conditions that are hard to change. Irreversible degradation of ecosystems (e.g. warm water coral reefs), chronic poverty and marginalization, and insecure land tenure arrangements are drivers of vulnerability that in combination with climatic hazards determine risks which often persist over decades (see CC-KR), for example as observed in the Sahel Zone. In this way, communities or social-ecological systems (e.g. coastal communities dependent on fishing or mountain communities dependent on specific soil conditions) may reach a tipping point (or critical threshold) that would cause a partial or full collapse of the system, including displacement (see Renaud *et al.*, 2010; section 19.4.2.1). Inability to replace such a system or compensate for potential and actual losses and damages (i.e., irreversibility) is a critical criterion for determining what is "key".
5) *Presence of conditions that make societies highly susceptible to cumulative stressors in complex and multiple-interacting systems.* Conditions that make communities or social-ecological systems highly susceptible to the imposition of additional climatic hazards or that impinge upon their ability to cope and adapt, such as violent conflicts (e.g. during drought disaster in Somalia (see Menkhaus, 2010)) are considered under this criteria. Also, the critical dependence of societies on highly interdependent infrastructures (e.g. energy/power supply, transport and health care) (see Atzl and Keller, 2013; Rinaldi *et al*., 2001; Wang *et al*., 2012a) leads to key vulnerabilities regarding multiple-interacting systems where capacity to cope or adapt to their failure is low (see Reed *et al*., 2010; Copeland, 2005; Table 19-4).

19.2.2.2. Criteria for Identifying Key Risks

Risks are considered "key" due to high hazard or high vulnerability ("key vulnerability") of societies and systems exposed, or both. Criteria for determining key risks build on the criteria for key vulnerabilities, since vulnerability is a component of risk. As such, risk is strongly determined by coping and adaptive capacities. However, the criteria for identifying key risks also take into account the magnitude, frequency and intensity of hazardous events and trends linked to climate change to which vulnerable systems are exposed. Accordingly, the following four additional criteria are used to judge whether risks are key:

1) *Magnitude:* Risks are key if associated harmful consequences have a large magnitude, determined by a variety of metrics including human mortality and morbidity, economic loss, losses of cultural importance, and distributional consequences (see Schneider *et al.*, 2007; IPCC, 2012a). Magnitude and frequency of the hazard as well as socioeconomic factors that determine vulnerability and exposure contribute.
2) *Probability that significant risks will materialize and their timing.* Risks are considered key when there is a high probability that the hazard due to climate change will occur under circumstances where societies or social-ecological systems exposed are highly susceptible and have very limited capacities to cope or adapt and consequently potential consequences are severe. Both the timing of the hazard and the dynamics of vulnerability and exposure contribute. Risks which materialize in the near term may be evaluated differently than risks which materialize in the distant future, since the time available for building up adaptive capacities is different (Oppenheimer, 2005; Schneider *et al.*, 2007; Section 19.6.3.6*).*
3) *Irreversibility and persistence of conditions that determine risks.* Persistence of risks refers to the fact that underlying drivers and root causes of these risks, either socioeconomic (e.g. chronic poverty) or physical, cannot be rapidly reduced. The criteria for assessing key vulnerabilities include the persistence of socioeconomic conditions contributing to vulnerability that also apply here (Section 19.2.2.1, point 4). In addition, some hazards are associated with the potential for persistent physical impacts, such as loss of an ice sheet causing irreversible sea level rise or release of methane clathrates from the seabed.
4) *Limited ability to reduce the magnitude and frequency or other characteristics of hazardous climatic events and trends and the vulnerability of societies and social-ecological systems exposed.* Criterion 3 pertaining to key vulnerabilities (Section 19.2.2.1) discusses limited ability of societies to improve coping and adaptive capacities in order to manage risk. This criterion also applies here. In addition, risks are also considered to be key when societies together have very limited prospects for reducing the magnitude, frequency or intensity of the associated climate hazards. For example, risks that may be reduced or limited by greenhouse gas reductions which reduce the probability of the associated hazard are less threatening than those for which the likelihood of the hazard cannot be effectively altered (see also 19.7.1). For example, risks which are already projected to be large during the next few decades under a range of Representative Concentration Pathways (RCPs) are much more difficult to influence by reducing emissions than those projected to become large late in this century (for example, see discussion of risk from extreme heat in Section 19.6.3.3).

19.2.3. Criteria for Identifying Emergent Risks

A risk that arises from the interaction of phenomena in a complex system is defined here as an *emergent risk*. For example, feedback processes between climatic change, human interventions involving mitigation and adaptation, and processes in natural systems can be classified as emergent risks if they pose a threat to human security. Emergent risks could arise from unprecedented situations, such as the increasing urbanization of low lying coastal areas that are exposed to sea-level rise or where new pluvial flooding risk emerges due to urbanization of vulnerable areas not historically populated. Some emergent risks have been identified or discussed only recently in the scientific literature and as a result, our ability to assess whether they are key risks is limited. In this chapter, the only emergent risks discussed are those which have the potential to become key risks once sufficient understanding accumulates.

19.2.4. Identifying Key and Emergent Risks under Alternative Development Pathways

Key risks are determined by the interaction of climate-related hazards with exposure and vulnerabilities of societies or ecosystems. Development pathways describing possible trends in demographic, economic, technological, environmental, social and cultural conditions (Hallegatte *et al.*, 2011) will affect key risks because they influence both the likelihood and nature of climate-related hazards, and the societal and ecological conditions determining exposure and vulnerability. Therefore some risks could be judged to be key under some development pathways but not others. Emergent risks can depend on development pathways as well, since whether or not they become key risks may be contingent on future socio-economic conditions.

The effect of development pathways on climate-related hazards occurs through their effects on emissions and other radiative forcing factors such as land use change (see AR5 WGI Chapter 12). Components of development pathways such as economic growth, technical change, and policy will influence the rates and spatial distributions of emissions of greenhouse gases and aerosols, and of land use change, and therefore influence the magnitude, timing, and heterogeneity of hazards (see AR5 WGIII Chapter 5).

Development pathways will also influence the factors determining key vulnerabilities of human and ecological systems, including exposure, susceptibility or sensitivity to impacts, and adaptive capacity (Yohe and Tol, 2002; Füssel and Klein, 2006; Hallegatte *et al.*, 2011; O'Neill *et al.*, 2013; Birkmann *et al.*, 2013a). The magnitude of the aggregate exposure and sensitivity of socio-ecological systems will depend on population growth and spatial distribution, economic development patterns, and social systems. The particular elements of the social-ecological system that are most exposed and sensitive to climate hazards, and that are considered most important, will depend on spatial development patterns as well as on cultural preferences, attitudes toward nature/biodiversity, and reliance on climate-sensitive resources or services, among other factors (Adger, 2006; Füssel, 2009). The degree to which persistent or difficult to reverse vulnerabilities are built into social systems, as well as the degree of inequality in exposure and vulnerability across social groups or regions, also depend on characteristics of development pathways (Adger *et al.*, 2009).

19.2.5. Assessing Key Vulnerabilities and Emergent Risks

The criteria above for assessing vulnerability and risk provide a sequence of potential assessment steps. While the initial assessment phase would explore whether and how a society or social-ecological system is exposed to climate related hazards, the assessment would subsequently focus on the predisposition of societies or ecosystems to be adversely affected (vulnerability) and the potential occurrence of severe adverse consequences for humans and social-ecological systems once the hazard interacts with the vulnerability of societies and systems exposed. In addition, the importance of the system at risk and the ability of a society or system to cope and to adapt to these stressors would be assessed. Finally, the application of the criteria would also require the assessment of the irreversibility of the consequences and the persistence of vulnerable conditions. Hence, the assessment criteria for risks focus on the internal conditions of a person, a community (e.g. age structure, poverty), or a social-ecological system and the contextual conditions that influence their vulnerability (e.g. governance conditions and systems of norms), in addition to the assessment of hazards, such as storm intensity, heat waves, and sea level rise, which are directly influenced by climate change. Examples of such key vulnerabilities and key risks drawn from other chapters of this assessment are provided in section 19.6 and particularly Tables 19-4 and CC-KR.

19.3. Emergent Risk: Multiple Interacting Systems and Stresses

19.3.1. Limitations of Previous Approaches Imply Key Risks Overlooked

Interactions of climate change impacts on one sector with changes in exposure and vulnerability, or with adaptation and mitigation actions affecting the same or a different sector are generally not included or well integrated into projections of risk (Warren, 2011). However, their consideration leads to the identification of a variety of *emergent risks* that were not previously assessed or recognized. This chapter identifies several such complex-system interactions that increase vulnerability and risk synergistically [Section 19.3, *high confidence*]. There are a very large number of potential interactions, and many important ones have not yet been quantified, meaning that some key risks have been overlooked [*high confidence*]. In some cases, literature analyzing these risks is very recent. The six interaction processes listed below, while not exclusive, are systemic and may lead to further key vulnerabilities as well as a larger number of less significant impacts. Several of these are discussed in more detail in the following sections.

- Biodiversity loss induced by climate change that erodes ecosystem services, in turn increasing vulnerability and exposure of human systems dependent on those services. (*19.3.2.1)*
- Alterations in extreme weather events induced by climate change which affect human systems and ecosystems, increasing vulnerability and exposure to the effects of mean climate change. Most impacts projections are based only on changes in mean climate (Rosenzweig and Hillel, 2008; IPCC, 2012a, Box 3-1).
- The interaction between non-climate stressors such as those related to land management, water management, air pollution (which has drivers in common with climate change) and energy production and climate change. Heretofore, mainly climate interactions with population/economic growth were assessed (*19.3.2.2).*
- Climate changes which increase human exposure and vulnerability to disease. *(19.3.2.3)*
- Locations where risks in different sectors are compounded because impacts, hazards, vulnerability, and exposure interact non-additively. (*19.3.2.4)*
- Mitigation or sectoral adaptation that has unintended consequences for the functioning of another sector. (*19.3.2.5)*

19.3.2. Examples of Emergent Risks

19.3.2.1. Emergent Risks Arising from the Effects of Degradation of Ecosystem Services by Climate Change

Biodiversity loss is linked to disruption of ecosystem structure, function and services (Cardinale, 2012; Díaz *et al.*, 2006; Gaston and Fuller, 2008; Maestre *et al.*, 2012; Midgley, 2012, Duraiappah *et al.*, 2005). Terrestrial and freshwater species face increased extinction risks under projected climate change during and beyond the 21st Century, especially as climate change interacts with other pressures (*high confidence*; Section 4.3.2.5). A large number of modelling studies project that species ranges decline in size as mean climate changes (Section 4.3.2.5), e.g., a global scale study of 50,000 species found that the range sizes of 57±6% of widespread and common plants and 34±7% of widespread and common animals are projected to decline by over 50% by the 2080s if global temperatures increase by 3.5^0C relative to pre-industrial times, when allowing for species to disperse at observed rates to areas that become newly climatically suitable (Warren *et al.*, 2013a). AR4 (Fischlin *et al*., 2007) estimated that "approximately 20 to 30% of plant and animal species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above preindustrial levels (*medium confidence*)." Evaluation of various lines of evidence including a range of modelling approaches and, since AR4, new and/or improved techniques (e.g., multi-factorial driven species distribution models, species specific population dynamics, tree-based and trait based modeling (for an overview see Bellard *et al.*, 2012, Table 1; also Staudinger *et al.*, 2012; Murray *et al.*, 2011; Dullinger *et al*., 2012; Foden *et al*., 2013), imply similar levels of risk as in AR4 with some new estimates indicating higher fractions of species at risk. However, there is *low agreement* on the completeness of these lines of evidence for assigning specific numerical values for fraction of species at risk (see Sections 19.5.1 and 4.3.2.5).

These extinction risks and possible declines in species richness are associated with change in mean climate, but ecosystems and species are also expected to be affected by projected climate-change induced increases in short-term extreme weather events and increased fire frequency in some locations (see IPCC, 2012a (SREX); AR5 WGI Table SPM.1; AR5 WGI Sections 12.4.3 and 12.4.5). Accordingly, despite the recognition of additional uncertainties in numerical estimates since AR4 (Section 4.3.2.5), the evidence for risk to a substantial fraction of species associated with increasing GMT is *robust*.

In both terrestrial and marine environments, the potential for the disruption of ecosystem functionality as a result of climate change translates into a key risk of large-scale loss of ecosystem services (Mooney *et al.*, 2009; Midgley, 2012; Table 19-4). At-risk services include water purification by wetlands, removal and sequestration of carbon dioxide by forests, crop pollination by insects, coastal protection by mangroves and coral reefs, regulation of pests and disease, and recycling of waste nutrients (Sections 4.3.4, 22.4.5.6, 27.3.2.1, Table 23-2, Box CC-WE; Chivian and Bernstein, 2008). Biodiversity loss can lead to an increase in the transmission of infectious diseases such as Lyme, Schistosoma and hantavirus in humans, and West Nile virus in birds, creating a newly identified dimension to the emergent risks resulting from biodiversity loss (Keesing *et al.*, 2010).

There are a number of examples of projected yield losses in the agricultural sector due to increased prevalence of pest species under climate change including *Fusarium graminearum* (a fungal disease of wheat), the European corn borer, the Colorado beetle, bakanae disease and leaf blights of rice, and Western corn root worm (Petzoldt and Seaman, 2006; Kocmankova *et al.*, 2010; Huang *et al.*, 2010; Chakraborty and Newton, 2011; Magan *et al.*, 2011; Aragón and Lobo, 2012); or declines in pollinators (Section 4.3.4; Rosenzweig and Hillel, 2008; Kuhlmann *et al.*, 2012; Giannini *et al.*, 2012; Abrol, 2012; Bedford *et al.*, 2012). Climate change impacts on pollinators places these valuable services at risk, and affects animals which are dependent upon the plants (see Chapter 4). Although the impacts of CO_2 fertilisation on plant-pathogen systems is not well understood (Section 7.3.2.3), these processes operate simultaneous with climate change’s direct effects on yields through changing temperature, precipitation, and carbon dioxide concentrations, creating an emergent risk. Climate change has caused, or is projected to cause range expansion in weeds that have the potential to become invasive (Bradley *et al.*, 2010; Clements and Ditommaso, 2011). These can damage agriculture and threaten other species with extinction, with costs to economies being extremely high (e.g. $120 billion annually in the USA, Pimentel *et al.*, 2005; Crowl *et al.*, 2008). Although there are also examples of projected decreases in insect damage to crops, there is a tendency for risk of insect damage to plants to increase with climate change (section 7.3.2.3). Any one of the above mechanisms could result in harmful outcomes that act in synergy with existing climate change impacts on agriculture. Hence, these various susceptibilities to loss of ecosystem services comprise a key vulnerability, and in interaction with climate change, imply a potential key risk that global scale yields of a number of crops will be reduced by such interactions.

Severe decline of coral reefs (section 19.3.2.4) would result in widespread loss of income for many countries, for example $Au5.4 billion to the Australian economy from international tourism, and of US$1.6 billion to the US economy from damage to Florida’s reefs (CC-CR). More generally, for many Small Island Developing States, increases in vulnerability due to loss of such ecosystem services interact with physical impacts of climate change such as sea level rise to create an emergent risk (*high confidence*).

Various studies of ecosystem services nationally or globally, illustrate the very large values that are attributed to these services (Table 19-1). Such costs are represented only very crudely in aggregate global models of the economic impacts of climate change where ‘non-market impacts’ are estimated very broadly if at all (Section 19.6.3.5). These costs contribute to the large magnitude of the risks to human systems resulting from loss of ecosystem services, which in some cases would be irreversible. Hence the increase in vulnerability due to loss of ecosystem services interacting with climate change hazards comprises a key risk (*high confidence*). In some regions (e.g., South America) payment for ecosystem services (PES) has been implemented to support landowners to maintain the provision of services over time (Section 27.6.2, Table 27-8). Studies on degraded ecosystems examine the cost of restoring ecosystem services. Willingness to pay to restore degraded services along the Platte River (US) (Loomis *et al.*, 2000) greatly exceeded estimated costs of restoration. A meta-analysis of 89 studies looking at the restoration of ecosystem services measured using 526 different metrics found that restoration increased the amount of biodiversity and ecosystem services by 44 and 25% respectively, but restored services were still lower than in intact ecosystems (Benayas *et al.*, 2009). Hence, restoration of damaged ecosystems may be cost-effective, but can only partially compensate for loss of services.

Concomitant stress from land use change adds to the extinction risk from climate change, increasing the projected extinction rate (e.g. Şekercioğlu *et al.*, 2012) - and contributing to the emergent risk of ecosystem service loss. A synthesis of empirical studies across the globe reveals that ecosystem impacts due to land use change correlate locally with current maximum temperature and recent precipitation decline, indicating a potential for climate change to exacerbate the impacts of land use change (Mantyka-Pringle *et al.*, 2012; Chapter 4).

Land clearing releases carbon to the atmosphere and removes carbon sinks (AR5 WGI Section 6.4.3.3) such as old growth forests which would otherwise accumulate carbon (Luyssaert *et al.*, 2008). Studies that value ecosystem services have tended to underestimate the importance of carbon sinks in ecosystems, due to a tendency to consider only the carbon currently stored in the systems and not the fluxes (Anderson-Teixeira and DeLucia, 2011) and overlooking other aspects such as changes in albedo (e.g. Betts *et al.*, 2012).

[INSERT TABLE 19-1 HERE
Table 19-1: Examples of global and national ecosystem service valuation studies. This table is not intended to be comprehensive. Furthermore, it encompasses studies based on a wide range of methodologies.]

19.3.2.2. Emergent Risk Involving Non-Climate Stressors: the Management of Water, Land, and Energy

Human management of water, land, and energy interacts with climate change and its impacts, to profoundly affect risks to the amount of carbon that can be stored in terrestrial ecosystems, the amount of water available for use by humans and ecosystems, and the viability of adaptation plans for cities or protected areas. Failure to manage land, water and energy in a synergistic fashion can exacerbate climate change impacts globally (Wise *et al*., 2009; Searchinger *et al.*, 2008; Lotze-Campen *et al.*; 2010; Warren *et al.*, 2011) producing emergent risks which are also potential key risks. For example, the use of water by the energy sector, by thermo-electric power generation, hydropower and geothermal energy, or biofuel production, can contribute to water stress in arid regions (Kelic, 2009; Pittock, 2011). 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 (Sections 3.7.2, 7.3.2, 10.2, 10.3.4; McMahon and Price, 2011; Macknick *et al*., 2012a; Ackerman and Fisher, 2013). 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 (Gerten *et al*., 2011). Recent studies address the energy, water, and land 'nexus' to explore risks to the agricultural and energy sectors (Tidwell *et al.*, 2011; Skaggs *et al.*, 2012; Smith *et al.*, 2013; Box CC-WE).

Biofuels can potentially mitigate GHG emissions when used in place of fossil fuels such as gasoline, diesel, and more carbon-intensive fuels from tar sands and heavy oil (Cherubini *et al.*, 2009). One simulation of stringent mitigation (e.g. RCP2.6, which constrains radiative forcing to 2.6 W/m^2 and therefore limits global mean temperature increase to 2°C over preindustrial levels during the 21st century) shows an increased reliance on biofuels (van Vuuren *et al.*, 2011). However, due to the potential negative consequences of its use as a mitigation strategy, bioenergy development leads to several emergent risks, which are summarized in Table 19-2. Systems that may be vulnerable to bioenergy development are food systems (*high confidence*, due to bioenergy feedstocks replacing food crops, see Table 19-2.iii, Sections 19.4.1.) and ecosystems (*high confidence*), where biofuel cropping can directly or indirectly induce land use change, displacing terrestrial ecosystems such as forests, which can otherwise also act as carbon sinks, see Table 19-2.i).

While *direct* land-use change (LUC) from impacts of biofuel development (from crop substitution and/or biofuel feedstock crop expansion, c) are a concern, *indirect* land-use change (iLUC) has received more attention in the literature – both due to the magnitude of its potential impact (twice as great as direct LUC, Mellilo *et al*., 2009) and controversy over the uncertainty in accurately quantifying it. iLUC connotes land-use change resulting from biofuel impacts on agricultural commodity markets (Fargione *et al.*, 2008; Searchinger *et al.*, 2008). Reductions of greenhouse gas emissions from biofuel production and use (compared to fossil fuels) may be offset partly or entirely for decades or centuries from iLUC-induced CO_2 emissions from deforestation and the draining of peatlands (*medium confidence*, IPCC, 2011 (SRREN), Chapter 2; Bringezu *et al.*, 2009; van Vuuren *et al.*, 2010, Miettinen *et al.*, 2012, Smith *et al.* 2013). In Brazil, further biofuel expansion would be expected to impinge upon the Cerrado, the Amazon and the Atlantic rainforest - all three of which have high levels of biodiversity (Table 19-2.v) and high levels of endemism (Lapola *et al.,* 2010). Another study of biofuel production in Brazil (Barr *et al.*, 2011) found that when pasture is accounted for, direct expansion into unexploited forest land is minor, i.e., most of additional cropland is predicted to come from conversion of pastureland. However, unless the density of livestock operations is increased in tandem, the latter can also lead to *i*LUC. To the extent that biofuel feedstock crops are grown on areas that were previously fallow or degraded, the iLUC effects might be minimized and CO_2 potentially sequestered (IPCC, 2011 (SRREN); Fargione *et al.*, 2010) – although the amount, alternative uses, and potential productivity of so-called degraded lands are still contested (Dauber *et al.*, 2012). (For more information on the effects of biofuel production on terrestrial ecosystems see 4.4.4; for more information on the effects of land acquisition for biofuel production on the poor, see 13.3.1.4)

Whether such land management dynamics confound or contribute to mitigation depends on important interactions with global emissions mitigation policies (Table 19-2.ii, Van Vuuren *et al.*, 2011). A failure to include land use change emissions within a carbon mitigation regime – for example by applying a carbon price to fossil fuel and industrial emissions only – has been projected to lead to large-scale deforestation of natural forests and conversion of many other natural ecosystems by the end of the 21st century in 450 ppmv CO_2-e and 550 ppmv CO_2-e scenarios (Wise *et al.*, 2009; Mellilo *et al.* 2009a). This dynamic is due primarily to enhanced bioenergy production without a corresponding incentive to limit the resulting land use change emissions. If, instead, an equal carbon price is applied to terrestrial carbon (which, however, presents monitoring difficulties) along with fossil and industrial carbon, deforestation could slow down or even reverse.

That said, there are many equally compelling reasons for a country to encourage biofuel production including: a means to produce downward pressure on oil prices, rural development and reduced oil imports – all of which could be prioritized over biofuels as a GHG mitigation strategy depending on the country (Cherubini *et al.*, 2009). Per-litre GHG emissions from biofuels *decrease* as agriculture is further intensified through row cropping, fertilizer and pesticide use, and irrigation, while other per-litre environmental impacts like eutrophication *increase* (Burney *et al.*, 2010; Grassini and Cassman, 2012). This creates an implicit conflict between alternative development priorities. Second-generation biofuels, such as those based on non-food crops (grasses, algae, timber) and agricultural residues, are expected to offer reduced emissions of GHG and other air pollutants compared to most first-generation biofuels. This is due primarily to their having a smaller adverse interaction with food systems resulting in less LUC and *i*LUC (Plevin, 2009; Cherubini and Ulgiati, 2010; Fargione, 2010; Sander and Murthy, 2010). Further, bioelectricity and biogas both may be more effective at mitigating GHG emissions than liquid biofuels (Power and Murphy, 2009; Campbell *et al.*, 2009).
Other emergent risks from bioenergy development are summarized in Table 19-2. Nearly all of the risks presented here are driven by the increased need for raw agricultural feedstocks. Competition for cultivable lands, irrigation resources (CC-WE), and other inputs are not unique to biofuel related issues. The approximate doubling of agricultural demand projected between 2005 and 2050 (Tilman *et al.*, 2011) similarly increases competition for land and water, and would be expected to exacerbate greenhouse gas emissions from agriculture (see also AR5 WGI Section 8.3.5).

[INSERT TABLE 19-2 HERE
Table 19-2: Emergent risks related to biofuel production as a mitigation strategy.]

Projected changes in the hydrological cycle due to climate change (AR5 WGI Section 12.4.5) combined with increasing water demand leads to an emergent, potentially key risk of water stress exacerbated by the reduction of groundwater which serves as ‘an historical buffer against climate variability’ (Green *et al.*, 2011), and potentially further exacerbated by existing governance constraints which can act as barriers to reduce vulnerability. Climate change and increasing food demand are expected to drive expansion of irrigated cropland (Wada *et al.* 2013), increasing the demand for energy intensive extraction and conveyance of (ground or desalinated sea) water for irrigation (CC-WE). If water is provided through groundwater extraction, pumping, or construction and use of de-salinisation plants, local energy demand (and greenhouse gas emissions) will increase, although advanced irrigation systems are available that minimize enhancement of emissions (Rothausen and Conway, 2011).

A further potential key risk arises from increased water stress due to unsustainable groundwater extraction, which is expected to increase as an adaptation to climate change. Groundwater extraction is generally increasing globally with particularly large extraction in India and China (Wang *et al.*, 2012b). The effects of climate change on groundwater are varied with some areas expecting decreased recharge whilst others are projected to experience increased recharge (Green *et al.*, 2011; Portmann *et al*., 2013). Where extraction rates increase or recharge decreases, water tables will be depleted with potential key risks to local ecosystems and human systems (such as agriculture, tourism and recreation), while water quality will decrease. One projection shows insufficient water availability in Africa, Latin America and the Caribbean to satisfy both agricultural demands and ideal environmental flow regulations for rivers by 2050, a situation that is exacerbated by climate change (Strzepek and Boehlert, 2010).

19.3.2.3. Emergent Risks Involving Health Effects

Climate change will act through numerous direct and indirect pathways to alter the prevalence and distribution of diseases that are climate and weather sensitive. These effects will differ substantially depending on baseline epidemiologic profiles, reflecting the level of development and access to clean and plentiful water, food and adequate sanitation and health care resources. Furthermore, the impact of climate change will differ within and between regions, depending upon the adaptive capacity of public health and medical services and key infrastructure that ensures access to clean food and water.

A principal emergent global public health risk is malnutrition secondary to ecological changes and disruptions in food production as a result of changing rainfall patterns, increases in extreme temperatures (IPCC, 2012a; Sections 7.3.2.5, 11.6.1; *high confidence*), and increased atmospheric CO_2 (Taub *et al.*, 2008; Lobell and Burke, 2010). Modeling of the magnitude of the effect of climate change on future under-nutrition in five regions in South Asia and sub-Saharan Africa in 2050 (using SRES A2 emissions scenario) suggests an increase in moderate nutritional stunting, an indicator linked to increased risk of death and poor health (Black *et al.*, 2008), of 1% to 29%, depending of the region assessed, compared to a future without climate change, and a much greater impact on severe stunting for particular regions, such as 23% for central sub-Saharan Africa and 62% for south Asia (Lloyd *et al.*, 2011). The impact of climate induced drought and precipitation changes in Mali include the southward movement of drought-prone areas which would result in a loss of critical agriculturally-productive land by 2025 and increase food insecurity (Jankowska *et al.*, 2012).

In densely populated megacities, especially those with a pronounced urban heat island effect, a principal emergent health risk results from the synergistic interaction between increased exposure to extreme heat and degraded air quality with the convergence of increasing vulnerability of an aging population and a global shift to urbanization (Sections 8.2.3.5, 8.2.4.6,11.5.3, CC-HS; *high confidence*). These trends will increase the risk of relatively higher mortality from exposure to excessive heat (Knowlton *et al.*, 2007, Luber and McGeehin, 2008, Kovats and Hajat, 2008). The health risks of such interactions include increased injuries and fatalities as a result of severe weather events including heat waves (see Section 19.6.3.3); increased aeroallergen production in urban areas leading to increases in allergic airway diseases (see Section 19.5.3); and respiratory and cardiovascular morbidity and mortality secondary to degraded air quality and ozone formation (see Section 19.6.3.3). While the association between ambient air quality and health is well established, there is an increasingly *robust* body of evidence linking spikes in respiratory diseases to weather events and to climate change. In New York City, for example, each single degree (Celsius) increase in summertime surface temperature has been associated with a 3% increase in same-day hospitalizations due to respiratory diseases, and an increase of up to 3.6% in hospitalizations due to cardiovascular diseases (Lin *et al.*, 2009). Respiratory health outcomes will be exacerbated by climate change through increased production and exposure to ground-level ozone (particularly in urban areas), wildfire smoke, and increased production of pollen (D'Amato *et al.*, 2010).

19.3.2.4. Spatial Convergence of Multiple Impacts: Areas of Compound Risk

In this chapter, we define an *area of compound risk* as a region where climate-change induced impacts in one sector affects other sectors in the same region, or a region where climate change impacts in different sectors are compounded, resulting in extreme or high-risk consequences. The frequent and ongoing spatial and temporal coincidence of impacts in different sectors in the same region has consequences that are more serious than simple summation of the sectoral impacts indicates (*medium confidence*). Such synergistic processes are difficult to identify through sectoral assessment and are apt to be overlooked in spite of their potential importance in considering key vulnerabilities and risks. For example, a large flood in a rural area may damage crop fields severely, causing food shortages (Stover and Vinck, 2008). The flood may simultaneously cause a deterioration of hygiene in the region and the spread of water borne diseases (Schnitzler, 2007; Hashizume *et al.*, 2008; Kovats and Akhtar, 2008). The coincidence of disease and malnutrition can thus create an area of compound risk for health impacts, with the elderly and children most at risk.

As a systematic approach, identification of areas of compound risk could be achieved by overlaying spatial data of impacts in multiple sectors, but this cannot indicate synergistic influences and dynamic changes in these influences quantitatively. For global analysis, certain types of integrated assessment models which allow spatial analysis of climate change impacts have been used to identify regions that are affected disproportionately by climate change (MNP, 2006; Kainuma *et al.*, 2007; Warren *et al.*, 2008; Füssel, 2010). Recent efforts attempt to collect and archive spatial data on impact projections and facilitate their public use. These have created overlays for identifying areas of compound risk with web-GIS technology (Adaptation Atlas (Resources for the Future, 2009). There are also efforts to coordinate impacts assessments adopting identical future climatic and/or socio-economic scenarios at various spatial scales (Parry *et al.*, 2004; Piontek *et al.*, 2013). Areas of compound risk identified by overlaying spatial data of impacts in multiple sectors can be used as a starting point for regional case studies on vulnerability and multifaceted adaptation strategies (Piontek *et al.*, 2013).

General equilibrium economic models (see Chapter 10) may facilitate quantitative evaluation of synergistic influences. An analysis of the EU by the PESETA project (Projections of economic impacts of climate change in sectors of Europe based on bottom-up analysis) showed sub-regional welfare loss by considering impacts on agriculture, coastal system, river floods, and tourism together in the CGE (Computable General Equilibrium) model, which is designed to represent interrelationships among economic activities of sectors. The result indicated the largest percentage loss due to climate change in Southern Europe (Ciscar *et al.*, 2011).

[INSERT FIGURE 19-2 HERE
Figure 19-2: Some examples of areas of compound risk identified in this assessment. Symbols indicate one or two of the main sectors or systems subject to compound risk but in each case, additional sectors and systems are at risk.]

The following examples illustrate different types of areas of compound risk where climate change impacts coincide and interact:

1) **Cities in deltas,** which are subject to sea level rise, storm surge, coastal erosion, saline intrusion and flooding. Extreme weather events can also disrupt access to food supplies, enhancing malnutrition risk (Ahmed *et al.*, 2009; Section 19.3.2.3). Based on national population projections, if contemporary rates of effective sea level rise (a net rate, defined by the combination of eustatic sea-level rise and local contributions from fluvial sediment deposition and subsidence and subsidence due to groundwater and hydrocarbon extraction) continue through 2050, over 6 million people would be at risk of enhanced inundation and increased coastal erosion in three megadeltas and 8.7 million in 40 deltas, absent measures to adapt (Ericson *et al.,* 2006). Examples of urbanized delta areas at risk include, for example, those where Mumbai and Dhaka are located (see Chapter 8, Chapter 24, Section 19.6.3.4, Table 19-4).
2) **The Arctic,** where indigenous people (Crowley, 2011) are projected to be exposed to the disruption, and possible destruction of, their hunting and food sharing culture (see Chapter 28). Risk arises from a combination of sea ice loss and the concomitant local extinctions of the animals dependent upon the ice (Johannessen and Miles, 2011). Thawing ground also disrupts land transportation, buildings and infrastructure whilst exposure of coastal settlements to storms also increases due to loss of sea ice. Arctic ecosystems are broadly at risk (Kittel *et al.*, 2011).
3) **Coral reefs,** which are highly threatened due to the synergistic effects of sea surface temperature rise and perturbed ocean chemistry, reducing calcification and also increasing sensitivity to other impacts such as the loss of coral symbionts (Chapter 6). The importance of reef sensitivity to climate change was recently highlighted in the near-equatorial Indo Pacific, the area of greatest reef diversity worldwide (Lough, 2012). A second highly diverse reef system at risk for warming was identified around Micronesia, Mariana Island and Papua New Guinea (Meissner *et al.*, 2012).

In Figure 19-2, these and other examples of areas of compound risk identified in this assessment are indicated on a world map. The map focuses on the key role that exposure plays in determining risk, particularly compound risk, rather than vulnerabilities per se.

19.4. Emergent Risk: Indirect, Trans-Boundary, and Long-Distance Impacts

Climate change impacts can have consequences beyond the regions in which they occur. Global trade systems transmit and mediate a variety of impacts – the most prominent example of this is the global food trade system. The competitive market forces which dominate trade do not account for considerations of justice, and thus can incidentally diminish or enhance inequality in the distribution on impacts (see 19.6.3.4). Where prices on food, land, and other resources increase, vulnerability increases, *ceteris paribus*, for those most in need and least able to pay (see section 19.6.1.2 on differential vulnerability). Additionally, both mitigation and other adaptation responses have unintended consequences beyond the locations in which they are implemented (Oppenheimer, 2013). All of these mechanisms can create emergent risks (*high confidence*).

19.4.1. Crop Production, Prices, and Risk of Increased Food Insecurity

Recent literature indicates that climate trends have already influenced the yield trends of important crops (e.g. Kucharik and Serbin, 2008; Tao *et al.*, 2008; Brisson *et al.*, 2010 and Lobell *et al.*, 2011). Chapters 7 and 18 provide a detailed overview of these impacts, and have assessed with *medium confidence* that the effects of climate trends on maize and wheat yield trends have been negative in many regions over the past several decades, and have been small for major rice and soybean production areas (see Sections 7.2.1.1. and 18.4.1.1.). For projected impacts, "Without adaptation, local temperature increases in excess of about 1^{o}C above pre-industrial is projected to have negative effects on yields for the major crops (wheat, rice and maize) in both tropical and temperate regions, although individual locations may benefit (*medium confidence*) (7.4, Figures 7-4,7-5,7-7)" (Chapter 7 ES). Across all studies projecting crop yield impacts (some of which include both CO_2 fertilization and adaptation, and some which account for only one or neither of these), negative impacts on average yields become *likely* from the 2030s (Figure 7-5). Median yield impacts of 0 to -2% per decade are projected for the rest of the century (compared to yields without climate change) (Figure 7-7), and after 2050 the risk of more severe impacts increases (*medium confidence*) (Chapter 7 ES, Figure 7-5). Among the smaller number of studies that have projected global yield and price impacts, negative net effects of climate change, CO_2 increases, and agronomic adaptation on global yields are *about as likely as not* by 2050 and *likely* later in the 21st century.

Climate impacts on crop production influence food prices directly and through complex interactions with a variety of factors, including biofuel crop production and mandates, as well as other domestic policies like crop export bans (Sections 7.1.2, 7.2.2, 7.4.4). If climate changes reduce crop yields, international food prices and the number of food insecure people are expected to increase globally (*limited evidence, high agreement*, Section 7.4.4). For example, global rice prices exhibit sensitivity both to yield impacts from climate changes as well as the loss of arable land to sea level rise (Chen *et al*., 2012). While the evidence base of how climate change will affect future food consumption patterns is limited (Section 7.3.3.2.), there are large numbers of households that would be especially vulnerable to a loss of food access if food prices were to increase, for example, agricultural producers in low-income countries who are net food buyers (Section 7.3.3.2, Table 7-1).

In addition to the direct impacts of climate change, biofuel production in service of climate change mitigation may also affect food prices. Accurately tracking and quantifying the direct and indirect impacts of biofuel production on the food-system has become an intense area of study since AR4. As witnessed in the United States, US maize-ethanol production increased 800% since 2000, with maize commodity prices more than tripling and harvested land growing by more than 10%, mainly at the expense of soy (EIA, 2013). Ethanol recently consumed one quarter of US maize production, even after accounting for feed by-products returned to the market (USDA, 2013). However, isolating biofuels' exact contribution to food-system changes from other factors such as extreme weather events, climate change, changing diets, and increasing population have proven difficult (Zilberman et al., 2011). Still, estimates of the supply and demand elasticity of basic grain commodities lead to a prediction that the 2009 US Renewable Fuel standard could increase commodity prices of maize, wheat, rice, and soybeans by roughly 20%, *ceteris paribus*, assuming one third of the calories used in ethanol production can be recycled as animal feed

(Roberts and Schlenker, 2013). More generally, there is *high confidence* that pressure on land use for biofuels will further increase food prices (see Table 19-2.iii).

In summary, through the global food trade system, climate change impacts on agriculture can have consequences beyond the regions in which those impacts are directly felt. Food access can be inhibited by rising food price levels and volatility (Sections 7.3.1. and 7.3.3.2), as demonstrated during the recent 2007-2008 price rise episode that resulted from the combination of poor weather in certain world regions combined with a demand for biofuel feedstocks, increased demand for grain-fed meat, and historically low levels of food stocks (Abbot and Borot de Battisti, 2011; Adam and Ajakaiye, 2011; Figure 7-3). These episodes provide an analog elucidating how reduced crop yields due to impacts of climate variability and biofuel cropping work synergistically to create a risk of increased food insecurity: hence this interaction of climate change and mitigation actions with the food system via markets comprises an *emergent risk* of the impacts of climate change acting at a distance, affecting the food security of vulnerable households (Section 7.3.3.2.).

19.4.2. Indirect, Trans-boundary, and Long-Distance Impacts of Adaptation

Risk can also arise from unintended consequences of adaptation (see Section 14.7), and this can act across distance, if for example, there is migration of people or species from one region to another. Adaptation responses in human systems can include land use change, which can have both trans-boundary and long distance effects; and changes in water management, which often has downstream consequences.

19.4.2.1. Risks Associated with Human Migration and Displacement

Human migration is one of many possible adaptive strategies or responses to climate change (Reuveny, 2007; Piguet 2010; Tacoli, 2009; McLeman, 2011), assessed in detail in Chapter 12 in the context of the many other causes of migration. Displacement refers to situations where choices are limited and movement is more or less compelled by land loss due to sea level rise or extreme drought, for example (see Section 12.4). A number of studies have linked past climate variability to both local and long distance migration (see review by Lilleør and Van den Broeck, 2011). In addition to yielding positive and negative outcomes for the migrants, migration indirectly transmits consquences of climate variability and change at one location to people and states in the regions receiving migrants, sometimes at long distances. Consequences for receiving regions, which can be assessed by a variety of metrics, could be both positive and negative, as may also be the case for sending regions (McLeman, 2011; Foresight, 2011; Chapter 12). A rapidly growing literature examines potential changes in migration patterns due to future climate changes, but projections of specific positive or negative outcomes are not available. Furthermore, recent literature underscores risks previously ignored: risks arising from the lack of mobility in face of a changing climate, and risks entailed by those migrating into areas of direct climate-related risk, like low-lying coastal deltas (Foresight, 2011; see Section 12.4.1.2).

Climate change induced sea level rise, in conjunction with storm surges and flooding, creates a threat of temporary and eventually permanent displacement from low-lying coastal areas, the latter particularly the case for small island states (Pelling and Uitto 2001; Chapter 12). The distance and permanence of the displacement will depend on whether governments develop strategies such as relocating people from highly vulnerable to less vulnerable areas nearby, and conserving ecosystem services which provide storm surge protection (Perch-Nielsen, 2004) in addition to so-called “hardening” including building sea walls and surge barriers [CC-EA]. Numbers of people at risk from coastal land loss have been estimated on a regional basis (Nicholls and Tol, 2006; Ericson *et al.*, 2006; Nicholls *et al.*, 2011) yet projections of resulting anticipatory migration or permanent versus temporary displacement are not available.

Taken together, these studies indicate that 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 (*high confidence*). Urbanization is a pervasive aspect of recent migration which brings benefits but, in the climate change context, also significant risks (see 19.2.3, 19.6.1, 19.6.2; 19.6.3.3; 8.2.2.4). While the literature projecting climate-driven migration has grown recently (Chapter 12.4), there is as of yet insufficient literature to permit assessment of projected region-specific consequences of such migration. Nevertheless, the potential for negative outcomes from migration in such complex, interactive situations is an emergent risk of climate change, with the potential to become a key risk (CC-KR).

19.4.2.2. Risk of Conflict and Insecurity

Violent conflict between individuals or groups arises for a variety of reasons (Section 12.5). Factors such as poverty and economic shocks that are associated with a higher risk of violent conflict are themselves sensitive to climate change and variability (*high confidence*; Sections 12.5.1, 12.5.2; 13.2). In this section, we focus on evidence for the magnitude of a climate effect on violent conflict in order to assess its potential to become a key risk.

The only meta-analysis of the literature (Hsiang *et al.*, 2013), examining 60 quantitative empirical studies generally published since AR4, implicates climatic events as a contributing factor to the onset or intensification of several types of personal violence, group conflict and social instability in contexts around the world, at temporal scales ranging from a climatologically anomalous hour to an anomalous millennium and at spatial scales ranging from the individual level (Vrij *et al*., 1994; Ranson, 2012) to the communal level (Hidalgo *et al.*, 2010; O'Loughlin *et al*., 2012) to the national level (Burke *et al*., 2009; Dell *et al*., 2012) to the global level (Hsiang *et al.*, 2011). Nevertheless, some individual studies have been unable to obtain evidence that violence has a statistically significant association with climate (Buhaug, 2010; Theisen *et al.* 2011). In detection and attribution of their impact on human conflict, there is *low confidence* that climate change has an effect (Section 18.4.6) and *medium confidence* that climate variability has an effect.

Evidence suggests that climatic events over a large range of time and spatial scales contribute to the likelihood of violence through multiple pathways discussed in section 12.5 (Scheffran *et al*., 2012; Bernauer *et al.*, 2012; Hsiang and Burke, 2013). Results from modern contexts (1950-2010) indicate that the frequency of violence between individuals rises 2.3% and the frequency of intergroup conflict rises 13.2% for each standard deviation change towards warmer temperatures (Hsiang *et al.*, 2013). Because annual temperatures around the world are expected to rise 2-4 standard deviations (as measured over 1950-2008) above temperatures in 2000 by 2050 (A1B scenario) (Hsiang *et al.*, 2013), there is potential *ceteris paribus* for large relative changes to global patterns of personal violence, group conflict and social instability in the future.

Social, economic, technological, and political changes that might exacerbate or mitigate this potential impact are discussed in Chapter 12. These changes may cause future populations to respond to their climate differently than modern populations; however the influence of climate variability on rates of conflict is sufficiently large in magnitude that such advances may need to be dramatic to offset the potential influence of future climate changes.

The effect of climate change on conflict and insecurity has the potential to become a key risk because factors such as poverty and economic shocks that are associated with a higher risk of violent conflict are themselves sensitive to climate change (*medium confidence*; Sections 12.5.1, 12.5.2, 13.2) and in numerous statistical studies the influence of climate variability on human conflict is large in magnitude (*medium confidence*).

19.4.2.3. Risks Associated with Species Range Shifts

One of the primary ways species adapt to climate change is by moving to more climatically suitable areas (range shifts). These shifts will affect ecosystem functioning, potentially posing risks to ecosystem services (Dossena *et al.*, 2012; Millennium Ecosystem Assessment, 2005; *medium confidence*), including those related to climate regulation and carbon storage (Wardle *et al.*, 2011). One example of a key impact is the warming-driven expansion and intensification of Mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in North American pine forests and its current and projected impacts on carbon regulation and economies (Section 26.4.2.1). Risks also arise from projected range shifts of important resource species (e.g. marine fishes; Sections 6.3.6, 6.4.6.1), as well as from potential introductions of diseases to people, livestock, crops and native species (see Sections 7.3.2.3, 28.2.3, 23.4.2, 26.6.1.6, 5.4.2.3, 22.3.5). Many newly arrived species prey on, outcompete or hybridize with existing biota (e.g., by becoming weeds or pests in agricultural systems, Section 4.2.4.6) . The ecological implications of species reshuffling into novel, no-analogue communities largely remain unknown and pose additional risks that cannot yet be assessed (Root and Schneider 2006; Sections 6.5.3, 19.5.1, 21.4.3).

Current legal frameworks and conservation strategies face the challenge of untangling desirable species range shifts from undesirable invasions (Webber and Scott, 2012), and identifying circumstances when movement should be facilitated versus inhibited. New agreements may be needed recognizing climate change impacts on existing, new, or altered trans-boundary migration, (e.g., under the Convention on Migratory Species). As target species and ecosystems move, protected area networks may become less effective, necessitating re-evaluation and adaptation, including possible addition of sites, particularly those important as either 'refugia' or migration corridors (Warren *et al*., 2013a; Sections 9.4.3.3, 24.4.2.5, 24.5.1). Assisted colonisation – moving individuals or populations from currently occupied areas to locations with higher probability of future persistence – is arising as a potential conservation tool for species unable to track changing climates (Sections 4.4.2.4, 21.4.3). The value of these approaches, however, is contested and implementation is very limited giving *low confidence* that this would be an effective technique (Loss *et al.*, 2011). *Ex situ* collections (Section 4.4.2.5) have often been put forward as fall-back resources for conserving threatened species, yet the expense and the relatively low representation of global species and genetic diversity (Balmford *et al*., 2011; Conde *et al.*, 2011) minimizes the effectiveness of this technique.

19.4.3. Indirect, Trans-Boundary, and Long-Distance Impacts of Mitigation Measures

Mitigation, too, can have unintended consequences beyond its boundaries, which may affect natural systems and/or human systems. If mitigation involves a form of land use change, then regional implications can ensue in the same way as they can for adaptation (see Section 14.7).

Mitigation can potentially reduce direct climate change impacts on biodiversity (Warren *et al.*, 2013a). However, impacts on biodiversity as a result of land use change induced by biofuel production can offset benefits associated with biofuels (see Box 4.1, Sections 4.2.4.1, 9.3.3.4, 19.3.2.2, 22.6.3, 24.6, Box 25-10, 27.2.2.1). Climate change mitigation through 'clean energy' substitution can also have negative impacts on biodiversity. However, attention to siting and monitoring can decrease some negative ecological and socioeconomic impacts (*medium confidence*) while maximizing positive ones (Section 4.4.4). For example, the U.S. Government performed an intensive study of suitable sites for solar power on public lands in the western U.S. The end result opened 285,000 acres of public land for large-scale solar deployment while blocking development on 78 million acres to protect "natural and cultural" resources (US BLM, 2012). The construction of large hydroelectric dams can affect both terrestrial and aquatic ecosystems along river systems (World Commission on Dams, 2000; Sections 3.7.2.1, 4.4.4, 24.4.2.3, 24.9.1).

Mitigation strategies will have a range of effects on human systems. Reforestation that properly mimics existing forest ecosystems in structure and composition would potentially benefit human systems by stabilizing micro-climatic variation (Canadell and Raupach, 2008) and allowing benefits from the sustainable harvest of non-timber forest products for food, medicine and other marketable commodities (Guariguata *et al.*, 2010). However, there is a generally longer time frame and greater expense involved in recreating a diverse forest system. Afforestation creates a similar set of costs and benefits (Sections 3.7.2.1, 17.4.1, 22.3.2.1, 22.6.3). Mitigation strategies designed to reduce dependence on carbon-intensive fuels present a very different set of circumstances in relation to human systems. The development of alternative and renewable energy sources will have significant economic and market effects potentially influencing food prices (see also Section 19.4.1). This would especially affect populations that already devote a considerable portion of their household income to food (Hymans and Shapiro, 1976).

19.5. Newly Assessed Risks

Newly assessed risks are those for which the evidence base in the scientific literature has only recently become sufficient to allow for assessment. Furthermore, these risks have at least the potential to become key based on the criteria in 19.2.2. Several of the emergent risks discussed in sections 19.3 and 19.4., including those associated with human migration [19.4.2.1] and mitigation measures [19.4. 3], can be considered newly assessed. Others are related to diverse aspects of climate change, including the impacts of a large temperature rise, ocean acidification and other direct consequences of CO_2 increases, and the potential impacts of geoengineering implemented as a climate change response strategy.

19.5.1. Risks from Large Global Temperature Rise >4°C Above Pre-Industrial Levels

Most climate change impact studies focus on climate change scenarios corresponding to global mean temperature rises of up to 3.5°C relative to 1990 (slightly more than 4°C above pre-industrial levels) with only a few examples of assessments of temperature rise significantly above that level (Parry *et al.*, 2004; Hare, 2006; Warren *et al.*, 2006; Fischlin *et al.*, 2007; Easterling *et al.*, 2007). Recently the potential for larger amounts of warming has received increasing attention and preliminary assessment of impacts above that level of warming is possible for agriculture, ecosystems, water, health and large-scale singular events. In this section all temperature changes are global and relative to pre-industrial levels. Relevant climate scenarios include those based on RCP8.5, which in 2081-2100 is projected to result in a temperature rise of 4.3+/- 0.7 °C with temperature above 4°C *as likely as not* (WGI section 12.4.1, Table 12.3), and some simulations using SRES A2 and A1FI, which can reach 5.9 and 6.9°C warming, respectively, by 2100 (AR4 WG1 SPM). Literature that uses these scenarios but assumes low climate sensitivity and hence less than 4°C of warming is excluded.

Relatively few studies have considered impacts on cropping systems for scenarios where global mean temperatures increase by 4^{o}C or more (Section 7.4.1). Among these, one indicates substantial reductions in yields in sub-Saharan Africa (Thornton *et al.*, 2011) and another indicates reversal of gains in yields and substantial reductions for Finland (Rötter *et al.*, 2011). Other studies at or below 4 ^{o}C anticipate yield losses, particularly in tropical regions, even when taking agronomic adaptations into account (Section 7.5.1.1.1). The possibility of compensation for these losses due to other responses of the food system to impacts on production, such as land use change and adjustment of trade patterns, cannot yet be adequately assessed for a world with GMT>4^{o}C (Sections 19.6.3.4 and 19.4.1).

Assessments of ecological impacts at and above 4°C warming imply a high risk of extensive loss of biodiversity with concomitant loss of ecosystem services (*high confidence*, 19.3.2.1, 4.3.2.5). AR4 estimated that 20-30% of species were likely at increasingly high risk of extinction as global mean temperatures exceed a warming of 2-3°C above pre-industrial levels (*medium confidence*; Fischlin *et al*., 2007); hence 4°C warming implies further increases to extinction risks for an even larger fraction of species. However, there is *low agreement* on the numerical assessment since as more realistic details have been considered in models, it has been shown that extinction risks may be either under- or overestimated when using the simpler models (Section 4.3.2.5), among other reasons due to the existence of microrefugias or to delay in population decline leading to extinction debts (e.g. Dullinger *et al.*, 2012). Additional risks include biome shifts of 400km (Gonzalez *et al*., 2010), the disappearance of analogs of current climates in regions of exceptional biodiversity in the Himalayas, Mesoamerica, E and S Africa, the Philippines and Indonesia (Beaumont *et al.*, 2011), and loss of more than half of the climatically determined geographic ranges of 57+/-6% of plants and 34+/-7% of animals studied (Warren *et al*., 2013a). Widespread coral reef mortality is expected at 4°C due to the concomitant effects of warming and a projected decline of ocean pH of 0.43 since preindustrial times (AR5 WG1 TS, AR5 WGII 5.4.2.4, Box CC-CR, Box CC-OA, *high confidence*). The corresponding CO_2 concentration in such a scenario is more than 900 ppm (AR5 WG1 Figure 12.36) whereas the onset of large scale dissolution of coral reefs is projected if CO_2 concentrations reach 560 ppm (Sections 5.4.1.6, 5.4.2.4, 26.4.2.1).

A number of studies project increases in water stress, flood and drought in a number of regions with > 4°C warming, and decreases in others (Li *et al.*, 2009; Arnell, 2011; Fung *et al.*, 2011; Dankers *et al.*, 2013; Gerten *et al*., 2013; Gosling and Arnell 2013). For example, projections of the proportion of global population exposed to water stress due to climate change range from 5-50% (Gosling and Arnell, 2013) by 2100. The proportion of cropland exposed to drought disaster (one or more months with PDSI drought indicator below -3) is projected to increase from 15% today to 44+/-6% by 2100, based on a range of projections including some that reach or exceed 4°C global warming (Li *et al*., 2009). Concurrently irrigation water demand in currently cultivated areas in the N. hemisphere is projected to rise by 20% in the summer by 2100 under RCP8.5 due to climate change alone (Wada *et al.* 2013), although this could be partly buffered by decreasing evapotranspiration due to plant physiological responses to increased atmospheric CO_2 (Konzmann *et al*., 2013; Box CC-VW). One study (Portmann *et al*., 2013) projects 27-50% of global population affected by a >10% decrease in groundwater recharge, mostly in water stressed arid areas, and although 20-45% also receive a >10% increase, this occurs mainly in areas of low population density where water stress is not an issue. Annual runoff is projected to fall by up to 75% across the Danube, Mississippi, Amazon and Murray Darling river basins, and to increase by up to 100% in the Nile and Ganges basins (Fung *et al.*, 2011) with 4°C warming. Under RCP8.5 in 2100, nine global hydrological models driven by five global circulation models project increases in flood frequency in over half of the land surface, and decreases in roughly a third of the land surface (Dankers *et al.*, 2013). According to one study, even if human population remained constant in Europe, without adaptation, 3.5°C –4.8°C global warming by the 2080s would expose an additional 250,000 – 400,00 people to river flooding, doubling economic damages since the 1970s, and expose an additional 851,000 – 5,552,000 to coastal flooding (Ciscar *et al.*, 2011), compared to 36,000 in 1995.

Under 4°C warming most of the world land area will be experiencing 4-7°C higher temperatures than the recent past which means that important tipping points for health impacts may be exceeded in many areas of the world during this century, including coping mechanisms for daily temperature/humidity making potentially large areas seasonally uninhabitable for normal human activities, including growing food or working outdoors [11.8] (*high confidence*). Exceedance of human physiological limits is projected in some areas for a global warming of 7°C, and in most areas for global warming of 11-12°C (*low confidence*, Sherwood and Huber, 2010), a temperature increase that is possible by 2300 (AR5 WGI Figure 12.5).

The risk of large-scale singular events such as ice sheet disintegration, methane release from clathrates, and regime shifts in ecosystems (including Amazon dieback), is higher with increased warming (and therefore higher above 4°C than below it) although there is *low confidence* in the temperature changes at which thresholds might exist for these processes (Section 19.6.3.6; AR5 WGI Sections 12.4.5, 12.5.5, and 13.4). There are also more gradual changes that become large with global temperature rise of 4^0C or more, such as decline in the Atlantic Meridional Overturning Circulation (AMOC) and release of carbon from thawed permafrost (CTP). The AMOC is considered *very likely* to weaken for such warming, with best estimates of loss over the 21st century under RCP8.5 ranging from 36-44% (AR5 WGI Sections 12.4.7.2 and 12.5.5.2). The best estimated range for CTP by 2100 is from 50 to more than 250 PgC for RCP8.5 (AR5 WGI Section 6.4.3.4) although there are large uncertainties. Larger decreases in AMOC and increases in CTP are thus implied for a global warming of above 4°C. Similarly, since a nearly ice-free Arctic Ocean in September before mid-century is *likely* under RCP8.5, by which time projected GMT rise amounts to 2.0 ± 0.4°C above the 1986-2005 baseline (*medium confidence,* AR5 WGI Section 12.4.61), the likelihood is even higher for global warming of above 4°C. Regions of the boreal forest could witness widespread forest dieback (*low confidence*) putting at risk the boreal carbon sink, estimated at 0.5 Pg $year^{-1}$ in 2000-2007 (AR5 WGI Section 12.5.5; AR5 WGII Section 4.3.3.1.1). Forest susceptibility to fire is projected to increase substantially in many areas for the high emissions scenario (RCP 8.5, Box 4-3) and hence larger changes are implied for global warming above 4°C.

Based on the assessment in this section, we conclude that climate change impacts at 4°C and above would be of greater magnitude and more widespread than at lower levels of global temperature rise (*medium evidence, high agreement, high confidence*), extending to higher temperature levels previous findings that risks increase with increasing global average temperature (AR4 WGII SPM.2; NRC, 2011). Few studies yet consider the interactions between these effects, which could create significant additional risks (Warren *et al.*, 2011; Section 19.7.5).

19.5.2. Risks from Ocean Acidification

Ocean acidification is defined as "a reduction in pH of the ocean over an extended period, typically decades or longer, caused primarily by the uptake of carbon dioxide from the atmosphere" (AR5 WGI 3.3.2, Box 3.2; Box CC-OA; see also WGII Glossary). Acidification is a physical and biogeochemical impact resulting from CO_2 emissions that poses risks to marine ecosystems and the societies that depend on them. Research on impacts on organisms, ecological responses, and consequences for ecosystem services is relatively new; the potential for associated risks to become key is magnified by the fact that acidification is a global phenomenon and, without a decrease in atmospheric CO_2 concentration, it is irreversible on century timescales.

It is *virtually certain* that ocean acidification is occurring now (AR5 WGI Section 3.9) and will continue to increase in magnitude as long as the atmospheric CO_2 concentration increases (NRC, 2010). Risks to society and ecosystems result from a chain of consequences beginning with direct effects on biogeochemical processes and organisms and extending to indirect effects on ecosystems, ecosystem services, and society (Figure 19-3). The degree of confidence in assessing risks decreases along this chain due to the complexity of interactions across these scales and the relatively small number of studies available for quantitative risk assessment.

[INSERT FIGURE 19-3 HERE
Figure 19-3: The pathways by which ocean acidification affects marine processes, organisms, ecosystems, and society. The confidence in quantifying the impacts decreases along the pathway.]

Most studies have focused on the direct effects of ocean acidification on marine organisms and biogeochemical processes. The overall effects on organisms can be assessed with *medium confidence* (Section 6.3.2; Box CC-OA), but the effects vary widely across processes (e.g., photosynthesis, growth, calcification; Section 6.3.2) and across organisms and their life stages (Section 6.3.2; Box CC-OA).

Far fewer studies have assessed the impacts on ecosystems (Section 6.3.2.5) and ecosystem services (Section 6.4.1), and most of these studies have focused on the economic impacts on fisheries (Section 6.4.1.1). For example, changes in overall availability and nutritional value of desired mollusk species could affect economies (Narita *et al.*, 2012) and food availability (Section 6.4.1.1). In Table 19-3, we assess the risks to ecosystem services through the impact of acidification on two key marine processes, marine calcification and nitrogen fixation, using the criteria for key risks (19.2.2.2).

[INSERT TABLE 19-3 HERE
Table 19-3: An assessment of the risks to ecosystem services posed by the impacts of ocean acidification on coral calcification and nitrogen fixation, based on the four criteria for key risks (19.2.2.2).]

Based on Table 19-3, the response of coral calcification to ocean acidification and the resulting consequences for coral reefs constitute a key risk to important ecosystem services (*high confidence*). The effect of ocean acidification on marine N_2-fixation could potentially become a key risk, given that it could have potentially large consequences for marine ecosystems, but currently there is *limited evidence* on the likelihood of this risk materializing.

19.5.3. Risks from CO_2 Health Effects

There is increasing evidence that the impacts of elevated atmospheric CO_2 on plant species will affect health via two distinct pathways: the increased production and allergenicity of pollen and allergenic compounds, and the nutritional quality of key food crops. The evidence for these impacts on plant species is increasingly *robust* and recent evidence in the public health literature points to a *medium to high confidence* in the potential for these risks to be sufficiently widespread in geographical scope and large in *magnitude* of their impact on human health to be considered key risks.

Climate change is expected to alter the spatial and temporal distribution of several key allergen-producing plant species (Shea, 2008), and increased atmospheric CO_2 concentration, independent of climate effects, has been shown to stimulate pollen production (Rasmussen, 2002; Clot, 2003; Galán *et al.*, 2005; Garcia-Mozo *et al.*, 2006; Ladeau and Clark, 2006; Damialis *et al.*, 2007; Frei and Gassner, 2008). A series of studies (Ziska *et al.* 2000; Ziska *et al.*, 2003; Ziska and Beggs, 2012) found an association of elevated CO_2 concentrations and temperature with faster growing and earlier flowering ragweed species *(Ambrosia artemisiifolia*) along with greater production of ragweed pollen (Wayne *et al.*, 2002; Singer *et al.*, 2005; Rogers *et al.*, 2006) leading, in some areas, to a measurable increase in hospital visits for allergic rhinitis (Breton *et al.*, 2006). Experimental studies have shown that poison ivy, another common allergenic species, responds to atmospheric CO_2 enrichment through increased photosynthesis, water use efficiency, growth, and biomass. This stimulation, exceeding that of most other woody species, also produces a more potent form of the primary allergenic compound, urushiol (Mohan *et al.*, 2006).

While climate change and variability is expected to affect crop production (see Chapter 7), emerging evidence suggests an additional stressor on the food system: the impact of elevated levels of CO_2 on the nutritional quality of important foods. A prominent example of the effect of elevated atmospheric CO_2 is the decrease in the nitrogen (N) concentration in vegetative plant parts as well as in seeds and grains and, related to this, the decrease in the protein concentrations (Cotrufo *et al.*, 1998; Taub *et al.*, 2008; Wieser *et al.*, 2008). Experimental studies of increasing CO_2 to 550 ppm demonstrated effects on crude protein, starch, total and soluble B-amylase, and single kernel hardiness, leading to a reduction in crude protein by 4 to 13% in wheat and 11 to 13% in barley (Erbs *et al*., 2010). Other CO_2 enrichment studies have shown changes in the composition of other macro- and micronutrients (Ca, K, Mg, Fe, Zn) and in concentrations of other nutritionally important components such as vitamins and sugars (Idso and Idso, 2001). Declining nutritional quality of important global crops is a potential risk that would broadly affect rates of protein-energy and micronutrient malnutrition in vulnerable populations. While there is *medium confidence* that this risk has the potential to become key when judged by its *magnitude* and other criteria (Sections 19.2.2.1, 19.2.2.2) there is currently insufficient information to assess under what ambient CO_2 concentrations this would occur.

19.5.4. Risks from Geoengineering (Solar Radiation Management)

Geoengineering refers to a set of proposed methods and technologies that aim to alter the climate system at a large scale to alleviate the impacts of climate change (WGII Glossary; IPCC, 2012b; AR5 WGI Sections 6.5 and 7.7; WGIII Chapter 6). The main intended benefit of geoengineering would be the reduction of climate change that would otherwise occur, and the associated reduction in impacts (Shepherd *et al.*, 2009). Here we focus on risks, consistent with the goal of this chapter. Although geoengineering is not a new idea (e.g., Rusin and Flit, 1960; Budyko and Miller, 1974; Enarson and Morrow, 1998, and a long history of geoengineering proposals as detailed by Fleming, 2010), it has received increasing attention in the recent scientific literature.

Geoengineering has come to refer to both carbon dioxide removal (CDR, discussed in detail in AR5 WGI Section 6.5, FAQ 7.3) and solar radiation management (SRM; Shepherd *et al.*, 2009; Lenton and Vaughan, 2009; Izrael, 2009; discussed in detail in AR5 WGI, Section 7.7, FAQ 7.3). These distinct approaches to climate control raise very different scientific (e.g., Shepherd *et al.*, 2009), ethical (Morrow *et al.*, 2009; Preston, 2013) and governance (Lloyd and Oppenheimer, 2013) issues. Many approaches to CDR are considered to more closely resemble mitigation rather than other geoengineering methods (AR5 WGI, Chapter 6.5; IPCC, 2012b). In addition, CDR is thought to produce fewer risks than SRM if the CO_2 can be stored safely (AR5 WGI Section 6.5; Shepherd *et al.*, 2009) and unintended consequences for land use, the food system and biodiversity can be avoided (19.4.3). For these reasons, in addition to the more substantial recent literature on SRM's potential impacts, we only address SRM in this section. SRM is a potential key risk because it is associated with impacts to society and ecosystems that could be large in magnitude and widespread. Current knowledge on SRM is limited and our confidence in the conclusions in this section is *low*.

Studies of impacts on society and ecosystems have been based on two of the various SRM schemes that have been suggested: stratospheric aerosols and marine cloud brightening. These approaches in theory could produce large-scale cooling (Salter *et al.*, 2008; Lenton and Vaughan, 2009), although it is not clear that it is even possible to produce a stratospheric sulfate aerosol layer sufficiently optically thick to be effective (Heckendorn et al., 2009; English *et al.*, 2012). Observations of volcanic eruptions, frequently used as an analogue for SRM (Robock *et al.*, 2013), indicate that while stratospheric aerosols can reduce the global average surface air temperature, they can also produce regional drought (e.g., Oman *et al.*, 2005; Oman *et al.*, 2006; Trenberth and Dai, 2007), cause ozone depletion (Solomon, 1999), and reduce electricity generation from solar generators that use focused direct sunlight (Murphy, 2009). Climate modeling studies show that the risk of ozone depletion depends in detail on how much and when stratospheric aerosols would be released in the stratosphere (Tilmes *et al.*, 2008) and find that global stratospheric SRM would produce uneven surface temperature responses and reduced precipitation (Schmidt *et al.*, 2012; Kravitz *et al.*, 2013), weaken the global hydrological cycle (Bala *et al.*, 2008), and reduce summer monsoon rainfall relative to current climate in Asia and Africa (Robock *et al.*, 2008). Hemispheric geoengineering would have even larger effects (Haywood *et al.*, 2013).

The net effect on crop productivity would depend on the specific scenario and region (Pongratz *et al.*, 2012). Use of SRM also poses a risk of rapid climate change if it fails or is halted suddenly (AR5 WGI Section 7.7; Jones *et al.*, 2013), which would have large negative impacts on ecosystems (Russell et al., 2012; *high confidence*) and could offset the benefits of SRM (Goes *et al.*, 2011). There is also a risk of "moral hazard;" if society thinks geoengineering will solve the global warming problem, there may be less attention given to mitigation (e.g., Lin, 2013). In addition, without global agreements on how and how much geoengineering to use, SRM presents a risk for international conflict (Brzoska *et al.*, 2012). Since the direct costs of stratospheric SRM have been estimated to be in the tens of billions of US dollars per year (Robock *et al.*, 2009; McClellan *et al.*, 2012), it could be undertaken by non-state actors or by small states acting on their own (Lloyd and Oppenheimer, 2012), potentially contributing to global or regional conflict (Robock, 2008a; Robock, 2008b). Based on magnitude of consequences and exposure of societies with limited ability to cope, geoengineering poses a potential key risk.

19.6. Key Vulnerabilities, Key Risks, and Reasons for Concern

In this section, we present key vulnerabilities, key risks, and emergent risks that have been identified by many of the chapters of this report based on the material assessed by each in light of criteria discussed in 19.2.2 and 19.2.3. We then discuss dynamic characteristics of exposure, vulnerability and risk, features which are influenced by development pathways in the past, present and future. Illustrative examples of climate-related hazards, key vulnerabilities, key risks and emergent risks in Table 19-4 are representative, having been selected from a larger number provided by the chapters of this report. The table demonstrates how these four categories are related, as well as how they differ, and how they interact with non-climate stressors. The table also provides information on how key risks actually develop due to changing climatic hazards and vulnerabilities. This knowledge is an important prerequisite for effective adaptation and risk reduction strategies that must address climate related hazards, non-climatic stressors and various vulnerabilities that often interact in complex ways and change over time.

19.6.1. Key Vulnerabilities

Several of the risks discussed in this and other chapters and noted in Table 19-4 arise because vulnerable people must cope and adapt not only to changing climate conditions, but to multiple, interacting stressors simultaneously (see Sections 19.3 and 19.4), which means that effective adaptation strategies would address these complexities and relationships.

19.6.1.1. Dynamics of Exposure and Vulnerability

This sub-section deals with the meaning and the importance of dynamics of exposure and vulnerability, while section 19.6.1.3 assesses recent literature regarding observed trends of vulnerability mostly at a global or regional scale. The literature provides increasing evidence that structures and processes that determine vulnerability are dynamic and spatially variable (IPCC, 2012a; and Section 19.6.1.3). SREX states with *high confidence* that vulnerability and exposure of communities or social-ecological systems to climatic hazards related to extreme events are dynamic, thus varying across temporal and spatial scales due to influences of and changes in social, economic, demographic, cultural, environmental, and governance factors (IPCC, 2012c, SPM.B).

Examples of such dynamics in exposure and vulnerability encompass, e.g. population dynamics, such as population growth or changes in poverty (Table 19-4; Birkmann *et al.*, 2013b) and increasing exposure of people and settlements in low lying coastal areas or flood plains in Asia (see Nicholls and Small, 2002; Fuchs *et al.*, 2011; IPCC, 2012a; Peduzzi *et al.*, 2012). Also, demographic changes, such as aging of societies, have a significant influence on people's vulnerability to heat stress (see Stafoggia *et al.*, 2006; Gosling *et al.*, 2009). Changes in poverty or socio-economic status, ethnic compositions as well as age structures had a significant influence on the outcome of past crises and in addition were modified and reinforced through disasters triggered by climate and weather related hazards. For the United States for example, Cutter and Finch (2008) found that social vulnerability to natural hazards increased over time in some areas due to changes in socio-economic status, ethnic composition, age, and density of population. Changes in the strength of social-networks (e.g., resulting in social isolation of elderly) and physical abilities to cope with such extreme events modify vulnerability (see e.g. Khunwishit and Arlikatti, 2012).

In some cases human vulnerability might also change in different phases of crises and disasters. Hence, the factors that might determine vulnerability before a crisis or disaster (drought crises, flood disaster) might differ from those that determine vulnerability thereafter (post-disaster and recovery phases). Disaster response and reconstruction processes and policies can modify exposure and vulnerability e.g. of coastal communities (Birkmann and Fernando, 2008; Birkmann, 2011). A comprehensive assessment of vulnerability would account for these dynamics by evaluating long-distance impacts (e.g., resulting from migration or global influence of regional crop production failures following floods) and multiple-stressors (e.g. recovery policies after disasters) that often influence dynamics and generate complex crises and even emergent risks. Furthermore, the SREX also underscores that the increased intensity, frequency and duration of some extreme events as climate continues to change, might make adaptation based only on recent experience or the extrapolation of historical trends largely ineffective (Lavell *et al*., 2012, p. 44-47); hence understanding the dynamics of vulnerability and its different facets is crucial.

19.6.1.2. Differential Vulnerability and Exposure

Wealth, education, ethnicity, religion, gender, age, class/caste, disability, and health status exemplify and contribute to the differential exposure and vulnerability of individuals or societies to climate and non-climate related hazards (see IPCC, 2012a). Differential vulnerability is, for example, revealed by the fact that people and communities that are similarly exposed encounter different levels of harm, damage and loss as well as success of recovery (see Birkmann, 2006). The uneven effects and uneven suffering of different population groups and particularly marginalized groups is well documented in various studies (Bohle *et al.*, 1994; Kasperson and Kasperson, 2001; Thomalla *et al.*, 2006; Birkmann, 2006a; Sietz *et al.*, 2011; Sietz *et al.*, 2012). Factors that determine and influence these differential vulnerabilities to climate-related hazards include, e.g. ethnicity (Fothergill *et al.*, 1999; Elliott and Pais, 2006; Cutter and Finch, 2008), socioeconomic class (O'Keefe *et al.*, 1976; Peacock, 1997; Ray-Bennett, 2009), gender (Sen, 1981), age (Jabry, 2003; Wisner, 2006; Bartlett, 2008) as well as migration experience (Cutter and Finch, 2008) and homelessness (Wisner, 1998; IPCC, 2012a). Differential vulnerabilities of specific populations can often be discerned at a particular scale using quantitative or qualitative assessment methodologies (Cardona, 2006; Cardona, 2008; Birkmann *et al.*, 2013b). Various population groups are differentially exposed to and affected by hazards linked to climate change in terms of both gradual changes in mean properties and extreme events. For example, in urban areas, marginalized groups (particularly due to gender or wealth status or ethnicity) often settle along rivers or canals where they are highly exposed to flood hazards or potential sea-level rise (see Table 19-4) (e.g., Neal and Phillips, 1990; Enarson and Morrow, 1998; Neumayer and Plümper, 2007; Sietz *et al*., 2012). Studies emphasize that vulnerability in terms of gender is not determined through biology, but in most cases by social structures, institutions and rule systems; hence women and girls are often (not always) more vulnerable due to the fact that they are marginalized from decision making or experience discrimination in development and reconstruction efforts (Fordham, 1998; Houghton, 2009; Sultana, 2010; IPCC, 2012a).

19.6.1.3. Trends in Exposure and Vulnerability

Vulnerability and exposure of societies and social-ecological systems to hazards linked to climate change are dynamic and depend on economic, social, demographic, cultural, institutional, and governance factors (see IPCC, 2012c, p.7). The literature shows that there is a *high confidence* that rapid and unsustainable urban development, international financial pressures, increases in socioeconomic inequalities, failures in governance (e.g. corruption), and environmental degradation are key trends that modify vulnerability of societies, communities and social-ecological systems (Maskrey, 1993a; Maskrey, 1993b; Maskrey, 1994; Mansilla, 1996; Maskrey, 1998; Cannon, 2006; Birkmann, 2013; de Sherbinin, 2013) at different scales. Consequently, many of the factors that reveal and determine differential vulnerability change over time in terms of their spatial distribution. These dynamics unfold in different places differently and therefore local or regional specific strategies are needed that strengthen resilience (Garschagen and Kraas, 2011; Holdschlag and Ratter, 2013) and reduce exposure and vulnerability. For example, countries characterized by rapid urbanization coupled with low economic performance and high social development barriers face amongst the highest levels of climate change vulnerability. However, urbanization in some areas can yield conditions conducive to building up coping and adaptation capacities particularly when urban socio-economic development and risk management is properly implemented (see Garschagen and Romero-Lankao, 2013). The following section outlines observed trends in vulnerability according to different thematic dimensions (e.g., socio-economic, environmental, institutional), within the constraint that relevant socioeconomic data is limited.

19.6.1.3.1. Trends in socioeconomic vulnerability

Poverty is a critical factor determining vulnerability of societies to climate change and extreme events (Section 13.1.3). For example, risk due to droughts – particularly in sub-Sahara Africa - is intimately linked to poverty and rural vulnerability (see UNISDR, 2011, p. 62; Birkmann *et al.*, 2011b; Welle *et al.*, 2012; World Bank, 2010; *high confidence*). In interpreting the following estimates, it should be borne in mind that diverse concepts of poverty lead to different estimates but that for some regions, e.g., sub-Saharan Africa, the trends are *robust*. Recent evaluation of conditions in 119 countries found that at the international level there had been a clear decrease in global poverty over the previous six years (Chandy and Gertz, 2011). The number of poor people globally fell, from over 1.3 billion in 2005 to under 900 million in 2010. This trend is expected to continue (e.g. Chandy and Gertz 2011; Hughes *et al.*, 2009). However, regional trends vary, as do differences between emerging and least developed economies. As a result, there is a growing climate-related risk in some regions associated with chronic poverty. For example, approximately 47% of the population of the highly drought exposed region sub-Sahara Africa still lives in poverty (poverty headcount ration at $1.25 per day; see World Bank 2012) and this area already has been defined as a global risk hotspot (see Birkmann *et al.*, 2011b; Welle *et al.*, 2012). However, various national-level poverty statistics provide little information about the actual distribution of poverty, for example between rural-versus-urban areas. Income distribution trends show significant increases in inequality in some countries in Africa, and particularly in Asia, such as in China, India, Indonesia and Bangladesh (World Bank, 2012). In Asia and South East Asia this trend overlaps with areas of compound climate risk (19.3.2.4) in terms of people currently exposed to floods and tropical cyclones as well as sea-level rise (Förster *et al.*, 2011; Peduzzi *et al.*, 2012; IPCC, 2012a). Assessing vulnerability (and risk) in these countries requires in-depth analysis of trends and distribution patterns of poverty, income disparities and exposure of people to changing climatic hazards.

New socio-economic vulnerabilities are emerging in some countries, for example in developed countries, where the impoverishment of some population groups is observed. For example, research underscores that old age increases the risk of poverty in Greece, since the majority of people working as farmers or in the private sector receive small pensions which are below the poverty line (Karamessini, 2010, p. 279). These factors might interact with limited physical means of elderly to cope with climatic hazards, such as heat waves, and hence increase vulnerability.

Health status of individuals and population groups affects vulnerability to climate change by limiting capacities to cope and adapt to climate hazards (see Chapter 11). Although at a global scale the percentage of people undernourished is decreasing (FAO, 2012) and this trend is expected to continue (Hughes *et al.*, 2009), the regional and national differences are significant: during 2010-12, 870 million people remained chronically undernourished (FAO, 2012). Particularly in certain regions highly exposed to current and projected climate-related hazards, the number of people undernourished has increased. In Sub-Sahara Africa where exposure to drought is episodically high, the number of undernourished increased by 64 million or about 38% during 2010-12 compared to 1990-92 (FAO, 2012, p. 10; Hughes *et al.*, 2009). Moreover, at many locations, climate change is expected to reduce the access to and the quality of natural resources that are important to sustain rural and urban livelihoods as well as the capacities of states to provide help to sustain livelihoods (Barnett and Adger 2007; Section 19.3.2.1). These multi-risk contexts require new approaches for climate change adaptation.

While these trends mainly point to particularly large exposure and vulnerability in developing countries, studies regarding extreme heat vulnerability, for example, underscore that developed countries face increasing challenges to adaptation as well. Heat waves are projected to increase in duration, intensity, and extent (AR5 WGI 11.3.2). Advanced age represents one of the most significant risk factors for heat-related death (Bouchama and Knochel, 2002), since in addition to limited thermoregulatory and physiologic heat-adaptation capacities, elderly have often reduced social contacts, and higher prevalence of chronic illness and poor health (Section 11.3.3; Khosla and Guntupalli, 1999; Klinenberg, 2002; O'Neill, 2003). The trend towards an aging society, for example in Japan or Germany, therefore increases the vulnerability of these societies to extreme heat stress.

19.6.1.3.2. Trends in environmental vulnerability

Societies depend on ecosystem services for their survival; however, these ecosystem services and functions (see e.g. Millenium Ecosystem Assessment, 2005) are vulnerable to climate change (see Cardona *et al*., 2012, p. 76-77; Table 19-4; Section 19.3.2.1). Various societies and communities that rely heavily on the quality of ecosystem services, such as rural populations dependent on rain fed agriculture where drying is projected (see also Table 19-4), will experience increased risk from climate change due to its negative influence on ecosystem services (see Sections 4.3.4 and 6.4.1, *high confidence*). Although no global overview is available, recent reports (UNDP, 2007; IPCC, 2012a) underscore that a number of current environmental trends threaten human wellbeing and thus increase human vulnerability (UNEP, 2007). Many communities that have suffered large losses due to extreme weather events - for example coastal flooding - also experienced earlier degradation of ecosystems providing protective services. Recent global studies and local studies, such as for the US East Coast, underscore that intact ecosystems, such as marshes, can have an important protective role against coastal hazards e.g. by wave attenuation (Beck *et al.*, 2013; Shepard *et al.*, 2011). Hence, coastal degradation, such as destruction of coral reefs in Asia, is increasing the exposure of communities to such hazards (Welle *et al.*, 2012). Moreover, the extinctions of species and the loss of biodiversity pose a threat of diminution of genetic pools that otherwise buffer the adaptive capacities of social-ecological systems dependent on these services in the medium and long-run (e.g. in terms of medicine and agricultural production).

19.6.1.3.3. Trends in institutional vulnerability

Institutional vulnerability refers, among other issues, to the role of governance. Governance is increasingly recognized as a key factor that influences vulnerability and adaptive capacity of societies and communities exposed to extreme events and gradual climate change (Kahn, 2005; Nordås and Gleditsch, 2007; Welle *et al.*, 2011). People in countries or places that are facing severe failure of governance, such as violent conflicts (e.g. Somalia, Afghanistan) are particularly vulnerable to extreme events and climate change, since they are already exposed to complex emergency situations and hence have limited capacities to cope or undertake effective risk management (see Ahrens and Rudolph, 2006; Menkhaus 2010). Countries classified as failed states are often not able to guarantee their citizens basic standards of human security and consequently do not provide adequate or any support in crises or disaster situations for vulnerable people. The Failed State Index (Fund for Peace, 2012; Foreign Policy, 2012) as well as the Corruption Perception Index (Transparency International, 2012) are used to characterize institutional vulnerability and governance failure. Trends in the Failed State Index from 2006 to 2011 show that countries with severe problems in the functioning of the state cannot easily shift or change their situation (*persistence* of institutional vulnerability). Studies at the global level also confirm that countries classified as failed states and affected e.g. by violence are not able to effectively reduce poverty compared to countries without violence (see World Bank, 2011). Countries characterized in the literature as substantially failing in governance or in some particular aspects of governance during some period, such as Somalia and Ethiopia, Afghanistan, or Haiti have shown in the past severe difficulties in dealing with extreme events or supporting people that have to cope and adapt to severe droughts, storms or floods (see e.g. Lautze *et al.*, 2004; Ahrens and Rudolph, 2006; Menkhaus, 2010, p. 320-341; Heine and Thompson, 2011; Khazai *et al.*, 2011, p. 30-31). In addition, climate change is also likely to undermine the capacity of some states to provide the services and support that help people to sustain their livelihoods in a changing climate (Barnett and Adger, 2007). Governance failure and violence as characteristics of institutional vulnerability have significant influence on socio-economic, and therefore climatic vulnerability. Furthermore, corruption has been identified as an important factor that hinders effective adaptation policies and crisis response strategies (Birkmann *et al.*, 2011b; Welle *et al.*, 2012). At the local level, various aspects of governance in developing and developed countries, particularly institutional capacities and self-organization as well as political and cultural factors, are critical for social-learning, innovations and actions that can improve risk management and adaptation to climate related risks and for empowering highly vulnerable groups (IPCC, 2012a).

Overall, unless governance improves in countries with severe governance failure, risk will increase and human security will be further undermined there as a result of climate change and increased human vulnerability (Lautze *et al.*, 2004; Ahrens and Rudolph 2006, Barnett and Adger, 2007; Menkhaus 2010; *high confidence*).

19.6.1.4. Risk Perception

Risk perceptions influence the behavior of people in terms of risk preparedness and adaptation to climate change (Burton *et al.*, 1993; van Sluis and van Aalst, 2006; IPCC, 2012a). Factors that shape risk perceptions and therewith also influence actual and potential responses (and thus exposure, vulnerability and risk) include a) interpretations of the threat, including the understanding and knowledge of the root cause of the problem, b) exposure and personal experience with the events and respective negative consequences, particularly recently (i.e., availability) c) priorities of individuals, d) environmental values and value systems in general (see e.g. O'Connor *et al.*, 1999; Grothmann and Patt, 2005; Weber, 2006; Kuruppu and Liverman, 2011). Furthermore, the perceptions of risk and reactions to such risk and actual events are also shaped by motivational processes (Weber, 2010). In this context people will often ignore predictions of climate-related hazards if those predictions fail to elicit emotional reactions. In contrast, if the event or forecast of such an event elicits strong emotional feelings of fear, people may overreact and panic (see Slovic *et al.*, 1982; Slovic, 1993; Slovic, 2010; Weber, 2006). Public perceptions of risks are not solely determined by the "objective" information, but rather are the product of the interaction of such information with psychological, social, institutional, and cultural processes and norms which are partly subjective, as demonstrated in various crises in the context of extreme events (Kasperson *et al.*, 1988; Sagiya, 2011; Funabashi and Kitazawa, 2012). Risk perceptions particularly influence and increase vulnerability in terms of false perceptions of security (Cardona *et al*, 2012, p. 70). Finally, it is important to acknowledge that everyday concerns and satisfaction of basic needs may prove more pressing than attention and effort toward actions to address longer-term risk factors e.g., climate change (Maskrey, 1989; Wisner *et al.*, 2004; Maskrey, 2011). Rather, peoples' worldviews and political ideologies guide attention toward events that threaten their preferred social order (Douglas and Wildavsky, 1982; Kahan, 2010).

19.6.2. Key Risks

19.6.2.1. Assessing Key Risks

Key risks arise from the interaction of climate-related hazards and key vulnerabilities of societies, communities, or systems exposed (see Figure 19-1). Various chapters in this report have assessed key risks from their particular perspectives. We asked each chapter author team to provide Chapter 19 authors with the key risks of highest concern to their chapter based on the criteria for defining key risks and key vulnerabilities as outlined in 19.2.2. A complete presentation of the key risks provided by chapters is found in CC-KR (allowing for some condensation by authors of Chapter 19 to avoid repetition). The key risks provided by the chapters represent the issues most pressing to each set of experts. The list is neither unique nor exhaustive: other authors might express other preferences; however, this compilation provides important insights about key risks and their determinants: hazard, exposure, and vulnerability. Chapter 19 authors further consolidated these key risks in Table 19-4 in order to produce the following list which, in their judgment (*high confidence*), is representative of the range of key risks forwarded to this chapter. Roman numerals preceding each key risk correspond with entries in Table 19-4. Each key risk is followed with a notation in brackets indicating the Reason(s) for Concern (RFCs, see 19.6.3.) with which it is aligned. Additionally, a representative set of lines of sight is provided from across the chapters. Examples of these risks are also displayed geographically in Figure 19-2:

- **(i) Risk of death, injury, and disruption to livelihoods, food supplies, and drinking water, in addition to loss of common-pool resources, sense of place, and identity due to sea level rise, coastal flooding and storm surges affecting high concentrations of people, economic activity, biodiversity, and critical infrastructure in low-lying coastal zones and small island developing states.** These risks further increase in regions where the capacity to adapt long-lived coastal infrastructure (e.g. electricity, water and sanitation infrastructure) to local sea level rise beyond one meter is limited. Urban populations with substandard housing and inadequate insurance, as well as marginalized rural populations with multidimensional poverty and limited alternative livelihoods are particularly vulnerable to these hazards. Inadequate local governmental attention to disaster risk reduction and adaptation can further increase the vulnerability of people and also the risk of adverse consequences (AR5 WGI Sections 3.7.1, 13.5.1, Table 13.5; AR5 WGII Sections 5.4.3, 8.1.4, 8.2.3, 8.2.4, 13.1.4, 13.2.2, 24.4, 24.5, Box 25-1, Box 25-7, 26.7, 26.8, 29.3.1, 30.3.1). [*RFC 1, 2, 3, 4, and 5*]

- **(ii) Risk of food insecurity and the breakdown of food systems linked to warming, drought and precipitation variability particularly in regions that are characterized by poorer populations in urban and rural settings. This risk is a particular concern for** farmers who are net food buyers and people in low-income, agriculturally dependent economies that are net food importers). Climatic hazards and the vulnerability of people (see above) may exacerbate malnutrition, giving rise to a larger burden of disease in these groups, especially among elderly and female-headed households having limited ability to cope. The reversal of progress in reducing malnutrition is a potential outcome (AR5 WGI Section 11.3.2; AR5 WGII Sections 7.4, 7.5, 11.3, 11.6.1, 13.2.1, 13.2.2, 19.3.2, 19.4.1, 22.3.4, 24.4, 26.8, 27.3.4). [*RFC 2, 3 and 4*]
- **(iii) Risk of severe harm due to inland flooding and the limited coping and adaptive capacities of large urban populations.** Particularly vulnerable are marginalized and poverty-stricken residents in low-income informal settlements as well as children, the elderly, and the disabled that have limited means to cope and adapt. Risks are increasing due to rapid and unsustainable urbanization especially in areas where risk governance capacities are constrained or limited attention is given to risk reduction and adaptation measures. Also, overwhelmed, aging, poorly maintained and inadequate infrastructure (e.g. drainage infrastructure, electricity, water supply, etc.) can further increase the risk of severe harm and threats to human security in the case of inland flooding (AR5 WGI Section 11.3.2.5; AR5 WGII Sections 3.2.7, 3.4.8, 8.2.3, 8.2.4, 13.2.1, 25.10, Box 25-8, 26.3, 26.7, 26.8, 27.3.5). [*RFC 2 and 3*]
- **(iv) Risk of loss of rural livelihoods and income of rural residents due to insufficient access to drinking and irrigation water, and reduced agricultural productivity, as well as risk of food insecurity, particularly for farmers and pastoralists with minimal capital in semi-arid regions. Interaction of warming and drought with lack of alternative sources of income, and the presence of regional and national conditions that lead to a breakdown of food distribution and storage systems increases risk.** Especially vulnerable are those with limited ability to compensate for losses in water-dependent farming and pastoral systems, as well as those subject to conflict over natural resources. Additionally, insufficient supply of water due to droughts and institutional vulnerabilities (e.g., lack of state capacities, conflicts) for both industry and urban populations lacking running water, yielding severe economic impacts and other harms (AR5 WGI Section 12.4.1, 12.4.5; AR5 WGII Sections 3.2.7, 3.4.8, 3.5.1, 8.2.3, 8.2.4, 9.3.3, 9.3.5, 13.2.1, 19.3.2.2, 24.4). [*RFC 2 and 3*]
- **(v) Systemic risks due to multiple interacting hazards affecting infrastructure in combination with a high dependency of people on critical services (electricity, water supply, health and emergency services) which may break down during extreme events.** Interdependency of critical infrastructure increases the risk of systemic breakdowns of vital services, for example, the risk of failure in systems dependent on electric power (such as drainage systems reliant on electric pumps) during extreme events. Health and emergency services rely on critical infrastructure (e.g. telecommunication) that can be disrupted during such power failures. For example, Hurricane Katrina left 1,220 electricity-dependent drinking water systems in Louisiana, Mississippi, and Alabama inoperable for several weeks (Copeland, 2005). Overly hazard-specific management planning and infrastructure design and/or low forecasting capabilities exacerbate such risks (AR5 WGI 11.3.2; AR5 WGII Sections 8.1.4, 8.2.4, 10.2, 10.3, 12.6, 23.9, 25.10, 26.7, 26.8). [*RFC 2, 3, and 4*]
- **(vi) Risk of loss of marine ecosystems and the services they provide for coastal livelihoods. Biodiversity and coastal ecosystem services important for fishing communities in the tropics and the Arctic are especially at risk due to rising water temperature and the increase of stratification and ocean acidification.** Loss of Arctic sea ice and degradation of coral reefs, as well as other natural barriers, presents a high risk to ecosystem services where many people are exposed to coastal hazards and also depend on coastal resources for livelihoods, such as Alaska, the Philippines and Indonesia (AR5 WGI Section 11.3.3; AR5 WGII Sections 5.4.2, 6.3.1, 6.3.2, 7.4.2, 9.3.5, 22.3.2.3, 25.6, 27.3.3, 28.2, 28.3, 29.3.1, 30.5, 30. 6, CC-OA, CC-CR). [*RFC 1, 2, 3, 4, and 5*]

- **(vii) Risk of loss of terrestrial ecosystems and the services they provide for terrestrial livelihoods. Biodiversity and terrestrial ecosystem services are important for rural and urban communities globally. These services are at risk due to rising temperatures, changes in precipitation patterns, and extreme weather events. Risks are high for communities whose livelihoods depend on provisioning services.** Human and natural systems are susceptible to loss of provisioning services such as food and fibre, regulating services such as water quality, fire and erosion, and cultural services such as aesthetic values and tourism (AR5 WGI Section 11.3.2.5; AR5 WGII Sections 4.3.4, FAQ 4.4, 19.3.2.1, 22.4.5.6, Table 23-2, 27.3.2.1, Box CC-WE). [*RFC 1, 3 and 4*]
- **(viii) Risk of mortality, morbidity, and other harms during periods of extreme heat, particularly for urban populations of the elderly, infants, people with chronic diseases or compromised immune systems, and expectant mothers. Increasing frequency and intensity of extreme heat (including exposure to the urban heat island effect and air pollution) interacts with an inability of some local organizations that provide health, emergency, and social services to adapt to new risk levels for vulnerable groups.** In addition, the impact of heat stress on aging populations, such as during the heat wave disaster in 2003 in Europe, shows how changing climatic conditions interact with trends in population structure, health conditions and social isolation (characteristics of vulnerability) to create key risks [AR5 WGI Section 11.3.2; AR5 WGII Sections 8.2.3, 11.3, 11.4.1, 13.2, 23.5.1, 24.4.6, 25.8.1, 26.6, 26.8, CC-HS). [*RFC 2 and 3*]

An important common characteristic of all key risks associated with anthropogenic climate change is that they are determined by hazards due to changing climatic conditions on the one hand and the vulnerability of exposed societies, communities and social-ecological systems, e.g. in terms of livelihoods, infrastructure, ecosystem services and management/governance systems on the other (see Table 19-4). The compilation of key risks underscores that effective adaptation and risk reduction measures would address all three components of risk (*high confidence*).

[INSERT TABLE 19-4 HERE
Table 19-4: A selection of the hazards, key vulnerabilities, key risks, and emergent risks identified in various chapters in this report (Chapter 4, 6, 7, 8, 9, 11, 13, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30). Key risks are determined by hazards interacting with vulnerability and exposure of human systems, and ecosystems or species. The table underscores the complexity of risks determined by various climate-related hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, unsustainable and rapid urbanization, other demographic changes, failure in governance and inadequate governmental attention to risk reduction, and tolerance limits of species and ecosystems which often provide important services to vulnerable communities, generate the context in which climatic change related harm and loss can occur. The table illustrates that current global megatrends (e.g. urbanization and other demographic changes) in combination and in specific development context (e.g. in low-lying coastal zones), can generate new systemic risks in their interaction with climate hazards that exceed existing adaptation and risk management capacities, particularly in highly vulnerable regions, such as dense urban areas of low-lying deltas. Roman numerals correspond with key risks listed in 19.6.2.1. A representative set of lines of sight is provided from across AR5 WGI and WGII. See Section 19.6.2.1 for a full description of the methods used to select these entries.]

19.6.2.2. The Role of Adaptation and Alternative Development Pathways

As discussed in section 19.2.4, the identification of key risks depends in part on the underlying socio-economic conditions assumed to occur in the future, which can differ widely across alternative development pathways. This section assesses literature that compares impacts across development pathways, compares the contributions of anthropogenic climate change and socio-economic development (through changes in vulnerability and exposure) to climate-related impacts, and examines the potential for adaptation to reduce those impacts. Based on this assessment, risks vary substantially across plausible alternative development pathways and the relative importance of development and climate change varies by sector, region and time period, but in general both are important to understanding possible outcomes (*high confidence)*. In some cases, there is substantial potential for adaptation to reduce risks, with development pathways playing a critical role in determining challenges to adaptation, including through their effects on ecosystems and ecosystem services (Rothman *et al.*, 2013).

Direct comparison of impacts across alternative development pathways shows, for example, that socio-economic conditions are an important determinant of the impacts of climate change on food security, water stress and the consequences of extreme events and sea level rise. The additional effect of climate change and CO_2 fertilization on the number of people at risk from hunger by 2080 generally spans a range of +/- 10-30 million across the four marker SRES scenarios, each of which assumes different socio-economic futures. However, in a scenario (A2) with high population growth and slow economic growth, this effect becomes as high as 120-170 million in some analyses (Schmidhuber and Tubiello, 2007). Similarly, the number of people exposed to water stress in a global study is sensitive to population growth assumptions (Arnell and Lloyd-Hughes, 2013), as are projected water resources in the Middle East under an A1B climate change scenario (Chenoweth et al., 2011). Assessments of the risks from river flooding depend on alternative future population and land use assumptions (Bouwer *et al.*, 2010; te Linde *et al.*, 2011), and sea level rise impacts depend on development pathways through their effect on the exposure of both the population and economic assets to coastal impacts, as well as on the capacity to invest in protection (Anthoff *et al.*, 2010).

The view that development pathways are an important determinant of risk related to climate change impacts is further supported by two other types of studies: those that examine the vulnerability of subgroups of the current population, and those that compare the relative importance of climate and socio-economic changes to future impacts. The first type finds that variation in current socio-economic conditions explains some of the variation in risks associated with climate and climate change, supporting the idea that alternative development pathways, which describe different patterns of change in these conditions over time, should influence the future risks of climate change. For example, socio-economic conditions have been found to be a key determinant of risks to low-income households due to climate change effects on agriculture (Ahmed *et al*., 2009; Hertel *et al.*, 2010), to sub-populations due to exposure to heterogeneous regional climate change (Diffenbaugh *et al.*, 2007), and to low-income coastal populations due to storm surges (Dasgupta *et al.*, 2009). Assessments of environmentally induced migration have concluded that migration responses are mediated by a number of social and governance characteristics that can vary widely across societies (Warner, 2010; see Sections 19.4.2.1, 12.4).

The second type of study finds that within a given projection of future climate change and change in socio-economic conditions, typically both are important to determining risks. In fact, the effect of the physical impacts of climate change on globally-aggregated changes in food consumption or risk of hunger have been found to be small relative to changes in these metrics driven by socio-economic development alone (Schmidhuber and Tubiello, 2007; Nelson *et al.*, 2010; Wiltshire *et al.*, 2013). Similarly, future population growth is found to be an equally (Murray *et al.*, 2012) or more (Fung *et al.*, 2011; Shewe *et al.*, in press) important determinant of globally-aggregated water stress as the level of climate change, and population growth, economic growth, and urbanization are expected to largely drive potential future damages to coastal cities due to flooding (*high confidence*, Section 5.4.3.1; Hallegatte *et al.*, 2013) and to be important determinants of damages from tropical cyclones (Bouwer *et al.*, 2007; Pielke Jr., 2007; Mendelsohn et al., 2012). At the regional level, socio-economic development has also been found to be equally or more important than climate change to impacts in Europe due to sea level rise, through coastal development (Hinkel *et al.*, 2010); heat stress, especially when acclimatization (Watkiss and Hunt, 2012) or aging (Lung *et al.*, 2013) is taken into account; and flood risks, through exposure due to land use and distributions of buildings and infrastructure (Feyen *et al.*, 2009; Bouwer *et al.*, 2010). Climate change was the dominant driver of flood risks in Europe when future changes in the value of buildings and infrastructure at risk were excluded from the analysis (te Linde *et al.*, 2011; Lung *et al.*, 2013) or when biophysical impacts such as stream discharge, rather than its consequences, were assessed (Ward *et al.*, 2011).

Land use is another socio-economic factor that can affect risks in addition to climate change, but until recently few studies have addressed the combined impacts of climate change and land use on ecosystems (Warren *et al.*, 2011). Studies of land use change scenarios alone project a large increase in extinction rates in the coming decades (Sala *et al.*, 2000; Millenium Ecosystem Assessment, 2005). A study of land bird extinction risk found some sensitivity to four alternative land use scenarios, but by 2100 risk was dominated by the climate change scenario (Şekercioğlu, 2008). A study of European land use found that while land use outcomes were more sensitive to the assumed socio-economic scenario, consequences for species depended more on the climate scenario (Berry *et al*., 2006).

Explicit assessments of the potential for adaptation to reduce risks have indicated that there is substantial scope for reducing impacts of several types, but the capacity to undertake this adaptation is dependent on underlying development pathways. Assessments of the impacts of sea level rise, for example, show that if development pathways allow for substantial investment of resources in adaptation through coastal protection, as opposed to accommodation or abandonment strategies, reducing impacts by investing in coastal protection can be an economically rational response for large areas of coastline globally (Nicholls *et al.*, 2008a; Nicholls *et al.*, 2008b; Anthoff *et al.*, 2010; Nicholls and Cazenave, 2010; Hallegatte *et al.*, 2013) and in Europe (Bosello *et al.*, 2012b). For the specific case of sea level rise impacts in Europe, adaptation in the form of increasing dike heights and nourishing beaches, at a cost reaching about €2 billion per year by 2100, was found to reduce the number of people affected by coastal flooding in 2100 from hundreds of thousands to a few thousand per year depending on the socio-economic and sea level rise scenario (A2 vs B1), and total economic damages from about €17 billion to about €2 billion per year (Hinkel *et al.*, 2010). In contrast, in some areas with higher current and anticipated future vulnerability such as low-lying island states and parts of Africa and Asia, impacts are expected to be greater and adaptation more difficult (Nicholls *et al.*, 2011).

Similarly, the risk to food security in many regions could be reduced if development pathways increase the capacity for policy and institutional reform, although most impact studies have focused on agricultural production and accounted for adaptation to a limited and varying degree (Lobell *et al.*, 2008; Nelson *et al.*, 2009; Ziervogel and Ericksen, 2010). A study of response options in Sub-Saharan Africa identified some scope for adapting to climate change associated with a global warming of 2°C above pre-industrial levels (Thornton *et al.*, 2011), given substantial investment in institutions, infrastructure, and technology, but was pessimistic about the prospects of adapting to a world with 4°C of warming (Thornton *et al.*, 2011; see also section 19.7.1). Improved water use efficiency and extension services have been identified as the highest priority agricultural adaptation options available in Europe (Iglesias *et al.*, 2012) and a potentially large role for expanded desalination has been identified for the Middle East (Chenoweth *et al.*, 2011).

19.6.3. Updating Reasons for Concern

The Reasons for Concern (RFCs) are the relationship between global mean temperature increase and five categories of impacts that were introduced in the IPCC TAR (Smith *et al.*, 2001) in order to facilitate interpretation of Article 2 (1.2.3, Box 19-2). In AR4, new literature related to the five RFCs was assessed, leading in most cases to confirmation or strengthening of the judgments about their relevance to defining dangerous anthropogenic interference based on evidence that some impacts were already apparent, higher likelihoods of some climate-related hazards, and improved identification of currently vulnerable populations (Schneider *et al.*, 2007; Smith *et al.*, 2009).

RFCs are related to the framework of key risks, climate-related hazards, and vulnerabilities used in this chapter because each RFC is understood to represent a broad category of key risks to society or ecosystems associated with a specific type of hazard (extreme events, large-scale singular events), system at risk (unique and threatened systems), or characteristic of risk to social-ecological systems (aggregate impacts on those systems, distribution of impacts to those systems). For example, the RFC for extreme events implies a concern for risks to society and ecosystems posed by extreme events, rather than a concern for extreme events *per se*. Accordingly, in this chapter we have reworded the definition of RFCs to emphasize risk.

In this section we assess new literature related to each of the RFCs, concluding that, compared to judgments presented in AR4 and in Smith *et al.* (2009), levels of risk associated with extreme events and distribution of impacts are similar but can be assessed with higher confidence; risks associated with aggregate impacts are similar and confidence in the assessment unchanged; and risks to unique and threatened systems and those associated with large-scale singular events are higher above 2°C (compared to a 1986-2005 baseline), than assessed previously. These judgments are illustrated in Figure 19-4, an updated version of the "burning embers" diagram that describes how the additional risk due to climate change for each RFC changes with increasing GMT. We retain the color scheme employed in previous versions of this figure (Smith *et al.* 2001; Smith *et al.*, 2009) with some refinement. White, yellow, and red indicate neutral, moderate, and high additional risk, respectively. Risk is low in the transition between white and yellow, and substantial in the transition between yellow and red. We add a new color (purple) indicating very high risk as elaborated below.

Sub-sections below assess risks for each RFC and locate transitions between colors using the criteria for key risks as a guide (19.2.2.2). The transition from white to yellow is partly defined by the GMT at which there is at least medium confidence that impacts associated with a given risk are both detectable and attributable to climate change, while also accounting for the magnitude of the risk. We draw on Section 18.6.4 to inform the placement of this transition relative to recent GMT. The transition from yellow to red is defined by increasing magnitude (including pervasiveness) or likelihood of impacts, with high risk (red color) defined as risk of severe and widespread impacts that is judged to be "high" on one or more criteria for assessing key risks (19.2.2.2). The transition from red to purple is defined by very high risk of severe impacts and the presence of significant irreversibilities or persistence of climate-related hazards combined with limited ability to adapt due to the nature of the hazard or impact. As was true in the TAR and Smith et al. (2009), transitions are fuzzy due to uncertainties in a variety of factors determining the relation between GMT and risk, including the rate of climate change, the time at which the temperature is reached, and the extent and agreement of the evidence base in the literature.

We also clarify the concept of RFCs: because risks depend not only on physical impacts of climate change but also on exposure and vulnerability of societies and ecosystems to those impacts, RFCs as a reflection of those risks depend on both factors as well (see also Section 19.1).

19.6.3.1. Variations in RFCs across Socio-Economic Pathways

The determination of key risks as reflected in the Reasons for Concern (RFCs) has not previously been distinguished across alternative development pathways. In the TAR and AR4, RFCs took only autonomous adaptation into account (Smith *et al.*, 2001; Schneider *et al*., 2007, AR4 WGII Chapter 19). However, the RFCs represent risks that are determined by both climate-related hazards and the vulnerability and exposure of social and ecological systems to climate change stressors. Figure 19-5 illustrates this dependence on vulnerability and exposure in a modified version of the burning embers diagram. Current literature is not sufficient to support confident assessment of specific RFCs using this approach.

As literature accumulates, it could inform new versions of this figure applied to specific RFCs. For example, studies that employ particular scenarios of socio-economic conditions could be categorized according to the levels of vulnerability represented by those scenarios (van Vuuren *et al.*, 2012) to locate results along the horizontal axes, while climate conditions assumed in those studies would locate results along the vertical axis. As with previous versions of the burning embers, however, this new figure does not explicitly address issues related to rates of climate change or to when impacts might be realized. The updates of RFCs in 19.6.3.2-19.6.3.6 which follow (and are illustrated in Figure 19-4) do not account for differences in vulnerability across development paths; rather, they are based on the same assessment framework as used in AR4 and Smith *et al.* (2009), but with additional elaboration.

[INSERT FIGURE 19-4 HERE
Figure 19-4: The dependence of risk associated with the Reasons for Concern (RFCs) on the level of climate change, updated from TAR and Smith *et al.* (2009). The color scheme indicates the additional risk due to climate change as described in the text. The shading of each ember provides a qualitative indication of the increase in risk with temperature for each individual "reason." The transition from red to purple, introduced here, is defined by very high risk of severe impacts and the presence of significant irreversibilities or persistence of climate-related hazards combined with limited ability to adapt due to the nature of the hazard or impact. Comparison of the increase of risk across RFCs indicates the relative sensitivity of RFCs to increases in GMT. In general, assessment of RFCs takes autonomous adaptation into account, as was done previously (Smith *et al.*, 2001; Schneider *et al.*, 2007, AR4 WGII Chapter 19). In addition, this assessment took into account limits to adaptation in the case of RFC1, RFC3, and RFC5, independent of the development pathway. The rate and timing of climate change and physical impacts, not illustrated explicitly in this diagram, was taken into account in assessing RFC1 and RFC5. Comments superimposed on RFCs provide additional details which were factored into the assessment. The levels of risk illustrated reflect the judgments of Chapter 19 authors.]

[INSERT FIGURE 19-5 HERE
Figure 19-5: Illustration of the dependence of risk associated with a Reason for Concern (RFC) on the level of climate change and exposure and vulnerability (E&V) of society. This figure is schematic; the degree of risk associated with particular levels of climate change or E&V has not been based on a literature assessment, nor associated with a particular RFC (the “burning ember” in the figure refers generically to any of the embers in Figure 19-4). The E&V axis is relative rather than absolute: “Medium” E&V indicates a future development path in which E&V changes over time are driven by moderate trends in socio-economic conditions. “Low” and “High” E&V indicate futures that are substantially more optimistic or pessimistic, respectively, regarding exposure and vulnerability. Judgments made in other burning ember diagrams of the RFCs (Smith *et al.*, 2001, 2009) including Figure 19-4, which do not explicitly take changes in E&V into account, are consistent with Medium future E&V. Arrows and dots illustrate the use of SRES scenario-based literature to locate particular impact or risk assessments on the figure according to the evolution of climate and socio-economic conditions over time. This figure does not explicitly address issues related to the rates of climate change or when impacts might be realized.]

19.6.3.2. Unique and Threatened Systems

Unique and threatened systems include a wide range of physical, biological and human systems that are restricted to relatively narrow geographical ranges and are threatened by future changes in climate (Smith *et al.*, 2001). Where consequences are *irreversible* and *importance* to society and other systems is high, the potential for loss of or damage to such systems constitutes a key risk. AR4 stated with *high confidence* that a warming of up to 2°C above preindustrial levels would result in significant impacts on many unique and vulnerable systems and would increase the endangered status of many threatened species, with increasing adverse impacts (and increasing confidence in this conclusion) at higher temperatures (Schneider *et al.*, 2007). Since AR4, there is a growing body of literature suggesting that the number of threatened systems and species is greater than previously thought.

Chapters 4, 22, 23, 24, 25, 26, and 27 highlight areas where unique and threatened systems are particularly vulnerable to climate change. Evidence for severe and widespread impacts to humans and social systems, ecosystems and species in polar regions as warming progresses has continued to accrue (Sections 4.3.3.4, 28.2). Projections of Arctic sea ice melt rates have increased since AR4 (WGI Section 12.4.6), increasing risks to the Inuit and the sea ice-dependent ecosystems upon which they subsist . CMIP5 model runs for September with all RCPs show substantial additional losses of Arctic Ocean ice for a global warming of 1^0C relative to 1986-2005 and a nearly ice-free Arctic Ocean for global warming greater than 2^0C (AR5 WGI Figures 12-30). Futhermore, a nearly ice-free Arctic Ocean in September before mid-century is *likely* under RCP8.5 (*medium confidence*, AR5 WGI Section 12.4.6).

Coral reef ecosystems are still considered amongst the most vulnerable of unique marine systems (Sections 5.4.2.4, 19.3.2.4), with corals’ evolutionary responses being outpaced by climate change (Hoegh-Guldberg, 2012) resulting in projections of extensive reef decline throughout the 21st century. Globally, large-scale reef dissolution may occur if CO_2 concentrations reach 560 ppm (Sections 5.4.2.4) due to the combined effects of warming and ocean acidification. Even if global temperature rise in the 2090s is constrained to 1.2-2.0°C above pre-industrial levels (AR5 WGI Table 12.3, RCP2.6), 9-60% of reefs are projected to be subject to long-term degradation; whilst 30-88% of reefs are projected to eventually degrade if global temperature rises in the 2090s by 1.9-2.9°C above pre-industrial levels (RCP4.5; Box CC-CR, Coral Reefs; temperatures from AR5 WGI Table 12.3). Loss of corals and mangrove ecosystems would endanger the livelihoods of unique human communities and cause economic damage (Section 4.3.3 for global discussion; Sections 22.3.2.3, 24.4.3, 25.6 for Africa, Asia, and Australia; section 26.4 for N. America; section 27.3.3.1 and Figure 27.5 for S. America).

There is a large and increasing amount of evidence for escalating risks of species range loss, extirpation and extinction based on studies for global temperatures exceeding 2°C above pre-industrial levels (1.4°C above 1986-2005; Warren *et al.*, 2011; Şekercioğlu *et al.*, 2012, Foden *et al.*, 2013; Warren *et al.*, 2013a). An assessment of 16,857 species (Foden *et al.*, 2013) found that with approximately 2°C of warming above preindustrial (A1B, 2050s), 24-50% of the birds, 22-44% of the amphibians and 15-32% of the corals were highly vulnerable to climate change defined as having high sensitivity, high exposure, and low adaptive capacity.

An increasing number of threatened systems has been identified, in the form of projected species range losses and extinction risks, although without yet tying risks to specific levels of warming. Evidence of climate risks to unique mountain ecosystems and their numerous endemic alpine species has continued to accrue in Europe, Asia, Australia and South America (Sections 23.6.4, 24.4.2.3, 25.6.1, 27.3.2.1). Siberian, tropical, and desert ecosystems in Asia (24.4.2.3), Africa (Warren *et al.*, 2013a), and Mediterranean areas in Europe (Klausmeyer and Shaw, 2009; Maiorano *et al.*, 2011), the Southwest Kakadu, and Queensland rainforests in Australia (Section 25.6.1), Amazonian ecosystems in South America (Foden *et al.*, 2013; Warren *et al.*, 2013a) and freshwater ecosystems in Africa (specifically Ethiopia, Malawi, Mozambique, Zambia and Zimbabwe) (Sections 4.3.3.3, 22.3.2.2) are particularly at risk, as are the Fynbos and succulent Karoo areas of South Africa (Midgley and Thuiller, 2011; Kuhlmann *et al.*, 2012; Huntley and Barnard, 2012) and dune systems in temperate climates (Section 23.6.5). Recent research has identified risks to highly biodiverse tropical wet and dry forests (Sections 4.3.3 and 24.4.2.3; Wright et al., 2009; Kearney *et al.*, 2009, Toms *et al.*, 2012) and tropical island endemics (Fordham and Brook, 2010). Globally amphibians were found to be the most vulnerable of vertebrate taxa (Stuart *et* al., 2004; Brito, 2008; Rohr and Raffel, 2010; Liu *et al*., 2013; Warren *et al.*, 2013a).

Owing to higher projections of sea level rise than in AR4 (AR5 WGI Sections 13.5, 13.6, 13.7), risk of partial inundation of small island states has increased.

Since AR4, almost all glaciers world-wide have continued to shrink as revealed by the time series of measured changes in glacier length, area, volume and mass (*very high confidence*, AR5 WGI Chapter 4 ES). There is substantial new evidence that across most of Asia glaciers have been shrinking, except in some areas in the Karakorum and Pamir (section 18.5.3). In the Andes, glacier loss threatens to reduce the water and electricity supplies of large cities and hydropower projects, as well as the agricultural and tourism sectors (27.3.1.1, 27.3.1.2, Table 27.3, case study 27.6.1). Some climate model simulations show significant loss of glacial cover in central Asia by 2100 under “the higher climate change scenarios considered by IPCC AR4” (Section 24.9.2). Loss of glacial cover has been projected to significantly reduce water supplies in meltwater-dependent arid regions (Kaser, 2010), potentially threatening the food security of 60 million people in the Brahmaputra and Indus basins by the 2050s (Immerzeel *et al.*, 2010). A caveat is that recent work has suggested that glacier melt rates were overestimated and precipitation may increase, so that runoff would rise at least until 2050 (Immerzeel *et al*., 2013). Large uncertainties in projections of Himalayan ice cover and runoff dynamics remain (Bolch *et al.*, 2012).

In Figure 19-4, we locate the transition to moderate risk (white to yellow) below recent global temperatures because there is at least *medium confidence* in attribution of a major role for climate change for impacts on at least one each of ecosystems, physical systems, and human systems (AR5 WGII Section 18.6.4). A transition to purple is located around 2°C above 1986-2005 levels to reflect the very high risk to species and ecosystems projected to occur beyond that level as well as limited ability to adapt to impacts on coral reef systems and on Arctic sea ice-dependent systems (Chapters 4, 24) if that level of warming were exceeded (*high confidence)*. A transition to red is located at 1°C above 1986-2005 levels, midway between current temperature and the transition to purple, indicating the increasing risk to unique and threatened systems, including Arctic sea ice and coral reefs, as well as threatened species as temperature increases over this range.

19.6.3.3. Extreme Events

Extreme weather events (e.g., heat waves, intense precipitation, drought, tropical cyclones) trigger impacts that can pose key risks to societies that are exposed and vulnerable (Lavell *et al*., 2012 (SREX, Chapter 1)). With regard to the physical hazard aspect of risk, AR5 assesses a higher likelihood of attribution of heat waves and extreme hot days and nights to human activity than AR4. AR5 WGI states, “We assess that it is *very likely* that human influence has contributed to the observed changes in the frequency and intensity of daily temperature extremes on the global scale since the mid-20th century” (AR5 WGI 10.6.1.1) and “it is *likely* that human influence has substantially increased the probability of occurrence of heat waves in some locations” (AR5 WGI Section 10.6.2). WGI finds *medium confidence* in attribution of intensification of heavy precipitation over Northern Hemisphere land areas with sufficient data (AR5 WGI Section 10.6.1.2), and *low confidence* in detection and attribution of changes in drought over global land areas (AR5 WGI Section 10.6.1.3) and global changes in tropical cyclone activity (AR5 WGI Section 10.6.1.4) to human influence. There is *high confidence* in attribution of impacts of weather extremes (as opposed to the physical hazards alone) on coral reef systems (Section 18.6.4; Table 18-10; Section 19.6.3.2), with evidence for impact attribution limited and highly localized otherwise.

The likelihood of projected 21st century changes in extremes has not changed markedly since AR4 (AR5 WGI Chapters 10 and 12), but for the first time near-term changes (for the period 2016-2035 relative to 1986-2005) are assessed (AR5 WGI Chapter 1), a period during which the increase in the model and scenario averaged GMT is projected to remain below 1°C relative to 1986-2005 (AR5 WGI Figure 11.8; AR5 WGI Section 11.3.6.3). Among the conclusions are, "In most regions the frequency of warm days and warm nights will *likely* increase in the next decades, while that of cold days and cold nights will decrease" (AR5 WGI Chapter 11 ES). Specifically, 15% of currently observed maximum daily temperatures exceed the historical 90th percentile values (rather than the historical 10%) and by about 2035, 25-30% of daily maximums are projected to exceed the historical 90th percentile value (AR5 WGI Figures 11-17). WGI also notes that "Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells" (AR5 WGI Section 11.3.2.5.1, Table SPM.1). With regard to extreme precipitation events, WGI finds "The frequency and intensity of heavy precipitation events over land will *likely* increase on average in the near term. However, this trend will not be apparent in all regions because of natural variability and possible influences of anthropogenic aerosols and land use change" (AR5 WGI Chapter 11 ES). In addition, SREX (Figure SPM 4B) projects a reduction in return period for historical once-in-20-yr precipitation events globally (land only) to about once-in-14-yr or less by 2046-65.

With regard to the vulnerability and exposure aspects of risk, SREX reviewed literature on the relationship between changes in these factors and the risk of extreme events (SREX Sections 4.5.4, 4.5.6). Increases in local vulnerability and exposure to extreme precipitation can lead to a disproportionate increase in overall risk (SREX sections 4.3.5.1, 9.2.8; Douglas *et al.*, 2008; Douglas, 2009; Hallegate *et al.*, 2011; Ranger, 2011). For example, growth of megacities both concentrates exposure and vulnerability and can generate "synchronous failure" that spreads beyond the immediate vicinity of extreme events. Megacities increase nighttime temperature extremes via the urban heat island effect (Section 8.2.3.1; IPCC, 2012a Section 4.4.5.2) while also enhancing exposure to high air pollution levels (Fang *et al*., 2013; IPCC, 2012 Section 9.2.1.2.3) and consequent health effects (Sections 11.5.3.2, 11.5.3.4, Table 11-2), with widespread impacts by midcentury in some studies. Densely populated areas of East and South Asia and North America are projected to be especially affected by climate-related air pollution (Fang *et al.*, 2013). Projections of the global socioeconomic (Mendelsohn *et al.*, 2013) impact of tropical cyclones demonstrate increasing risk due to interactions of increasing storm intensity with exposure. Hazard projection suggests a disproportionate increase in exposure to tropical cyclone risk with increasing temperature at New York City due to combined effects of storm intensification and sea level rise (Lin *et al.*, 2012). Other studies (Jongman *et al.*, 2012; Hallegate *et al*., 2013; Preston, 2013) project increasing coastal flood risk due to increasing exposure, although the first two do not disaggregate to specific types of extreme events. Taken together, this evidence supports a conclusion of disproportionate increase in risk associated with extreme events as temperature, and in many cases, exposure and vulnerability increase as well.

Based on the above assessments of the physical hazard alone, we find increased confidence in the AR4 assessment of the risk from extreme events. Based on the attribution of heat and precipitation extremes to anthropogenic climate change, the attribution to climate change of impacts of climate extremes on one unique and threatened system, and the current vulnerability of other exposed systems, we assign a "yellow" level of risk at recent temperatures in Figure 19-4 [*high confidence*], consistent with Smith *et al.*, (2009). We assign a transition to "red" beginning below 1°C compared to 1986-2005 (also consistent with Smith *et al.*, (2009)) based primarily on the *magnitude* and *likelihood* and *timing* (see 19.2.2.2) of the projected change in hazard of extreme events, indicating that impacts will become more severe and widespread over the next few decades [*medium confidence*].

19.6.3.4. Distribution of Impacts

The distribution of impacts is a category of climate change consequences that includes key risks to particular societies and social-ecological systems that may be disproportionately affected due to unequal distribution of hazards, exposure, or vulnerability. AR4 concluded that there is *high confidence* that low-latitude, less-developed areas are generally at greatest risk and found that, because vulnerability to climate change is also highly variable within countries, some population groups in developed countries are also highly vulnerable even to a warming of less than 2°C above 1990-2000 (Schneider *et al.*, 2007). These conclusions remain valid and are now supported by a limited number of impact studies that explicitly consider differences in socio-economic conditions that affect vulnerability across regions or populations (Müller *et al.* 2011, Mougou *et al.* 2011, Schewe *et al.* 2013, Gosling and Arnell, 2013). Furthermore, we have increased confidence in the AR4 assessment of the risk arising in the near term from the distribution of impacts from extreme events because, by their very nature, these events change in a locally and temporally variable fashion with, e.g., a larger change in extreme temperatures at higher latitudes (SREX Figure SPM 4A).

Impacts of climate change on food security depend on both production and non-production aspects of the food system, including not just yield effects but also changes in the amount of land in production and adjustments in trade patterns (Section 7.1.1). Effects on prices are often taken as an indicator of impacts on food security, and the combined effect of climate and CO_2 change (but ignoring O_3 and pest and disease impacts) appears *about as likely as not* to increase prices by 2050, with few new studies examining prospects at longer time horizons (Section 7.4.4). Most studies have focused on geographical differences in the effects of climate change on crop yields. With regard to such distributional consequences, yields of maize and wheat begin to decline with 1-2°C of local warming in the tropics, with or without adaptation taken into account. Temperate maize and tropical rice yields are less clearly affected at these temperatures, but significantly affected with local warming of 3-5°C particularly without adaptation (based on studies with various baselines, see Section 7.3.2.1). These data confirm AR4 findings that even small warming will decrease yields in low-latitude regions (*medium evidence, high agreement*) (Section 7.3.2.1.1), and increase the risk assigned to yields in mid- to high-latitude regions (compared to AR4), suggesting that temperate wheat yield decreases are *about as likely as not* for moderate warming.

Risks of climate change related to freshwater systems such as extreme water shortage increase with global mean temperature rise (*high agreement, medium evidence*) (Chapter 3 ES, Table 3-2). Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (*high agreement, robust evidence)* (Section 3.5). One study using multiple climate and hydrological models to simulate impacts of scenario RCP8.5 and SSP2 project that global warming of 1.7 °C above pre-industrial will reduce water resources by more than one standard deviation, or by more than 20%, for 8% of the global population, whilst for warming of 2.7 °C above pre-industrial this increases to 14% (model range 10-30%) (Schewe *et al*., 2013); and for warming of 3.7 °C above pre-industrial it reaches a mean of 17% across models (Schewe *et al.* 2013). Additionally, in another study (Gosling and Arnell, 2013), climate change amplifies water scarcity by 30-40% for 1.7-2.7 °C of warming, with around 40% of the global population under increased water stress. In one model, exposure to water scarcity increases steeply up to 2.3°C above pre-industrial in N and E Africa, Arabia and S. Asia (Gosling and Arnell, 2013). In Africa water resources risks are 'medium-high' at 2°C and 'high-very high' at 4°C (Chapter 22 Table 22-6). Model projections generally agree that discharge will decrease in the Mediterranean and in large parts of N. and S. America (Schewe *et al.*, 2013). However, there are opportunities for adaptation in the water resources sector, particular for municipal water supply (Section 3.6.5).

The first global scale analysis of climate change impacts on almost 50,000 species of plants and animals has highlighted that risks are not distributed equally, with sub-Saharan Africa, Central America, Amazonia and Australia at risk for plants and animals, and North Africa, Central Asia and Southeastern Europe for many plants (Warren *et al*., 2013a). A traits-based analysis of more than 16,000 species identified Amazonia and Mesoamerica as being at risk for birds and amphibians and central Eurasia, the Congo Basin, the Himalayas and Sundaland for birds, and the Coral Triangle region for corals (Foden *et al.*, 2013).

In summary, since AR4, new evidence has emerged highlighting the *magnitude* of risk for particular regions, for example in relation to the potential for regional impacts upon ecosystems (see Section 19.6.3.2), megadeltas (see

Sections 8.2.3.4 and Chapter 5], and agricultural systems, which is exacerbated by the potential for changes in the monsoon systems (see Section 19.6.3.5; AR5 WGI 12.5.5.). Overall there is increased evidence that low-latitude and less-developed areas generally face greater risk than higher-latitude and more-developed countries (Smith *et al.*, 2009). At the same time, there has been an increase in appreciation for vulnerability (e.g., to extreme events) in developed countries, especially, localised issues of differential vulnerability in particular areas of the developed world [SREX 2.5.1.2].

Regionally differentiated impacts on crop production have been detected and attributed to climate change *with medium to high confidence* (Section 18.4.1.1), and we interpret this as an early warning sign of attributable impacts on food security. For this reason, as well as for reasons of *timing* and *likelihood* and *magnitude* of these risks, the transition from “white” to “yellow” levels of risk in Figure 19-4 is assessed to occur at recent temperatures. Based on risks to regional crop production and water resources the transition from yellow to red is assessed to occur between 1° and 2°C above the 1986-2005 global mean temperature [*medium confidence*]. Both assessments are consistent with Smith *et al.*, (2009). Furthermore, given evidence that agronomic adaptations would be more than offset for tropical wheat and maize where increases in local temperature of more than 3°C above preindustrial occur (*limited evidence, medium agreement;* Section 7.5.1.1.1; AR5 WGII Chapter 7 ES) the intensity of red increases non-linearly toward purple in recognition of the temperature sensitivity of crop productivity and limited efficacy of agronomic adaptation above 2°C compared to 1986-2005.

19.6.3.5. Aggregate Impacts

The RFC pertaining to aggregate impacts includes risks that are aggregated globally into a single metric, such as monetary damages, lives affected, lives lost, or species or ecosystems lost. Estimates of the aggregate, economy-wide risks of climate change since AR4 continue to exhibit a *low level of agreement*. Studies at the sectoral level have been refined with new data and models, and have assessed new sectors.

AR4 stated with *medium confidence* that approximately 20-30% of the plant and animal species assessed to date are likely at increasing risk of extinction as global mean temperatures exceed a warming of 2-3°C above pre-industrial levels (Fischlin *et al.*, 2007). There is *high confidence* that climate change will contribute to increased extinction risk for terrestrial and marine species over the coming century (Section 4.3.2.5). Since AR4 a substantial amount of additional work has been done, looking at many more species and using new and/or improved modelling and traits-based techniques, strengthening the evidence of increasing risk of extinction with increasing temperature (e.g. Hunter *et al.*, 2010; Amstrup *et al.*, 2010; Pearman *et al.*, 2011; Lenoir *et al.*, 2008; Balint *et al.*, 2011; Barnosky *et al.*, 2012; Norberg *et al.*, 2012; Bellard *et al.*, 2012; Foden *et al.*, 2013). More studies have scrutinized caveats to previous studies and assesed their role in either under- or overestimating extinction risks (e.g. Beale *et al.*, 2008; Cressey, 2008; Randin *et al.*, 2009; He and Hubbell, 2011; Harte and Kitzes, 2012), including the role of evolution (Norberg *et al.*, 2012), while others have carefully examined risk considering other species traits (looking at exposure, sensitivity and potential adaptive capacity for large numbers of species; Foden *et al.*, 2013).Literature incorporating multiple new assessment techniques quantifying extinction risks supports the conclusion that the dependence between increasing extinction risk and temperature is *robust* [*medium confidence]*, albeit varying across biota. However, there is *low agreement* on assigning specific numerical values for species at risk (Sections 19.3.2.1, 19.5.1).

Since AR4 it has been found that species that are widespread geographically, not only endemics (which have tended to be the focus of many previous studies) are at risk (Warren *et al.*, 2013a) implying a significant and widespread potential loss of ecosystem services (Section 4.3.2.5, Gaston and Fuller, 2008; Allesina *et al.*, 2009, Staudinger *et al.* 2012), comprising a new emergent risk (Table 19-4). At a global temperature rise of 3.5-4°C above preindustrial, Foden *et al.* (2013) estimated that 20 - 60% of the birds, amphibians and corals studied are highly vulnerable to climate change. Taking this estimate conservatively as a maximum (i.e., assuming all species not studied are able to adapt at least as well as the groups investigated), and combining this estimate with the finding of >50% loss of potential range in 57% of plants and 34% of animals studied globally for the a global temperature rise of 3.5-4°C by the 2080s allowing for realistic dispersal rates (Warren *et al.*, 2013a), there is *high confidence* that climate change will significantly affect biodiversity, and related ecosystem services.

Much new work has focused on future projected synergistic impacts of climate-change induced increases in fire, drought, disease, and pests (Flannigan *et al.*, 2009; Krawchuk *et al.*, 2009; Hegland *et al.*, 2009; Koeller *et al.*, 2009; Garamszegi, 2011). New work has demonstrated that the expected large turnovers of up to 60% in marine species assemblages in response to unmitigated (SRES A1B and SRES B1) climate change by the 2050s, combined with shrinkage of fish body weight of 14–24% (SRES A2) (Cheung *et al.*, 2009; Cheung *et al.*, 2012) put marine ecosystem functioning at risk with negative consequences for fishing industries, coastal communities and wildlife that are dependent on marine resources (Lam *et al.*, 2012).

Consistent with AR4, global aggregate economic impacts from climate change are highly uncertain, with most estimates a small fraction of gross world product up until at least 2.5°C of warming above preindustrial (Section 10.9.1). Some studies suggest net benefits of climate change at 1°C of warming (10.9.1). Little is known about global aggregate damages above 3°C (Sections 10.9.1, 19.5.1) (Ackerman *et al.*, 2010; Weitzman, 2010; Ackerman and Stanton, 2012; Kopp *et al.*, 2012). Aggregate damages vary with alternative development pathways, but the relationship between development pathway and aggregate damages is not well explored. In many sectors, damages as a fraction of output are expected to be larger in low-income economies, although monetized damages are expected to be larger in high-income economies (e.g., Anthoff and Tol, 2010). Adaptation is treated differently across modeling studies (Hope, 2006; de Bruin *et al.*, 2009; Bosello *et al.*, 2010; Füssel, 2010; Patt *et al.*, 2010) and affects aggregate damage estimates in ambiguous ways.

Estimates of global aggregate damages omit a number of factors (Yohe and Tirpak, 2008; Kopp and Mignone, 2012). While some studies of aggregate damages include market interactions between sectors in a computable general equilibrium framework (e.g., Bosello *et al.*, 2012a; Roson and van der Mensbrugghe, 2012), none treat non-market interactions between impacts (Warren, 2011), such as the effects of the loss of biodiversity among pollinators and wild crops on agriculture or the effects of land conversions owing to shifts in agriculture on terrestrial ecosystems (see sections 19.3, 19.4). They do not include the effects of the degradation of ecosystem services by climate change (19.3.2.1) and ocean acidification (19.5.2), and in general assume that market services can substitute perfectly for degraded environmental services (Kopp *et al.,* 2012; Sterner and Persson, 2008; Weitzman, 2010). The global aggregate damages associated with large-scale singular events (19.6.3.6) are not well explored (Kopp and Mignone, 2012; Lenton and Ciscar, 2013).

The risk associated with aggregate impacts is similar to that expressed in AR4 and Smith *et al.*, (2009) as indicated in Figure 19-4, with risk based primarily on economic damages and confidence in the assessment unchanged. For aggregate economic impacts, there is *low* to *medium* confidence in attribution of climate change influence on a few sectors (AR5 WGII Table 18-11 and Section 18.6.4) so that this RFC is still shaded white at recent temperature in Figure 19-4. The “white” to “yellow” transition occurs around 1°C warming compared to 1986-2005 reflecting increasing confidence that the global aggregate economic impact of climate change will become negative and moderate in magnitude [*medium confidence*]. The “yellow” to “red” transition occurs around 3°C, reflecting an increase in the *magnitude* and *likelihood* of both aggregate economic risks (*low confidence*) and risk of extensive loss of biodiversity with concomitant loss of ecosystem services (*high confidence*, 19.3.2.1).

19.6.3.6. Large-Scale Singular Events: Physical, Ecological, and Social System Thresholds and Irreversible Change

Large-scale singular events (sometimes called “tipping points”, or critical thresholds) are abrupt and drastic changes in physical, ecological, or social systems in response to smooth variations in driving forces (Smith *et al.*, 2001; Smith *et al*., 2009; McNeall *et al*., 2011). Combined with widespread vulnerability and exposure, they pose key risks because of the potential magnitude of the consequences, the rate at which they would occur, and depending on this rate, the limited ability of society to cope with them. Research on the societal impacts associated with such events is limited; we focus in this section on physical hazards and ecological thresholds.

Regarding singular events in physical systems, AR4 expressed *medium confidence* that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic Ice Sheet (WAIS), would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1-4°C (relative to 1990-2000), causing a contribution to sea-level rise of 4-6 m or more (Schneider *et al.*, 2007). Studies since AR4 are consistent with these judgments but provide a more detailed view (see AR5 WGI Chapter 13). The Greenland ice sheet (*very likely*) and the Antarctic ice sheet (*medium confidence*) contributed to the 5m (*very high confidence*) to 10m (*high confidence*) sea level rise that occurred during the Last Interglacial (AR5 WGI SPM; Kopp *et al.* 2009; McKay *et al.*, 2011; Dutton and Lambeck, 2012). This period provides a partial analog for the magnitude of mid-to-late 21st century warming because GMT was not more than 2°C warmer than pre-industrial (AR5 WGI SPM, *medium confidence*). However, the resulting sea level rise may have taken millennia to complete.

With regard to projection, AR5 WGI finds that "The available evidence indicates that sustained warming greater than a certain threshold above preindustrial would lead to the near-complete loss of the Greenland Ice Sheet over a millennium or more, causing a global mean sea level rise of up to 7 m. Current estimates indicate that the threshold is greater than 1°C but less than 4°C global mean warming with respect to preindustrial, but *confidence* is *low"* (AR5 WGI SPM). A threshold for the disintegration of WAIS remains difficult to identify due to shortcomings in various aspects of ice sheet modeling, including representation of the dynamical component of ice loss and ocean processes. AR5 notes that sea level rise by 2300 larger than 1-3m "could result from sustained mass loss by ice sheets, and some part of the mass loss might be irreversible" (AR5 WGI SPM). Extreme exposure and vulnerability to the *magnitude* of sea level rise associated with loss of a significant fraction of either ice sheet is found worldwide (Nicholls and Tol, 2006) but millennial timescales for ice loss allow greater opportunities to adapt successfully than do century scales so *timing* is a critical and highly uncertain factor in assessing the risk.

There is also additional evidence regarding singular events in other physical systems. Feedback processes in the Earth system could cause accelerated emissions of methane from wetlands, permafrost and ocean hydrates. There are large uncertainties in the size of carbon stores, the timescales of release and the fate of the carbon once released. The risk of substantial carbon release in the form of methane or carbon dioxide increases with warming. (AR5 WGI Section 6.4.7.3, Figure 6.37; Archer *et al*., 2009; O'Connor *et al.*, 2010). AR5 WGI finds "*low confidence* in modelling abilities to simulate transient changes in hydrate inventories, but large CH_4 release to the atmosphere during this century is *unlikely*" (AR5 WGI Section 6.4.7.3). Due to such uncertainties, the existence of a tipping point cannot be ascertained.

AR4 stated that Arctic summer sea ice disappears almost entirely in some projections by the end of the century (AR4 WGI Section 10.3); WGI AR5 finds that a "nearly ice-free Arctic Ocean (sea ice extent less than 1×10^6 km^2) in September before mid-century is *likely* under RCP8.5 (*medium confidence)* but global climate models show no evidence of a tipping point" (AR5 WGI Chapter 12 ES). Whether or not the physical process is reversible, effects of ice loss on biodiversity may not be.

Large uncertainties remain in estimating the probability of a shutdown of the Atlantic meridional overturning circulation (AMOC). One expert elicitation finds the chance of a shutdown to be between 0 and 60% for global average warming between 2-4°C, and between 5 and 95% for 4-8°C of warming relative to 2000 (Zickfeld *et al.*, 2007; Kriegler *et al.*, 2009). AR5 judges that "It is *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century for the scenarios considered. There is *low confidence* in assessing the evolution of the AMOC beyond the 21st century because of the limited number of analyses and equivocal results. A collapse beyond the 21st century for large sustained warming cannot be excluded" (AR5 WGI SPM).

Regarding regime shifts in ecosystems, there are "early warning signs" from detection and attribution analysis that both Arctic and warm-water coral reef systems are experiencing irreversible regime shifts (Section 18.6.4). Recent observational evidence confirms the susceptibility of the Amazon to drought and fire (Adams *et al.*, 2009), and recent improvements to models provide increased confidence in the existence of a tipping point in the Amazon from humid tropical forest to seasonal forest or grassland as the dominant ecosystem (Jones *et al.*, 2009; Lapola *et al.*, 2009; Malhi *et al.*, 2009; Section 4.3.3.1). In contrast, one recent study suggests that the Amazon may be less susceptible to crossing a tipping point than previously thought (Cox *et al.*, 2013), although this is contingent upon the uncertain role of CO_2 fertilisation being as strong as models project. Overall, recent multi-model estimates based on different CMIP3 climate scenarios and different dynamic global vegetation models predict a moderate risk of tropical forest reduction in South America (AR5 WGI Section 12.4.8.2).

Based on the weight of the above evidence, we judge that the overall risk from large-scale singular events is somewhat higher than assessed in AR4 and indicated by Smith *et al.* (2009). The position of the transition from "white" to "yellow" between 0°C and 1°C compared to 1986-2005 remains as before but with higher confidence due to the existence of early warning signs regarding regime shifts in Arctic and warm-water coral reef systems. The transition from "yellow" to "red" occurs over the 1-4°C range, consistent with Smith et al. (2009) and based primarily on the uncertainty in the warming level associated with eventual ice sheet loss. However, we assess a faster increase in risk as temperature increases between 1°C and 2°C compared to 1986-2005, largely determined by the risk arising from a very large sea level rise due to ice sheet loss as occurred during the Last Interglacial (AR5 WGI Section 5.6.2) when GMT was no more than 2°C warmer than preindustrial (*medium confidence*). This assessment of risk is based primarily on the *magnitude* and *irreversibility* of such sea level rise and the widespread exposure and vulnerability to it. However, as noted, the slower the rate of rise, the more feasible becomes adaptation to reduce vulnerability and exposure. Due to this uncertainty in *timing*, we refrain from imposing a transition to purple in Figure 19-4.

19.7. Assessment of Response Strategies to Manage Risks

The management of key and newly identified risks of climate change can include mitigation that reduces the likelihood of climate changes and physical impacts and adaptation that reduces the exposure and vulnerability of society and ecosystems to both. Key risks, impacts, and vulnerabilities to which societies and ecosystems may be subject will depend in large part on the mix of mitigation and adaptation measures undertaken, as will the evaluation of Reasons for Concern (Section 19.6.3). This section therefore assesses relationships between mitigation, adaptation, and the residual impacts that generate key risks. It also considers limits to both mitigation and adaptation responses, because understanding where these limits lie is critical to anticipating risks that may be unavoidable. Potential impacts involving thresholds for large changes in physical, ecological, and social systems (Section 19.6.3.6) are particularly important elements of key risks, and the section therefore assesses response strategies aimed at avoiding them or adapting to crossing them.

19.7.1. Relationship between Adaptation Efforts, Mitigation Efforts, and Residual Impacts

Under any plausible scenario for mitigation and adaptation, some degree of risk from residual damages is unavoidable (*very high confidence*). Evaluating potential mixes of mitigation, adaptation, and impacts requires joint consideration of outcomes for climate change and socio-economic development. A principal way in which these different mixes are assessed is comparing the impacts that result from scenarios with little or no mitigation (and therefore more climate change) to those with substantial mitigation (and less climate change). Climate change mitigation costs have been extensively explored (AR5 WGIII Chapter 6), but there has been less work on quantifying the impacts avoided by mitigation and, with the exception of studies of the impacts of sea level rise (Nicholls *et al.*, 2011), treatment of adaptation has been limited and uneven. In this section, unless otherwise stated global temperature rise is given relative to pre-industrial levels.

Impact studies generally indicate that mitigation can reduce a large proportion of climate change impacts that would otherwise occur *(high confidence).* In one study, mitigation that stabilizes global CO_2 concentrations at 500ppm reduces by 80-95% the number of people additionally at risk of hunger (largely in Africa) in 2080 under a SRES A2 scenario with CO_2 concentrations of 800ppm, avoiding an estimated 23-34 billion US$ of damage to agricultural output (Tubiello and Fischer, 2007). In Africa, there are much greater impacts upon crop productivity, freshwater resources, and ecosystems at 4ºC than 2ºC with adaptation failing to reduce risk below a 'high' level at 4ºC ('very high' for crop productivity), whereas at 2ºC risks are lower and adaptation could reduce these risks to a 'medium' level (Chapter 22 Table 22-6). In North America, with 4ºC warming, adaptation is not expected to reduce risks below 'high' for urban flooding (both riverine and coastal) or for fire damage in ecosystems, or below 'medium' for heat-related human mortality. Without adaptation risk is 'very high' for these sectors. In contrast at 2ºC risks are 'high' in these sectors, with adaptation expected to reduce urban flooding risk to 'medium' and heat-related human mortality risk to 'low' (Chapter 26 Table 26-1). Impacts on water resources would also be reduced (Chapter 3 Table 3-2). Fung *et al.* (2011) and Gosling and Arnell *et al.* (2013) both found that climate change-induced increases in water stress (defined as persons with <1700 or <1000 m3/capita/yr respectively in the two studies) globally would be reduced significantly were global temperature rise to be constrained to 2°C rather than 3.5 °C. Reducing climate change from an RCP8.5 scenario to and RCP2.6 scenario reduces the proportion of the global population that experiences >10% declines in available groundwater from 27-50% to 11-39% (Portmann *et al*., 2013).

Figure 19-6 highlights results from three studies that estimated the global avoided impacts for multiple sectors when global average temperature is limited to 2^{o}C rather than following scenarios with no mitigation, such as the SRES A1B or A1FI baseline scenarios in which global average temperature reaches 4 and 5.6°C respectively (Arnell *et al.*, 2013; Warren *et al.*, 2013a; Warren *et al.*, 2013b). The studies isolate the effects of climate change by using common socioeconomic assumptions in mitigation and baseline scenarios. Overall, sector-specific impacts were reduced by 20-80%, with aggregate global economic damages reduced by about one half (Warren *et al*., 2013b). The largest impacts avoided were for crop productivity, drought in cropland, biodiversity, exposure to coastal and pluvial flooding, energy use for cooling, while avoided impacts were smaller for water resources stress. Since some areas become wetter and others drier (AR5 WGI Section 12.4.5) there are regions where climate change results in decreases in flood, drought or water stress. There are shown as the blue bars in Figure 19-6. Avoided impacts are significantly larger when an A1FI baseline is used compared to an A1B baseline (Figure 19-6) because emissions and global temperature rise is greater in the A1FI baseline scenario. All these studies employed an ensemble of climate change projections based on emulation of 7 different GCM models. The proportion of impacts avoided at the global scale was relatively robust to uncertainties in regional climate projection, but the magnitude of avoided impacts varied considerably with climate projection uncertainty.

The timing of emissions reductions strongly affects impacts. In general fewer impacts can be avoided when mitigation is delayed (Arnell *et al*., 2013; Warren *et al*., 2013a; Warren *et al.*, 2013b; Figure 19-6 panel b) because there are limits to how fast emissions can be reduced subsequently to compensate for the delay (19.7.2). For example, if global emissions peak in 2016 and are then reduced at 5% annually, one half of global aggregate economic impacts might be avoided (Figure 19-6, panel b, orange bars), or around 42% if emissions are reduced more slowly at 2% annually (Figure 19-6, panel b, pink bars); compared to only one third if emissions peak in 2030 even if emissions are reduced at 5% thereafter (Warren *et al.,* 2013b, Figure 19-6, panel b, brown bars).

Avoided impacts vary significantly across regions as well as sectors (*high confidence*) due to (a) differing levels of regional climate change, (b) differing numbers of people and levels of resources at risk in different regions, and (c) differing sensitivities and adaptive capacities of humans, species or ecosystems (Tubiello and Fischer, 2007; Ciscar *et al*., 2011; Arnell *et al.*, 2013; Section 25.10.1). The length of time it takes for avoided impacts to accrue is determined partly by the nature of the climate system. Benefits accrue least rapidly for impacts associated with sea level rise such as coastal flooding, loss of mangroves and coastal wetlands because sea level rise responds very slowly to mitigation efforts (Meehl *et al.*, 2012). Nevertheless, mitigation limits 21st century impacts of increased coastal flood damage, dry land loss and wetland loss substantially (*limited evidence, medium agreement*) albeit there is *little agreement* on the exact magnitude of this reduction (Section 5.4.3.1). Benefits accrue more rapidly for impacts associated with global temperature change (AR5 WGI Section 12.5.2) and those associated with reduced ocean acidification since surface pH responds relatively quickly to changes in emissions of CO_2 (Chapter 30 FAQ 30.1).

[INSERT FIGURE 19-6 HERE
Figure 19-6: Panel **a**: Climate change impacts avoided by an early, rapid mitigation scenario in which global emissions peak in 2016 and are reduced at 5% thereafter, compared to two no-mitigation baseline cases SRES A1B (orange bars) and SRES A1FI (red bars). Impacts avoided are larger if the A1FI baseline scenario is used than if the A1B baseline is used, because greenhouse gas emissions in A1FI exceed those in A1B (see 19.7.1). Panel **b**: The dependence of the potential to avoid climate change impacts upon the timing of emission reductions is illustrated. Climate change impacts avoided by the same early, rapid mitigation scenario compared to the no-mitigation baseline case SRES A1B (orange bars) are shown. The information displayed is identical to the orange bars in panel a, but a comparison is now made with the impacts avoided from two other less stringent mitigation scenarios. Impacts avoided if global emissions peak in 2016 but are subsequently reduced more slowly (2% annually) are lower (pink bars compared to orange bars). However, if mitigation occurs later, so that global emissions do not peak until 2030, even if emissions are subsequently reduced at 5% annually, the avoided impacts are smaller than in either of the

other two cases (brown bars compared to orange and pink bars). Both panels show the uncertainty range (error bars) due to regional climate change projected with 7 GCMs. Errors due to uncertainty within impacts models are not shown. Uncertainties associated with sea level rise related impacts are smaller because the models used encompass a narrow range of alternative sea level rise projections. Since increases and decreases in water stress, flood risks and crop suitability are not co-located and affect different regions, these effects are not combined. From Arnell *et al.*, 2013, Warren *et al*, 2013a; Warren *et al.*, 2013b]

In AR5 WGIII Chapter 6, the emission scenarios in the literature (as collected in the AR5 database) have been categorized on the basis of the 2100 radiative forcing (in total 7 categories). Most IAM models provide information on concentration, forcing and temperature. However, as the climate components of the IAMs differ, all scenarios were reanalyzed in the simple climate model MAGICC (Meinshausen et al. 2011) using its probabilistic set-up. The results of this categorization can be used to connect emission trajectories to climate outcomes (Figure 19-7, panel a) and impacts and risks (Figure 19-7, panel b, and Table 19-4).

Mitigation scenarios in category 1 with a 2100 CO_2-equivalent concentration of 430-480 ppm CO_2e constrain global temperature rise to between 1.3 and 2.3^{o}C above pre-industrial (Figure 19-7, panel a). These scenarios correspond to a 2011-2100 cumulative emission level of around 800-1250 $GtCO_2$ (AR5 WGIII Table 6.3). Under these scenarios, based on the MAGICC calculations, warming is *likely* to stay below 2^{o}C and *very likely* to stay below 2.5^o C during the 21st century. This significantly reduces the key risks listed in Table 19-4, as well as others discussed in this chapter. Constraining global temperature rise to 2^{o}C would constrain the risks associated with Aggregate Impacts to the 'white' or 'neutral' level, to the 'yellow' or 'moderate' level for Large Scale Singular Events and Distribution of Impacts and to the lower part of the 'red' 'high' level for Unique and Threatened Systems and Extreme Weather Events. The temperature levels in the RCP2.6 scenario are 1.2-2.0^o C (AR5 WG1 Table 12.2) matching closely the scenarios in this category.

Mitigation scenarios in category 2 with a 2100 concentration of 480-530 ppm CO_2e in 2100 correspond to a global temperature rise between 1.4 and 2.7^{o}C in the MAGICC calculations. These scenarios correspond to a cumulative emission level over the 2011-2100 period on the order of 1000-1500 $GtCO_{2.}$ (AR5 WGIII Table 6.3) and lead to likelihood of staying below roughly 2^{o}C of *more-likely-than-not (50-66%)*. Thus, scenarios in category 2 also reduce risks, but to a lesser extent than for category 1. If global temperature rise reaches 2.5^o C in 2100, levels of risk due to Extreme Weather Events are at the 'red' 'high' level, whilst those to Unique and Threatened Systems now reach the 'very high' or 'purple' level reflecting inability to adapt. Risks associated with Aggregate Impacts reach the 'yellow' 'moderate' level, whilst risks to the Distribution of Impacts and Large Scale Singular Events closely approach the 'red' or 'high' level.

Mitigation scenarios in category 3 with 530-580 ppm CO_2e constrain temperature rise to between 1.7 and 2.9^o C above pre-industrial levels, affording little protection to coral reefs, so that risks to Unique and Threatened Systems remain 'high' or 'very high' indicating inability to adapt. Risks associated with Extreme Weather Events remain at the 'high' level. Risks to Distribution of Impacts may be 'moderate' or 'high'. Levels of risk in Aggregate Impacts and Large Scale Singular Events are constrained to the upper 'moderate' level.

Mitigation scenarios in category 4 with 580-720 ppm CO_2e result in range of possible temperature outcomes between 1.8 and 3.6^o C above pre-industrial levels, affording very little protection to coral reefs, whilst risks to Unique and Threatened Systems remain 'high' or 'very high' indicating inability to adapt. Risks associated with Extreme Weather Events and Distribution of Impacts remain 'high'. Levels of risk associated with Aggregate Impacts and Large Scale Singular Events may be 'moderate' or 'high'. *(high confidence).* Global temperature rise in RCP4.5 in 2100 is 1.9-2.9^o C above pre-industrial levels (AR5 WG1 Table 12.2) matching the low scenarios in this category.

Onset of large-scale dissolution of coral reefs is projected if CO_2 concentrations reach 560 ppm (Section 5.4.1.6, 5.4.2.4, 19.6.3.2, 26.4.2.1; Silverman *et al.* 2009), due to the combined effects of warming and ocean acidification. However already at 450 ppm, reef growth rates are projected to be reduced by more than 60% globally; and by at least 20% globally at 380ppm (Silvermann *et al.*, 2009). Coral organisms themselves are projected to be damaged by warming at concentrations below 560 ppm: specifically, RCP4.5 is projected to result in long term degradation of

2/3 of coral reefs, compared with 1/3 of them under RCP3PD (Box CC-CR) *(medium confidence)*. Hence, maintenance of moderately healthy coral reefs is consistent only with scenarios in the scenarios in the 430-480 ppm CO_2e category; while some reef protection is achieved with scenarios in the category 480-530 ppm CO_2e. A low level of protection exists for the category 530-580 ppm CO_2e while all other categories exceed the 560ppm level.

Finally, scenarios in category 6 with a concentration level above >1000 ppm CO_2e are projected to result in temperature rise of between 3.3 and 6.3^{o}C above pre-industrial with negligible chances to constrain it below 2.5^{o}C above pre-industrial (panel a) and would allow significant key risks to persist in all the areas listed in Table 19-4.Risk is at the 'red' level for all Reasons for Concern except Unique and Threatened Systems, where risk is at the purple level indicating infeasibility of adaptation. For Distribution of Impacts, risk reaches the transition to purple if temperatures rise in excess of 4^{o}C above pre-industrial levels. For the scenarios with a concentration level between 720 ppm and 1000 ppm, category 5, outcomes for risk levels are similar to the highest category, except that risk to Aggregate Impacts is at the 'yellow' 'moderate' level.

Scenarios with rapid, early mitigation (particularly those which with a 2100 CO_2-equivalent concentration of 430-480 ppm CO_2e) generally delay the onset of a given global annual mean temperature rise until several decades later in the century than is the case for scenarios with slower, delayed mitigation or no mitigation (such as those with a 2100 CO_2-equivalent concentration of 720-1000 ppm), thus allowing impacts to be further reduced by adaptation during this time.

[INSERT FIGURE 19-7 HERE
Figure 19-7: Relationship between mitigation scenarios considered in AR5 WGIII, in terms of their CO_2e concentrations and global temperature rise outcomes relative to pre-industrial times, and level of risk associated with Reasons for Concern. Panel **a** shows the projected increase in global mean temperature in 2100 compared to preindustrial, calculated using the MAGICC climate model for the scenarios defined in Chapter 6, Working Group III, indicating the uncertainty range resulting both from the range of emission scenario projections within each category and the uncertainty in the climate system as represented by MAGICC (data taken from Chapter 6 – AR5 WGIII). Panel **b** reproduces Figure 19-4 for ease of comparison. Note the different temperature baselines used in Figure 19-4. Beyond 2100, temperature, and therefore risk, decreases in most of the lowest three scenarios and increases further in most of the others.]

19.7.2. Limits to Mitigation

Mitigation possibilities, such as those implicit in scenarios discussed in 19.7.1, are not unlimited. Assessment of maximum feasible mitigation (and lowest feasible emissions pathways) must account for the fact that feasibility is a subjective concept encompassing technological, economic, political, and social dimensions (Hare *et al.*, 2010, UNEP Chapter 2). Most mitigation studies have focused on technical feasibility, for example demonstrating that it is possible to reduce emissions enough to have at least a 50% chance of limiting warming to less than 2 °C relative to pre-industrial (den Elzen and van Vuuren, 2007; Clarke *et al.*, 2009; Edenhofer *et al.*, 2010; Hare *et al.*, 2010; O'Neill *et al.*, 2010), taking into account uncertainty in climate and carbon cycle response to emissions (see AR5 WGI Section 12.5.4 for a discussion of uncertainties in the relationship between emissions and long-term climate stabilization targets). RCP2.6, based on an integrated assessment model-based mitigation scenario (van Vuuren et al., 2012), is *unlikely* to produce more than 2°C of warming relative to pre-industrial (*medium confidence*; AR5 WGI Section 12.4.1.1). Such scenarios lead to pathways in which global emissions peak within the next 1-2 decades and decline to 50-85% below 2000 levels by 2050 (or 40-70% compared to 1990 levels), and in some cases exhibit negative emissions before the end of the century (Metz *et al.*, 2007, den Elzen *et al.*, 2007, Den Elzen *et al.*, 2010, van Vuuren et al. 2012). Very few integrated assessment model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5 °C with at least 50% likelihood (Rogelj et al., 2012); most 1.5 °C scenarios have been based on stylized emissions pathways (Hare *et al.*., 2010; Ranger *et al.*, 2012). The highest emission reduction rate considered in most integrated modeling studies that attempt to minimize mitigation cost is typically between 3 and 4% but with larger values not ruled out although some studies find that for an additional cost higher rates may be achievable (den Elzen *et al.*, 2010; O'Neill *et al.*, 2010).

However, most studies of feasibility include a number of idealized assumptions, including availability of a wide range of mitigation technologies such as large-scale renewable and biomass energy, and carbon capture and storage (CCS). Most also assume universal participation in mitigation efforts beginning immediately, economically optimal reductions (i.e., reductions are made wherever they are cheapest), and no constraints on policy implementation. Any deviation from these idealized assumptions can significantly limit feasible mitigation reductions (Knopf *et al.*, 2010; Rogelj *et al.*, 2012). For example, delayed participation in reductions by non-OECD countries made concentration limits such as not exceeding 450 ppm CO_2eq (roughly consistent with a 50% chance of remaining below 2 °C relative to pre-industrial), and in some cases even 550 ppm CO_2eq, unachievable in some models unless temporary overshoot of these targets (Izrael and Semenov, 2006) were allowed (Clarke *et al.*, 2009), but not in others (Waldhoff and Fawcett, 2011). Technology limits, such as unavailability of CCS or limited expansion of renewables or biomass makes stabilization at 450 ppm CO_2eq (or 2 °C with a 50% chance) unachievable in some models (Krey and Riahi, 2009; van Vliet *et al.*, 2012). Similarly, if the political will to implement coordinated mitigation policies within or across a large number of countries were limited, peak emissions and subsequent reductions would be delayed (Webster *et al.*, 2010).

These considerations have led some analysts to doubt the plausibility of limiting warming to 2 °C (Anderson and Bows, 2008; Tol, 2009; Anderson and Bows, 2011). "Emergency mitigation" options have also been considered that would go beyond the measures considered in most mitigation analyses (Swart and Marinova, 2010). These include drastic emissions reductions achieved through limits on energy consumption (Anderson and Bows, 2011) or geoengineering through management of the earth's radiation budget (19.5.4; AR5 WGI Chapters 6, 7).

19.7.3. Avoiding Thresholds, Irreversible Change, and Large-Scale Singularities in the Earth System

Section 19.6.3.6 discussed the Reasons for Concern related to non-linear changes in the Earth system (“large-scale singular events”), whereby anthropogenic forcings might cause irreversible and potentially rapid transitions over a wide range of time scales (see, for example, WGI: SPM, TS, TFE5, and section 12.5, WGII: section 19.6.3, as well as Lenton *et al*., 2008). The risk of triggering such transitions generally increases with increasing anthropogenic climate forcings / climate change (Lenton *et al.*, 2008; Kriegler *et al.*, 2009; Levermann *et al.*, 2012). Reducing greenhouse gas emissions is projected to reduce the risks of triggering such transitions [*medium confidence*]. Adaptation could reduce their potential consequences, but the efficacy of adaptation might be limited, for example for rapid transitions (19.7.5).

Several studies have sought to identify levels of atmospheric greenhouse gas concentrations or global average temperature change that would limit the risks of triggering these transitions (e.g., Keller *et al.*, 2005, 2008; Kriegler *et al.*, 2009; Lenton *et al.*, 2008). Section 19.6.3.6 assesses evidence regarding the relationship between global average temperature and risks of disintegration of major ice sheets, loss of Arctic sea ice, shutdown of the Atlantic meridional overturning circulation (AMOC), carbon releases from temperature-related feedback processes, and regime shifts in ecosystems. Additional aspects of these risks are important to mitigation strategies. For example, it is important to distinguish between triggering and experiencing a threshold response because model simulations suggest that there can be sizeable delays between the two (e.g., Lenton *et al.*, 2008). The location of these trigger points can be difficult to determine from process-based models alone, as some of these models lack potentially important processes (see e.g., AR5 WGI Chapter 13). In this situation, expert elicitations can provide additional useful information for risk assessments. One such assessment based on expert elicitation (Lenton *et al.*, 2008) finds that limiting global mean temperature increase to approximately 3°C above recent (1980–1999) values would considerably reduce the risks of triggering some nonlinear responses. In general, there is *low confidence* in the location of such temperature limits due to disagreements among experts. Estimates of such temperature limits can change over time (Oppenheimer et al., 2008) and may be subject to overconfidence that can introduce a downward bias in risk estimates of low-probability events (Morgan and Henrion, 1990). The climate threshold responses can interact (e.g., Kriegler *et al*., 2009). Other climate change metrics (e.g., rates of changes or atmospheric carbon dioxide concentrations) can also be important in the consideration of response strategies aimed at reducing the risk of crossing thresholds (Lenton, 2011a; McAlpine *et al.*, 2010).

Several analyses have performed risk- and decision-analyses for specific thresholds, mostly focusing on a persistent weakening or collapse of the AMOC (Bahn *et al.*, 2011; McInerney *et al.*, 2012; Urban and Keller, 2010; Zickfeld and Bruckner, 2008). Experiencing AMOC collapse has been assessed as *very unlikely* in this century and there is *low confidence* in assessing the AMOC beyond the 21st century [AR5 WGI SPM]. However, due to lags in the ocean system, the probability of triggering an eventual collapse differs from that of experiencing such an outcome (Urban and Keller, 2010). A probabilistic analysis sampling a subset of the relevant uncertainties concluded that reducing the probability of a collapse within the next few centuries to one in ten requires emissions reductions of roughly 60% relative to a business-as-usual strategy by 2050 (McInerney and Keller, 2008). Bruckner and Zickfeld (2009) show that, under their worst-case assumptions about key parameter values, emissions mitigation would need to begin within the next two decades to avoid reducing the overturning rate by more than 50%.

Threshold risk estimates and evaluations of risk-management strategies are sensitive to factors such as the representation of uncertainties and the decision-making frameworks used (McInerney *et al.*, 2012; Polasky *et al.*, 2011). Several analyses have examined how the consideration of threshold events affects response strategies. For example, the design of risk-management strategies could be informed by observation and projection systems that would provide an actionable early warning signal of an approaching threshold response. Learning about key uncertain parameters (e.g., climate sensitivity or impacts of a threshold response) can considerably affect risk-management strategies and have a sizeable economic value of information (Keller *et al.*, 2004; Lorenz *et al.*, 2012). However, there is limited evidence about the feasibility and requirements for such systems due to the small number of studies and their focus on highly simplified situations (Keller and McInerney, 2008; Lenton, 2011b, Lorenz *et al.*, 2012). In some decision-analytic frameworks, knowing that a threshold has been crossed can lead to reductions in emissions mitigation and a shift of resources toward adaptation and/or geoengineering (Guillerminet and Tol, 2008; Keller *et al.*, 2004; Lenton, 2011b; Swart and Marinova, 2010).

19.7.4. Avoiding Tipping Points in Social/Ecological Systems

Tipping points (see Glossary) in socio-ecological systems are defined as thresholds beyond which impacts increase non-linearly to the detriment of both human and natural systems. These can be initiated rapidly, inducing a need for rapid response. For example, regime shifts have already occurred in marine food webs (Byrnes *et al.*, 2007; Alheit, 2009, Green *et al*., 2008, section 6.3.6) due to (observed) changes in sea surface temperature, changes in salinity, natural climate variability, and/or overfishing.

Because human and ecological systems are linked by the services that ecosystems provide to society (Lubchenko and Petes, 2010; McLeod and Leslie 2009), tipping points may be crossed when either the ecosystem services are disrupted and/or social/economic networks are disrupted (Renaud *et al.*, 2010). Climate change provides a stress that increases the risk that tipping points will be crossed, although they may be crossed due to other types of stresses even in the absence of climate change. For example, in dryland ecosystems overgrazing has caused grassland-to-desert transitions (Pimm, 2009). The likelihood of crossing tipping points due to climate change may be reduced by preserving ecosystem services through (i) limiting the level and rate of climate change [*medium confidence*] *and*/or (ii) removing concomitant stresses such as overgrazing, fishing, habitat destruction, and pollution. Most literature currently focuses on strategy (ii), and there is limited information about the exact levels and rates of climate change that specific coupled socio-economic systems can withstand. Examples of strategy (ii) include maintaining resilience of coral reefs, cephalopod or piscivorous seabird populations by removal of concomitant stress from fishing (Andre *et al*., 2010; Anthony *et al*., 2011; Sections 6.3.6, 30.6.2) or expanding protected area networks (Brodie *et al*., 2012). Removal of concomitant stress such as nutrient loading can reduce the chance of a regime shift (Jurgensone *et al.*, 2011) in coral reef ecosystems (De'ath *et al.*, 2012). Sometimes management can reverse the crossing of a tipping point, e.g. by adding sediment to a submerged salt marsh (Stagg and Mendelssohn, 2010). Strategy (ii) is enhanced by resilience-based management approaches in ecosystems (Walker and Salt 2006; Lubchenko and Petes 2010; Allen *et al*. 2011; Selig *et al.*, 2012). A high level of biodiversity increases ecosystem resilience and can enable recovery after crossing a tipping point (Brierley and Kingsford, 2009; Lubchenko and Petes, 2010). Strategy (ii) generally becomes ineffective once climate changes beyond an uncertain and spatially variable threshold; also successive thresholds may be crossed as stress increases (Renaud *et al.*, 2010).

Monitoring that aims to detect a slow-down in the recovery of systems from small changes (van Nes and Scheffer, 2005) or to measure an appropriate indicator (Biggs *et al*., 2008) may give warning that a system is a approaching a regime shift, justifying intervention of type (ii) (Guttal and Jayaprakash, 2009; Brock and Carpenter, 2010). Such indicators have been identified for the desertification process in the Mediterranean (Alados *et al*., 2011) and for landscape fire dynamics (Zinck *et al.*, 2011; McKenzie and Kennedy, 2012).

19.7.5. Limits to Adaptation

Chapter 16.2 and 16.5 provide a thorough assessment of the literature on limits to adaptation. Discussions are beginning on the nature of such limits, e.g. in terms of different dimensions of the limits to adaptation, including financial or economic limits to adapt, but also social and political or cognitive limits of adaptation. Limits to adaptation (see e.g. Adger *et al*., 2009) are also recognized in terms of specific geographies, for example small island developing states and their limited ability to adapt to increasing impacts of sea level rise, the limits to adaptation of urban agglomerations in low-laying coastal zones (see e.g. Birkmann *et al*., 2010), or in relation to loss of water supplies as a result of glacier retreat (Orlove, 2009). Overall, the concept of limits to adaptation is closely related to key vulnerabilities and key risks including those identified in Table 19-4 and cross-chapter Box CC-KR, because this concept helps define residual risk.

Frequently Asked Questions

FAQ 19.1: Does science provide an answer to the question of how much warming is unacceptable?

[to be placed in Section 19.1.3]

No. Careful, critical scientific research and assessment can provide information to help society consider what levels of warming or climate change impacts are unacceptable. However, the answer is ultimately a subjective judgment that depends on values and culture, as well as socioeconomic and psychological factors, all of which influence how people perceive risk in general and the risk of climate change in particular. The question of what level of climate change impacts is unacceptable is ultimately not just a matter of the facts, but how we feel about those facts.

This question is raised in Article 2 of the UN Framework Convention on Climate Change (UNFCCC). The criterion, in the words of Article 2, is “dangerous anthropogenic interference with the climate system” - a framing that invokes both scientific analysis and human values.

Agreements reached by governments since 2009, meeting under the auspices of the UNFCCC, have recognized “the scientific view that the increase in global temperature should be below 2 degrees Celsius” (Chapter 19.1, UNFCCC, Copenhagen Accord). Still, as informed on the subject as the scientists referred to in this statement may be, theirs is just one valuable perspective. How each country or community will define acceptable or unacceptable levels, essentially deciding what is ‘dangerous’, is a societal judgment.

Science can certainly help society think about what is unacceptable. For example, science can identify how much monetary loss might occur if tropical cyclones grow more intense or heat waves more frequent, or identify the land that might be lost in coastal communities for various levels of higher seas. But “acceptability” depends on how each community values those losses. This question is more complex when loss of life is involved and yet more so when damage to future generations is involved. These are highly emotional and controversial value propositions that science can only inform, not decide.

The purpose of this chapter is to highlight key vulnerabilities and key risks that science has identified; however, it is up to people and governments to determine how the associated impacts should be valued, and whether and how the risks should be acted upon.

FAQ 19.2: How does climate change interact with and amplify pre-existing risks?

[to be placed in Section 19.3.2.4]

There are two components of risk: the probability of adverse events occurring and the impact or consequences of those events. Climate change increases the probability of several types of harmful events that societies and ecosystems already face, as well as the associated risks. For example, people in many regions have long faced threats associated with weather-related events like extreme temperatures and heavy precipitation (which can trigger flooding). Climate change will increase the likelihood of these two types of extremes as well as others. Climate change means that impacts already affecting coastal areas, like erosion and loss of property in damaging storms, will become more likely due to sea level rise. In many areas, climate change increases the already high risks to people living in poverty or to people suffering from food insecurity or inadequate water supplies. Finally, climate and weather already pose risks for a wide range of economic sectors, including agriculture, fisheries, and forestry: climate change increases these risks for much of the world.

Climate change can amplify risks in many ways, including through indirect interactions with other risks. These are often not considered in projections of climate change impacts. For example, hotter weather contributes to increased amounts of ground level ozone (smog) in polluted areas, exacerbating an existing threat to human health, particularly for the elderly and the very young and those already in poor health. Also, efforts to mitigate or adapt to climate change can have negative as well as positive effects. For example, government policies encouraging expansion of biofuel production from maize have recently contributed to higher food prices for many, increasing food insecurity for populations already at risk, and threatening the livelihoods of those like the urban poor who are struggling with the inherent risks of poverty. Increased tapping of water resources for crop irrigation in one region in response to water shortages related to climate change can increase risks to adjacent areas that share those water resources. Climate change impacts can also reverberate by damaging critical infrastructure like power generation, transportation, or health care systems.

FAQ 19.3: How can climate change impacts on one region cause impacts on other distant areas?

[to be placed in Section 19.4.3.2]

People and societies are interconnected in many ways. Changes in one area can have ripple effects around the world through globally linked systems like the economy. Globalized food trade means that changed crop productivity as a result of extreme weather events or adverse climate trends in one area can shift food prices and food availability for a given commodity worldwide. Depletion of fish stocks in one region due to ocean temperature rise can cause impacts on the price of fish everywhere. Severe weather in one area that interferes with transportation or shipping of raw or finished goods, like refined oil, can have wider economic impacts.

In addition to triggering impacts via globally linked systems like markets, climate change can alter the movement of people, other species, and physical materials across the landscape, generating secondary impacts in places far removed from where these particular direct impacts of climate change occur. For example, climate change can create stresses in one area that prompt some human populations to migrate to adjacent or distant areas. Migration can affect many aspects of the regions people leave, as well as many aspects of their destination points, including income levels, land use and the availability of natural resources, and the health and security of the affected populations – these effects can be positive or negative. In addition to these indirect impacts, all regions experience the direct impacts of climate change.

Cross-Chapter Box

Box CC-KR. A Selection of the Hazards, Key Vulnerabilities, Key Risks, and Emergent Risks Identified in the WGII Contribution to the Fifth Assessment Report

The accompanying table provides a selection of the hazards, key vulnerabilities, key risks, and emergent risks identified in various chapters in this report (Chapter 4, 6, 7, 8, 9, 11, 13, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30). Key risks are determined by hazards interacting with vulnerability and exposure of human systems, and ecosystems or species. The table underscores the complexity of risks determined by various climate-related hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, unsustainable and rapid urbanization, other demographic changes, failure in governance and inadequate governmental attention to risk reduction, and tolerance limits of species and ecosystems which often provide important services to vulnerable communities, generate the context in which climatic change related harm and loss can occur. The table illustrates that current global megatrends (e.g. urbanization and other demographic changes) in combination and in specific development context (e.g. in low-lying coastal zones), can generate new systemic risks in their interaction with climate hazards that exceed existing adaptation and risk management capacities, particularly in highly vulnerable regions, such as dense urban areas of low-lying deltas. A representative set of lines of sight is provided from across WGI and WGII. See Section 19.6.2.1 for a full description of the methods used to select these entries. [NB: See tables file for the table embedded in Box CC-KR.]

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Table 19-1: Examples of global and national ecosystem service valuation studies. This table is not intended to be comprehensive. Furthermore, it encompasses studies based on a wide range of methodologies.

Ecosystem Service	**Region**	**Value**	**Currency**	**Citation**
Pollination of crops	Globe	153 bn	Euro	Gallai *et al*. 2008
Pollination of crops and wild plants	UK	430 m	£	NEA, 2011
Woodland cover increase from 6 to 12%	UK	680m	£	NEA, 2011
CO_2 fixation, O_2 release, nutrient recycling, soil protection, water holding capacity and environmental purification	Chinese terrestrial ecosystems	3×10^{13}	RMB/yr	Ke and Hong, 1999
Climate regulation provided by forests	US	1bn-6bn	$/yr	Krieger, 2001
Recreation provided by forests	US	1.3bn-110bn	$/yr	Krieger, 2001
Biodiversity supported by forests	US	5bn-54bn	$/yr	Krieger, 2001
Coral reef services	Australia	5.4bn	Au$	19.3.2.4, Box CC-CR
Coral reef services	Florida (USA)	1.6	$	19.3.2.4

Table 19-2: Emergent risks related to biofuel production as a mitigation strategy.

Issue number	**Issue description**	**Nature of emergent risk**	**Reference**
(i) Direct and/or indirect land use change (iLUC)	Potential for enhancement of greenhouse gas emissions	Mitigation benefit of biofuels reduced or negated	Wise et al., 2009, Melillo et al., 2009, Khanna et al., 2011
(ii) Policies targeting only fossil carbon	Biofuel cropping competes with agricultural systems and ecosystems for land and water	Mitigation benefit of policies reduced, harmful interactions with other key systems	Wise et al., 2009, Mellilo et al., 2009, Searchinger et al., 2008, Fargione et al., 2010
(iii) Food/fuel competition for land	Competition for land driving up food prices	Emergent risk of food insecurity due to mitigation-driven land use change	Hertel et al., 2010, Searchinger et al., 2008, Pimentel et al., 2009
(iv) Biofuels production affects water resources	Competition for water affects biodiversity and food cropping	Emergent risk of biodiversity loss and food insecurity due to mitigation-driven water stress	Fargione et al., 2010, Fingerman et al., 2010, Yang et al., 2012, Poudel et al., 2012
(v) Biofuels production affects biodiversity	Competition for land reduces natural forest and biodiversity	Emerging risk of biodiversity loss due to mitigation-driven land use change	Lapola et al., 2010, Koh et al., 2009, Fizherbert et al., 2008, Fletcher Jr. et al., 2011
(vi) Land conversion causes air pollution	Potential for increased production of tropospheric ozone from palm/sugarcane-induced LUC	Emergent risk of GHG-mitigation-driven plant and human health damage caused by tropospheric ozone	Hewitt et al., 2009, Cançado et al., 2006
(vii) Fertilizer application	Potential for increased emissions of N2O	Offsets some benefits of other mitigation measures	Donner and Kucharik, 2008, Searchinger et al., 2008, Fargione et al., 2010
(viii) Invasive properties of biofuel crops	Potential to become an invasive species	Unintended consequences that damage agriculture and/or biodiversity	Barney and Ditomaso 2008, DiTomaso et al., 2007, Raghu et al., 2006

Table 19-3: An assessment of the risks to ecosystem services posed by the impacts of ocean acidification on coral calcification and nitrogen fixation, based on the four criteria for key risks (19.2.2.2).

Criterion for key risk	**Coral calcification**	**Nitrogen fixation**
1. Magnitude of consequences for ecosystem services	Ecosystem services include supporting habitats, provisioning of fish, regulating shoreline erosion, and tourism. Potential magnitude of consequences is *medium* to *high* (Box CC-CR).	Ecosystem services include nitrogen cycling, which supports ecosystem structure and food chains (Hutchins et al., 2009). Potential magnitude of consequences has not been investigated.
2. Likelihood that risks will materialize and their timing	A reduction in coral calcification rate and an increase in reef dissolution rates are *very likely* (6.1.2), so that reefs will progressively shift toward net dissolution (*medium confidence*, Section 5.4.2.4; Box CC-CR; Box CC-OA)	Both increases and decreases in nitrogen fixation have been observed in various N2-fixing organisms (Section 6.3.2.2) but there is *limited in situ evidence* and *medium agreement* on how N_2-fixation rates will change in response to ocean acidification.
3. Irreversibility and persistence of ocean acidification impacts	Decreases in ocean pH will persist as long as atmospheric CO2 levels remain elevated. (AR5 WGI Section 3.8.2). Reductions in coral calcification will persist unless corals can physiologically adapt to maintain calcification rates. Reversibility of impacts on ecosystem services of coral reefs is unknown and depends on ecological factors such as hysteresis.	Decreases in ocean pH will persist as long as atmospheric CO2 levels remain elevated. (AR5 WGI Section 3.8.2). Reversibility and persistence of impacts on nitrogen fixation are unknown.
4. Limited ability to reduce the magnitude and frequency or nature of ocean acidification impacts	Reduction of ocean acidification will require global reductions in atmospheric CO2. Feasibility of mitigating ocean acidification at the local scale is unknown.	Reduction of ocean acidification will require global reductions in atmospheric CO2.

Table 19-4: A selection of the hazards, key vulnerabilities, key risks, and emergent risks identified in various chapters in this report (Chapter 4, 6, 7, 8, 9, 11, 13, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30). Key risks are determined by hazards interacting with vulnerability and exposure of human systems, and ecosystems or species. The table underscores the complexity of risks determined by various climate-related hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, unsustainable and rapid urbanization, other demographic changes, failure in governance and inadequate governmental attention to risk reduction, and tolerance limits of species and ecosystems which often provide important services to vulnerable communities, generate the context in which climatic change related harm and loss can occur. The table illustrates that current global megatrends (e.g. urbanization and other demographic changes) in combination and in specific development context (e.g. in low-lying coastal zones), can generate new systemic risks in their interaction with climate hazards that exceed existing adaptation and risk management capacities, particularly in highly vulnerable regions, such as dense urban areas of low-lying deltas. Roman numerals correspond with key risks listed in 19.6.2.1. A representative set of lines of sight is provided from across AR5 WGI and WGII. See Section 19.6.2.1 for a full description of the methods used to select these entries.

#	Hazard	Key vulnerabilities		Key risks	Emergent risks
i	Sea level rise, coastal flooding including storm surges. [AR5 WGI Sections 3.7.1, 13.5.1, Table 13-5; AR5 WGII Sections 5.4.3, 8.1.4, 8.2.3, 8.2.4, 13.1.4, 13.2.2, 24.4, 24.5, Box 25-1, Box 25-7, 26.7, 26.8, 29.3.1, 30.3.1]	High exposure of people, economic activity, and infrastructure in low-lying coastal zones and Small Island Developing States (SIDS). Urban population unprotected due to substandard housing and inadequate insurance. Marginalized rural population with multidimensional poverty and limited alternative livelihoods. Insufficient local governmental attention to disaster risk reduction.	exposure social vulnerability institutional vulnerability	Death, injury, and disruption to livelihoods, food supplies, and drinking water. Loss of common-pool resources, sense of place, and identity, especially among indigenous populations in rural coastal zones.	Interaction of rapid urbanization, sea level rise, increasing economic activity, disappearance of natural resources, and limits of insurance; burden of risk management shifted from the state to those at risk leading to greater inequality.
ii	Warming, drought, and precipitation variability [AR5 WGI Section 11.3.2; AR5 WGII Sections 7.4, 7.5, 11.3, 11.6.1, 13.2.1, 13.2.2, 19.3.2, 19.4.1, 22.3.4, 24.4, 26.8, 27.3.4]	Poorer populations in urban and rural settings are susceptible to resulting food insecurity; includes particularly farmers who are net food buyers and people in low-income, agriculturally dependent economies that are net food importers. Limited ability to cope among the elderly and female-headed households.	social vulnerability institutional vulnerability	Risk of harm and loss of life due to reversal of progress in reducing malnutrition.	Interactions of climate changes, population growth, reduced productivity, biofuel crop cultivation, and food prices with persistent inequality, and on-going food insecurity for the poor increases malnutrition, giving rise to larger burden of disease. Exhaustion of social networks reduces coping capacity.
iii	Extreme precipitation and inland flooding. [AR5 WGI Section 11.3.2.5; AR5 WGII Sections 3.2.7, 3.4.8, 8.2.3, 8.2.4, 13.2.1, 25.10, Box 25-8, 26.3, 26.7, 26.8, 27.3.5]	Large numbers of people exposed in urban areas to flood events, particularly in low-income informal settlements. Overwhelmed, aging, poorly maintained, and inadequate urban drainage infrastructure and limited ability to cope and adapt due to marginalization, high poverty, culturally imposed gender roles.	exposure social vulnerability	Death, injury, and disruption of human security, especially among children, elderly, and disabled.	Interaction of increasing frequency of intense precipitation, urbanization, and limits of insurance; burden of risk management shifted from the state to those at risk leading to greater inequality, eroded assets due to infrastructure damage, abandonment of urban districts, and the creation of high risk/high

		Inadequate governmental attention to disaster risk reduction.	institutional vulnerability		poverty spatial traps.
iv	Drought. [AR5 WGI Section 12.4.1, 12.4.5; AR5 WGII Sections 3.2.7, 3.4.8, 3.5.1, 8.2.3, 8.2.4, 9.3.3, 9.3.5, 13.2.1, 19.3.2.2, 24.4]	Urban populations with inadequate water services. Existing water shortages (and irregular supplies), and constraints on increasing supplies. Lack of capacity and resilience in water management regimes including rural-urban linkages.	social vulnerability institutional vulnerability	Insufficient water supply for people and industry yielding severe harm and economic impacts.	Interaction of urbanization, infrastructure insufficiency, groundwater depletion.
		Poorly endowed farmers in drylands or pastoralists with insufficient access to drinking and irrigation water. Limited ability to compensate for losses in water-dependent farming and pastoral systems, and conflict over natural resources. Lack of capacity and resilience in water management regimes, inappropriate land policy, and misperception and undermining of pastoral livelihoods.	exposure social vulnerability institutional vulnerability	Loss of agricultural productivity and/or income of rural people. Destruction of livelihoods particularly for those depending on water-intensive agriculture. Risk of food insecurity.	Interactions across human vulnerabilities: deteriorating livelihoods, poverty traps, heightened food insecurity, decreased land productivity, rural outmigration, and increase in new urban poor in low and middle income countries. Potential tipping point in rain-fed farming system and/or pastoralism.
v	Novel hazards yielding systemic risks. [AR5 WGI Section 11.3.2; AR5 WGII Sections 8.1.4, 8.2.4, 10.2, 10.3, 12.6, 23.9, 25.10, 26.7, 26.8]	Populations and infrastructure exposed and lacking historical experience with these hazards. Overly hazard-specific management planning and infrastructure design, and/or low forecasting capability.	exposure institutional vulnerability	Failure of systems coupled to electric power system, e.g., drainage systems reliant on electric pumps or emergency services reliant on tele-communications. Collapse of health and emergency services in extreme events.	Interactions due to dependence on coupled systems lead to magnification of impacts of extreme events. Reduced social cohesion due to loss of faith in management institutions undermines preparation and capacity for response.
vi	Rising ocean temperature, ocean acidification, and loss of Arctic sea ice [AR5 WGI Section 11.3.3; AR5 WGII Sections 5.4.2, 6.3.1, 6.3.2, 7.4.2, 9.3.5, 22.3.2.3, 25.6, 27.3.3, 28.2, 28.3, 29.3.1, 30.5, 30. 6, CC-OA, CC-CR]	High susceptibility of warm water coral reefs and respective ecosystem services for coastal communities; high susceptibility of polar systems, e.g., to invasive species	environmental vulnerability	Loss of coral cover, Arctic species, and associated ecosystems with reduction of biodiversity and potential losses of important ecosystem services. Risk of loss of endemic species, mixing of ecosystem types, and increased dominance of invasive organisms.	Interactions of stressors such as acidification and warming on calcareous organisms enhancing risk.
		Susceptibility of coastal and SIDS fishing communities depending on these ecosystem services; and of Arctic settlements and culture.	economic vulnerability environmental vulnerability		

vii	Rising land temperatures, changes in precipitation patterns, and frequency and intensity of extreme heat [AR5 WGI Section 11.3.2.5; AR5 WGII Sections 4.3.4, FAQ 4.4, 19.3.2.1, 22.4.5.6, Table 23-2, 27.3.2.1, Box CC-WE]	Susceptibility of societies to loss of provisioning, regulation, and cultural services from terrestrial ecosystems. Susceptibility of human systems, agro-ecosystems and natural ecosystems to (i) loss of regulation of pests and diseases, fire, landslide, erosion, flooding, avalanche, water quality, and local climate (ii) loss of provision of food, livestock, fibre, bioenergy (iii) loss of recreation, tourism, aesthetic and heritage values, and biodiversity,	economic vulnerability environmental vulnerability	Reduction of biodiversity and potential losses of important ecosystem services. Risk of loss of endemic species, mixing of ecosystem types, and increased dominance of invasive organisms.	Interaction of social-ecological systems with loss of ecosystem services upon which they depend.
viii	Increasing frequency and intensity of extreme heat, including urban heat island effect. [AR5 WGI Section 11.3.2; AR5 WGII Sections 8.2.3, 11.3, 11.4.1, 13.2, 23.5.1, 24.4.6, 25.8.1, 26.6, 26.8, CC-HS]	Increasing urban population of the elderly, the very young, expectant mothers, and people with chronic health problems in settlements subject to higher temperatures. Inability of local organizations which provide health, emergency and social services to adapt to new risk levels for vulnerable groups.	social vulnerability institutional vulnerability	Increased mortality and morbidity during periods of extreme heat.	Interaction of changes in regional temperature extremes, local heat island, and air pollution, with demographic shifts. Overloading of health and emergency services. Mortality, morbidity, and productivity loss among manual workers in hot climates.

Box CC-KR Table

Examples of Hazards/Stressors, Key Vulnerabilities, Key Risks and Emergent Risks
(using input from chapter 4, 6, 7, 8, 9, 11, 13, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30)

Hazard	Key vulnerabilities	Key risks	Emergent risks
Terrestrial and inland water systems (chapter 4)			
Rising air, soil, and water temperature [4.2.4, 4.3.2, 4.3.3]	Exceedance of eco-physiological climate tolerance limits of species (limited coping and adaptive capacities), increased viability of alien organisms.	Risk of loss of native biodiversity, increase in non-native organism dominance.	Cascades of native species loss due to interdependencies.
	Health response to spread of temperature-sensitive vectors (insects).	Risk of novel and/or much more severe pest and pathogen outbreaks.	Interactions between pest, drought and fire can lead to new risks and large negative impacts on ecosystems.
Change in seasonality of rain [4.3.3]	Increasing susceptibility of plants and ecosystem services, due to mismatch between plant life strategy and growth opportunities.	Changes in plant functional type mix leading to biome change with respective risks for ecosystems and ecosystem services.	Fire-promoting grasses grow in winter-rainfall areas and provide fuel in dry summers.
Ocean systems (chapter 6)			
Rising water temperature, increase of (thermal and haline) stratification, and marine acidification [6.1.1]	Tolerance limits of endemic species surpassed (limited coping and adaptive capacities), increased abundance of invasive organisms, high susceptibility and sensitivity of warm water coral reefs and respective ecosystem services for coastal communities. [6.3.1, 6.4.1]	Risk of loss of endemic species, mixing of ecosystem types, increased dominance of invasive organisms. Increasing risk of loss of coral cover and associated ecosystem with reduction of biodiversity and ecosystem services. [6.3.1]	Enhancement of risk due to interactions, e.g., acidification and warming on calcareous organisms. [6.3.5]
	New vulnerabilities can emerge due to shifted productivity zones and species distribution ranges, largely from low to high latitudes [6.3.4, 6.5.1], shifting fishery catch potential with species migration. [6.3.1, 6.5.2, 6.5.3]	Risks due to unknown productivity and services of new ecosystem types. [6.4.1, 6.5.3]	Enhancement of risk due to interactions of warming, hypoxia, acidification, new biotic interactions. [6.3.5, 6.3.6]
Expansion of oxygen minimum zones and coastal dead zones with stratification and eutrophication. [6.1.1]	Increasing susceptibility because hypoxia tolerance limits of larger animals surpassed, habitat contraction and loss for midwater fishes and benthic invertebrates. [6.3.3]	Risk of loss of larger animals and plants, shifts to hypoxia adapted, largely microbial communities with reduced biodiversity. [6.3.3]	Enhancement of risk due to expanding hypoxia in warming and acidifying oceans. [6.3.5]
Enhanced harmful algal blooms in coastal areas due to rising water temperature.	Increasing susceptibility and limited adaptive capacities of important ecosystems and	Increasing risk due to enhanced frequency of dinoflagellate blooms and	Disproportionate enhancement of risk due to interactions of various

[6.4.2.3]	valuable services due to already existing multiple stresses. [6.3.5, 6.4.1]	respective potential losses and degradations of coastal ecosystems and ecosystem services. [6.4.2]	stresses. [6.3.5]
Food production systems and food security (chapter 7)			
Rising average temperatures and more frequent extreme temperatures [7.1, 7.2, 7.4, 7.5]	Susceptibility of all elements of the food system from production to consumption, particularly for key grain crops.	Risk of crop failures, breakdown of food distribution and storage processes.	Increase in the global population to ca. 9 billion combined with rising temperatures and other trace gases such as ozone affecting food production and quality. Upper temperature limit to the ability of some food systems to adapt.
Extreme precipitation and droughts [7.4]	Crops, pasture, and husbandry are susceptible and sensitive to drought and extreme precipitation.	Risk of crop failure, risk of limited food access and quality.	Flood and droughts affect crop yields and quality, and directly affect food access in most developing countries. [7.4]
Urban areas (chapter 8)			
Inland flooding [8.2.3, 8.2.4]	Large numbers of people exposed in urban areas to flood events. Particularly susceptible are people in low-income informal settlements with inadequate infrastructure (and often on flood plains or along river banks). These bring serious environmental health consequences from overwhelmed, aging, poorly maintained and inadequate urban drainage infrastructure and widespread impermeable surfaces. Local governments are often unable or unwilling to give attention to needed flood-related disaster risk reduction. Much of the urban population unable to get or afford housing that protects against flooding, or insurance. Certain groups more sensitive to ill health from flood impacts – that may include increased mosquito and water borne diseases.	Risks of deaths and injuries and disruptions to livelihoods/incomes, food supplies and drinking water.	In many urban areas, larger and more frequent flooding impacting much larger population. No insurance available or 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.
Coastal flooding (including sea level rise and storm surge) [8.1.4, 8.2.3, 8.2.4]	High concentrations of people, businesses and physical assets including critical infrastructure	Risks from deaths and injuries and disruptions to livelihoods/incomes, food supplies and drinking water.	Additional 2 billion or so urban dwellers expected over the next 3 decades. Sea level rise means

	exposed in low-lying and unprotected coastal zones. Particularly susceptible is urban population that is unable to get or afford housing that protects against flooding or insurance. Local government unable or unwilling to give needed attention to disaster risk reduction.		increasing risks over time, yet with high and often increasing concentrations of population and economic activities on the coasts. No insurance available or 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.
Heat and cold (including urban heat island effect) [8.2.3]	Particularly susceptible is a large and often increasing urban population of infants, young children, older age groups, expectant mothers, people with chronic diseases or compromised immune system in settlements exposed to higher temperatures (especially in heat islands) and unexpected cold spells. Inability of local organizations for health, emergency services and social services to adapt to new risk levels and set up needed initiatives for vulnerable groups.	Risk of mortality and morbidity increasing, including shifts in seasonal patterns and concentrations due to hot days with higher or more prolonged high temperatures or unexpected cold spells. Avoiding risks often most difficult for low-income groups.	Duration and variability of heat waves increasing risks over time for most locations due to interactions with multiple stressors such as air pollution.
Water shortages and drought in urban regions [8.2.3, 8.2.4]	Lack of piped water to homes of hundreds of millions of urban dwellers. Many urban areas subject to water shortages and irregular supplies, with constraints on increasing supplies. Lack of capacity and resilience in water management regimes including rural-urban linkages. Dependence on water resources in energy production systems.	Risks from constraints on urban water provision services to people and industry with human and economic impacts. Risk of damage and loss to urban ecology and its services including urban and peri-urban agriculture.	Cities' viability may be threatened by loss or depletion of freshwater sources – including for cities dependent on distant glacier melt water or on depleting groundwater resources.
Changes in urban meteorological regimes lead to enhanced air pollution [8.2.3]	Increases in exposure and in pollution levels with impacts most serious among physiologically susceptible populations. Limited coping and adaptive capacities, due to lacking implementation of pollution control legislation of urban governments.	Increasing risk of mortality and morbidity, lowered quality of life. These risks can also undermine the competitiveness of global cities to attract key workers and investment.	Complex and compounding health crises.
Geo-hydrological hazards	Local structures and	Risk of damage to	Potential for large local and

(salt water intrusion, mud/land slides, subsidence) [8.2.3, 8.2.4]	networked infrastructure (piped water, sanitation, drainage, communications, transport, electricity, gas) particularly susceptible. Inability of many low-income households to move to housing on safer sites.	networked infrastructure. Risk of loss of human life and property.	aggregate impacts. Knock on effects for urban activities and wellbeing.
Wind storms with higher intensity [8.1.4, 8.2.4]	Sub-standard buildings and physical infrastructure and the services and functions they support particularly susceptible. Old and difficult to retro-fit buildings and infrastructure in cities. Local government unable or unwilling to give attention to disaster risk reduction (limited coping and adaptive capacities).	Risk of damage to dwellings, businesses and public infrastructure. Risk of loss of function and services. Challenges to recovery, especially where insurance is absent.	Challenges to individuals, businesses and public agencies where the costs of retrofitting are high and other sectors or interests capture investment budgets; potential for tensions between development and risk reduction investments.
Changing hazard profile including novel hazards and new multi-hazard complexes [8.1.4, 8.2.4]	Newly exposed populations and infrastructure, especially 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 (e.g. geophysical rather than hydrometeorological).	Risks from failures within coupled systems, e.g. reliance of drainage systems on electric pumps, reliance of emergency services on roads and telecommunications. Potential of psychological shock from unanticipated risks.	Loss of faith in risk management institutions. Potential for extreme impacts that are magnified by a lack of preparation and capacity in response.
Compound slow-onset hazards including rising temperatures and variability in temperature and water [8.2.2, 8.2.4]	Large sections of the urban population in low- and middle-income nations with livelihoods or food supplies dependent on urban and peri-urban agriculture are especially susceptible.	Risk of damage to or degradation of soils, water catchment capacity, fuel wood production, urban and peri-urban agriculture and other productive or protective ecosystem services. Risk of knock-on impacts for urban and peri-urban livelihoods and urban health.	Collapsing of peri-urban economies and ecosystem services with wider implications for urban food security, service provision and disaster risk reduction.
Climate change induced or intensified hazard of more diseases and exposure to disease vectors [8.2.3, 8.2.4]	Large urban population that is exposed to foodborne and waterborne diseases and to malaria, dengue and other vector borne diseases that are influenced by climate change.	Risk due to increases in exposure to these diseases.	Lack of capacity of public health system to simultaneously address these health risks with other climate related risks like flooding.
Rural areas (chapter 9)			
Drought in pastoral areas [9.3.3.1, 9.3.5.2]	Increasing vulnerability due to encroachment on pastoral rangelands, inappropriate land policy, misperception	Risk of famine. Risk of loss of revenues from livestock trade.	Increasing risks for rural livelihoods through animal disease in pastoral areas combined with direct

	and undermining of pastoral livelihoods, conflict over natural resources, all driven by remoteness and lack of voice.		impacts of drought.
Effects of climate change on artisanal fisheries [9.3.3.1, 9.3.5.2]	Artisanal fisheries affected by pollution and mangrove loss, competition from aquaculture and the neglect of the sector by governments and researchers as well as complex property rights.	Risk of economic losses for artisanal fisherfolk, due to declining catches and incomes and damage to fishing gear and infrastructure.	Reduced dietary protein for those consuming artisinally-caught fish, combined with other climate-related risks.
Water shortages and drought in rural areas [9.3.5.1, 9.3.5.1]	Rural people lacking access to drinking and irrigation water. High dependence of rural people on natural resource-related activities. Lack of capacity and resilience in water management regimes (institutionally driven). Increased water demand from population pressure.	Risk of reduced agricultural productivity of rural people, including those dependent on rainfed or irrigated agriculture, or high-yield varieties, forestry and inland fisheries. Risk of food insecurity and decrease in incomes. Decreases in household nutritional status. [9.3.5.1]	Impacts on livelihoods driven by interaction with other factors (water management institutions, water demand, water used by non-food crops), including potential conflicts for access to water. Water-related diseases.
Human health (chapter 11)			
Increasing frequency and intensity of extreme heat	Older people living in cities are most susceptible to hot days and heat waves, as well as people with pre-existing health conditions. [11.3]	Risk of increased mortality and morbidity during hot days and heat waves. [11.4.1] Risk of mortality, morbidity and productivity loss, particularly amongst manual workers in hot climates.	The number of elderly people is projected to triple from 2010-2050. This can result in overloading of health and emergency services.
Increasing temperatures, increased variability in precipitation	Poorer populations are particularly susceptible to climate-induced reductions in local crop yields. Food insecurity may lead to undernutrition. Children are particularly vulnerable. [11.3]	Risk of a larger burden of disease and increased food insecurity for particular population groups. Increasing risk that progress in reducing mortality and morbidity from undernutrition may slow or reverse. [11.6.1]	Combined impacts of climate impacts, population growth, plateauing productivity gains, land demand for livestock, biofuels, persistent inequality, and on-going food insecurity for the poor.
Increasing temperatures, changing patterns of precipitation	Non-immune populations that are exposed to water- and vector-borne disease which are sensitive to meteorological conditions. [11.3]	Increasing health risks due to changing spatial and temporal distribution strains public health systems, especially if this occurs in combination with economic downturn. [11.5.1]	Rapid climate and other environmental change may promote emergence of new pathogens.
Increased variability in precipitation	People exposed to diarrhoea aggravated by higher temperatures, and unusually high or low precipitation. [11.3]	Risk that the progress to date in reducing childhood deaths from diarrhoeal disease is compromised. [11.5.2]	Increased rate of failure of water and sanitation infrastructure due to climate change leading to higher diarrhoea risk.
Livelihood and poverty (chapter 13)			
Increasing frequency and	Poorly endowed farmers	Risk of irreversible harm	Deteriorating livelihoods

severity of droughts, coupled with decreasing rainfall and/or increased unpredictability of rainfall [13.2.1.2; 13.2.1.4; 13.2.2.2]	(high and persistent poverty) particularly in drylands are susceptible to these hazards, since they have a very limited ability to compensate for losses in water-dependent farming systems and/or livestock.	due to short time for recovery between droughts, approaching tipping point in rain-fed farming system and/or pastoralism.	stuck in poverty traps, heightened food insecurity, decreased land productivity, outmigration, and new urban poor in LICs and MICs.
Floods and flash floods in informal urban settlements and mountain environments, destroying physical assets (e.g. homes, roads, terraces, irrigation canals) [13.2.1.1; 13.2.1.3; 13.2.1.4]	High exposure and susceptibility of people, particularly children and elderly as well as disabled in flood-prone areas. Inadequate infrastructure, culturally imposed gender roles, and limited ability to cope and adapt due to political and institutional marginalization and high poverty adds to the susceptibility of these people in informal urban settlements, limited political interest in development and building adaptive capacity.	Risk of a high morbidity and mortality to floods and flash floods. Factors that further increase risk may include a shift from transient to chronic poverty due to eroded human and economic assets (e.g. labor market); economic losses due to infrastructure damage	Exacerbated inequality between better-endowed households able to invest in flood-control measures and/or insurance and increasingly vulnerable populations prone to eviction, erosion of livelihoods, and outmigration.
Increased variability of precipitation; shifts in mean climate and extreme events [13.2.1.1; 13.2.1.4]	Limited ability to cope due to exhaustion of social networks, especially among the elderly and female-headed households; mobilization of labor and food no longer possible.	Hazard combines with vulnerability to shift populations from transient to chronic poverty due to persistent and irreversible socio-economic and political marginalization. In addition the lack of governmental support, as well as limited effectiveness of response options increase the risk.	Increasing yet invisible multidimensional vulnerability and deprivation at the convergence of climatic hazards and socio-economic stressors.
Successive and extreme events (floods, droughts) coupled with increasing temperatures and rising water demand [13, 2.1.1; 13.2.1.5]	Rural communities are particularly susceptible, due to the marginalization of rural water users to the benefit of urban users, given political and economic priorities (e.g. Australia, Andes, Himalayas, Caribbean).	Risk of loss of rural livelihoods, severe economic losses in agriculture and damage to cultural values and identity; mental health impacts (including increased rates of suicide).	Loss of rural livelihoods that have existed for generations, heightened outmigration to urban areas; emergence of new poverty in MICs and HICs.
Sea level rise [13.1.4; 13.2.1.1; 13.2.2.1; 13.2.2.3]	High number of people exposed in low-lying areas coupled with high susceptibility due to multidimensional poverty, limited alternative livelihood options among poor households, and exclusion from institutional decision-making structures.	Risk of severe harm and loss of livelihoods. Potential loss of common-pool resources; of sense of place, belonging, and identity, especially among indigenous populations.	Loss of livelihoods and mental health risks due to radical change in landscape, disappearance of natural resources, and potential relocation; increased migration.
Increasing temperatures and heat waves [13.2.2.4; 13.2.1.5; 13.2.2.3]	Agricultural wage labourers, small-scale farmers in areas with multidimensional	Risk of increased morbidity and mortality due to heat stress, among male and	Declining labor pool for agriculture coupled with new challenges for rural

	poverty and economic marginalization, children in urban slums, and the elderly particularly susceptible.	female workers, children, and the elderly, limited protection due to socio-economic discrimination and inadequate governmental responses.	health care systems in LICs and MICs; aging and low-income populations without safety nets in HICs at risk.
Increased variability of rainfall and/or extreme events (floods, droughts, heat waves) [13.2.1.1; 13.2.1.3; 13.2.1.4; 13.2.1.5]	People highly dependent on rain-fed agriculture particularly at risk. Persistent poverty among subsistence farmers and urban wage labourers who are net buyers of food with limited coping mechanisms.	Risk of crop failure, spikes in food prices, reduction in consumption to protect household assets, risk of food insecurity, shifts from transient to chronic poverty due to limited ability to reduce risks.	Food riots, child food poverty, global food crises, limits of insurance and other risk-spreading strategies.
Changing rainfall patterns (temporally and spatially)	Households or people with a high dependence on rain-fed agriculture and little access to alternative modes of income.	Risks of crop failure, food shortage, severe famine.	Coincidence of hazard with periods of high global food prices leads to risk of failure of coping strategies and adaptation mechanisms such as crop insurance (risk spreading).
Stressor from soaring demand (and prices) for biofuel feedstocks due to climate policies.	Farmers and groups that have unclear and/or insecure land tenure arrangements exposed to the dispossession of land due to land grabbing in developing countries.	Risk of harm and loss of livelihoods for some rural residents due to soaring demand for biofuel feedstocks and insecure land tenure and land grabbing.	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.	Pastoralists and small farmers subject to damage to their productive assets (e.g. herds of livestock; dykes, 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.
Emergent risks and key vulnerabilities (chapter 19)			
Warming and drying (precipitation changes of uncertain magnitude) [AR5 WGI TS.5.3, WGI SPM, WGI 11.3, WGI 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, 19.6.1.1, 19.3.2.2 19.6.3.4]	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. [19.3.2.2, 19.6.3.4]	Competition for water from diverse sectors (e.g. energy, agriculture, industry) interacts with climate changes to produce locally severe shortages. [19.3.2.2, 19.6.3.4]
Changes in regional and seasonal temperature and precipitation over land [AR5 WGI TS.5.3, WGI SPM, WGI 11.3, WGI 12.4]	Communities highly dependent on ecosystem services [19.2.2.1, 19.3.2.1] which are negatively affected by changes in regional and seasonal temperature.	Risk of large-scale species richness loss over most of the global land surface. 57±6% of widespread & common plants and 34±7% of widespread & common animals expected to lose	Widespread loss of ecosystem services, including: *provisioning*, such as food and water; *regulating*, such as the control of climate and disease; *supporting*, such as

		≥50% of their current climatic range by the 2080s leading to loss of services. [19.3.2.1]	nutrient cycles and crop pollination; and *cultural*, such as spiritual and recreational benefit. [19.3.2.1, 19.6.3.4]
Africa (chapter 22)			
Increasing Temperature	Children, pregnant women, and those with compromised health status are particularly at risk for temperature-related changes in diarrheal and vector-borne diseases, and for temperature-related reductions in crop yields. Outdoor workers, older adults, and young children are most susceptible to hot weather and heat waves. [22.3.5.2, 22.3.5.4]	Risk of changes in the geographic distribution, seasonality, and incidence of infectious diseases, leading to increases in the health burden. Risk of increased burdens of stunting in children. Risk of increase in morbidity and mortality during hot days and heat waves.	Interactions among factors lead to emerging and re-emerging epidemics.
	Populations dependent on aquatic systems and aquatic ecosystem services that are sensitive to increased water temperatures.	Loss of aquatic ecosystems and risks for people who might depend on these resources; reduction in freshwater fisheries production. [22.3.2.2, 22.3.4.4]	Risk of loss of livelihoods due to interactions of loss of ecosystem services and other climate-related stressors on poor communities.
	Rural and urban populations whose food and livelihood security is diminished.	Risk of harm and loss due to increased heat stress on crops and livestock resulting in reduced productivity; Increased food storage losses due to spoilage. [22.3.4.1, 22.3.4.2]	Range expansion of crop pests and diseases to high elevation agroecosystems. [22.3.4.3]
Extreme Events, e.g. floods and flash floods (& drought)	Population groups living in informal settlements in highly exposed urban areas; women and children often the most vulnerable to disaster risk. [22.3.6, 22.4.3]	Increasing risk of mortality, harm and losses due to water logging triggered by heavy rainfall events.	Compounded risk of epidemics including diarrhoeal diseases (cholera).
	Susceptible groups include those who experience diminished access to food resulting from reduced capacity to transport, store, and market food, such as the urban poor.	Risk of food shortages and of damages to the food system due to storms and flooding.	Food price spikes due to convergence of climatic and non-climatic forces that reduce food access for the poor whose income is disproportionately spent on food. [22.3.4.5]
	Children, pregnant women, and those with compromised health status are particularly vulnerable to reduced access to safe water and improved sanitation and increasing food insecurity. [22.3.5.2, 22.3.5.3]	Risk of crop and livestock losses from drought. Risk of reduced water supply and quality for household use. [22.3.4.1, 22.3.4.2] Risk of increased incidence of food and waterborne diseases (e.g. cholera) and undernutrition. Risk of drinking water contamination due to heavy	Compound effects of high temperature and changes in rainfall on human and natural systems. Increased incidence of stunting in children. [22.3.5.3].

		precipitation events and flooding. [22.3.5.2]	
Europe (chapter 23)			
Extreme weather events [23.9]	Sectors with limited coping and adaptive capacity as well as high sensitivity to these extreme events, such as transport, energy and health are particularly susceptible.	Risk of new systemic threats due to stress on multiple and interconnected sectors. Risk of failure of service provision of one or more sectors.	Disproportionate intensification of risk due to increasing interdependencies.
Climate change increases the spatial distribution and seasonality of pests and diseases. [23.4.1, 23.4.3, 23.4.4]	High susceptibility of plants and animals that are exposed to pests and diseases.	Risk of increases in crop losses and animal diseases or even fatalities of livestock.	Increasing risks due to limited response options and various feedback processes in agriculture, e.g. use of pesticides or antibiotics to protect plants and livestock increases resistance of disease vectors.
Extreme weather events and reduced water availability due to climate change. [23.3.4]	Low adaptive capacity of power systems might lead to limited energy supply as well as higher supply costs during such extreme events and conditions.	Increasing risk of power shortages due to limited energy supply, e.g. of nuclear power plants due to limited cooling water during heat stress.	Continued underinvestment in adaptive energy systems might increase the risk of mismatches between limited energy supply during these events and increased demands, e.g. during a heat wave.
Asia (chapter 24)			
Rising average temperatures and more frequent extreme temperatures, as well as changing rainfall patterns (temporally and spatially).	Food systems and food production system for key grain crops, particularly rice and other cereal crop farming systems are highly susceptible. [24.4.4.3]	Risk of crop failures and lower crop yield also can increase the risk of major losses for farmers and rural livelihoods. [24.4.4.3]	Increase in Asian population combined with rising temperatures affecting food production. Upper temperature limit to the ability of some food systems to adapt could be reached.
Rising sea level	Paddy fields and farmers near the coasts are particularly susceptible. [24.4.4.3]	Risk of loss of arable areas due to submergence. [24.4.4.3]	Migration of farming communities to higher elevation areas entails risks for migrants and receiving regions.
Projected increase in frequency of various extreme events (heat-wave, floods and droughts) and sea level rise.	Increasing exposure due to convergence of livelihood and properties into coastal megacities. People in areas that are not sufficiently protected against natural hazards are particularly susceptible.	Risk of loss of life and assets due to coastal floods accompanied by increasing vulnerabilities.	Projected increase in disruption of basic services such as water supply, sanitation, energy provision, and transportation system, which themselves could increase vulnerabilities.
Australasia (chapter 25)			
Rising air and sea surface temperatures, drying trends, reduced snow cover, increased intensity of severe cyclones, ocean acidification [25.2, Table 25-1, Figure 25-4, AR5 WGI Chapter 14	Species that live in a limited climatic range and that suffer from habitat fragmentation as well as from external stressors (pollution, run-off, fishing, tourism, introduced	Risk of significant change in community composition and structure of coral reefs and montane ecosystems and risk of loss of some native species in Australia. [25.6.1, 25.6.2, 25.10.2]	Increasing risk from compound extreme events across time and space, and cumulative adaptation needs, with recovery and risk reduction measures hampered further by impacts

and Atlas]	predators and pests) are especially susceptible. [25.6.1, 25.6.2]		and responses reaching across different levels of government. [25.10.2, 25.10.3, Box 25-9]
Increased extreme rainfall related to flood risk in many locations [25.2, Table 25-1]	Adaptation deficit of existing infrastructure and settlements to current flood risk; expansion and densification of urban areas; effective adaptation includes transformative changes such as land-use controls and retreat. [25.3, Box 25-8, 25.10.2]	Increased frequency and intensity of flood damage to infrastructure and settlements in Australia and New Zealand. [Box 25-8, 25.10.2]	
Continuing sea level rise, with projections spanning a particularly large range and continuing beyond 2100, even under mitigation scenarios [25.2, Box 25-1, AR5 WGI Chapter 13]	Long-lived and high asset value coastal infrastructure, and low-lying ecosystems are highly susceptible. Expansion of coastal populations and assets into coastal zones increases the exposure. Conflicting priorities constrain adaptation options and limit effective response strategies. [25.3, Box 25-1]	Increasing risks to coastal infrastructure and low-lying ecosystems in Australia and New Zealand, with widespread damages towards the upper end of projected ranges. [Box 25-1, 25.6.1, 25.6.2, 25.10.2].	
North America (chapter 26)			
Increases in frequency and/or intensity of extreme events, such as heavy precipitation, river and coastal floods, heat waves and droughts. [26.2.2, 26.3.1, 26.8.1]	Physical infrastructure in a declining state in urban areas particularly susceptible. Also increases in income disparities and limited institutional capacities might result in larger proportions of people susceptible to these stressors due to limited economic resources. [26.7, 26.8.2]	Risk of harm and loss in urban areas, particularly in coastal and dry environments due to enhanced vulnerabilities of social groups, physical systems and institutional settings combined with the increases of extreme weather events. [26.8.1]	Inability to reduce vulnerability in many areas results in increase in risk more so than change in physical hazard. [26.8.3]
Higher temperatures, decreases in runoff and lower soil moisture due to climate change [26.2, 26.3]	Vulnerability of small rural landholders, particularly in Mexican agriculture, and of the poor in rural settlements. [26.5, 26.8.2.2]	Risk of increased losses and decreases in agricultural production. Risk of food and job insecurity for small landholders and social groups in regions exposed to these phenomena. [26.5, 26.8.2.2]	Increasing risks of social instability and local economic disruption due to internal migration. [26.2.1, 26.8.3]
Wildfires and drought conditions [Box 26-2]	Indigenous groups, low-income residents in peri-urban areas, and forest systems. [Box 26-2, 26.8.2]	Risk of loss of ecosystem integrity, property loss, human morbidity and mortality due to wildfires. [Box 26-2, 26.8.3]	
Extreme storm and heat events, air pollution, pollen, and infectious diseases [26.6.1]	Susceptibility of individuals is determined by factors such as economic status, pre-existing illness, age, and access to assets. [26.6.1]	Increasing risk of extreme temperature-, storm-, pollen, and infectious diseases-related human morbidity or mortality. [26.6.2]	
River and coastal floods, and sea level rise [26.2.2,	Increasing exposure of populations, property, as	Risk of property damage, supply chain disruption,	Multiple risks from interacting hazards on

26.4.2, 26.8.1]	well as ecosystems, partly resulting from overwhelmed drainage networks. Groups and economic sectors that highly depend on the functioning of different supply chains; public health institutions that can be disrupted; and groups that have limited coping capacities to deal with supply chain interruptions and disruptions to their livelihoods are particularly susceptible. [26.7, 26.8.1]	public health, water quality impairment, ecosystem disruption, infrastructure damage, and social system disruption from urban flooding due to river and coastal floods and floods of drainage networks. [26.4.2, 26.8.1]	populations' livelihoods, infrastructure and services. [26.7, 26.8.3]
Central and South America (chapter 27)			
Reduced water availability in semi arid regions and regions dependent on glacier meltwater; flooding in urban areas due to extreme precipitation [27.2.1, 27.3.3]	Groups that cannot keep agricultural livelihoods and are forced to migrate are especially vulnerable. Limited infrastructure and planning capacity can further increase the lack of coping and adaptive capacities to rapid changes expected (precipitation), especially in large cities.	Risk of loss of human lives, livelihood and property.	Increase in infections diseases. Economic impacts due to reallocation of populations.
Ocean acidification and warming [27.3.3, CC-OA]	Coral reef systems.	Risk of loss of biodiversity (species) and risk of a reduced fishing capacity with respective impacts for coastal livelihoods.	Economic losses and impact on food (fishery) production in certain regions.
Extremes of drought/precipitation [27.2.1, 27.3.4]	Elevated CO_2 decreases nutrient contents in plants, especially nitrogen in relation to carbon in food products.	Risk of loss of (food) production and productivity in some regions where extreme events may occur. Need to adjust diet due to decrease in food quality (e.g. less protein due to lower nitrogen assimilation). Decrease in bioenergy production.	Strong economic impacts related to the need to move crops to more suitable regions. Teleconnections (related to food quality) related to the intense exportation of food by the region. Impacts on energy system and carbon emissions with consequent increase in fossil fuel demand.
Higher temperatures and humidity leads to a spread of vector-borne diseases in altitude and latitude [27.3.7]	People exposed and vulnerable to vector borne diseases and an increase in mosquito biting rates that increase the probability of human infections.	Risk of increase in morbidity and in disability-adjusted life years (DALYs); Risk of loss of human lives; Risk of decrease in school and labour productivity.	High economic impacts owing to the necessity to increase the financing of health programs, as well as the costs of DALYs, increase in hospitals and medical infrastructure adequate enough to cope with increasing disease incidence rates, and the spread of diseases to newer regions.
Polar Systems (chapter 28)			

Loss of multi-year ice and reductions in the spatial extent of summer sea ice [28.2.5, 28.3.2, 28.4.1]	Indigenous communities that dependent on sea ice for traditional livelihoods are vulnerable to this hazard, particularly due to loss of breeding and foraging platforms for marine mammals.	Risk of loss of traditional livelihoods and food sources.	Top down shifts in food-webs.
	Ecosystems are vulnerable due to the shifts in the distribution and timing of ice algal and ocean phytoplankton blooms.	Risk of disruption of synchronized timing of zooplankton ontogeny and availability of prey. Increased variability in secondary production while zooplankton adapt to shifts in timing. Risks also to local marine foodwebs.	Bottom up shifts in food webs. Potential changes in pelagic and benthic coupling.
Ocean acidification [28.2.2, 28.3.2]	Tolerance limits of endemic species surpassed. Impacts on exoskeleton formation for some species and alteration of physiological and behavioural properties during larval development.	Localized loss of endemic species, local impacts on marine foodwebs.	Localized declines in commercial fisheries. Local declines in fish, shellfish, seabirds and marine mammals.
Shifts in boundaries of marine eco-regions due to rising water temperature, shifts in mixed layer depth, changes in the distribution and intensity of ocean currents. [28.2.2, 28.3.2]	Marine organisms that are susceptible to spatial shifts are particularly vulnerable.	Risk of changes in the structure and function of marine systems and potentially species invasions.	Disputes over international fisheries and shared stocks
Declining sea ice, changes in snow and ice timing and state, decreasing predictability of weather. [28.1, 28.4.1]	Many traditional subsistence food sources – especially for indigenous peoples - such as Arctic marine and land mammals, fish and waterfowl. Various traditional livelihoods are susceptible to these hazards.	Risk of loss of habitats and changes in migration patterns of marine species.	Enhancement of risk to food security and basic nutrition – especially for indigenous peoples - from loss of subsistence foods and increased risk to subsistence hunters', herders', and fishers' health and safety in changing ice conditions.
Increased river and coastal flooding and erosion and thawing of permafrost [28.2.4, 28.3.1, 28.3.4]	Rural and remote communities as well as urban communities in low-lying Arctic areas are exposed. Susceptibility and limited coping capacity of community water supplies due to potential damages to infrastructure.	Community and public health infrastructure damaged resulting in disease from contamination and sea water intrusion.	Reduced water quality and quantity may result in increased rates of infection, other medical problems and hospitalizations.
Extreme and rapidly changing weather, intense weather and precipitation events, rapid snow and ice melt, changing river and sea ice conditions, permafrost thaw. [28.2.4]	People living from subsistence travel and hunting, herding and fishing, for example indigenous peoples in remote and isolated communities are particularly susceptible.	Accidents, physical/mental injuries, death, and cold-related exposure, injuries and diseases.	Enhanced risks to safe travel or subsistence hunting, herding, fishing activities affect livelihoods and wellbeing.

Diminished sea ice; earlier sea ice melt-out; faster sea ice retreat; thinner, less predictable ice in general; greater variability in snow melt/freeze; ice, weather, winds, temperatures, precipitation. [28.2.5, 28.2.6, 28.4.1]	Livelihoods of many indigenous peoples (e.g. Inuit and Saami) depend upon subsistence hunting and access to and favourable conditions for animals. These livelihoods are susceptible. Also marine ecosystems are susceptible (e.g. marine mammals).	Risk of loss of livelihoods and damage due to: (e.g., Inuit: more difficult access to marine mammals associated with diminishing sea ice) and (e.g., Saami: loss of access by reindeer to their forage under snow due to ice layers formed by warming winter temperatures and “rain on snow”).	Enhanced risk of loss of livelihoods and culture of increasing numbers of indigenous peoples, exacerbated by increasing loss of lands and sea ice for hunting, herding, fishing due to enhanced petroleum and mineral exploration and increased maritime traffic.
Small Islands (chapter 29)			
Increases in intensity of tropical cyclones [AR5 WGI 14.6, 14.8.4]	Various countries and communities are vulnerable to these hazards due to their high dependence on natural and ecological systems for security of settlements and tourism [29.3.3.1], human health [29.3.3.2] and water resources [29.3.2].	Risk of loss of ecosystems, settlements and infrastructure, as well as negative impacts on human health and island economies. [Figure 29-4]	Increased risk of interactions of damages to ecosystems, settlements, island economies and risks to human life. [29.6, Figure 29-4].
Ocean warming and acidification leading to coral bleaching [29.3.1.2, 30.5.4.2, 30.5.6.1.1, 30.5.6.2]	Tropical island communities are highly dependent on coral reef ecosystems for subsistence life styles, food security, coastal protection and beach and reef-based tourist economic activity and hence are highly susceptible to the hazard of coral bleaching. [29.3.1.2, 30.6.2.1.2]	Risk of decline and possible loss of coral reef ecosystems through thermal stress. Risk of serious harm and loss of subsistence lifestyles. Risk of loss of coastal protection and beaches, risk of loss of tourist revenue. [29.3.1.1, 29.3.1.2]	Impacts on human health and loss of subsistence lifestyles. Potential increase in internal migration / urbanisation. [29.3.3.3, Chapter 9]
Sea level rise [29.3.1.1, 30.3.1.2; AR5 WGI 3.7.1]	Many small island communities and associated settlements and infrastructure are in low-lying coastal zones (high exposure) and are also vulnerable to increasing inundation, erosion and wave incursion. [5.3.2, 29.3.1.1, Figure 29-2]	Risk of loss and harm due to sea level rise in small island communities. Global Mean Sea Level is likely to increase by 0.35 to 0.70 m for RCP 4.5 during the 21st century, threatening low-lying coastal areas and atoll islands. [29.4.3, Table 29-1; AR5 WGI 13.5.1, Table 13.5]	Incremental upwards shift in sea-level baselines results in increased frequency and extent of marine flooding during high tides and episodic storm surges These events could render soils and fresh groundwater resources unfit for human use before permanent inundation of low-lying areas. [29.3.1.1, 29.3.2, 29.3.3.1, 29.5.1].
Regional Oceans (chapter 30)			
Increasing ocean temperatures. Increased frequency of thermal extremes	Corals and other organisms whose tolerance limits are exceeded are particularly susceptible (especially CBS, STG, SES and EUS ocean regions). [30.5.2, 30.5.4, 30.5.5, CC-CR, 30.5.6, CC-OA, 6.2.2.1, 6.2.2.2]	Risk of increased mass coral bleaching and mortality (loss of coral cover) with severe risks for coastal fisheries, tourism and coastal protection. [30.5.2, 30.5.3, 30.5.4, 30.5.5, Box CC-CR, 6.3.2. 6.3.5, 5.4.2.4, 7.2.1.2, 6.4.1.4, 29.3.1.2]	Loss of coastal reef systems, risk of decreased food security and reduced livelihoods, and reduced coastal protection. [30.6.2.1, 30.6.5, 7.2.1.2]

	Marine species and ecosystems as well as fisheries and coastal livelihoods and tourism that cannot cope or adapt to changing temperatures and changes in the distribution are particularly vulnerable, especially for HLSBS, CBS, STG, and EBUE. [30.5, CC-BIO, 6.3.2, 6.3.4, 7.3.2.6]	Risk for fishery and coastal livelihoods. Fishery opportunity changes as stock abundance may rise or fall; increased risk of disease and invading species impacting ecosystems and fisheries. [6.3.5, 6.4.1.1, 6.5.3, 7.3.2.6, 7.4.2, 29.5.3, 29.5.4]	Significant risk of fisheries collapse may develop as the capacity for fisheries to resist fundamental change to fishery composition as well as the increased migration of disease and other organisms is accelerated. [6.5.3, 7.5.1.1.3]
	Coastal ecosystems and communities that might be exposed to phenomena of elevated rates of microbial respiration leading to reduced oxygen at depth and increased spread of dead zones are particularly vulnerable (particularly for EBUE, SES, EUS).	Risk of loss of habitats and fishery resources as well as losses of key fisheries species. Oxygen levels decrease leading to impacts on ecosystems (e.g. loss of habitat) and organisms (e.g. physiological performance of fish) results in reduced capture of key fisheries species.	Increasing risk of loss of livelihoods.
	Deep sea life is sensitive to hazards and to change given the very constant conditions under which it has evolved. [30.1.3.1.3, 30.5.2, 30.5.5]	Risk of fundamental changes in conditions associated with Deep Sea (e.g. oxygen, pH, carbonate, CO_2, temperature) drive fundamental changes that result in broad scale changes throughout the ocean. [30.1.3.1.3, 30.5.2, 30.5.5, CC-UP, CC-NPP]	Changes in the deep ocean may be a prelude to ocean wide changes with planetary implications.
Rising ocean acidification	Reef systems, corals and coastal ecosystems that are exposed to a reduced rate of calcification and greater decalcification leading to potential loss of carbonate reef systems, corals, molluscs and other calcifiers in key regions, such as the CBS, STG [6.2.2.2]	Risk of the alteration of ecosystem services including risks to food provisioning with impacts on fisheries and aquaculture. [7.2.1.2, 7.3.2, 7.4.2, 6.2.5.3]	Income and livelihoods for communities are reduced as productivity of fisheries and aquaculture diminish. [7.5.1.1.3, 30.6]
	Marine organisms that are susceptible to changes in pH and carbonate chemistry imply a large number of changes to the physiology and ecology of marine organisms (particularly in CBS, STG, SES regions). [30.3.2.2, .2 .2, 6.3.4, 6.2.5]	Risk of fundamental shifts in ecosystems composition as well is organism function occur, leading to broad scale and fundamental change. Income and livelihoods from dependent communities are affected as ecosystem goods and services decline, with the prospect that recovery may take tens of thousands of years. [6.1.1.2]	Risk to ecosystems and livelihoods is increased by the potential for interaction among ocean warming and acidification to create unknown impacts. [CC-OA]
	Coastal systems are increasingly exposed to upwelling in upwelling systems which results in	Risk of loss and harm to fishery and aquaculture operations and respective livelihoods (e.g. oyster	Background pH and carbonate chemistry are also such that harmful conditions are always present (avoiding

	periods of high CO_2, low 0_2 and pH. [CC-UP, 6.2.2.2, 6.2.5.3]	cultivation) especially those exposed periodically to harmful conditions during elevated upwelling, which trigger adaptation responses. [30.6.2.1.4]	impacts via adaptation not possible any more. [30.6.2.1.4]
Increased stratification as a result of ocean warming; Reduced ventilation.	Ocean ecosystems are vulnerable due to the reduced regeneration of nutrients as mixing between the ocean and its surface is reduced (EUS, STG and EBUE). [30.5.2, 30.5.4, 30.5.5; 6.2, 6.3, 6.5]	Risk of productivity losses of oceans and respective negative impacts on fisheries. The concentration of inorganic nutrients in the upper layers of the ocean is reduced leading to lower rates of primary productivity. [CC-NPP]	Reduced primary productivity of the ocean impacts fisheries productivity leading to lower catch rates and effects on livelihoods. [6.4.1.1, CC-NPP]
	Ecosystems and organisms that are sensitive to decreasing oxygen levels. [30.5.2, 30.5.3, 30.5.5, 30.5.6, 30.5.7]	Increased risk of dead (hypoxic) zones reducing key ecosystems and fisheries habitat. [30.3.2.3, .1 .1 .3]	
Changes to wind, wave height and storm intensity.	Shipping and industrial infrastructure is vulnerable to wave and storm intensity. [30.6.2]	Risk of increasing losses and damages to shipping and industrial infrastructure.	Risk of accidents increases for enterprises such as shipping, as well as deep sea oil gas and mineral extraction.

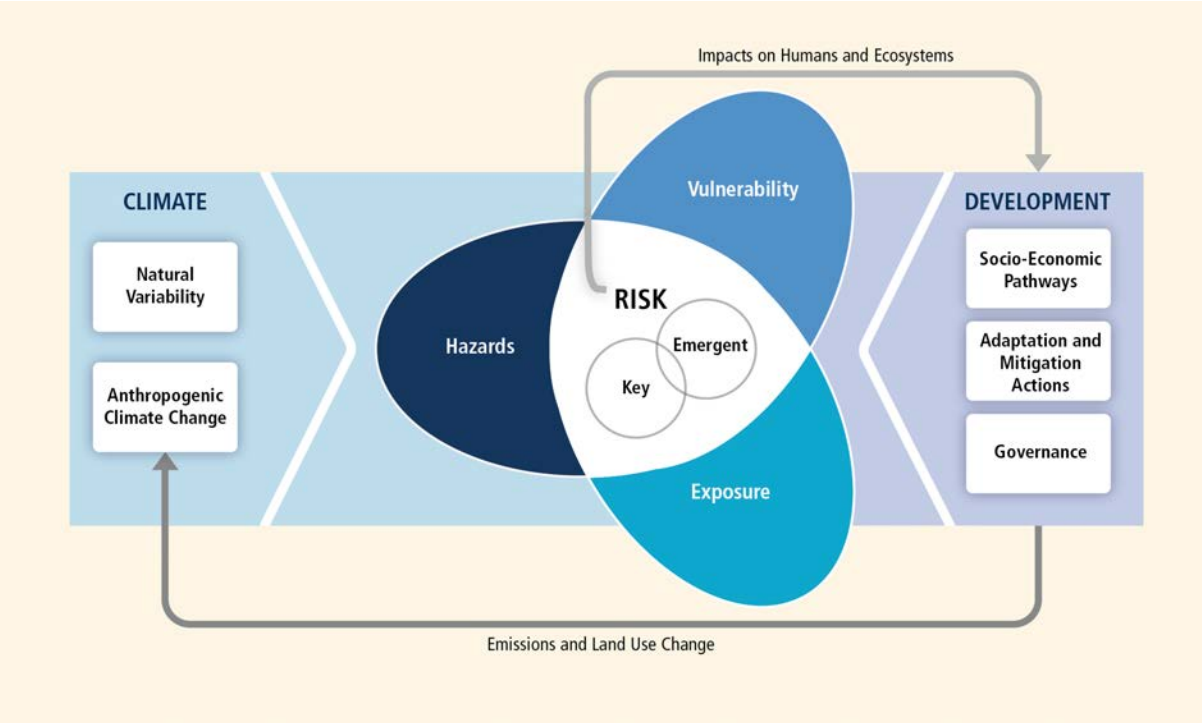

Figure 19-1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. The figure visualizes the different terms and concepts discussed in this chapter. It underscores that risks are a product of a complex interaction between physical hazards associated 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 Box 19-2 and the Glossary. Vulnerability and exposure are, as the figure shows, largely the result of socio-economic development pathways and societal conditions (although changing hazard patterns also play a role, see 19.6.1.1). Changes in both the climate system (left side) and development processes (right side) are key drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk (modified version of Figure 1, IPCC 2012a).

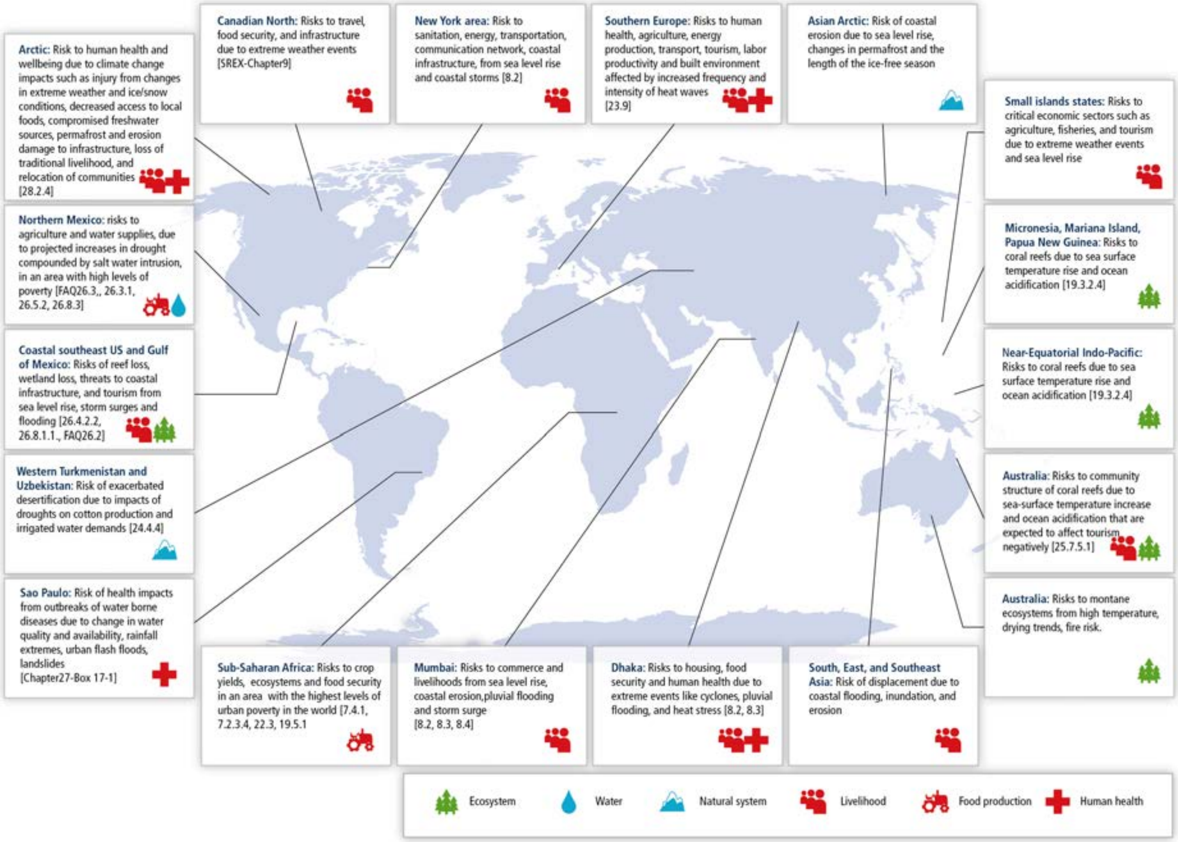

Figure 19-2: Some examples of areas of compound risk identified in this assessment. Symbols indicate one or two of the main sectors or systems subject to compound risk but in each case, additional sectors and systems are at risk.

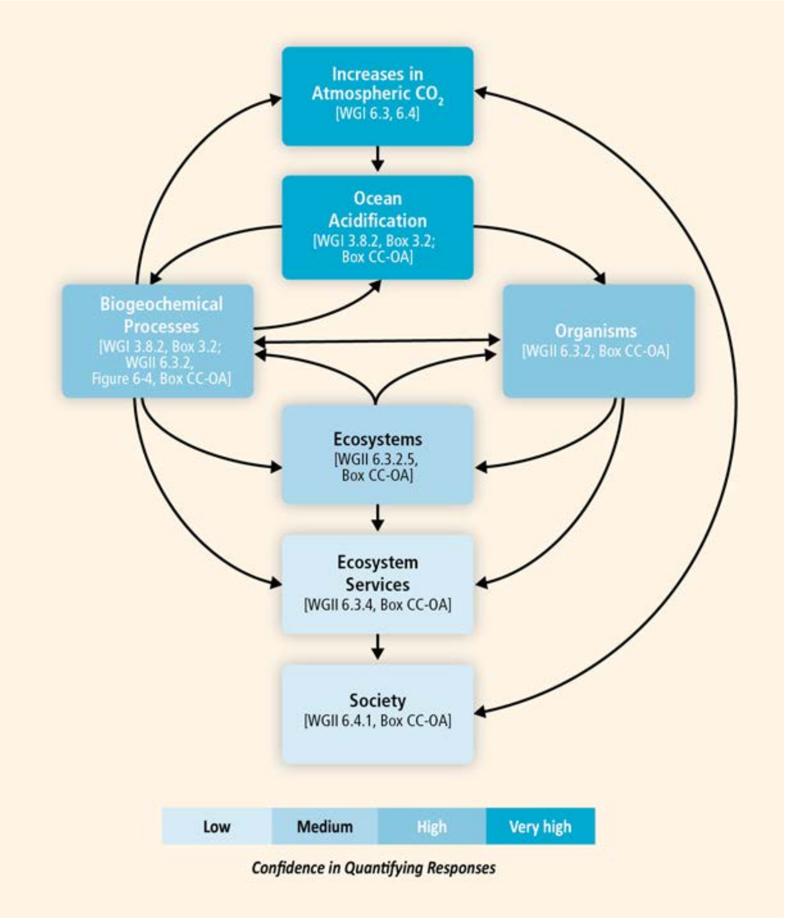

Figure 19-3: The pathways by which ocean acidification affects marine processes, organisms, ecosystems, and society. The confidence in quantifying the impacts decreases along the pathway.

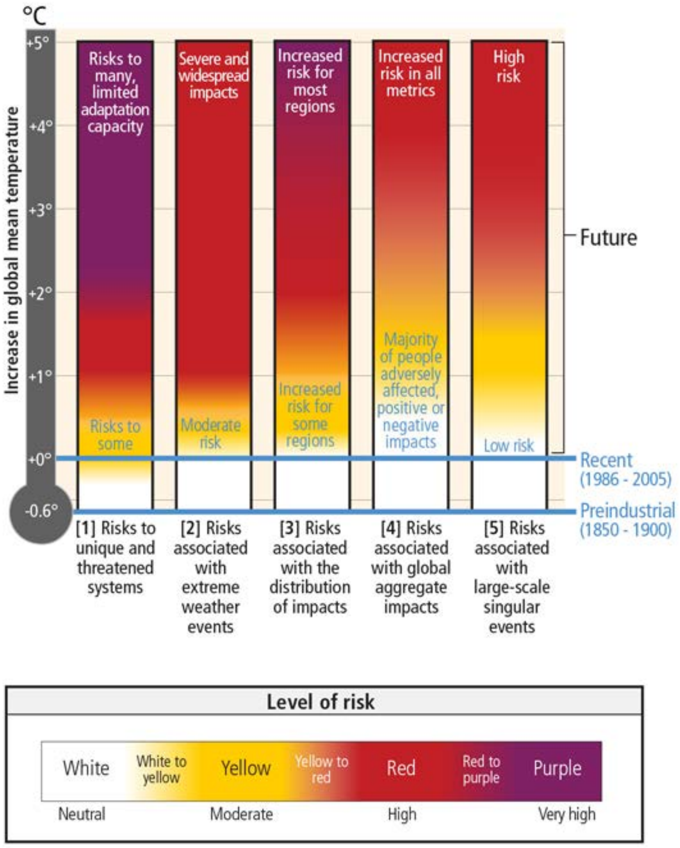

Figure 19-4: The dependence of risk associated with the Reasons for Concern (RFCs) on the level of climate change, updated from TAR and Smith *et al.* (2009). The color scheme indicates the additional risk due to climate change as described in the text. The shading of each ember provides a qualitative indication of the increase in risk with temperature for each individual "reason." The transition from red to purple, introduced here, is defined by very high risk of severe impacts and the presence of significant irreversibilities or persistence of climate-related hazards combined with limited ability to adapt due to the nature of the hazard or impact. Comparison of the increase of risk across RFCs indicates the relative sensitivity of RFCs to increases in GMT. In general, assessment of RFCs takes autonomous adaptation into account, as was done previously (Smith *et al.*, 2001; Schneider *et al.*, 2007, AR4 WGII Chapter 19). In addition, this assessment took into account limits to adaptation in the case of RFC1, RFC3, and RFC5, independent of the development pathway. The rate and timing of climate change and physical impacts, not illustrated explicitly in this diagram, was taken into account in assessing RFC1 and RFC5. Comments superimposed on RFCs provide additional details which were factored into the assessment. The levels of risk illustrated reflect the judgments of Chapter 19 authors.

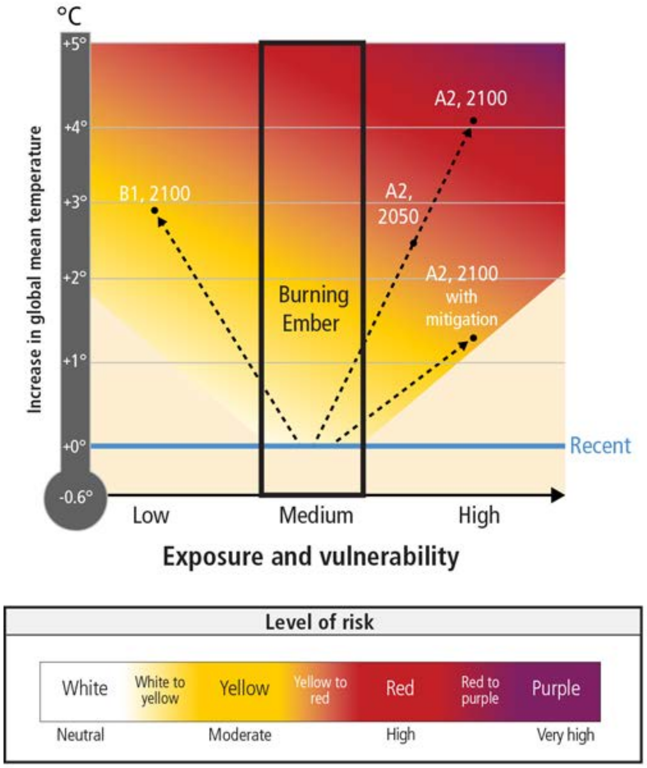

Figure 19-5: Illustration of the dependence of risk associated with a Reason for Concern (RFC) on the level of climate change and exposure and vulnerability (E&V) of society. This figure is schematic; the degree of risk associated with particular levels of climate change or E&V has not been based on a literature assessment, nor associated with a particular RFC (the “burning ember” in the figure refers generically to any of the embers in Figure 19-4). The E&V axis is relative rather than absolute: “Medium” E&V indicates a future development path in which E&V changes over time are driven by moderate trends in socio-economic conditions. “Low” and “High” E&V indicate futures that are substantially more optimistic or pessimistic, respectively, regarding exposure and vulnerability. Judgments made in other burning ember diagrams of the RFCs (Smith *et al.*, 2001, 2009) including Figure 19-4, which do not explicitly take changes in E&V into account, are consistent with Medium future E&V. Arrows and dots illustrate the use of SRES scenario-based literature to locate particular impact or risk assessments on the figure according to the evolution of climate and socio-economic conditions over time. This figure does not explicitly address issues related to the rates of climate change or when impacts might be realized.

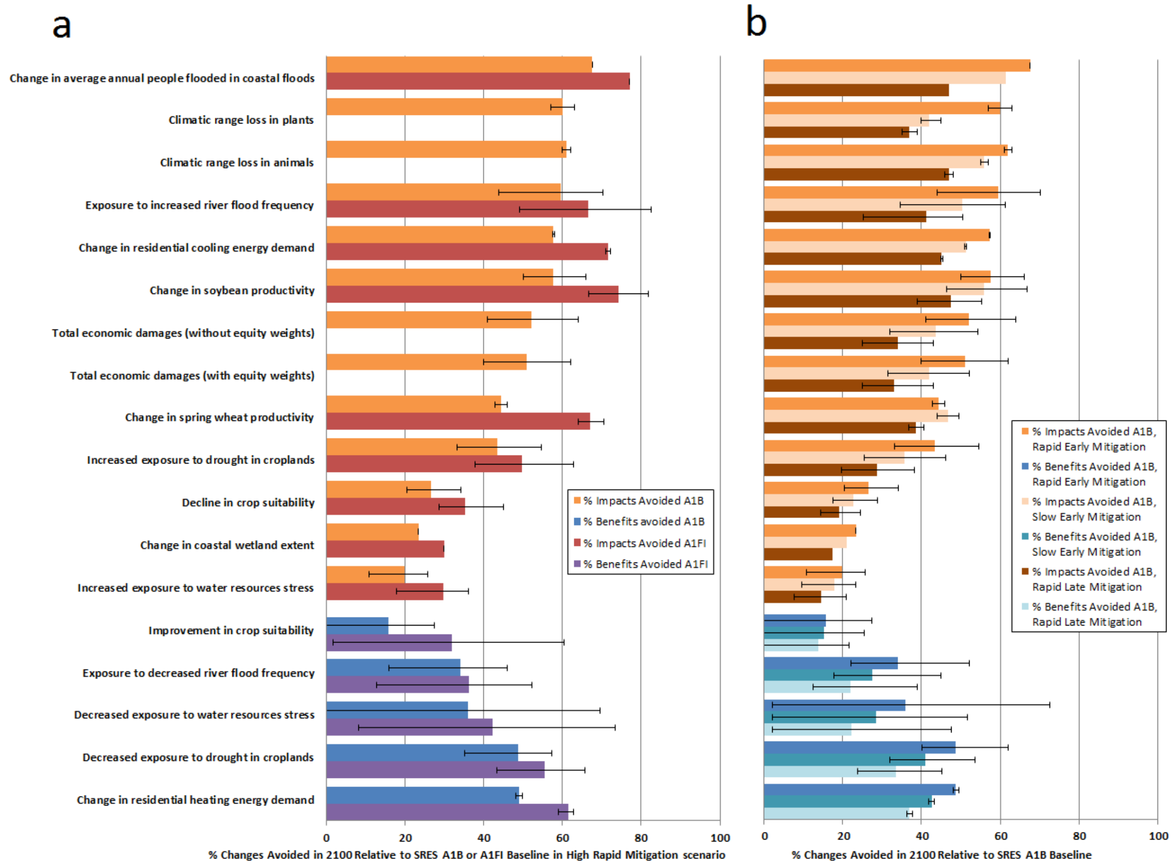

Figure 19-6: Panel **a**: Climate change impacts avoided by an early, rapid mitigation scenario in which global emissions peak in 2016 and are reduced at 5% thereafter, compared to two no-mitigation baseline cases SRES A1B (orange bars) and SRES A1FI (red bars). Impacts avoided are larger if the A1FI baseline scenario is used than if the A1B baseline is used, because greenhouse gas emissions in A1FI exceed those in A1B (see 19.7.1). Panel **b**: The dependence of the potential to avoid climate change impacts upon the timing of emission reductions is illustrated. Climate change impacts avoided by the same early, rapid mitigation scenario compared to the no-mitigation baseline case SRES A1B (orange bars) are shown. The information displayed is identical to the orange bars in panel a, but a comparison is now made with the impacts avoided from two other less stringent mitigation scenarios. Impacts avoided if global emissions peak in 2016 but are subsequently reduced more slowly (2% annually) are lower (pink bars compared to orange bars). However, if mitigation occurs later, so that global emissions do not peak until 2030, even if emissions are subsequently reduced at 5% annually, the avoided impacts are smaller than in either of the other two cases (brown bars compared to orange and pink bars). Both panels show the uncertainty range (error bars) due to regional climate change projected with 7 GCMs. Errors due to uncertainty within impacts models are not shown. Uncertainties associated with sea level rise related impacts are smaller because the models used encompass a narrow range of alternative sea level rise projections. Since increases and decreases in water stress, flood risks and crop suitability are not co-located and affect different regions, these effects are not combined. From Arnell *et al.*, 2013, Warren *et al*, 2013a; Warren *et al.*, 2013b.
[Illustration to be redrawn to conform to IPCC publication specifications.]

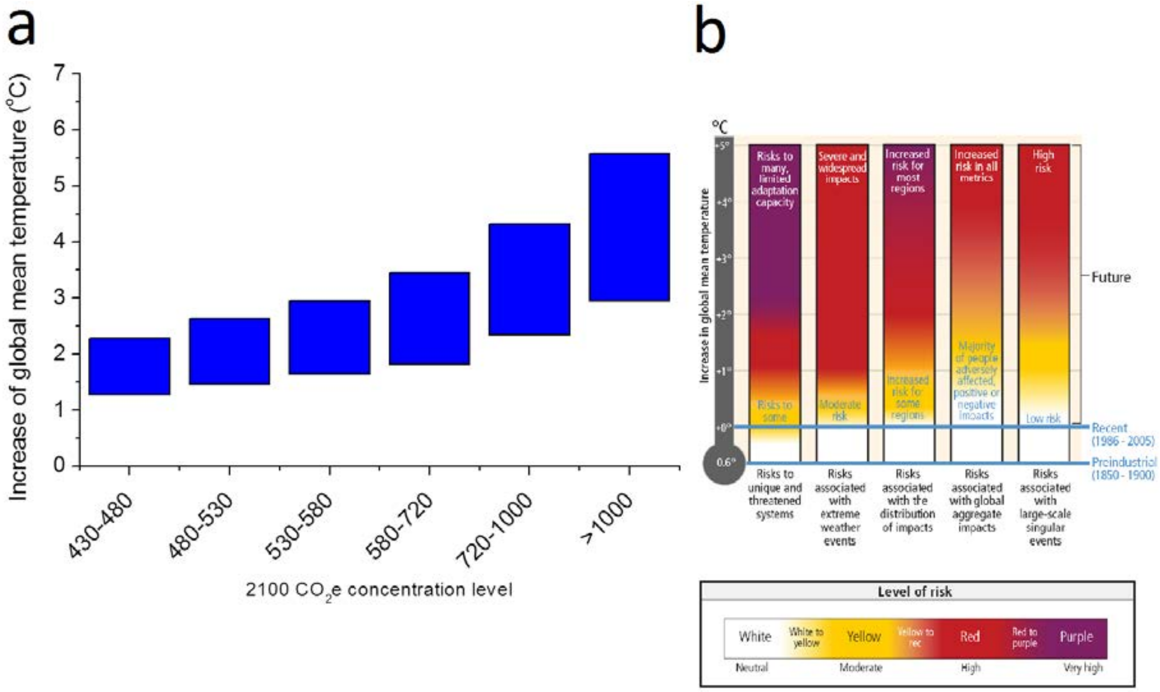

Figure 19-7: Relationship between mitigation scenarios considered in AR5 WGIII, in terms of their CO_2e concentrations and global temperature rise outcomes relative to pre-industrial times, and level of risk associated with Reasons for Concern. Panel **a** shows the projected increase in global mean temperature in 2100 compared to preindustrial, calculated using the MAGICC climate model for the scenarios defined in Chapter 6, Working Group III, indicating the uncertainty range resulting both from the range of emission scenario projections within each category and the uncertainty in the climate system as represented by MAGICC (data taken from Chapter 6 – AR5 WGIII). Panel **b** reproduces Figure 19-4 for ease of comparison. Note the different temperature baselines used in Figure 19-4. Beyond 2100, temperature, and therefore risk, decreases in most of the lowest three scenarios and increases further in most of the others.

[Illustration to be redrawn to conform to IPCC publication specifications.]