Chapter 19. Emergent Risks and Key Vulnerabilities

Coordinating Lead Authors
Michael Oppenheimer (USA), Maximiliano Campos (Costa Rica), Rachel Warren (UK)

Lead Authors
Joern Birkmann (Germany), George Luber (USA), Brian O'Neill (USA), Kiyoshi Takahashi (Japan)

Contributing Authors
Franz Berkhout (Netherlands), Pauline Dube (Botswana), Wendy Foden (South Africa), Stefan Greiving (Germany), Solomon Hsiang (USA), Matt Johnston (USA), Klaus Keller (USA), Joan Kleypas (USA), Robert Kopp (USA), Rachel Licker (USA), Carlos Peres (UK), Jeff Price (UK), Alan Robock (USA), Wolfram Schlenker (USA), John Richard Stepp (USA), Richard Tol (UK), Detlef van Vuuren (Netherlands)

Review Editors
Mike Brklacich (Canada), Sergey Semenov (Russian Federation)

Chapter Scientist
Rachel Licker (USA)

Contents

Executive Summary

This chapter assesses the interaction of changing physical characteristics of the climate system with evolving characteristics of human, socioeconomic, and biological systems (exposure and vulnerability) to produce risk [19.2], in relation to Article 2 of the UN Framework Convention on Climate Change. Alternative development paths influence risk by changing both the likelihood of physical impacts (through their effects on greenhouse gas emissions) and by altering vulnerability and exposure [19.2.4, Figure 19-1].

A particular focus is placed on interactions among climate change impacts in various sectors and regions, and human vulnerability and adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions. Such interactions are generally not included, or not well integrated, into projections of climate change impacts, but their consideration leads to the identification of a variety of *emergent risks* that were not previously recognized. This chapter identifies several such complex-system interactions that increase vulnerability and risk [19.3, *high confidence*]. For example:

- The risk of severe harm and loss due to climate change-related hazards and various vulnerabilities is particularly high in large urban and rural areas in low-lying coastal zones. These areas, many characterized by increasing populations, are exposed to multiple hazards and potential failures of critical infrastructure, generating new systemic risk [19.3.2.4].
- The risk of climate change to human systems is increased by the loss of ecosystem services (e.g. water and air purification, protection from extreme weather events, preservation of soils, recycling of nutrients, and pollination of crops), which are supported by biodiversity [19.3.2.1, *high confidence*].
- In some water stressed regions, groundwater stores that have historically acted as buffers against climate change impacts are being depleted, with adverse consequences for human systems and ecosystems, whilst at the same time climate change may directly increase or decrease regional groundwater resources [19.3.2.2, *high confidence*].
- Climate change adversely affects human health, increasing exposure and vulnerability to a variety of other stresses, for example by altering the prevalence and distribution of diseases that are weather and climate sensitive, increasing injuries and fatalities resulting from extreme weather events, and eroding mental health in response to population displacement [19.3.2.3, *high confidence*].
- Spatial convergence of impacts in different sectors creates impact 'hotspots' involving new interactions (*high confidence*). Examples include the Arctic (where sea ice loss and thawing disrupts transportation, buildings, other infrastructure, and potentially disrupts Inuit culture); the environs of Micronesia, Mariana Island, and Papua New Guinea (where coral reefs are highly threatened due to exposure to concomitant sea surface temperature rise and ocean acidification); and Sub-Saharan Africa (where global warming at the high end of the range projected for this century, i.e., more than 4°C above preindustrial levels, would be especially disruptive, resulting in high risk of reduced extent of croplands, reduced length of the growing season, increased hunger, and increased malaria transmission) [19.3.2.4].
- Adaptation designed for one sector may interfere with the functioning of another sector, creating new risks (*high confidence*). For example, increasing crop irrigation in response to a drying climate can exacerbate water stress in downstream wetlands, where the latter otherwise provide important water cleaning services [19.3.2.5].

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

- Increasing prices of food commodities on the global market due to local climate impacts, sometimes in conjunction with demand for biofuels, decrease food security and exacerbate malnutrition at distant locations [19.4.1].
- Climate change will bear significant consequences for migration flows at particular times and places, creating risks as well as benefits for migrants and for sending and receiving regions and states (*high confidence*) [19.4.2.1].
- The possibility that climate change will alter patterns of violence is a risk emerging in the literature. The effect of climate change on conflict and insecurity has the potential to become a key risk because the reported magnitude of the influence of the climate's variability on security is large [19.4.2.2].
- Shifting species ranges in response to climate change adversely affect ecosystem function and services while presenting new challenges to conservation efforts [19.4.2.3]. Where range shifts cannot track climatic changes, species are at risk of eventual extinction (*high confidence*).

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

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

Global and local socio-economic, environmental and governance trends confirm that vulnerability and exposure of communities or social-ecological systems to climatic hazards are dynamic and thus varying across temporal and spatial scales. Effective risk reduction and adaptation strategies consider these dynamics and the inter-linkages between socio-economic development pathways and the vulnerability and exposure of people. Changes in poverty or socio-economic status, race and ethnicity compositions as well as age structures and changes in governance had a significant influence on the outcome of past crises associated with climatic hazards [19.6.1.3].

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

Assessment of existing frameworks pertinent to Article 2 of the UNFCCC, based on Key Risks, Key Vulnerabilities, and Reasons for Concern, has led to evaluations of risk being updated in light of the advances since AR4, including SREX and the current report's discussions of vulnerability, human security, and adaptation, [19.6.3].

Several *key risks* resulting from the interaction of hazardous climate changes and physical impacts with the vulnerability of societies and exposed systems were identified in this chapter [19.6.2.1.].

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

The determination of key risks as reflected, for example, in the Reasons for Concern did not previously distinguish between alternative development pathways. The development of risk profiles from Shared Socioeconomic Pathways and Representative Concentration Pathways is an important area of research that can lead to improvement in the framework developed in this chapter [19.6.3.1].

Updating of the Reasons for Concern leads to the following assessment:

- **Unique human and natural systems tend to have very limited adaptive capacity, and hence we have *high confidence* that climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C over preindustrial levels were exceeded.** In addition, there is new and stronger evidence to support the previous judgment of *high confidence* that a warming of up to 2°C above 1990-2000 levels would result in significant impacts on many unique and vulnerable systems, and would likely increase the endangered status of many threatened species, with increasing adverse impacts and increasing risk of extinctions (and increasing confidence in this conclusion) at higher temperatures [19.6.3.2].

- **The overall risk from extreme events due to climate change has not changed significantly since AR4 but there is higher confidence in the attribution of some types of extreme events to human activity and in the assessment of the risk from extreme events in the coming decades.** In addition, there is a new appreciation for the importance of exposure and vulnerability, in both developed and developing countries [19.6.3.3], in assessing risk associated with extreme events. Many of the key vulnerabilities, key risks, and emergent risks identified in individual chapters of this report reflect differential vulnerability between groups due to, for example, age, wealth, or income status, and deficiencies in governance [19.6.1], which are particularly important in assessing this Reason for Concern and also the following one associated with the distribution of impacts.
- **Risk associated with the distribution of impacts is generally greatest in low-latitude, less developed areas, but because vulnerability is unevenly distributed within countries, some populations in developed countries are highly vulnerable to warming of less than 2°C, as noted in AR4 (*high confidence*) [19.6.3.4].**
- **Globally aggregated risk is underestimated because it does not include many non-monetized impacts, such as biodiversity loss, and because it omits many known impacts that have only recently be quantified, such as reduced labor productivity [19.6.3.5, *high confidence*]. In addition, aggregated estimates of costs mask significant differences in impacts across sectors, regions, countries and populations [19.6.3.5, *very high confidence*].** The overall assessment of aggregate risk and confidence in that assessment has not changed since AR4.
- **The risk associated with large-scale singular events such as the at least partial deglaciation of the Greenland ice sheet remains comparable to that assessed in AR4 [19.6.3.6].**

The management of key and emergent risks of climate change and Reasons for Concern includes (i) mitigation that reduces the likelihood of physical impacts and (ii) adaptation that reduces the vulnerability and exposure of societies and ecosystems to those impacts [19.7]. Advances in the assessment and implementation of mitigation measures and adaptation strategies include for the first time evaluation of avoided damages from a range of strategies.

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 ocean acidification and least immediate for impacts related to sea level rise. Since mitigation reduces the rate as well as the magnitude of warming, it also delays the need to adapt to a particular level of climate change impacts, potentially by several decades.

Under any plausible scenario for mitigation and adaptation, some degree of risk from residual damages is unavoidable (*very high confidence*). For example, no model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5°C with at least 50% likelihood and recent findings suggest that comprehensive adaptation to current climate risk is prohibitively expensive, indicating that adaptions to future changes are similarly constrained [19.7.2.1]. Assessments of stringent mitigation scenarios suggest that they can potentially avoid one half of the aggregate economic impacts that would otherwise accrue by 2100, and between 20-60% of the physical impacts, depending on sector and region [19.7.1].

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

The risk of crossing tipping points in socio-ecological systems may be reduced by preserving ecosystem services (*medium confidence*). Tipping points are thresholds beyond which adverse impacts increase non-linearly.

Some tipping points may be avoided by limiting the level of climate change and/or removing concomitant stresses such as overgrazing, overfishing, and pollution [19.7.4] but there is *low confidence* in location of 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).

[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" 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. Both the changes in the climate system (left side) and the development processes (right side) are key drivers of the different core components (vulnerability, exposure, and physical hazards) that constitute risk (modified version of Figure 1, IPCC, 2012).]

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, meriting particular attention in respect to Article 2 (see Box 19-2 for definitions of Reasons for Concern and Key Vulnerabilities [KVs]). AR4 emphasized the differences in vulnerability between developed and developing countries but also assessed emerging 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". 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, 2012) provides additional insights with respect to one RFC (the risk of extreme weather events) and particularly the distribution of capacities to adapt to such events between countries, communities, and other groups, and the limitations of 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 the dynamic nature of our understanding by assessing *emergent and emerging risks* (see Box 19-2, Table 19-3). These risks are, respectively, those which arise out of complex interactions involving climate and socioecological systems, and those which have only recently emerged in the scientific literature in sufficient detail to permit assessment. In this chapter, we consider only those emergent and emerging risks which have the potential to become relevant to interpreting Article 2 as additional understanding accumulates. For example, since AR4, sufficient literature has emerged to allow initial assessment of the 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 "hotspots" (see 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 (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 based on its intimate relationship to development.

We consider a variety of types of emergent risks, including for example, vulnerability to impacts arising from multiple interacting systems and stresses, indirect impacts, trans-boundary impacts, and impacts occurring at a long distance from the location of the climate change which causes them (Oppenheimer, 2012). One example which illustrates all of these properties is the extent to which climate change impacts on agriculture, water resources, and sea level affect migration flows. These shifts entail both risks and potential benefits for the migrants, for the regions where they originate, and for the destination regions (see 19.5.2.1 and 12.4). 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.

_____ START BOX 19-1 HERE ____

Box 19-1. Article 2 of the UNFCCC and the Copenhagen Accord

<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.

Copenhagen Accord (excerpt)

To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change.

_____ END BOX 19-1 HERE ____

____ START BOX 19-2 HERE ____

Box 19-2. Definitions

Vulnerability - The propensity or predisposition to be adversely affected. A broad set of factors such as wealth, social status, and gender determine vulnerability and exposure to climate-related risk.

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

Impacts - Effects on natural and human systems. In this chapter, the term is used to refer to the effects on natural and human systems of hazardous physical events, of disasters, and of climate change. Impacts are also referred to as *consequences* and *outcomes*. They are a function of exposure and vulnerability, and generally refer to adverse effects on lives, livelihoods, health status, ecosystems, economic, social and cultural assets, services (including environmental), and infrastructure due to the interaction of hazardous events or trends occurring within a specific time period and the vulnerability of a society or system exposed. We refer to the effects of climate changes on geophysical systems, such as floods, droughts, and sea level rise, as *physical impacts*.

Hazard - The potential occurrence of a natural or human-induced physical event 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 chapter, hazard usually refers to climate-related events or trends or their physical impacts.

Stressors - Those events and trends which are not-climate-related but 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 a hazardous event(s) multiplied by the consequences if the event(s) occurs.

Risk = Probability of Event(s) 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 policy makers in that context.

Key risks are potential adverse consequences for humans and social-ecological systems due to the interaction of hazardous climate changes and physical impacts with vulnerabilities of societies and systems exposed. Risks are not considered “key” due to high physical impact alone, absent significant vulnerability and exposure.

Vulnerabilities are considered "key" if they have the potential to combine with climate changes and physical impacts to result in severe consequences for society or social-ecological systems. Vulnerabilities that have little influence on risk would not be considered key.

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 in the receiving region.

Emerging Risk**:** A risk that has emerged only recently in the scientific literature in sufficient detail to permit assessment. For example, the initial consequences associated with these risks may have only recently been detected above the natural variability of the climate system, as is the case for certain effects of ocean acidification on calcareous organisms. For clarity, where these emerging risks arise from the interaction of phenomena in a complex system (and are thus also emergent risks) they are discussed in sections 19.3 and 19.4 relating to emergent risks.

In this chapter, the only emergent and emerging 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 (updated from TAR, WGII, Chapter 19):

"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 concerns 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 and Emerging Risks

19.2.1. Risk and Vulnerability

Definitions and frameworks that systematize physical impacts, 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; UN/ISDR, 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, 2012; Costa and Kropp, 2012; Birkmann *et al*., 2013); however, most of the concepts and the respective literature differentiates between vulnerability, risk, impacts and hazards (see e.g. Hutton *et al*., 2011; IPCC, 2012; Birkmann *et al*., 2013). The following section serves not solely as an update of existing knowledge about key vulnerabilities and key risks since the AR4, but also provides a more coherent framework to systematize these concepts and to enhance the understanding of these phenomena based on new literature, including SREX (IPCC, 2012).

The large body of literature (see above) underscores that risks to climate change are not solely externally generated circumstances to which societies respond, but rather, the results of complex interactions among societies or communities, ecosystems, and physical impacts arising from climate change (Susman *et al*., 1983; Comfort *et al*., 1999; Birkmann *et al*., 2011; UNISDR, 2011; IPCC, 2012b; Birkmann *et al*., 2013). We refer to the effects of climate changes on geophysical systems, such as floods, droughts, deglaciation, and sea level rise, as *physical impacts*. In contrast, vulnerability refers primarily to characteristics of human or social-ecological systems exposed to hazardous climatic or non-climatic events and trends (UNDRO, 1980; Liverman, 1990; Cannon, 1994; Blaikie *et al*., 1996; UN/ISDR, 2004; Cannon, 2006; Birkmann, 2006; Cannon, 2006; Thywissen, 2006; Füssel and Klein, 2006; IPCC, 2012). Ecosystems or geographic areas can be classified as vulnerable, and merit particular attention if vulnerability of humans arises from impacts on 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 (MEA, 2005)

Compared to the AR4 which did not fully differentiate key vulnerabilities, impacts and risks, the new conceptualization used here provides a more coherent and precise systematization (see Figure 19-1). In addition, the framework underscores that the development process of a society has significant implications for vulnerability and risk. Climate change is not a risk per se; rather climate changes and related physical impacts interact with the vulnerability of exposed systems to determine the level of risk (see Table 19-3). Identifying key vulnerabilities facilitates estimating key risks when coupled with information about the climate and climate change. The new differentiation provides the basis for criteria developed in this chapter for assessing vulnerability and risk.

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 hazardous events and trends (see IPCC, 2012). 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*., 2013). Perceptions and cognitive constructs about risks and adaptation options as well as cultural contexts influence adaptive capacities and thus vulnerability (Grothmann and Patt 2005; Rohmberg 2009; Kuruppu and Liverman 2011; see section 19.4.2.3). 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, 2012, p. 17, 67-106).

Key vulnerability and key risk are defined in Box 19-2. Vulnerabilities that have little influence on overall risk would not be considered key. Similarly, the magnitude or other characteristics of physical impacts, such as glacier melting or sea level rise, 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 IPCC, 2012, p. 45; IPCC, 2007, p. 785). Generally, vulnerability merits particular attention when the survival of communities, societies, or ecosystems is threatened (see UN/ISDR 2011; Birkmann *et al*., 2011). Climate change will influence both the nature of the climatic hazards societies and ecosystems are exposed to and also contribute to deterioration or improvement of coping and adaptive capacities of systems exposed to these changes. Consequently, many studies

(Wisner *et al*., 2004; Cardona, 2010; Birkmann *et al*., 2011) focus with a priority on the vulnerability of humans and societies as a key feature, rather than solely on the physical impacts of climatic change.

19.2.2.1. Criteria for Identifying Key Vulnerabilities

AR4 WGII Ch. 19 highlighted seven criteria that may be used to identify key vulnerabilities: Here we reorganize and further develop these criteria in order to improve the differentiation between key vulnerabilities, key risks and physical impacts – taking into account recent literature (Blaikie *et al*., 1994; Bohle, 2001; Turner *et al*., 2003a; Turner *et al*., 2003b; 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*., 2013). The criteria for identifying vulnerabilities as "key" used in the AR4 are: magnitude of impacts, timing of impacts, persistence and reversibility of impacts, likelihood (estimates of uncertainty) of impacts and vulnerabilities and confidence in those estimates, potential for adaptation, distributional aspects of impacts and vulnerabilities, and importance of the system(s) at risk. These criteria do not provide a systematic differentiation of vulnerability and risk. Revised criteria for assessing *key vulnerabilities* used here should provide an improved basis to distinguish between changes in the physical climate and associated physical impacts (like sea level rise), vulnerability and risk for societies or social-ecological systems. The following eight criteria are used to judge whether vulnerabilities are key:

1) *Exposure of a society, community, or social-ecological system to climatic stressors*. While exposure as used 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 future exposed to hazardous climatic trends or events, it is less important to consider its vulnerability to such hazards. The exposure to climatic hazards and non-climatic stressors can be assessed based on spatial and temporal dimensions.
2) *Probability that societies or social-ecological systems exposed to climatic changes and associated physical impacts would experience major harm, loss and damages*. Vulnerability is considered key when there is a high probability that a climatic hazard, often in combination with non-climatic stressors (e.g. price fluctuations, migration, land-grabbing), would cause major harm to an exposed and particularly susceptible society or social-ecological system. This criterion can be made specific with vulnerability assessments. For example, communities in low-lying areas in developing countries with limited resources to adapt and a low awareness about climatic hazards are often more vulnerable than regions and communities in highly developed countries that can afford coastal protection systems (Nicholls and Small 2002; Klein *et al*., 2003, p. 109). Criteria that might be used to assess such susceptibilities or sensitivities encompass among other factors poverty and wealth status, demographic characteristics, and aspects of governance (see IPCC, 2012).
3) *Importance of the vulnerable system(s)*. Societies and people in differing regions and cultural contexts view the importance of systems, impacts, and services differently (see Kienberger, 2012). However, the identification of key vulnerabilities is less subjective when it involves those systems that are crucial for the survival of societies or when it refers to resources essential for coping and adapting to adverse consequences, such as important ecosystem services on which societies depend. For example, drought exposed-farmer households in the Sahel are heavily dependent on ecosystem services such as water and fertile soils, and some storm-exposed islands nations are highly dependent on coral reefs. Inability to replace such a system or compensate for potential and actual losses and damages is a feature of importance. Defining key vulnerabilities regarding various societal groups (as in criterion #2), or ecosystem services takes into account the contextual conditions that make these societies or exposed elements or groups highly vulnerable compared to similar systems in other contexts(Leichenko and O'Brien, 2008; O'Brien *et al*., 2009).
4) *Limited ability of societies or communities to cope with the climate-related hazards within existing capacities*. Coping refers primarily to capacities that are available here and now to reduce the negative impacts of climatic stress on communities or social-ecological systems exposed. Coping is part of the formula that determines vulnerability at any one moment in time. Coping also connotes the protection of the current system and institutional settings (see Birkmann, 2011; Birkmann et al. 2013) rather than improving these to increase capacities against climate risks (IPCC 2012, p. 51). Limits of coping provide a criterion for key vulnerabilities.

5) *Limited ability of societies to build adaptive capacities to reduce or limit vulnerability as environmental and climate conditions change*. The capacity of societies (including communities) to build adaptive capacities is a central issue when assessing vulnerability (IPCC 2007, AR4). Adaptation is a continuous process which includes – compared to coping – also learning, experimentation and change of the system exposed (Smithers and Smit, 1997; Pielke Jr, 1998; Smit *et al*., 1999; Frankhauser *et al*., 1999; Adger *et al*., 2005; Smit, 2006; Pelling, 2010). This understanding of adaptation is also based on an emerging consensus from climate change literature (Kelly and Adger, 2000; Yohe, 2002; Pelling *et al*., 2008) where coping describes actions taken within existing constraints (including vision and knowledge), while adaptation signifies expanding the boundaries of those constraints, for instance, through institutional changes (e.g. rule systems, modes of governance) (Pelling *et al*., 2008; Garschagen, 2011; Tschakert and Dietrich; 2012).

6) Persistence of vulnerable conditions and degree of irreversibility of consequences. Vulnerabilities are considered key when they are persistent and difficult to alter as well as having a high potential to interact with a hazardous event to produce irreversible negative changes. This is particularly the case when the susceptibility or sensitivity is high, implying that the capacities to cope or adapt are low. 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 that would cause a partial or full collapse of the system, including displacement (see Renaud *et al*., 2010; section 19.4.2.1).

7) *Presence of conditions that make societies highly susceptible or sensitive to cumulative stressors in complex and multiple-interacting systems*. Conditions that make communities or social-ecological systems highly susceptible to additional climatic hazards or that limit their ability to cope and adapt, such as chronic poverty or living in a failed state (e.g. during drought disaster in Somalia) should be taken into account. Also the critical dependence of societies on interdependent, interconnected infrastructure, such as those providing energy/power supply, transport and health care delivery, might lead to complex and multiple-interacting systems with low coping and adaptive capacity (see Chapter 23).

19.2.2.2. Criteria for Identifying Key Risks

Key risks are the product of the interaction of climate-related hazards with key vulnerabilities of exposed societies and communities. A risk would not be considered "key" if the climatic hazard had a low probability and/or magnitude and would affect a society, community or a social-ecological system with low vulnerability.

In contrast to the criteria for identifying key vulnerabilities, the criteria for identifying key risks take into account the magnitude, frequency and severity of hazardous climate trends, events, and physical impacts to which vulnerable systems are exposed. The following four criteria are used to judge whether risks are key:

1) Magnitude: Risks are key if associated negative consequences have a large magnitude, determined by a variety of metrics including human mortality and morbidity, economic loss, cultural importance, and distributional consequences (see Schneider *et al*., 2007; Below 2009; IPCC, 2012).

2) Likelihood that 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 have very limited capacities to cope or adapt. 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).

3) Irreversibility and persistence of conditions and drivers that determine risks. Risks are considered key when there is a high probability that they would involve irreversible harm, losses and damages. Persistence of risks refers to the fact that underlying drivers and root causes of these risks cannot be rapidly reduced, or the damage to societal and social-ecological systems cannot be quickly reversed (see point 7 above). Critical infrastructures, such as electric power, communications, and transport networks in developed countries often embody systemic risks due to their interdependencies and the high dependency of vulnerable groups (e.g. elderly) on their services. Moreover, the breakdown of critical infrastructure (e.g. electricity or water supply) can also have long distance impacts (teleconnections) that may result in risks far away from the area where the critical infrastructure is located, and hence it can be more difficult to address these risks in areas potentially affected. In addition, 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, for example as observed in the Sahel Zone.

4) *Limited ability to reduce the magnitude and frequency or nature of hazardous climatic events and trends and the vulnerability of societies and social-ecological systems exposed*. Risks are considered to be key when societies have very limited means through development (either by reducing emissions of greenhouse gases or improving coping and adaptation) to reduce the magnitude, frequency or intensity of risks due to climatic hazards. These hazards and the vulnerability of societies or social-ecological systems – and hence risk – are also dynamic and change over time, e.g. due to different socio-economic development processes.

19.2.3. Criteria for Identifying Emergent and Emerging Risks

A risk that arises from the interaction of phenomena in a complex system is defined here as an *emergent risk*. For example, unforeseen feedback processes between climatic change, human interventions and processes in natural systems can be classified as emergent risks if they pose a threat to human security. Alternatively, emergent risks could be linked to unprecedented situations, such as the increasing urbanization of low laying coastal areas that are prone to sea-level rise or where new pluvial flooding risk emerges due to urbanization of vulnerable areas not historically populated. An *emerging risk* is a risk that has emerged only recently in the scientific literature in sufficient detail to permit assessment. For example, the initial consequences associated with these risks may have only recently been detected above the natural variability of the climate system, as is the case for certain effects of ocean acidification on calcareous organisms. For clarity, where these emerging risks arise from the interaction of phenomena in a complex system (and are thus also emergent risks) they are discussed in sections 19.3 and 19.4 relating to emergent risks. In this chapter, the only emergent and emerging 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 physical impacts of climate change with 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 changes and physical impacts, and the societal and ecological conditions determining vulnerability. Therefore some risks could be judged to be key under some development pathways but not others. Emergent and emerging risks can depend on development pathways as well, since their identification as potentially key risks may be contingent on future socio-economic conditions.

Different development pathways will lead to different key risks because they affect the magnitude, timing, and heterogeneity of physical impacts of climate change through their effects on emissions and other forcing such as land use change, and consequently on climate change (see Chapter 12, WG1). 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 (Chapter 5, WG3).

Development pathways will also influence the factors involved in identifying key vulnerabilities of human and ecological systems, including both sensitivity to impacts and adaptive capacity(Yohe and Tol, 2002; Füssel and Klein, 2006; Hallegatte *et al*., 2011; O'Neill *et al*., submitted). The size or scale of populations, ecosystems, or economic sectors that are vulnerable to particular impacts 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; Fuessel, 2009). The degree to which persistent or difficult to reverse vulnerabilities are built into social systems, as well as the degree of inequality in vulnerability across social groups or regions, also depend on elements 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 first assessment phase would explore whether and how a society or social-ecological system is exposed to climate related hazards, the assessment thereafter would focus on the probability of loss and harm in case an event or events would affect a society or social-ecological system 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, the persistence of vulnerable conditions as well as the presence of conditions that make societies susceptible. Hence, the assessment criteria focus on the inner conditions of a person, a community (e.g. age structure, poverty), or a social-ecological system as well as on the contextual conditions that influence their vulnerability (e.g. larger governance conditions and systems of norms). Examples of such key vulnerabilities and key risks drawn from other chapters of this assessment are provided in section 19.6 and particularly Table 19-3.

19.3. Emergent Risk: Multiple Interacting Systems and Stresses

19.3.1. Limitations of Previous Approaches Imply Key Risks Overlooked

Interactions between climate change impacts in various sectors and regions, and between these impacts and human adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions (the latter also considered in section 19.4.3), are generally not included, or not well integrated, into projections of climate change impacts (Warren, 2011). These interactions create emergent risks and/or key vulnerabilities not previously recognized. There is a very large number of potential interactions, and many important ones have not yet been quantified, meaning that some key risks have been overlooked. In some cases, new knowledge about these risks is just now emerging. The six interaction processes listed below, while not exclusive, are systemic and are *likely* to 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.

- Climate change induced biodiversity loss erodes ecosystem services, in turn affecting human systems dependent on those services. (*19.3.2.1)*
- Climate change induced changes in extreme weather events affect human systems and ecosystems, which preconditions these systems and increases vulnerability to the effects of mean climate change. Most impacts projections are based only on changes in mean climate (Rosenzweig and Hillel, 2008).
- Interactions with non-climate stressors: the interaction between climate change impacts and population/economic growth is well studied, but a large literature now addresses interactions of climate change with other factors such as land management, water management, air pollution (which has drivers in common with climate change) and energy production. (*19.3.2.2)*
- Interactions related to climate change and disease emergence. *(19.3.2.3)*
- Co-location of impacts in different sectors creating impact 'hotspots' involving new interactions. (*19.3.2.4)*
- Adaptation designed for one sector interacts with functioning of another sector (e.g. increasing irrigation to crops in response to a drying climate can exacerbate water stress in downstream areas such as wetlands, in cases where the latter provide important water cleaning services). (*19.3.2.5)*

19.3.2. 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 (Díaz *et al.*, 2006; Gaston and Fuller, 2008; Maestre *et al.*, 2012; Midgley, 2012). A large number of studies project how species ranges are projected to decline in size as mean climate changes (see Chapter 4), e.g. a study of 50,000 species found that 57±6% of widespread & common plants and 34±7% of widespread & common animals are projected to lose ≥50% of their current climatic range by the 2080s (Warren *et al.*, in press) and there is *high confidence* that projected climate changes imply increased extinction risk for a substantial fraction of species during the 21st century (see Chapter 4). These processes of decline in species richness and extinction will combine with damage due to climate-change induced increases in short-term extreme weather events expected for some regions, as well as (see WGI SPM and 7.6.2) increased forest losses due to fire. The resulting potential for disruption of the functionality of the ecosystems translates into an emergent risk of large-scale loss of ecosystem services in both terrestrial and marine systems (Mooney *et al.*, 2009; Table 19-3, Entry 2, Chapter 19). At-risk services include water purification provided by wetlands, air purification by forests, crop pollination by insects, coastal protection from storm surge by mangroves and coral reefs, regulation of pests and disease, recycling of waste nutrients, and removal of carbon from the atmosphere (Chivian and Bernstein, 2008, Chapter 4). Biodiversity loss has now also been linked to increased transmission of infectious diseases such as Lyme, Schistosoma and hantavirus in humans, and West Nile virus in birds, creating a newly emerging dimension to the emergent risks resulting from biodiversity loss (Keesing *et al.*, 2010).

The following studies provide examples of projected ecosystem service loss in the agricultural sector due to climate change: projected crop damage due to increased prevalence of pest species including *Fusarium graminearum* (a fungal disease of wheat), the European corn borer, the Colorado beetle, bakanae disease and leaf blights of rice, and the 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); and projected declines in crop yields due to climate change effects on pollinating species (Rosenzweig and Hillel, 2008; Kuhlmann *et al.*, 2012; Giannini *et al.*, 2012; Abrol, 2012; Bedford *et al.*, 2012). These effects are simultaneous with climate change's direct effects on yields through changing temperature, precipitation, and ambient carbon dioxide concentrations, creating an emergent risk. Climate change has caused, or is projected to cause range expansion in a number of weeds that have the potential to become invasive (Bradley *et al.*, 2010a; Clements and Ditommaso, 2011). Invasive species can damage agriculture and cause extinction of other species, with attempts to control them being extremely costly (eg $120 billion annually in the USA, Crowl *et al.*, 2008). Whilst the balance of gains and losses for invasive species will vary locally (Bradley *et al.*, 2010b) and no single aspect stands out, any one of the mechanisms mentioned in this paragraph has the potential to cause outcomes that are very damaging and act in synergy with existing climate change impacts on agriculture. Hence, these various susceptibilities to loss of ecosystem services taken together comprise a key vulnerability, and in interaction with climate change, an emergent risk.

The global value share of pollination of crops for 2005 has been calculated as 153 billion Euro (Table 4.6). Similarly, the value of the ecosystem services of pollinators for crops and wild plants combined in the UK has been estimated at UK £430 million per year, yet this service is currently becoming less effective (NEA, 2011). Climate change impacts on pollinators therefore places these valuable services at risk, and disruption of wild plant pollination will also affects animals which are dependent upon those plants (see Chapter 4). An increase in woodland cover from 6 to 12% of the UK's land area over the past 60 years (with the reverse being a measure of the cost of degradation) was valued at £680 million per year in carbon sequestration value alone (NEA, 2011). Ecological function analysis for Chinese terrestrial ecosystems yielded estimated economic values of approximately 0.3-1.6 x 10^{13} Yuan annually for services such as CO_2 fixation, O_2 release, nutrient recycling, soil protection, water holding capacity and environmental purification (Ouyang *et al.*, 2006). Similarly, the value of ecosystem services in US forests has been estimated at values ranging from US$1 to 6 billion annually for climate regulation, US$4-54 billion for biodiversity, and US$1 to 100 billion annually for recreation (Krieger, 2001). The potential loss of coral reefs (section 19.3.2.4) would result in a loss of income of $Au4 billion to the Australian economy from international tourism, of US$1.6 billion to the Caribbean economies for tourism and fishing on reefs, and loss almost equal to the value of the entire economy of the Maldives and the Seychelles (Hoegh-Guldberg *et al.*, 2011). Such costs are represented only very crudely, if at all, 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 large costs show how human systems are vulnerable to loss of ecosystem services, and hence this comprises a key risk as defined in 19.2.

Some of the work on degraded ecosystems and their interaction with economic sectors examines the cost of restoring ecosystem services. For example, interviewed households along the Platte River (US) showed a willingness to pay, in terms of increased water bills, an additional US$20 per month in order to improve five ecosystem services (i.e. natural purification of water, erosion control, habitat for fish and wildlife, dilution of wastewater, and recreation use) (Loomis *et al*., 2000), which would provide US$19 to US$70 million dollars which greatly exceeds the estimated costs of improving degraded ecosystem services (US$1.13 to US$12.3 million). 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 the restored services were still lower than those in intact ecosystems (Benayas *et al*., 2009). Hence, although restoration of damaged ecosystems may often be cost-effective, it 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. Sekercioglu *et al*., 2012) and hence an emergent risk of ecosystem service loss. Empirical studies reveal that ecosystem impacts due to habitat loss correlate with current maximum temperature and recent precipitation decline, indicating a synergy between climate change and habitat loss effects (Mantyka-Pringle *et al*., 2012). Due to land use change, adaptation to climate change is now impeded by the fragmented nature of natural habitats.

Land clearing also releases carbon to the atmosphere and removes carbon sinks (WGI section 6.4.3.3) such as old growth forests which would otherwise continue to accumulate carbon (Luyssaert *et al*., 2008) in the future. A new approach has quantified the 'Greenhouse Gas Value' of ecosystems (Anderson-Teixeira and DeLucia, 2011), taking into account both fluxes and storage of carbon, implying that published values of ecosystem services from carbon sequestration have tended to underestimate their importance due to a tendency to consider only the carbon currently stored in the systems.

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

One of the most important interactions affecting the well-being of humans and ecosystems and the level and rate of climate change, are those involving human management of water, land, and energy. These profoundly affect the amount of carbon which 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, for example. Failure to manage land, water and energy in a synergistic fashion can exacerbate climate change impacts globally (Wise et al 2008, Searchinger *et al*., 2008; Lotze-Campen *et al*.; 2009; Warren *et al*., 2011).

Projected changes in climate variability combined with water extraction leads to an emergent risk: that of water stress exacerbated by the removal of groundwater which serves as 'an historical buffer against climate variability' (Green *et al*., 2011). The use of energy by the water sector, including domestic use for heating, accounts for between 5-6% of the greenhouse gas emissions of the US and India(Green *et al*., 2011; Rothausen and Conway, 2011). Extraction and conveyance of water for irrigation is energy intensive and this demand is projected to rise as adaptation to climate change and increasing food demand drives the need for an expansion of irrigated cropland. In areas where drought is frequent, water might be provided through construction and use of de-salinisation plant. All this has implications for projected energy use and hence mitigation strategies. However, there are opportunities for adapting the agricultural sector to climate change in drying regions in ways which reduce greenhouse gas emissions, such as advanced irrigation systems(Rothausen and Conway, 2011).

The second issue is that of groundwater extraction, which is *likely* to increase as an adaptation to climate change, since current demand for surface water will not be met under various scenarios of a changed climate(Barnett *et al*., 2008). For example, following a ten-fold increase in groundwater extraction in China, 70% of the irrigated cropland in China is now groundwater fed, and it is estimated that 0.5% of the country's greenhouse gas emissions are attributable to exploitation of this resource(Wang *et al*., 2012). 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). However, in areas where extraction rates increase or recharge decreases, water tables will be depleted with consequence for ecosystems and the human systems (such as agriculture, tourism and recreation) which depend upon them, while water quality will also decrease. One projection shows insufficient water availability in Africa, Latin America and the Caribbean to satisfy both agricultural demands and environmental regulations by 2050, owing to increases in demand for water use for municipal and industrial use, combined with increases in demand for food, a situation that is exacerbated by climate change (Strzepek and Boehlert, 2010).

Concurrently, the use of water by the energy sector, by thermo-electric power generation, hydropower and geothermal energy, or biofuel production, can also be an issue (Pittock, 2011) especially in cases where energy generation is concentrated in arid regions, whilst Kelic (2009) have explored how the energy sector could best adapt to drought conditions. Other studies have addressed the energy, water, land nexus that drought conditions present to the agricultural and energy sectors (Tidwell *et al*., 2011; Skaggs *et al*., 2012).

Simulations of stringent mitigation (e.g. that required to constrain radiative forcing to 2.6 W/m^2 during the 21^{st} century) show an economic necessity to include a major contribution from biofuels (van Vuuren *et al*., 2011). If production is not carefully managed, biofuel feedstocks can displace land for food cropping or natural, unmanaged ecosystems. Reductions of greenhouse gas emissions from biofuel production and use (compared to fossil fuels) may be offset partly or entirely for decades or centuries by emissions from the resulting indirect land-use changes (iLUC) (IPCC SRREN, 2011, Chapter 2; Bringezu *et al*., 2009; Van Vuuren *et al*., 2010a), some of which are not only indirect but have transboundary and/or distant impacts (see 19.4). The placement of a carbon tax (as a surrogate for the effect of a variety of policies) to fossil carbon only, with a goal of limiting CO_2 concentrations to 450 ppm-550 ppm, is projected to lead to large scale deforestation of all natural forests by the end of the 21^{st} century, with conversion of most other natural ecosystems, in part due to enhanced biofuel production (Wise *et al*., 2009; Mellilo *et al*., 2009a,b). This could bring so much terrestrial carbon, converted into CO_2, in the atmosphere that it could offset partly or entirely the effect of substituting fossil fuel with biocarbon and obstruct the original goal of limiting atmospheric CO_2. If instead the tax is applied also on terrestrial carbon, the deforestation could slow down or even reverse, depending on the level of the tax. Alternatively (or additionally), land set-asides such as the Conservation Reserve Program in the US may be more effective at long-term GHG mitigation than maize-ethanol (Piñeiro *et al*., 2009).

Indirect land use changes can be reduced using the strategies for reducing food-system competition through markets, as discussed in section 19.4.1. Liquid biofuels can 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). Successful mitigation, however, is highly dependent on what feedstock is used, how it is grown, and how well subsidies and incentives prioritize GHG reductions. Second-generation biofuels, 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 due primarily to less adverse interactions with food-systems (Plevin, 2009; Fargione, 2010; Sander, 2010; Cherubini, 2010). Further, bioelectricity and biogas may both be more successful at mitigating GHG emissions than liquid biofuels (Power and Murphy, 2009; Campbell *et al*., 2009).

However, there are many equally compelling reasons for a country to encourage biofuel production including, among other things, competition for high oil prices, rural development and reduced oil imports – all of which could be prioritized over GHG reductions depending on the country (Cherubini *et al*., 2009). Another inherent conflict is that per-litre GHG emissions *decrease* as agriculture is further intensified through row cropping, fertilizer and pesticide use, and irrigation, while other per-litre environmental impacts *increase* (Burney *et al*., 2010; Grassini and Cassman, 2012). Conflicting biofuel deployment policies and priorities, and interactions with food-systems could therefore lead to a number of emergent risks as liquid biofuel supply increases, as shown in the Table 19-1.

[INSERT TABLE 19-1 HERE
Table 19-1: Emergent risks related to biofuel production as a mitigation strategy.]

19.3.2.3. Emergent Risks Involving Health Effects and Disease Emergence

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 current epidemiologic profiles, reflecting the level of development and access to clean and plentiful water, food and access to adequate sanitation and health care resources. Furthermore, the impact of climate change will differ within and between regions, depending upon the adaptive capacity of critical public health infrastructure that ensures access to clean food and water.

A principal emergent global risk is malnutrition secondary to ecological changes and disruptions in food production as a result of changing rainfall patterns, increases in extreme temperatures and precipitation events (IPCC, 2012), 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 the 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% compared to a future without climate change, and a much greater impact on severe stunting of 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.*, 2011).

In developed countries and large, highly populated megacities with developed public health infrastructure, principal emergent risks include increased injuries and fatalities as a result of severe storms and heat waves (see 19.6.3.3); changes in vector biology and disease ecology that impact infectious diseases; water and food contamination; increased pollen production leading to increases in allergic airway diseases (see 19.5.3); and respiratory and cardiovascular morbidity and mortality secondary to degraded air quality and ozone formation (see 19.6.3.3).

Increase in heat-related morbidity and mortality subsequent to the increase in the severity, duration, and frequency of heat waves (Luber and McGeehin, 2008) in urban areas is an emergent risk. These impacts will be greatest in urban areas with a pronounced urban heat island effect (Kovats and Hajat, 2008). The coupling of the increasing vulnerability of an aging population and a global shift to urbanization will increase the risk of relatively higher mortality from exposure to excessive heat (Knowlton *et al.*, 2007).

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, so that this interaction is an emergent risk. In New York City, for example, each single degree (Celsius) increase in 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). The principal pathways through which such respiratory health outcomes will be exacerbated by climate change are through increased production and exposure to tropospheric (ground-level) ozone, smoke produced by wildfires, and increased production of pollen (D'Amato *et al.*, 2010). Many of the same populations that are vulnerable to health effects from heat waves show increased risk for effects from poor air quality induced by heat, including: the very young and the very old and those with preexisting medical conditions, including respiratory and cardiovascular disease (see 19.6.3.3).

Projected changes in precipitation, temperature, humidity, and water salinity, have potential to affect the distribution and prevalence of food- and water-borne diseases resulting from bacteria and other pathogens, and increases in the frequency and range of harmful algal blooms (Curriero *et al.*, 2001; Moore *et al.*, 2008). Climate change and increased climatic variability would affect incidence of vector-borne diseases such as plague, Lyme's disease, malaria, hantavirus, and dengue fever which exhibit distinct seasonal patterns and sensitivity to ecologic changes (Githeko *et al.*, 2000; Gage, 2008; Parham *et al.*, 2011 submitted). These changes to food, water, and vector-borne diseases represent additional emergent risks.

19.3.2.4. Spatial Convergence of Multiple Impacts: Multi-Impacts Hotspots

"Hotspot" is an equivocal term that is defined and used in various manners (see also Box 21-4 in Chapter 21 for detail). In this chapter, we define a *multi-impacts hotspot* as a region where climate-change induced impacts in one sector affect 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 could have consequences that are more serious than simple summation of the sectoral impacts would suggest. Such synergistic processes are difficult to identify through sectoral assessment and apt to be overlooked in spite of their potential importance in considering key vulnerabilities. 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 a multi-impacts hotspot for health impacts, with the elderly and children most at risk.

As a systematic approach, identification of multi-impacts hotspots could be achieved by overlaying spatial data on 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 (Fussel, 2010; Tol and Fankhauser, 2008, Kainuma et al., 2003; Bowman et al., 2006; Warren et al., 2008). Recent efforts attempt to collect and archive spatial data on impact projections and facilitate their public use. These have created overlays for identifying hotspots with web-GIS technology (Adaptation Atlas (Vajjhala, 2009)). The Union of Concerned Scientists (2011) also identified many locations which could be classified as a multi-impacts hotspot based on robust scientific evidences published in peer-reviewed literature (Union of Concerned Scientists, 2011). There are also efforts to coordinate impacts assessments based on shared future scenarios at various spatial scales(Parry *et al*., 2004; ISI-MIP, 2012).

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

To illustrate some different types of multi-impacts hotspots where climate change impacts coincide and interact, the following examples are provided.

1) The Arctic is an example of a regional multi-impact hotspot, where the culture of indigeneous people (Crowley, 2011) is projected to be exposed to the disruption, and possible destruction of, their hunting and food sharing culture (see Chapter 28). This hotspot is due to the combination of sea ice loss and the concomitant potential extinction of the animals dependent upon the ice (Johannessen and Miles, 2011). Thawing ground is also disrupting transportation, buildings and infrastructure whilst there is increased exposure to storms. Arctic ecosystems are also at risk (Kittel *et al*., 2011).
2) Coral reefs are highly threatened due to the synergistic effects of sea surface temperature rise and perturbed ocean chemistry, which reduces calcification and also increases sensitivity to other impacts such as the loss of coral symbionts (Chapter 6). The importance of a hotspot of reef sensitivity to climate change in the area of greatest reef diversity in the world was recently highlighted in the near-equatorial Indo Pacific(Lough, 2012). A second hotspot for warming and thus damage to reefs was identified around Micronesia, Mariana Island and Papua New Guinea (Meissner *et al*., 2012).
3) Cities in deltas are often impact hotspots, being subject to sea level rise, storm surge, coastal erosion, saline intrusion and flooding. Extreme weather events can also disrupt access to food supplies, causing a malnutrition risk. Ericson *et al*. (2006); Chapter 24 revealed that 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. Examples of delta areas at risk include Mumbai, Dhaka and the Mekong (see Chapter 8, Chapter 24, and section 19.6.3.4).

General equilibrium economic models (see Chapter 10) may facilitate quantitative evaluation of synergistic influences. An analysis of the EU by the PESETA project evaluated 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, and indicated the largest percentage loss in Southern Europe (Ciscar *et al*., 2011)It should be noted, at any scale, choices of sectors are strongly constrained by availability of data or evaluation methods and they are not comprehensive.

19.3.2.5. Maladaptation

Maladaptation refers to adaptation strategies that increase a population's or sector's vulnerability to climate change. It can be viewed as a type of emergent risk since it arises from an interaction of a response by one group of people to climate change impacts which then interacts negatively with another group, often in a different sector or region. Maladaptation is discussed in detail in Chapter 14.7

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

Climate change impacts can have consequences beyond the regions in which they occur. Such long distance interactions may be mediated by global trade systems – the most prominent example of this is the global food trade system. However, the danger with relying only on global trade to mediate impacts is that competitive market forces do not account for considerations of justice. As prices on food, land, and other resources increase, those most in need may end up being the least able to pay (see section 19.6.1.2 on differential vulnerability). Additionally, both mitigation and other adaptation responses that are implemented on the ground can have unintended consequences beyond the locations in which they are implemented. All of these mechanisms can create emergent risks.

19.4.1. Indirect, Trans-Boundary, and Long-Distance Impacts of Climate Change Impacts on Agricultural Yields: Food Trade Patterns, Prices, Malnutrition

Climate change impacts on agriculture can have consequences beyond the regions in which those impacts are directly felt, through the global food trade system. Food access can be inhibited by rising food prices, as demonstrated during recent price rise episodes that resulted from the combination of poor weather in certain world regions combined with a demand for biofuel feedstocks, increased demand for grain-fed beef in China, and historically low levels of food stocks (Abbot and deBattisti, 2011; Adam and Ajakaiye, 2012). These episodes provide an analog elucidating how reduced crop yields due to climate variability impacts and biofuel cropping create a risk of malnutrition: hence this interaction of climate change with the food system via markets comprises an emergent risk of the impacts of climate change acting a distance. For further information see 7.2.2. on food security and 7.3.2.1.1. on how climate change can impact crop yields.

One study found that climate change may have already offset 30-years worth of technology-related increases in crop yields in Russia, Turkey, Mexico (wheat) and China (maize) (Lobell *et al*., 2011). Another study identified areas where past climate variability has induced sudden or prolonged drops in food production, e.g., Ukraine (a 13% decline in a single year due to high summer temperatures) and the Sahel (decadal scale losses due to prolonged drought and high temperatures; Battisti and Naylor, 2009). In the next few decades, areas where crop yields are projected to decline such as sub-Saharan Africa and the Sahel may come to rely more strongly on imported food (Schmidhuber and Tubiello, 2007). Whilst some studies (Jaggard *et al*., 2010) conclude that in the next few decades there may be increases in crop yields in temperate regions which may compensate in global terms for the losses in tropical regions (FAO, 2008), a recent empirical study suggests that these benefits may not be realized, based on indications that, to date, the positive effects of CO_2 fertilisation on yields and the effects of changes in precipitation and temperature have offset one another (Lobell and Field, 2007). Battisti and Naylor (2009) used climate projections from IPCC AR4 to show that by the end of the century, there is a probability of over 90% that growing season temperatures in the tropics and subtropics will exceed even the most extreme seasonal temperatures recorded from 1900 to 2006. Compared to the assessment in AR4, the evidence points to an *increased* risk that tropical and sub-tropical regions will experience significant crop yield declines due to climate change (see 7.3.2.1.1.). Taken together, regional climate change impacts on crop yields would result in increased prices of food commodities on the global market (Battisti and Naylor 2009; Lobell *et al*., 2011) even under an assumption of barrier-free ability to change the areas under cultivation (Juliá and Duchin, 2007).

Weather-induced yield losses which have affected food prices in many countries have already been documented in Australia and Europe in recent years (FAO, 2008; World Bank, 2011) – for example increasing the number of malnourished people by 75 million in 2007 (FAO, 2008). Climate change is projected to increase the frequency of extreme weather that can reduce crop yields and increase their year-to-year variability (Diffenbaugh *et al*., 2012; Urban *et al*., 2012), and there is some specific evidence that climate change induced yield losses are already affecting food prices (Lobell *et al*., 2011). Furthermore, developing countries that have limited financial capacity for trade, and/or food distribution networks may be damaged by increases in extreme weather events (FAO, 2008) leading to increased risk of poverty and malnutrition. One study used historical vulnerability to extreme weather events to project that Bangladesh, Mexico, Mozambique, Malawi, Tanzania and Zambia would be most at risk from future extreme weather events under 21st century climate change in the SRES A2 scenario (Ahmed *et al*., 2009). Developed countries which currently enjoy imported foods from tropical regions that become affected by climate change, would see the prices of those commodities rise. More generally, pressure on land use for biofuels is *likely* to further exacerbate food prices (see section 19.3.2.2).

On longer timescales, new techniques for assessing climate change impacts on yields of soybean, maize and cotton in the United States (Schlenker and Roberts, 2009) result in higher projections of yield declines compared to studies assessed in AR4: yield losses reach 30-46% by the end of the century under a low emissions scenario, or 63-82% under a high emissions scenario. However, these approaches are not necessarily accepted as better than earlier studies (see section 7.3.2.1.1.). Global rice prices may be particularly sensitive to climate change (Chen et al 2012), potentially rising by 7-13% in the wake of projected 1.6-2.7% losses in yield resulting from a combination of climate change and sea level rise. Another study (Warren *et al*., 2011) highlights that 50% of the global area where crops could be grown is projected to become less suitable for cultivation by the end of the century if global temperatures reach 4°C. Arnell *et al*. (2013) explains that once regional temperatures exceed 1° to 3°C above 1961-1990 mean, crop suitability falls back. A recent report (Foresight, 2011a) highlights the combined agricultural land losses expected in the next 40 years, due to desertification, erosion and sea level rise (the latter leading to increased salination). The report does not estimate the percentage of agricultural land involved, but if large, such changes would further increase global food prices, increasing the risk of poverty and malnutrition (World Bank, 2011).

Producing a significant proportion of energy from biofuels without inducing pressure on food and ecosystems through indirect land use change would require increasing available agricultural supplies through either decreasing existing demand and/or increasing production through intensification/extensification. Hence, there can be important interactions between global emissions mitigation policies and land management that can either confound, or contribute to, mitigation (Van Vuuren *et al*., 2011). Markets will respond to increasing liquid biofuel production in one of two ways: either through reduction in other demands for the feedstock crop or an increase in the supply, both of which will happen as commodity prices start to rise. 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 (USDA, 2011). 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, 2011). Still, estimates of the supply and demand elasticity of basic grain commodities (Roberts and Schlenker 2009) lead to a prediction that the 2009 US Renewable Fuel standard could increase commodity prices of maize, wheat, rice, and soybeans by roughly 20%, assuming one third of the calories used in ethanol production can be recycled as animal feed (Roberts and Schlenker, 2010).

Market responses to increased commodity prices are often the same mechanisms being viewed to potentially increase supply to the point where biofuels and food production can co-exist. These strategies can be grouped as follows: increasing supply either through extensification or intensification, and decreasing demand either by lifting biofuel mandates or reducing commodity usage from other demands.

The central question with regards to increasing the supply of commodity crops is how much will come from the intensive margin (higher yields per acre), and how much will come from the extensive margin (more acres). Keeney and Hertel (2009) argue that yields respond to prices and Foley *et al*. (2011) project that closing global 'yield gaps' for 16 important food and feed crops on lower productivity lands could increase agricultural supply by 58%. On the other hand, Roberts and Schlenker (2010) find that, historically, growing area responds to exogenous price shocks. If additional supply comes in part from planting new acres, Fargonie *et al*. (2008) and Searchinger *et al*. (2008) find large CO_2 effects of indirect land use change (iLUC) – currently one of the largest concerns surrounding liquid biofuels, both due to the magnitude of its potential impact and the uncertainty in accurately quantifying it. Deforestation would result in large indirect CO_2 emissions, as does the production of biodiesel using palm oil on peatlands that are drained (Miettinen *et al*., 2012). A study of biofuel production in Brazil (Barr *et al*., 2011) finds that once pasture is incorporated in the analysis, expansion into unexploited land is minor, i.e., most of additional cropland is predicted to come from conversion of pastureland. However, loss of pasture to biofuel might also trigger iLUC if the density of livestock operations is not increased in tandem. 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 SRREN 2012; Fargione *et al*., 2010) – although the amount, alternative uses, and potential productivity of so-called degraded lands are still contested (Dauber *et al*., 2012).

Market forces will impact demand for feedstock crops as prices increase. These reactions mirror many of the deliberate strategies to influence demand in the hopes of freeing up supply for biofuel production and/or minimize its iLUC impacts. Dietary changes could reduce the land requirements of food cropping embodied in these tradeoffs. A transition to a globally-implemented vegetarian diet would free up 2700 Mha of pasture and 100 Mha of cropland – a combined area representing approximately 70% of current agricultural and pasture land – much of which could then be used for biofuel cropping (Stehfest *et al*., 2009), whilst the remainder could revert to natural vegetation becoming a carbon sink (see 19.3.2.1). Another study found that eliminating meat from human diets could increase available calories by 49% (Foley *et al*., 2011). While extreme and an improbable response, these studies demonstrate that even small changes to diets and meat consumption could have large impacts. Reducing food-system losses might be another way demand responds to increased commodity prices. A recent FAO study found that approximately one third of food is never consumed – with losses in developed countries coming more from the consumer end (post-purchase spoilage before use) and losses in developing countries coming more from the production end (farm losses, spoilage before reaching markets) (Gustavsson *et al*., 2011). On the other hand, given that demand for biofuels is supported by mandates and subsidies, there has been a growing call for lawmakers to lift mandates or implement moratoriums on liquid biofuel development until the direct and indirect impacts on the food system, the climate and food security are better understood. A move to second-generation liquid biofuels or other forms of bioenergy such as bioelectricity or biogas, those that utilize non-food, crop residue or forest-based biomass, might help alleviate concerns. However, depending on where and how new feedstocks are grown they too could introduce their own iLUC impacts (Zilberman *et al*., 2011) and/or N_20 agricultural emissions uncertainty (Meyer-Aurich, 2012).

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

Risk can also emerge from unintended consequences of adaptation (see 19.3.2.5), and this can act across distance, if for example, there is migration of peoples 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. In some cases such interactions may contribute to conflict.

19.4.2.1. 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 AR5 WGII chapter12.4). 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 positive and negative outcomes for the migrants, migration from one region results in significant indirect, (and in some cases, long distance) effects on people and states in other regions. Consequences for receiving regions, determined by a variety of metrics, could be both positive and negative, as may also be the case for sending regions (McLeman, 2011; Foresight, 2011b; AR5 WGII Chapter 12). An emerging literature examines potential changes in migration patterns due to future climate changes, but projections of specific positive or negative outcomes are not yet available. Furthermore, recent literature underscores risks previously ignored: risk 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, 2011b; see Chapter 12).

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 later particularly the case for small island states (Pelling and Uitto 2001; Chapter 12). The extent to which these responses are employed 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" such as building sea walls and storm barriers (Nordenson and Seavitt 2011). Numbers of people at risk from coastal land loss have been estimated (Nicholls and Tol, 2006; Ericson *et al.*, 2006; Nicholls *et al.*, 2011) but projections of resulting anticipatory migration or episodic and permanent 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, 19.4.1, 19.6.1, 19.6.2; 19.6.3.3; Chapter 8). While a literature projecting climate-driven migration has emerged (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 (Table 19-3, Entry 1, Chapter 19).

19.4.2.2. Conflict and Insecurity

Violent conflict between individuals or groups arises for a variety of reasons (section 12.5). A large number of quantitative empirical studies have implicated climatic events as a contributing factor to the onset or intensification of personal violence, group conflict and social instability in contexts around the world and at temporal scales ranging from a climatologically anomalous hour to an anomalous millennium (Hsiang and Burke, 2012). Because most empirical studies have been released after AR4 (Kenrick and Macfarlane, 1986; Vrij *et al.*, 1994; Cohn and Rotton, 1997; Anderson *et al.*, 2000; Cullen *et al.*, 2000; Rotton and Cohn 2000; DeMenocal, 2001; Haug *et al.*, 2003; Miguel *et al.*, 2004; Levy *et al.*, 2005; Miguel, 2005; Mehlum *et al.*, 2006; Kuper and Kropelin, 2006; Zhang *et al.*, 2006; Hendrix and Glaser, 2007; Jacob *et al.*, 2007; Zhang *et al.*, 2007; Grove, 2007; Yancheva *et al.*, 2007; Burke *et al.*, 2009; Bai and Kung, 2010; Burke and Leigh, 2010; Tol and Wagner, 2010; Hidalgo *et al.* 2010; Buckley *et al.*, 2010; Bohlken and Sergenti, 2010; Patterson *et al.*, 2010; Hsiang *et al.*, 2011; Harari and Ferrara, 2011; Chaney, 2011; Bruckner and Ciccone, 2011; Zhang *et al.*, 2011; Burke, 2011; Larrick *et al.*, 2011; Buntgen *et al.*, 2011; Sarsons, 2011; Couttenier and Soubeyran, 2011; Hendrix and Salehyan, 2012; Theisen, 2012; O'Laughlin *et al.*, 2012; Kennett *et al.*, 2012; Fjelde and von Uexkull, 2012; Dell *et al.*, 2012; Ranson, 2012) the possibility that climate change will alter patterns of violence is an emerging risk. The result that high temperature exacerbates modern violence is the most consistent empirical finding, having been reported at spatial scales ranging from the individual level (Vrij *et al.*, 1994; Ranson, 2012) to the communal level (O'Laughlin *et al.*, 2012; Fjelde and von Uexkull, 2012) to the national level (Burke *et al.*, 2009; Dell et al, 2012) to the global level (Hsiang *et al.*, 2011).

It remains unknown whether climatic events contribute to the likelihood of violence through one or many of the pathways discussed in section 12.5 (Hsiang and Burke, 2012; Scheffran *et al.*, 2012; Bernauer *et al.*, 2012), and some authors have indicated that the identification of specific mechanisms is important for attribution and projections of future rates of violence (Sutton *et al.*, 2010; Buhaug, 2010; Butzer, 2012; Gleditsch, 2012). Nonetheless, because no study has provided systematic evidence that climatic events do not influence violence and a large literature provides systematic and consistent quantitative evidence that climatic events alter rates of modern violence (Hsiang and Burke, 2012; Hsiang, Burke and Miguel, 2013), it is *likely* that climate change will alter some patterns of human conflict and insecurity.

The effect of climate change on conflict and insecurity has the potential to become a key risk because the reported magnitude of the climate's influence on security is large. Median estimates from the literature indicate that in modern contexts (1950-2010), the frequency of interpersonal violence rises roughly 4% and the frequency of intergroup conflict rises 12% for each standard deviation change in annual conditions towards warmer temperatures or more extreme rainfall (Hsiang, Burke and Miguel, 2013). Because annual temperatures around the world are expected to rise at least two standard deviations (as measured over 1950-2008) above temperatures in 2000 by 2050, [WG1 Section *11.3.2.1.2*] (Hsiang, Burke and Miguel, 2013), there is potential for large changes to global patterns of personal violence, group conflict and social instability in the future. Social, economic and political changes which

might mitigate or exacerbate this potential impact are discussed in Chapter 12.
It is *likely* that socio-economic, political or technological advancements may cause future populations to respond to their climate somewhat differently than modern populations, however the estimated influence of the global climate on rates of conflict is sufficiently large in magnitude that these advancements may need to be dramatic in order to offset the potential influence of future climate changes. For example, Hsiang *et al.* (2011) estimate that the historical impact of a three-degree Celsius warming in the equatorial Pacific is sufficiently large that offsetting its impact on annual civil conflict risk for a low-income country requires raising average incomes by more than a factor of ten.

19.4.2.3. Species Range Shifts: Consequences

One of the main adaptations of species to climate extremes and climate change is shifting to more climatically suitable areas. The resulting losses, gains, and changes in species abundance are having, and will continue to have, profound impacts on ecosystem functioning, posing risks to the services they provide (Dossena et al., 2012; Millennium Ecosystem Assessment, 2005), including those related to climate regulation (Wardle et al. 2011). One example of a key impact would be the warming-driven expansion and intensification of Mountain pine beetle (*Dendroctonus* ponderosae) outbreaks in North American pine forests. These have already caused both declines in timber harvest and led to the conversion of these forests from net carbon sinks to large net carbon sources (Kurz et al., 2008), especially from forest fires. Potential key vulnerabilities would be the projected impacts of range shifts on important resource species (e.g. marine fishes), where catch potential is predicted to increase by 30-70% in high latitude regions but decline by 40% in the tropics (where fish are important sources of protein) by 2055 (Cheung et al. 2010)), as well as new introductions of diseases to people, livestock, crops and native species (Chakraborty & Newton, 2011; Jepsen et al., 2008; Gale et al., 2009; Lafferty, 2009). Newly arrived species may prey on, outcompete or hybridize with existing biota, becoming weeds or pests in agricultural systems (Thuiller 2007; Walther et al. 2009; Chown et al. 2012). The potential emergent risks and ecological implications of species reshuffling into novel, no-analogue communities largely remain, as yet, unknown (Root & Schneider 2006; J. W. Williams & Jackson 2007).

Current legal frameworks and conservation strategies face the challenges of untangling desirable species range shifts from undesirable invasions (Webber and Scott, 2011), and identifying circumstances when movement should be facilitated versus inhibited. New agreements (e.g., Memoranda Of Understanding) may be needed recognizing climate change impacts on existing, new, or altered national trans-boundary migration, for example under the Convention of Migratory Species (UNEP/CMS, 2006). As target species and ecosystems move, protected area networks may become less effective for conserving them, necessitating re-evaluation and adaptation, including possible addition of sites, particularly those important as either ‘refugia’ or migration corridors (Warren et al in press, Willis & Bhagwat 2009; Hole et al. 2011; Hannah 2011). Assisted colonisation – moving individuals or populations from currently occupied areas to locations with higher probability of future persistence – is emerging as a potential conservation tool for species unable to track changing climates (Hoegh-Guldberg et al. 2008; Richardson et al. 2009; Thomas 2011). The value of these approaches, however, it contested and implementation is very limited (Loss et al. 2011). *Ex situ* collections (i.e. in zoos, botanical gardens, and seed and gene banks) 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 (Wyse-Jackson 2002; FAO 2010; 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 (19.4.3.1, 19.4.3.2). If mitigation involves a form of land use change, then regional implications can ensue in the same way as they can for adaptation (see 19.3.2.5).

19.4.3.1. Effects on Biodiversity

Mitigation can reduce direct climate change impacts on biodiversity (Warren *et al*., 2012, ten Brink *et al*., 2010). However, especially in tropical regions, impacts on biodiversity (potential species loss) as a result of widespread habitat conversion for biofuel production could offset biodiversity impact reductions resulting from reduced levels of climate change attributable to use of such biofuels (ten Brink *et al*. 2010, Sala *et al*. 2009). Second generation bioenergy, or use of degraded land, would have reduced impacts on ecosystems (Searchinger *et al*. 2008, van Oorschot *et al*., 2010). It is possible to further offset losses due to land use change by increasing agricultural productivity, thus reducing some of the competition for land use. Tropical forests, in particular, can also be preserved under biofuel cropping strategies if the climate mitigation policy applied incorporates an economic price for emissions from land use change (Thomson *et al*., 2010). Increasing oil-yield efficiency of major biodiesel feedstocks could also reduce land pressures. See also 19.3.2.2.

Climate change mitigation through 'clean energy' substitution can have negative impacts on biodiversity. For example, poorly designed and sited wind farms (both on- and off-shore) can have population level impacts on some bird and bat species. However, these impacts can be reduced (especially on birds) and off-shore wind farms have been shown to have a positive impact on demersal fisheries (Wilhelmsson *et al*., 2006). The same can also be said for many of some other renewable energy proposals (e.g., wave energy, tidal barrages, and tidal turbines). Attention to siting and monitoring can decrease potentially large-scale negative ecological and socioeconomic impacts while maximizing positive ones. 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. In the case of hydropower, the construction of capital-intensive large hydroelectric dams, affects both terrestrial ecosystems within the hydroelectric reservoir and surrounding areas and the aquatic ecosystems far up- and downstream along the river system (World Commission on Dams, 2000). These impacts on biodiversity may include high deforestation rates in the surrounding landscape due to (i) new roads, power transmission lines, and new settlements to accommodate the large migrant workforce involved in building large dams, (ii) mass tree mortality within low-elevation inundated areas, and (iii) discontinuity of upstream fish migrations (World Commission on Dams, 2000; Anderson *et al*. 2006; Bertham and Goulding 1997; Finer and Jenkins 2012). In all cases, low-lying forests and savannas are disproportionately affected by the direct and indirect impacts of building and maintaining a large dam. The biodiversity losses from large dams are particularly large relative to benefits of the dams in relatively flat lowland areas where the ecological effect of dams — which is often expressed as the total inundated area (km^2) per unit of electricity produced (MW/yr) — tends to be very high. In addition to a wide range of ecological impacts, local indigenous populations are sometimes displaced from their traditional territories within the reservoir area and immediate vicinities — in direct contradiction of the UN Declaration of Indigenous Rights (UN General Assembly 2007). In sum, there is a wide range of detrimental biodiversity, carbon storage and socioeconomic consequences of augmenting hydropower generation through large dam construction, especially in tropical countries.

19.4.3.2. Effects on Human Systems

Mitigation strategies will have a range of effects on human systems, dependent on the type of mitigation strategy as well as the type of human system. Even within a particular mitigation strategy, effects may vary considerably. 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). It would also provide numerous benefits from the sustainable harvest of non-timber forest products (NTFPs) 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. As mitigation measures are implemented in the future, the short-term benefits from planting monoculture stands of tree species most beneficial for climate mitigation may be given greater weight than more complex reforestation efforts. In this scenario, human systems may still benefit from improved local climate effects but not benefit from the utilization of species in a diverse forest system (Guarigata *et al*., 2010). A current example of this approach is found in China where the world's largest reforestation effort has led to dense monoculture stands of fast growing tree species through the Three North Shelterbelt Development Program (Zhang and Song, 2005). Afforestation (foresting an area that was historically not forested) creates a similar set of costs and benefits. In both reforestation and afforestation, land tenure and ownership becomes an issue for human systems (Unruh, 2008). Relocation of human populations from agricultural lands in order to reforest would have negative consequences for those affected unless clear and thoughtful strategies are implemented. In this scenario, it would be necessary to "mitigate" the effects on human systems caused by climate mitigation. Efforts to preserve existing forests would have an overall benefit for human systems since over the long term, the costs to maintain an intact forest are much lower than the cost to restore a forest. Human populations utilizing NTFPs may continue to benefit as long as such utilization is carefully monitored for sustainability (Newton, 2008).

More generally, 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 which could influence food prices (see also 19.4.1). Some scenarios suggest a rise in energy costs solely due to the lower flexibility of renewable energy resources compared to fossil fuels, which would in turn affect prices in the energy-dependent agriculture sector. This would especially affect marginal populations who already devote a considerable portion of their household income to food (Hymans and Shapiro, 1976).

19.5. Emerging Risks

Emergent risks discussed above are related to multiple interacting systems and stressors (section 19.3) or to indirect and long-distance impacts (section 19.4). However, an additional set of risks has emerged in the literature recently, 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 have been based on climate change scenarios corresponding to global mean temperature rises of up to 3.5°C relative to 1990 (or 4°C above pre-industrial levels) (Parry *et al.,* 2004; Hare, 2006; Warren *et al.*, 2006; Fischlin *et al.*, 2007; Easterling *et al.*, 2007). In this section, all warming scenarios are relative to pre-industrial levels unless otherwise noted. Recently the potential for larger amounts of warming has received increasing attention in the literature, motivated by the possibilities that future radiative forcing could be higher than typically considered and that positive feedbacks between climate and the carbon cycle could be strong (Betts et al. 2011; Sanderson et al., 2011). In a 4°C world, the effects of climate change on water resources and ecosystems are projected to become dominant over other drivers such as population increases and land use change (Arnell et al 2009, Bellard et al 2012).

Under a warming of 5°C, 30-40% of the global population are projected to be exposed to water stress (Gerten *et al.*, submitted) under the A2 population projections. Similarly, 20-30% more people globally are expected to be affected by increased water stress, compared to those projected affected in a 2°C world (Arnell *et al.*, 2011). Annual runoff is projected to fall by 40-80% variously across the Danube, Mississippi, Amazon and Murray Darling river basins, and to increase by 40% in the Nile and Ganges (Fung *et al.*, 2011). The total 'drought disaster affected area' is expected to increase from 15% today to 44+/-6% in a range of scenarios which include some that reach 4°C by 2100 (Li et al 2009).

Globally, agricultural production is expected to decline in mid-high latitudes once local temperature rise exceeds 3°C (IPCC AR4) (and for lower temperature rise in the tropics), corresponding to global temperature rise below 4°C). Beyond 4°C there is high risk of marked yield loss even at high latitudes (Rotter et al. 2011, section 23.4.1). Ciscar et al (2011) estimated that a 3.5°C warming globally could reduce crop yields in Europe by 10%. There is concern that current crop modelling efforts cannot capture the non-linear responses shown by crops in response to past temperature variability, which led Schlenker and Roberts (2009) to project crop yield losses of 63-82% under 4°C warming. Today's crop models may be unable to capture well the impacts of large temperature rise (Rotter *et al.,* 2011) and also omit the concomitant effects of projected increase in pests and disease.

Under a 4°C warming, biomes in temperate zones are projected to be significantly affected, whereas under 2°C warming the effects are projected to affect mostly polar and tropical regions. Humid tropical forests are projected to lose 75% of their current extent (Zelazowski *et al*., 2011). Poleward latitudinal biome shifts of up to 400km are possible in a 4°C world (Gonzalez *et al*., 2010). Twelve to thirty-nine percent of the Earth's surface is projected to experience a novel climate (Williams *et al*., 2007) whilst on 10-48% of the Earth's surface, current climates will disappear locally as, for example, isotherms rise up mountains or towards coasts and are lost in a 4°C world. This includes highly biodiverse regions such as the Himalayas, Mesoamerica, E and S Africa, the Philippines and Indonesia. , Tropical and temperate eco-regions of exceptional biodiversity projected to experience monthly mean temperatures that deviate by between two and four standard deviations from those of the 1990s (Beaumont *et al*., 2011). Concomitantly, the climate envelopes of 60% of plants and 33% of animals are projected to shrink by more than 50% (Warren *et al*., in press.). Large climate change induced shifts in fire regimes are expected in ecosystems at 4°C. Widespread coral reef mortality is expected at 4°C, since this corresponds to CO_2 increases causing increase of about 150% in ocean acidity (World Bank 2012). Well below this threshold, at 3°C, coral reefs are expected to start to dissolve (see section 5.4.2.4). Hypoxic zones may be seen in the ocean, reducing the habitat for fish such as tuna (Stramma *et al.,* 2011). Together, these effects all point to a very extensive loss of biodiversity in a 4°C world (*high evidence, high confidence*), with concomitant loss of valuable and essential provisioning, regulating, supporting and cultural ecosystem service (*medium evidence, high confidence*). Loss of ecosystem services has negative economic and physical consequences for human agricultural and urban systems and upon human physical and mental health (Chivian and Bernstein, 2008).

An additional 250000 people are projected to be affected by river flooding in Europe in a 3.5°C world in the 2080s (Ciscar *et al*., 2011) assuming *no* population growth from today. A sea level rise of 0.5 to 1 m is *likely* by 2100 in a 4°C world (AR5 WGI Table 13.5) and would result in the inundation of many small island states.

Emerging risks associated with warming greater than 4°C above pre-industrial include the potential exceedance of human physiological limits in some areas for a global temperature rise of 7°C above pre-industrial (Sherwood and Huber, 2011); and reductions in labor productivity e.g., loss of 5% in economic output in a 6°C world (Roson and Mensbrugghe, 2010). Extreme heat waves such as that experienced in Russia in 2010 can become typical of a normal summer in a 4°C world (World Bank, 2012).

The following non-linear earth system responses would be expected to be triggered for a persistent 4°C temperature rise (a) Amazon dieback (Lenton *et al*. 2008; Malhi *et al*. 2009; Salazar and Nobre 2010) (*medium confidence*). (b) Eventual, irreversible loss of the Greenland Ice Sheet (see section 19.6.3.6, *high confidence*) (c) More widespread terrestrial carbon loss due to climate-carbon cycle feedback (AR5 WGI Ch. p.6-5, *very likely*). The chance of triggering other non-linear responses such as the collapse of the West Antarctic Ice Sheet is also greatly increased (see section 19.6.3.6).

Sub-Saharan Africa is identified as a multi-impacts hotspot in a 4°C world, with projected loss of 25-42% of plant species (Midgley and Thuiller, 2011), loss of 35% of cropland (Arnell *et al*., 2009), major reductions in growing season length (Thornton *et al*., 2011), increased risks of hunger (Sissoko *et al*., 2010, Mougou et al 2010) and areas where the probability of malaria transmission rises by 50% (Beguin, 2011). In the Upper Nile basin in Uganda, increased potential evapotranspiration as occurring under at high global temperature increases of 4°C or more is projected to decrease groundwater outflow to the river so much that the spring discharge peak disappears and the river flow regime changes from bimodal to unimodal (one seasonal peak only) (Kingston and Taylor, 2010; section 3.4.6).

More generally, simulations of climate change impacts at 4°C and above show greater and more significant impacts than at lower levels of global temperature rise (*medium evidence, high confidence*). The large projected increases in populations exposed to water stress, fluvial and coastal flooding, the potential for crop yield losses, and the projected widespread disruption of ecosystem function and services, alongside projected extinction of a significant proportion of the earth's biodiversity, would create large aggregate impacts of climate change on society generally and on the global economy (see 19.6.3.5). Furthermore, these effects will interact, risking a cascade of impacts which may induce the crossing of tipping points in socio-ecological systems in many areas (Warren *et al*., 2011; 19.7.5), potentially increasing the scope of migration, which is sometimes disruptive, or conflict (19.4.3, 12.4, 12.5).

[INSERT TABLE 19-2 HERE
Table 19-2: Key risks from large temperature rise.]

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" (WG1 Ch. 3; see also WG2 Glossary). It is a physical impact resulting from CO_2 emissions that poses emerging risks to marine ecosystems and the societies that depend on them. Ocean acidification impacts are a relatively new research area, and the potential for associated risks to become key is magnified by the fact that it 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 (Dore *et al*., 2009; Byrne *et al*., 2010; Table 3.2 of WG1 Ch. 3) and will continue to increase in magnitude as long as the atmospheric CO_2 concentration increases (National Academy of Sciences, 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. Confidence in quantifying these effects (as summarized from WG2 Chapter 6) decreases with each step 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* (WG2 Ch. 6), but this varies widely with process and organism, e.g., *medium confidence* that the increase in dissolved CO_2 will cause an increase in primary production, *low to medium confidence* that nitrogen fixation rates will be stimulated (depending on organism); *low to high confidence* that calcification rates will decrease (depending on organism); and *high confidence* that a decrease in pH will reduce the thermal tolerances of organisms (WG2 Ch. 6). Ocean acidification can also affect the availability of iron for marine photosynthesis and the chemical state and toxicity of some metals, although these effects are currently poorly understood (Millero *et al*., 2009, Hoffmann et al., 2012).

Far fewer studies have assessed the impacts on ecosystems and ecosystem services (Cooley, 2012), and most of these studies have focused on the economic impacts on fisheries (Cooley and Doney 2009; Cooley *et al*. 2011; Narita *et al*. 2012). For example, changes in overall availability and nutritional value of desired mollusk species could impact economies (Narita *et al*.; 2012) and food availability (Cooley and Doney, 2009; Cooley 2012). Figure 19-4 illustrates how evidence can be used to assess these risks, leading to the conclusion that risks to ecosystem services related to marine calcification are high and those related to nitrogen fixation are more uncertain. Changes in coral calcification are *likely* and we judge the potential magnitude of impacts to some ecosystem services (e.g., the role of coral reefs in supporting habitats, provisioning of fish, regulating shoreline erosion, and tourism) to be *medium to high*. Studies document significant changes in community composition, biodiversity, calcification rates, and recruitment of corals and other calcifiers caused by natural carbon dioxide seeps that produce acidification consistent with that expected to result from an atmospheric CO_2 concentration of 750 ppmv (Hall-Spencer *et al*., 2008; Fabricius *et al*., 2011). If such changes are representative of future changes to benthic calcifying systems, then the ecosystem services they provide will in turn be degraded. The loss of coral reef structure, for example, has been linked to changes in abundance and diversity of reef fishes (Jones *et al*. 2004; Wilson *et al*. 2012; Chong-Seng, *et al*. 2012).

[INSERT FIGURE 19-4 HERE
Figure 19-4: Risks of ocean acidification to ecosystems services through two effects on biogeochemical processes: (1) reductions in calcification rates (of corals) and (2) increases in nitrogen-fixation rates. Assessments are based on the estimated *likelihood* that the process will be affected by ocean acidification (horizontal axis) and the *magnitude* of the impacts on associated ecosystem services (vertical axis) should the process be affected. Heights and widths of boxes indicate the range of uncertainty in the magnitude of impacts on ecosystem services and likelihood of change in the process, respectively. Heights are greater than widths due to the lower confidence in responses of ecosystems and their services (Figure 19-3). Judgments are based on impacts expected with atmospheric CO_2 levels of 2-3x preindustrial levels (560-840 ppmv). This figure is meant to be broadly illustrative: with sufficient information Low, Medium, and High magnitudes of impacts would be defined quantitatively. The shading of the box represents the risk (*likelihood* x *magnitude*) to ecosystem services with the dashed contour showing the line of equal risk; the area above and to the right of this line is broadly indicative of key risks. Thus, the reduction in calcification due to ocean acidification is already considered a key risk to some ecosystem services, while the limited evidence regarding the nitrogen fixation response and its impacts implies that it may or may not become a key risk as uncertainty is reduced.]

In contrast, several laboratory studies show that nitrogen fixation rates increase under ocean acidification conditions (WG2 Ch. 6), but there is limited evidence for this in field studies and the magnitude of the impacts to ecosystem services (e.g. nitrogen cycling) is largely unknown, so that the risk of this impact is difficult to quantify.

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 the potential for these risks to be sufficiently widespread in geographical scope and large in their impact on human health to be considered an emerging risk.

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). Ziska *et al*. (2000, 2003, 2012) found an association between 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 at el, 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). The declining nutritional quality of important global crops is an emerging risk that has the potential to broadly affect rates of protein-energy and micronutrient malnutrition in vulnerable populations. While this emerging risk has the potential to become key, there is currently insufficient information to assess under what ambient CO_2 concentrations this risk will manifest as key.

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 in order to alleviate the impacts of climate change (WG2 Glossary; IPCC, 2012b). It is distinct from mitigation, in that mitigation aims to reduce or prevent actions that would change the climate, such as emissions of gases and particles and changes to the land surface, while geoengineering involves deliberate changes to the climate system itself. The main benefit of geoengineering would be the reduction of climate change that would otherwise occur, and the associated reduction in impacts (Pongratz *et al*., 2012; section 19.7.1). Here we focus on risks, consistent with the goal of this chapter.

Geoengineering is an emerging risk both because it poses risks to society and ecosystems that could be large and widespread and because, although it is not a new idea (e.g., Rusin and Flit, 1960; Environmental Pollution Panel, 1965; Budyko, 1974, and a long history of geoengineering proposals as detailed by Fleming, 2010), it has received increasing attention in the recent scientific literature, stimulated in part by suggestions that nations might consider geoengineering solutions to global warming in light of the absence of comprehensive global mitigation policy (Crutzen, 2006; Wigley, 2006). Geoengineering has come to refer to both carbon dioxide concentration reduction (CDR, discussed in detail in AR5 WG I, Chapter 6) and solar radiation management (SRM; Shepherd et al., 2009; Lenton and Vaughan, 2009; discussed in detail in AR5 WG I, Chapter 7), and both are discussed in AR5 WG I, FAQ 7.3. These two different approaches to climate control raise very different scientific (e.g. Izrael *et al*., 2009), ethical (Morrow et al., 2009; Preston, 2013) and governance issues (Lloyd and Oppenheimer, 2012). Many approaches to CDR are better defined as mitigation than as geoengineering (AR5 WGI, Chapter 6), and CDR is thought to produce fewer risks than SRM if the CO_2 can be removed from the atmosphere efficiently and stored safely (WGI Chapter 6; Royal Society 2009). For these reasons, in addition to the more substantial recent literature on SRM's potential impacts on physical (see WGI, Chapter 7), social and ecological systems, we only address SRM in this section.

Various SRM schemes have been suggested, and are described in detail in AR5 WG I, Chapter 7. However, studies of impacts on society and ecosystems have been based on stratospheric aerosols and marine cloud brightening, two approaches that seem to have the potential to produce large-scale, effective and inexpensive cooling (Salter *et al*., 2008; Lenton and Vaughan, 2009; McClellan *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; Trenberth and Dai, 2007), lead to famine (in the pre-industrial period; Oman *et al*., 2006), cause ozone depletion (Solomon, 1999), and reduce electricity generation from solar generators that use focused direct sunlight (Murphy, 2009). Climate modeling studies confirm the risk of ozone depletion (Tilmes *et al*., 2008, Rasch *et al*. 2008), and some find that stratospheric geoengineering would reduce summer monsoon rainfall relative to current climate in Asia and Africa, potentially threatening the food supply for billions of people (Robock *et al*., 2008; Jones *et al*., 2010), but others find different regional patterns (Rasch *et al*., 2008).

Use of SRM can also pose risks as a climate change response strategy, most importantly due to the risk of rapid climate change if it fails or is halted (Wigley, 2006; Matthews and Caldeira, 2007; Robock et al., 2008; WGI Ch 7), which would be *very likely* to have large negative impacts on ecosystems (Russell et al., 2012) and could offset the benefits of SRM (Goes et al., 2011). Also, without global agreements on how and how much geoengineering to use, SRM presents a risk for international conflict. Since SRM appears to be very inexpensive (Robock *et al*., 2009; McClellan *et al*., 2012) geoengineering could be undertaken by non-state actors or by small states acting on their own (Lloyd and Oppenheimer, 2012), potentially producing global or regional conflict (Robock, 2008b).

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. We then discuss dynamic characteristics of vulnerability and risk, features which are influenced by development pathways in the past, present and future. These illustrative examples of climate-related hazards (or non-climatic stressors), key vulnerabilities, key risks and emergent risks in Table 19-3 are selected from a larger number provided by the chapters of this report. The table (19-3) indicates how these four categories are related as well as how they differ. 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 have to address climate related hazards, non-climatic stressors and various vulnerabilities that often interact in complex phenomena and change over time. In addition to these examples, key risks may also arise from moderate vulnerability interacting with a very large physical impact.

19.6.1. Key Vulnerabilities

Several of the risks discussed in this and other chapters and noted in Table 19-3 arise because vulnerable people must cope and adapt not only to changing climate conditions, but to multiple, interacting stressors simultaneously (see 19.4), which means that effective adaptation strategies would address these complexities and relations.

19.6.1.1. Dynamics of Vulnerability

This sub-section deals with the meaning and the importance of dynamics of vulnerability, while section 19.6.1.3 assesses recent literature and data 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, 2012; 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, 2012, p. 7).

Examples of such dynamics in exposure and vulnerability encompass, e.g. population dynamics, such as population growth (Table 19-3, Entry 1, Chapter 19) and increasing exposure of people and settlements in low lying coastal areas or flood plains in Asia (see Nicholls and Small 2002; Levy, 2009; Fuchs *et al*., 2011; IPCC, 2012; Peduzzi *et al*., 2012). Also, demographic changes, such as aging of societies, have a significant influence on vulnerability to heat stress (see Staffogia *et al*., 2006; Gosling *et al*., 2009). Changes in poverty or socio-economic status, race-ethnicity 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. Cutter and Finch (2008) found that social vulnerability to natural hazards increased over time in some areas of the United States due to changes in socio-economic status, race-ethnicity 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, 2007).

In some cases human vulnerability might also change in different phases of crises and disasters. Hence, the factors that might determine vulnerability before the crises 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 vulnerability e.g. of coastal communities (Birkmann and Fernando, 2008; Birkmann, 2011b). 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.

19.6.1.2. Differential Vulnerability

Wealth, education, race, ethnicity, religion, gender, age, class/caste, disability, and health status exemplify and contribute to the differential vulnerability of individuals or societies to climate and non-climate related hazards (see

IPCC, 2012). Differential vulnerability is, for example, revealed by the fact that people and communities that are similarly exposed face 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, 2006; Sietz *et al*., 2011). Factors that determine and influence these differential vulnerabilities and exposure patterns to climate-related hazards encompass among other factors e.g. race and 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; Ben, 2006; Bartlett, 2008) as well as migration experience (Cutter and Finch, 2008) and homelessness (Wisner, 1998; IPCC, 2012a). These differential vulnerabilities are often attributed to specific populations at a particular scale using quantitative or qualitative assessment methodologies (Cardona, 2006; Cardona, 2008; Birkmann *et al*., 2013). Groups that are marginalized, particularly due to gender or wealth status or ethnicity, are differentially affected by physical impacts of climate change in terms of both gradual changes in mean properties and extreme events (e.g., Neal and Phillips, 1990; Enarson and Morrow, 1998; Neumayer and Plümper, 2007; Sietz *et al*., 2011b). 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 Vulnerability

Vulnerability and exposure of societies and social-ecological systems to physical impacts of climate change are dynamic and depend on economic, social, demographic, cultural, institutional, and governance factors (see IPCC, 2012, p.7). Population growth, rapid and unsustainable urban development, international financial pressures, increases in socioeconomic inequalities, failures in governance (e.g. corruption), and environmental degradation are trends that modify vulnerability of societies and communities (Maskrey, 1993a; Maskrey, 1993b; Maskrey, 1994; Mansilla, 1996; Maskrey, 1998; Cannon, 2006) at different scales. Consequently, many of the factors that reveal and determine differential vulnerability, such as socio-economic status, wealth, poverty, age, health conditions or migration experience and governance processes (see 19.6.1.2) are dynamic, often changing over time in terms of their spatial distribution. Consequently, identifying, assessing and reducing vulnerability requires accounting for such dynamics and changes in vulnerability over time, e.g. due to different socio-economic development trends and policies. The following section outlines observed trends in vulnerability according to different thematic dimensions (socio-economic, environmental, institutional), within the constraint that data for assessing such trends in vulnerability is still fragmentary and much of it only recently emerging.

19.6.1.3.1. Trends in socioeconomic vulnerability

Poverty is arguably one of the key factors determining vulnerability of societies to climate change and extreme events. For example, there is *high confidence* that drought risk – particularly in sub-Sahara Africa - is intimately linked to poverty and rural vulnerability (see GAR, 2011, p. 62; WRI, 2012; World Bank, 2010). Hence, the risk of loss of livelihoods and harm due to droughts is heavily influenced by the poverty patterns and livelihoods of communities exposed to drought, e.g. in Africa or Asia. Restocking by poor pastoralists' households in rural areas in Africa after a drought may take several years due to limited financial resources (see Chapter 13). Recent global studies for 119 countries found that at the international level there is a clear decrease in global poverty over the past six years (Chandy and Gertz, 2011). The number of poor people globally fell by nearly half a billion people, from over 1.3 billion in 2005 to under 900 million in 2010. This trend is expected to continue; hence at a global level most projections show a decreasing level of poverty and extreme poverty at the global scale (e.g. Chandy and Gertz 2011; Hughes *et al*., 2009). While the poverty rate at the global level is decreasing and now accounts for approximately 16 percent of the total global population (in 2010), regional differences are significant, as are differences between emerging and least develop economies. As a result, there is a growing climate-related risk in some regions due to chronic poverty. For example, the highly drought exposed region sub-Sahara Africa still has approximately 47% of its population living in poverty (poverty headcount ration at $1.25 per day; see World Bank

2012) and already has been defined as a global risk hotspot (see WRI, 2011; WRI, 2012). Moreover, even national-level poverty statistics provide little information about the actual distribution of poverty in a specific country, for example regarding rural-versus-urban areas or different ethnic and age groups. 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 (e.g, China, Indonesia or Bangladesh) this trend overlaps with climate impact hotspots in terms of people currently exposed to floods and tropical cylcones as well as sea-level rise (Förster *et al.*, 2011; Peduzzi *et al.*, 2012; IPCC, 2012a). Assessing vulnerability 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 the middle class can be observed or where poverty is newly increasing among, for example, elderly people that have limited physical means to cope with climatic hazards.

Health conditions of individuals and population groups affect vulnerability to climate change by limiting capacities to cope and adapt to climate hazards. 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: between 2010-12, 870 million people remained chronically undernourished. Particularly in countries highly exposed to current and projected climate-related hazards, such as droughts in Africa, more than one third of the population is undernourished (FAO, 2012, p. 10; Hughes *et al.*, 2009). Moreover, trends in HIV/AIDS, tuberculosis and malaria are also observed in regions that are highly exposed to climatic hazards, such as Africa and South-East Asia. These multi-hazard contexts may require new approaches in climate change adaptation; for example, countries exposed to these health risks often face significant limitations with regard to their health systems(Vitoria *et al.*, 2009) as indicated by the incidence of malaria and HIV/AIDS, in some cases of epidemic proportions.

While these trends mainly point to particularly severe vulnerabilities in developing countries, studies regarding extreme heat vulnerability and other challenges related to urbanization also underscore that developed and industrialized countries face increasing challenges to adapt. Extreme heat events, characterized by consecutive days with abnormally high temperatures, are projected to increase in duration, intensity, and extent (AR5 WGI SOD 11.3.2) signaling an emergent public health risk, particularly for urban populations. Advanced age represents one of the most significant risk factors for heat-related death (Bouchama and Knochel, 2002), since beside limited thermoregulatory and physiologic heat-adaptation abilities, elderly also have often reduced social contacts, and higher prevalence of chronic illness and poor health (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. Another demographic trend affecting vulnerability to extreme heat is high population growth rates in urban areas, where populations are expected to grow disproportionately over the coming decades (United Nations, 2008). By 2030, approximately 60% of the projected global population of 8.2 billion is expected to live in cities (United Nations, 2006).

19.6.1.3.2. Trends in environmental vulnerability

The environment provides a range of ecosystem services (see e.g. MEA, 2005) that are at risk due to climate change. Societies and communities in some regions that heavily rely on the quality of ecosystem services, such as rural populations dependent on rain fed agriculture where drying is projected (see also Table 19-3, Entries 1 and 2, Chapter 19, and Chapters 7, 13 and 26), are *very likely* to experience increased risk from climate change. Large proportions of the world’s rural population – particularly in developing countries – depend on ecosystem services and functions. Although a global overview is still impossible, recent reports (UNDP, 2007; IPCC, 2012a) underscore that a number of current environmental trends threaten human well-being and thus increase human vulnerability (UNEP, 2007). Many communities have suffered considerable losses due to extreme weather events in combination with the degradation of ecosystems and ecosystem services in the past. For example, agricultural productivity, food security, livelihoods and health are being affected by land degradation which often starts with soil sealing with artificial surfaces, erosion, salinization, fire risk, over production, and land fragmentation resulting from both natural and human-caused changes in climate, soil, vegetation conditions and economic and population pressures (Salvati and Zitti, 2009). In addition, coastal degradation is increasing the exposure of coastal communities to hazards (World Risk Report, 2012) particularly in Asia, e.g., severe degradation of coral reefs. 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 (Kahn, 2005; WRI, 2011). Severe climate change risks and vulnerabilities to climate change occur in countries that are characterized by failed governance. Countries classified as failed states are often not able to guarantee their citizens basic standards of human security (see Chapter 12) and consequently do not provide support in crises or disaster situations for vulnerable people. At a global level 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. Countries characterized in the literature as substantially failing in governance or in some particular aspects of governance, such as Somalia and Sudan, Haiti or Pakistan 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; Khazai *et al.*, 2011, p. 30-31; Menkhaus, 2010, p. 320-341). Studies at the global level 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). Hence, 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 (World Risk Report, 2011). There is *high confidence* that unless governance improves in countries with severe governance failure, an increase in risk is likely to occur as a result of climate changes and increased human vulnerability.

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 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'Conner 1999; Grothmann and Patt, 2005; Weber, 2006; Kuruppu and Liverman 2011). Furthermore, Weber (2010) argues that 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, 2000; 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; Hibbs, 2012). Risk perceptions particularly influence and increase vulnerability in terms of false perceptions of security. 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 or communities exposed (see Figure 19-1). Various chapters in this report have dealt with key risks from their specific chapter perspectives. In this regard it is difficult to provide a comprehensive overview. Rather, the following section highlights selected key risks in order to illustrate how key risks develop and why they are seen as fundamental in this report. Based on the input from other chapters and our evaluation of existing literature, the following key risks were identified:

- Risk of increased food insecurity (Chapter 7 and 13)
- Risk of dispossession of land (Chapter 13)
- Risk of loss and degradation of resource bases (e.g. water) and related livelihoods (Chapter 13, 24)
- Risk of increasing infrastructure failures and systemic risk (Chapter 23)
- Risk of serious harm and losses in urban areas, particularly in urban coastal environments (Chapter 26)
- Risk of increased disease burden (Chapter 23)
- Risk of loss of terrestrial, aquatic and marine ecosystems (Chapter 6, 22)
- Risk of species extinction (Chapter 6, 22)

An important common characteristic of all these key risks is that they are determined by influences of hazards due to of changing climatic conditions and climate variability on the one hand and the vulnerability of societies, communities and social-ecological systems, e.g. in terms of livelihoods, infrastructure, and management systems on the other. The following examples should underscore this systematic approach to identifying key risks.

[INSERT TABLE 19-3 HERE
Table 19-3: A selection of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in various chapters in this report (Chapter 4, 6, 7, 8, 11, 13, 19, 22, 23, 24, 25, 26). Key risks are determined by hazards and stressors interacting with vulnerability and exposure of human systems, infrastructure, and ecosystems or species. The table underscores the complexity of risks determined by various climatic hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, demographic changes or tolerance limits of species and ecosystems 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. climate change, urbanization and demographic changes) in combination and in specific development context (e.g. in low-laying coastal zones), can generate new systemic risks that go far beyond existing adaptation and risk management capacities, particularly in highly vulnerable regions.]

Risks of increased food insecurity emerge in various chapters and are linked to changes in e.g. rainfall patterns (temporally and spatially) that creates major stress for rainfed agriculture, particularly for those groups that have little access to alternative modes of income or income earning activities (Chapter 13). In addition, the risk of food insecurity can also be determined by the partial or total breakdown of food distribution and storage processes (Chapter 7) and limited coping and adaptation capacities. These examples also show that key risks might not solely be determined by local conditions, but also national or even regional capacities and limits on ability to manage crop failures and food shortages.

The *risks of dispossession of land* is also closely linked to rural livelihoods and the fact that shifts in energy policies and global markets might constrain access to agricultural land. The lack or limited access to land has contributed to risk when people face extreme events, such as major floods in Pakistan, since land is often used as a resource supporting coping and adaptation processes. Hence the dispossession of and limited access to agricultural land is seen in this report (e.g. Chapter 13) as a key risk in the light of climate change.

Such factors can also increase the *risk of loss of livelihoods*. Overall, there is *high confidence* that the risk of loss of livelihoods is high for people in low-laying coastal zones as well as for people engaged in rain-fed agriculture in developing countries and countries in transition due to changes in climatic conditions as well as socio-economic structures. These changes are already observed in large Delta regions, such as the Mekong Delta, where a strong migration towards urban areas is taking place due to socio-economic challenges farmers face as well as environmental changes such as salinization, saltwater intrusion and flooding linked to sea level rise.

Key risks identified in this report also encompass phenomena that are related to urban areas and infrastructure in developed and developing countries such as the *risks of increasing morbidity and infrastructure failure* as well as *new systemic risks*. In the context of extreme weather events, risks in the transport, energy and health sector are identified that emerge due to the interdependency of the different sectors, e.g. on energy supply (see Chapter 23). The potential for power shortages and the low adaptive capacity of power supply systems adds to the risk of heat stress during extreme events. These phenomena have been observed in both developing and developed countries. In this regard high temperature extremes in combination with ongoing urbanization trends, aging populations and vulnerable infrastructure increase the potential for infrastructure failure and the risk of morbidity and mortality (see Chapter 22 and 25).

The *risk of increase in disease burden* is also a primary example of the interaction of changes in the physical climate conditions and the vulnerability of people. Recent studies (see Chapter 22) underscore that increasing temperature affects the health of exposed, vulnerable groups due to heat stress (see also section 19.3). The impact of heat stress on an aging populations, such as during the heat wave disaster in 2003 in Europe, illustrates how changing climatic conditions interact with trends in population structure to create key risks.

Globally, the widespread and systemic observed and projected impacts of climate change on biodiversity and ecosystems (see Chapter 4, sections 6.3.1, 6.3.3 and 6.3.4) comprise a key risk in terms of the global loss of provisional, regulating, supporting and cultural ecosystem services. For example, regionally, increasing temperatures in combination with vulnerable aquatic systems and vulnerable aquatic ecosystem services contribute to *a key risk due to the loss of aquatic ecosystems and the services they provide for coastal livelihoods*. Newer studies regarding the degradation of coastal reefs (WRI, 2012) underscore that the degradation levels are particularly high in countries where many people depend on these resources and are also characterized by a high exposure to coastal hazards and a high vulnerability, such as the Philippines and Indonesia.

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, there is *high confidence* both that risks vary substantially across plausible alternative development pathways and that 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. 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 (Rothman *et al.*, submitted).

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 effect of climate change on the number of people at risk from hunger generally spans a range of +/- 10-30 million across the four marker SRES scenarios, each of which assumes different socio-economic futures, but becomes as high as 120-170 million in some analyses based on a scenario (A2) with high population growth (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, Submitted), as are projected water resources in the Middle East under an A1B climate change scenario (Chenoweth et al., 2012). 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 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 measures driven by socio-economic development alone (Schmidhuber and Tubiello, 2007; Nelson *et al*., 2010). Similarly, future population growth is found to be an equally (Murray *et al*., 2012) or more (Fung *et al*., 2011; Shewe *et al*., submitted) important determinant of globally-aggregated water stress than the level of climate change, and growth in population and wealth is expected to largely drive potential future damages from tropical cyclones (Bouwer *et al*., 2007; Pielke Jr., 2007). 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*., In Press) is taken into account; and flood risks, through 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*., In Press) or when biophysical impacts such as stream discharge, rather than its consequences, were assessed (Ward *et al*., 2011).

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; MEA, 2005), and by the end of the century climate change is generally projected to be an even stronger driver of extinction than is land use change. 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 (Sekercioglu, 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). Since development often drives land use change, future development that reduces vulnerability in human systems without taking ecosystem preservation into account will often directly reduce ecosystem services, in turn impacting on human systems. Ecosystem based adaptation and development can reduce vulnerability whilst avoiding or minimising ecosystem service loss.

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, a substantial reduction in impacts can be an economically rational response for large areas of coastline globally (Nicholls *et al*., 2008a, 2008b; Anthoff *et al*., 2010; Nicholls and Cazenave, 2010) 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 was found to reduce the number of people affected by coastal flooding by a factor of 110 to 228, and total economic damages by a factor of 7 to 9 (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 substantial 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 19.6.1). 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*., 2012).

19.6.3. Updating Reasons for Concern

The Reasons for Concern (RFCs) are five categories of impacts, or characteristics of impacts, that were introduced in the IPCC TAR(Smith *et al*., 2001)in order to facilitate interpretation of Article 2 by aggregating a wide range of individual consequences of climate change into a smaller number of broad categories. 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(Schneider *et al*., 2007; Smith *et al*., 2009)RFCs are related to the framework of key risks, physical impacts, 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 physical impact (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*.

In this section we assess new literature related to each of the RFCs, concluding that, compared to judgments presented in AR4 and literature published soon afterward (Smith *et al*., 2009)levels of risk associated with extreme events, distributional impacts, and large-scale singular events are similar but can be assessed with higher confidence; risks for aggregate damages are similar but confidence in the assessment unchanged, despite the availability of additional studies; and risks to unique and threatened systems are higher above 2°C than assessed previously (see Figure 19-5). We also conclude that because risks depend not only on physical impacts of climate change but also on vulnerabilities of societies and ecosystems to those impacts, RFCs as a reflection of those risks depend on both factors as well (see also 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, RFCs took only autonomous adaptation into account(Smith *et al*., 2001)An update based on literature assessed in AR4 concluded that the RFCs reflect more steeply increasing risk with global average temperature change in each category (Smith *et al*., 2009; Schneider *et al*., 2007, AR4 WG2 Chapter 19), but this conclusion was not based on a change in the assessment of future development pathways but rather on evidence of some impacts already becoming apparent, higher likelihoods of some biophysical impacts, and improved identification of currently vulnerable populations.

However, the RFCs represent risks that are determined by both the physical impacts of climate change and the vulnerability of social and ecological systems to climate change stresses. Figure 19-6 illustrates this dependence on vulnerability in a modified version of the burning embers diagram that has been used to characterize risks associated with RFCs (Smith *et al*., 2001; Smith *et al*., 2009). Current literature is not sufficient to support confident assessment of specific RFCs using this approach; rather, we discuss for each RFC below the degree to which literature supports the general features of such a diagram shown here. In particular, for a given amount of temperature change, risk will be higher for socio-economic conditions producing higher vulnerability and exposure, and lower for futures with lower vulnerability and exposure.

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 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 illustrated in Figure 19-5) 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).

[INSERT FIGURE 19-5 HERE
Figure 19-5: The dependence of risk associated with a Reason for Concern (RFC) 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 (with white to purple indicating the lowest to highest level of risk, respectively). The levels of risk illustrated reflect the judgments of Chapter 19 authors. Purple color, introduced here for the first time, reflects the assessment that unique human and natural systems tend to have very limited adaptive capacity (Chapters 4, 24), and hence we have *high confidence* that climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C were exceeded.]

[INSERT FIGURE 19-6 HERE
Figure 19-6: Illustration of the dependence of risk associated with a Reason for Concern (RFC) on the level of climate change and vulnerability of society. This figure is schematic; the degree of risk associated with particular levels of climate change or vulnerability has not been based on a literature assessment, nor associated with a particular RFC. The vulnerability axis is relative rather than absolute: "Medium" vulnerability indicates a future development path in which vulnerability changes over time driven by moderate trends in socio-economic conditions. "Low" and "High" vulnerability indicate futures that are substantially more optimistic or pessimistic, respectively, regarding vulnerability. We assume that judgments made in other burning ember diagrams of the RFCs (Smith *et al*., 2001, 2009) including Figure 19-5, which do not explicitly take changes in vulnerability into account, are consistent with Medium future vulnerability. 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.]

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). Loss of or damage to such systems are key risks when these systems have great importance to other systems and to society, and because in some cases such loss or damage would be irreversible. AR4 stated with *high confidence* that a warming of up to 2°C above 1990-2000 levels would result in significant impacts on many unique and vulnerable systems, and would 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 new and stronger evidence to support this judgment, particularly regarding species and ecosystems, which is now cited in sections 19.6.3.4 and 19.6.3.5 relating to distributional and aggregate impacts of climate change, because the evidence now suggests that climate change impacts on ecosystems is systemic and pervasive, and affects most ecosystems worldwide, not only unique and threatened ecosystems.

Since AR4 there has been increased understanding (see Chapter 4) confirming areas where natural ecosystems are *particularly* vulnerable to climate change and extinctions are *likely* or *very likely* to occur, for example the Wet

Tropics of Queensland, Australia (a World Heritage Area), SW Australia, and the Australian alpine zone (Klausmeyer and Shaw, 2009; Hughes, 2011) where even 1°C of local warming is projected to have negative effects. High extinction risks continue to be identified for the Fynbos and succulent Karoo areas of South Africa for both plants and insects (Midgley and Thuiller, 2011; Kuhlmann *et al*., 2012; Huntley and Barnard, 2012)Recent research has identified tropical ecosystems, including both tropical wet and dry forests (Deutsch *et al*., 2009; Wright et al., 2009; Kearney *et al*., 2009, Toms *et al*., 2012) and tropical island endemics (Fordham and Brook, 2010) as particularly vulnerable. A study estimated that 600-900 tropical bird species could be committed to extinction if GMT rises by 3.5°C by 2100, mostly in Central America, tropical parts of Mexico and the Andes, and the Brazilian Atlantic forest(Şekercioğlu *et al*., 2012). For these birds, and for unique ecosystems (e.g. biodiversity hotspots) more generally, extinctions are projected to rapidly increase once global temperatures exceed 2°C above pre-industrial levels(Warren *et al*., 2011; Şekercioğlu *et al*., 2012). Since IPCC AR4, there is increasing evidence of the climate risks to polar and mountain regions, including now the Himalayas (Colwell *et al*., 2008; Shrestha and Aryal, 2011) and to Mediterranean systems(Klausmeyer and Shaw, 2009; Maiorano *et al*., 2011). Amongst vertebrates, amphibians are still considered the most vulnerable taxon (IPCC AR4, Warren *et al*., in press.). Coral reef ecosystems are still considered amongst the most vulnerable of unique systems (see section 5.4.1.6), with corals' evolutionary responses to changing conditions being outpaced by climate change (Hoegh-Guldberg, 2012) resulting in projections of extensive reef decline throughout the 21st century, and reef dissolution projected to begin if CO_2 concentrations reach 560 ppm (see section 5.4.1.6). Mangroves continue to be considered particularly at risk, and the combined effect of damage to corals and mangrove threatens unique human communities (see sections 4.3.3, 22.3.3.1).

Regarding physical systems, there is a *high confidence* that an increase in annual mean global surface temperature greater than 2°C above present will eventually lead to a nearly ice-free Arctic Ocean in late summer, and a seasonally ice-free Arctic Ocean within the next 50 years is a very distinct possibility (AR5 WGI Chapter 12; section 19.6.3.6). CMIP5 projections of Arctic sea ice melt project faster loss, more consistent with observations than did the CMIP3 projections used in AR4 (AR5 WGI Chapter 12). Since Arctic sea ice is of critical importance to local peoples and Arctic ecosystems, hence there is a greater threat to the hunting and food sharing culture of the Inuit population and the ecosystems upon which they depend (Crowley, 2011) than was envisaged in AR4.

Similarly, owing to higher projections of sea level rise than in AR4 (AR5 SOD Ch.13), small island states are at greater risk of inundation than previously thought, and a global temperature rise in excess of 1.5°C would fail to protect many islands from inundation (section 24.9.2).

There is new evidence about the risks to human and ecological systems dependent on glacial meltwater. Rapid deglaciation is already occurring (see section 18.5.3). Significant loss of glacial cover in central Asia is possible by the end of the century under the higher climate change scenarios considered by IPCC AR4 (see section 24.9.3). Loss of glacial cover will affect water supplies in arid regions where meltwater contributes significantly to water supplies (Kassel, 2010). Thus projections of glacier melt by mid-century and its hydrological consequences, using an A1B SRES scenario, found projected reductions in meltwater flow from Himalayan glaciers which, if realized, would threaten the food security of 60 million people in the Brahmaputra and Indus basins (Immerzeel *et al*., 2010) Such threats to water security in parts of Asia(Chakraborty and Newton, 2011; Shrestha *et al*., 2012) and similar conditions in the foothills of the Andes have implications for tourism, hydropower and agriculture (Chevallier *et al*., 2011).

This assessment is summarized in the left hand bar in Figure 19-5. Similar to findings of AR4 and Smith *et al*. (2009) but with increased confidence, current literature supports a "yellow" level of risk (moderate risk to some species and systems at recent temperatures), since there are already widespread observed impacts of climate change on unique and threatened systems. A transition to red is located at 1°C, indicating the increasing risk to small islands, coral reefs, the Arctic and unique natural ecosystems as temperature increases. A transition to purple is located around 2°C, to reflect the projected escalating risks referred to above. Unique human and natural systems tend to have very limited adaptive capacity (Chapters 4, 24), and hence we have *high confidence* that climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C were exceeded.

19.6.3.3. Extreme Events

Extreme weather events (e.g., heat waves, intense precipitation, tropical cyclones) trigger impacts that can pose key risks to societies that are exposed and vulnerable. SREX (IPCC, 2012) and the WGI AR5 provide comprehensive assessments indicating overall small changes compared to AR4 in the projected frequency of occurrence, duration, intensity, and extent of extreme events (IPCC, 2012 Chapter 3; AR5 WGI SOD). SREX also clarifies the factors which contribute to vulnerability, and assesses approaches to addressing the latter. The WGI AR5 SOD assesses the physical hazard aspect of risk, stating that, "There has been a strengthening of the evidence for human influence on temperature extremes since AR4 and it is now judged *very likely* that human influence has contributed to the observed changes in temperature extremes since the mid-20th century."(WGI SOD p.10-3). The likelihood of projected 21st century changes in extremes has not changed markedly since AR4 (WGI SOD, Chapters 10,12), but for the first time near term changes (through 2035) are assessed. Among the conclusions are, "It is *very likely* that in the next decades the frequency of warm days and warm nights will increase, while the frequency of cold days and cold nights will decrease at the global scale."(AR5 WGI SOD 11-6) For instance, increases of ~30% occur in the rate of exceedence of daily maximum temperatures above the historical 90th percentile by 2040 (WGI SOD fig. 11-22). WGI also states with respect to temperature extremes that, "This trend will *likely* be visible in an increasing number of regions in the near term" and with regard to precipitation extremes that "in the near term, it is *likely* that the frequency and intensity of heavy precipitation events will increase at the global scale." (WGI SOD, p.11-6). In addition, SREX (Figure SPM 4B) projects a reduction in return period for historical once-in-20-yr precipitation events by about 1/3 by 2046-65. Based on these assessments of the physical hazard alone, we find increased confidence in the AR4 assessment of the risk from extreme events. We also 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).

SREX also reviewed literature on the relationship of risk of extreme events to changes in vulnerability and exposure (SREX sections 4.5.4, 4.5.6). For example, growth of megacities both concentrates vulnerability and generates "synchronous failure" which spreads beyond the immediate vicinity of extreme events. Thus 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). Similarly, megacities increase nighttime temperature extremes via the urban heat island effect (SREX section 4.4.5.2) while also enhancing exposure to high air pollution levels (SREX section 9.2.1.2.3). Taken together, evidence supports a worsening of air pollution risk under RCP scenarios in Asian megacities over the next few decades (WGI SOD section 11.3.5.2). This evidence supports a conclusion of disproportionate increase in risk as exposure and vulnerability increase.

Based largely on evidence discussed in AR4, Smith *et al*., (2009) assessed the risk of extreme weather events to increase already at recent temperature and to become large with less than 1°C warming above 1990 temperature, as supported by more recent literature (WGI SOD fig 11-22), which indicates an increase in currently observed 90th-percentile daily maximum temperature exceedences of more than 15% above historical values. Higher confidence expressed in AR5 on attribution of some types of extreme events to human activity, along with the assessment of increased likelihood of temperature and precipitation extremes over the next few decades when GMT (and local temperature) increases are projected to generally remain below 1°C, result in increased confidence in assigning a "yellow" level of risk at recent temperatures in Figure 19-5 and a transition to red beginning below 1°C, consistent with Smith *et al*., (2009). While the additional effect of changes in vulnerability and exposure has not been quantified, based on evidence reviewed in SREX, we judge that modest increases in the social elements of risk would support increasing the level of risk indicated in Figure 19-5 near recent temperatures. The same logic leads us to conclude that decreases in vulnerability and exposure would raise the red-to-yellow transition to higher temperatures.

19.6.3.4. Distribution of Impacts

The potential 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 vulnerability and of physical climate impacts. 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 (Schneider *et al*., 2007). These conclusions remain valid and are now supported by more impact studies that explicitly consider differences in socio-economic conditions across regions or populations that affect vulnerability across regions or populations.

Economic (including insured) disaster losses associated with weather, climate, and geophysical events are higher in developed countries, while fatality rates and economic losses expressed as a proportion of GDP are higher in developing countries (SREX-SPM), a finding that emphasizes the importance of exposure to risk to human systems.

For levels of global temperature rise between 1.5 and 4°C over preindustrial levels, agricultural yields may increase in some regions and decrease in others in ways that may be difficult to compensate for through international trade (Battisti and Naylor, 2009; Penny *et al*., 2010). Areas where there is a significant risk of a decline in regional food security for a global warming of 1.5-2°C(Hare *et al*., 2011) include those surrounding the Namib (Brauch, 2006); the southern half of Russia (Dronin and Kirilenko, 2011); North Africa (Mougou *et al*., 2011, Iglesias *et al*., 2011); the West African Sahel (Ben Mohamed, 2011; Sissoko, 2011), sub-Saharan Africa (Müller *et al*., 2011), South Asia (Lal, 2011), and Bangladesh (Mirza, 2011). Crop yields are expected to decline in Australia (Risbey, 2011; Steffen *et al*., 2011). There are also emerging risks to agriculture generally due to flooding, and of pests and tropospheric ozone (Reilly *et al*., 2007; Avnery *et al*., 2011; Lal, 2011; Sutherst *et al*., 2011; sections 7.3.2.1.2, 7.3.2.2). Whilst particular regions may be more prone to coastal flooding or tropospheric ozone damage, pests and disease may unpredictably affect any region at any time.

The first global scale analysis of climate change's impacts on almost 50,000 species of plants and animals has highlighted that species which are widespread geographically are also at risk (Warren *et al*., in press), not only endemics, which have tended to be the focus of many previous studies, implying a significant and widespread loss of ecosystem services(Gaston and Fuller, 2008; Allesina *et al*., 2009), comprising a new emergent risk (Table 19-3, Entry 2, Chapter 19).

Since AR4, new evidence has emerged highlighting the magnitude of risk of impacts in particular regions, for example in relation to the potential for regional impacts upon ecosystems (see 19.6.3.2), megadeltas, and agricultural systems, which is exacerbated by the potential for changes in the monsoon systems (see 19.6.3.5; WG I SOD 12.5.5.). Hence, 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 it has been found that developed countries have less resilience to, for example, recently experienced extreme weather events than previously thought, creating more localised issues of differential vulnerability in particular areas of the developed world. For this reason, and since climate change impacts are already beginning to emerge in observations (see Chapter 2), the transition from white to yellow levels of risk in Figure 19-5 is now assessed to occur at recent temperatures, and the transition from red to yellow is between 1 and 2°C, both as indicated in Smith *et al*., (2009).

19.6.3.5. Aggregate Impacts

The RFC pertaining to aggregate impacts includes risks to society or ecosystems that are aggregated globally into a single metric, such as monetary damages, lives affected, or lives lost, although most aggregations in the literature are carried out in monetary terms. 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.

For example, impacts on the health sector have not previously included the direct effects of heat and humidity on productivity. New studies indicate that there is *high confidence* that these effects will have a negative impact on global economic output and human welfare (see 10.9.2.1). Heat- and humidity-related declines in available workdays of up to 19% by the middle of the century have been projected in some regions (Kjellstrom et al., 2009; SRES A2 scenario). When considering effects of disease as well, labor productivity losses are projected to lead to a global output loss of ~1.8% with ~3°C of global average warming above pre-Industrial levels and ~4.6% with ~6°C of warming (Roson and Mensbrugghe, 2012).

AR4 stated with medium confidence that approximately 20-30% of the plant and animal species assessed to date are at increasing risk of extinction as global mean temperatures exceed a warming of 2-3°C above pre-industrial levels (Fischlin *et al.*, 2007). Since AR4 the literature has expanded in many ways with respect to climate change impacts on biodiversity. Firstly, new literature has added to the evidence of increased extinction risk, for example to species in unique and threatened systems (see 19.6.3.2) and in tropical, polar and mountain ecosystems (see 19.6.3.2). Secondly there are many more detailed studies quantifying extinction risks, of which several include also studies on possible adaptive measures to support conservation (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; Ledit *et al.*, 2012; Norberg *et al.*, 2012; Bellard *et al.*, 2012). More studies have scrutinized previously known caveats and tried to asses their role in either under- or overestimating notably 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 stressed the relevance of past climate change insights for this issue (e.g. Barnosky *et al.*, 2012) with varying success (e.g. Botkin *et al.*, 2009; Willis and Bhagwat, 2009; Willis *et al.*, 2010). Overall, the AR4 statement relating to extinction risk still stands.

There is increased evidence of observed climate change impacts (including those arising from changes in climate variability) on ecosystems, including range loss in plants and animals and changes in phenology(Gange *et al.*, 2007; Foden *et al.*, 2007; Pudas *et al.*, 2008; Devictor *et al.*, 2008; Kusano and Inoue, 2008; Beckage *et al.*, 2008; Thibault and Brown, 2008; Kelly and Goulden, 2008; Moreno-Rueda *et al.*, 2009; Furgal and Prowse, 2009), and on ecosystem composition and function (Blaum *et al.*, 2007; le Roux and McGeoch, 2008; Vittoz *et al.*, 2009; de Sassi and Tylianakis, 2012; Table 19-3, Entry 2, Chapter 19). Much new work has focused on 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). All this evidence accrues to a projection of more severe aggregate impacts of climate change on ecosystems and their services globally than in AR4.

New work has demonstrated that the expected large turnovers of up to 60% in marine species assemblages in response to unmitigated (SRES A1B) climate change by the 2050s, combined with shrinkage of fish body weight of 14–24% (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).

Assessments of risks to coastal populations due to sea level rise have advanced through the application of more geographically detailed coastal databases in models that include adaptation options (Hinkel and Klein, 2009). One global study found that without investment in coastal protection, under the SRES A1B population scenario 50 cm of globally uniform sea level rise would displace about 72 million people by 2100, while 2 m of globally uniform sea level rise would displace about 187 million people. The incremental annual costs of protection are estimated at $25 billion/year and $270 billion/year [in 1995 USD], respectively (Nicholls et al., 2011; A1B scenario). Similarly, an assessment of risks from tropical cyclones projected a doubling of cyclone damages globally due to climate change alone, (0.01% of global GDP), and a further doubling due to expected increases in GDP and related exposure, on top of present day baseline damages of $26 billion/yr (Mendelsohn et al., 2012; A1B scenario).

Assessments of economy-wide consequences of climate change report results either as total damages or as marginal damages, the latter represented by the social cost of carbon (SCC). Estimates of global aggregate impacts from integrated assessment models (Figure 19-7) exhibit *a low level of agreement* (Ackerman et al., 2011; Anthoff and Tol, 2010b; Bosello et al., 2012; Hope, 2013a, 2013b; Nordhaus, 2008, 2010; Roson and Mensbrugghe, 2012; Waldhoff et al., 2013). Sectoral breakdowns also exhibit *a low level of agreement* (Figure 19-8) (Anthoff and Tol, 2010b; Anthoff et al., 2013; Nordhaus, 2007, 2008; Roson and Mensbrugghe, 2012). There is *very high confidence* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. For this reason, as well as the existence of only a few studies with sectoral detail that employ alternative development pathways, it is difficult to detect a monotonic relationship between vulnerability and aggregate risks at the global scale. In some locations and amongst some groups of people with high exposure and high vulnerability, net costs per capita will be significantly larger than the global average (Anthoff *et al*., 2009; Nordhaus, 2011; Warren, 2011).

[INSERT FIGURE 19-7 HERE
Figure 19-7: Representative global damage estimates, shown as a percentage loss of global output as a function of temperature, from integrated assessment models employing their own reference scenarios. PAGE 2009: (Hope, 2013a, 2013b). FUND 3.8: (Anthoff and Tol, 2010b; Anthoff *et al*., 2013; Waldhoff *et al*., 2013). RICE 2010: (Nordhaus, 2010). CRED: (Ackerman et al., 2011). ENVISAGE: (Roson and Mensbrugghe, 2012). GECON: (Nordhaus, 2006). ICES: (Bosello *et al*., 2012a). For PAGE 2009 and FUND 3.8, the shaded region indicates the range spanned by the 5th and 95th percentile of outputs in Monte Carlo mode. For CRED 1.3, the shaded region indicates the range spanned by four alternative damage functions. In CRED at 6°C, mean damages are 32% of GDP and the largest of the four damage functions yields 50% loss of GDP.]

[INSERT FIGURE 19-8 HERE
Figure 19-8: Breakdown of damages at 2.5°C above pre-industrial by sector in the DICE 2007 calibration (Nordhaus, 2007; Nordhaus, 2008), FUND 3.8 (Anthoff and Tol, 2010b; Anthoff *et al*., 2013; Waldhoff *et al*., 2013) modal damages and ENVISAGE (Roson and Mensbrugghe, 2012), reflecting a *low level of agreement* among the integrated assessment models used to estimate global aggregate damages. Note that the DICE calibration does not include damages due to changes in water resources as distinct from temperature impacts on agriculture and forestry, and FUND and ENVISAGE do not include expected catastrophic damages. Representations of changes in energy demand, coastal/sea level impacts, health and labor productivity impacts, and impacts on settlements, ecosystem and tourism are included in all three models. Grey lines span the 5th to 95th percentile of estimates from FUND. The 95th percentile of energy sector damages in FUND is 2.2% of GDP.]

Uncertainty in estimates of global aggregate impacts is further increased because most IAMs exclude a number of potentially significant factors(Yohe, 2008; Füssel, 2010; Kopp *et al*., 2012), including the consequences of earth system tipping points (Kopp and Mignone, 2012; Lenton and Ciscar, 2013), intersectoral and interregional interactions (see section 19.3) (Bosello *et al*., 2012; Warren, 2011), and imperfectly substitutable environmental goods, which reflect the fact that impacts on (for example) ecosystems cannot be replaced 1-for-1 by an increased consumption of material goods (Kopp *et al*., 2012; Sterner and Persson, 2008; Weitzman, 2010). Additionally, studies lack evidence for extrapolating damages from temperature increases at which impact studies have been carried out to higher temperatures (Ackerman and Stanton, 2012; Ackerman *et al*., 2010; Kopp *et al*., 2012; Weitzman, 2010). There is *high confidence* that the exclusion of these factors together lead to an underestimate of global aggregate impacts. In addition, adaptation is treated differently across modeling studies (Bosello *et al*., 2010; de Bruin *et al*., 2009; Füssel, 2010; Hope, 2006; Patt *et al*., 2010) and affects aggregate damage estimates in ambiguous ways.

Alternative measures of global aggregate damages have been proposed based upon historical and geographic relationships between temperature and economic growth. *Limited evidence* suggests that higher temperatures decrease economic growth rates in low-income countries by ~1.3%-2.5%/year per 1°C (Dell et al., 2009, 2012; Hsiang, 2010) (see 10.9.2.1 and 18.4.2.1). Consistent with studies on the relationship between temperature and labor productivity, higher temperatures appear to reduce both agricultural and industrial output in low-income countries; they also appear to increase political instability, which will also contribute to decreased economic growth (Dell *et al*., 2012). Modest changes in economic growth rate can accumulate to large changes in output over time, although the studies conducted to date do not address the possibility of long-term adaptation.

The social cost of carbon (SCC) is an alternative index of aggregate damages that monetizes the expected welfare impacts of a marginal increase in carbon dioxide emissions in a given year (i.e., the welfare loss associated with an additional tonne of CO_2 emitted), aggregated across space, time, and probability (e.g., Newbold *et al*., 2010;

Nordhaus, 2011a; Tol, 2011; Kopp and Mignone, 2012). As of AR4, a survey of 103 estimates of the SCC from 28 published studies found a mean of \$25/tonne CO_2 and a 95th percentile value of \$95/tonne CO_2 (Tol, 2005). Numerical estimates of the SCC published since AR4 continue to span a large range. Peer-reviewed estimates (as compiled by Tol, 2011, 2013, with the addition of estimates from Kopp *et al.* 2012) range from -\$2 to \$1000/tonne CO_2, with most estimates between \$4 and \$50/tonne CO_2 (in inflation-adjusted 2010 dollars, for CO_2 emissions occuring in the first fifteen years of the twenty-first century) (Ackerman and Munitz, 2012; Ackerman and Stanton, 2012; Anthoff and Tol, 2010a; Anthoff *et al.*, 2009a, 2009b, 2009c; Cai et al., 2012; Hope, 2008a, 2013b, 2008b; Kopp et al., 2012; Marten and Newbold, 2012; Narita *et al.*, 2009, 2010; Newbold *et al.*, 2010; Nordhaus, 2008, 2010; Stern and Taylor, 2007; Tol, 2011, 2012, 2013).

Uncertainty in SCC estimates is high due to the uncertainty in underlying total damage estimates, under-representation of uncertainty in socio-economic scenarios, under-representation in some models of uncertainty in climate/carbon cycle, fidelity issues regarding the reduced-form climate/carbon cycle models used in the principal IAMs (Hof *et al.*, 2011; Marten, 2011; van Vuuren et al., 2011; Warren *et al.*, 2010), and low level of agreement regarding the appropriate framework for aggregating impacts over time (discounting), regions (equity weighing), and states of the world (risk aversion). Quantitative analyses have shown that SCC estimates can vary by at least ~2x depending on assumptions about future demographic conditions (Interagency Working Group on the Social Cost of Carbon, United States Government, 2010), at least ~3x due to the incorporation of uncertainty (Kopp *et al.*, 2012, p.2012), and at least ~4x due to differences in discounting (Tol, 2011) or alternative damage functions (Ackerman and Stanton, 2012). A further source of uncertainty is whether and how the possibility of catastrophic damages is accounted for (Dietz, 2010; Nordhaus, 2011b; Weitzman, 2009), which requires bounding potential losses with a parameter akin to the value of a statistical life (representing, essentially, willingness to pay to avoid human extinction) (Dietz, 2010; Kopp *et al.*, 2012, p.2012). Without such a parameter, SCC estimates incorporating risk aversion and potential catastrophic impacts can be unboundedly high.

Thus the risk for aggregate damages is similar to that expressed in AR4 and Smith *et al.*, (2009) as indicated in Figure 19-5, with confidence in the assessment unchanged.

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") 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). 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 the limited ability of society to cope with them.

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). Recent studies are consistent with these judgments but provide a more nuanced view (see WGI SOD Chapter. 13). At the current time, the Greenland ice sheet is making about twice the contribution to sea level rise as the Antarctic ice sheet (Shepherd *et al.*, 2013). Recent studies (Kopp *et al.* 2009; McKay *et al.*, 2011; Dutton and Lambeck 2012) suggest a comparable contribution from the two ice sheets during the Last Interglacial, which provides a partial analog for 21st century warming. One study (Robinson *et al.*, 2012) lowered the threshold for near-complete melting of the Greenland ice sheet to 0.8-3.2°C above preindustrial temperatures from 1.9-5.1°C global warming in AR4. Expert elicitations (Kriegler *et al.*, 2009) and other approaches (Good *et al.*, 2011) have led to assessments that a complete melting of Greenland is *unlikely* below 2°C and *likely* above 4°C compared to recent temperatures. The question of whether the melting of Greenland is irreversible, once a significant fraction of ice has been lost remains contested(Lunt *et al.*, 2004; Ridley *et al.*, 2010; Robinson *et al.*, 2012). AR5 notes that a significant decay of the ice sheet may be irreversible (AR5 WGI SOD SPM-17). A threshold for the disintegration of WAIS remains difficult to identify due to shortcomings in modeling the dynamical component of ice loss. 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).

There is also additional evidence regarding singular events in other physical systems. Feedback processes in the Earth system cause accelerated emissions of methane from wetlands, terrestrial permafrost and ocean hydrates but temperature sensitivity of these processes is not known and progress in determining this has been slow. However, the risk of a substantial carbon release from these processes increases with warming. Model results indicate additional cumulative methane emissions due to these sources potentially becoming comparable to cumulative direct anthropogenic emissions on a century timescale but no sudden, large release short of millennial timescales (AR5 WGI SOD 6.4, Figure 6.37; O'Connor *et al*., 2010, Archer *et al*., 2009, Zhang *et al*., 2009).

AR4 stated that Arctic summer sea ice disappears almost entirely in some projections by the end of the century (AR4 WGI 10.3); AR5 finds there is also a *high confidence* that an increase in annual mean global surface temperature greater than 2°C above present will eventually lead to a nearly ice-free Arctic Ocean in late summer. A seasonally ice-free Arctic Ocean within the next 50 years is a very distinct possibility, even though later dates cannot be excluded (AR5 WGI 12-5). 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 circulation. 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(Kriegler *et al*., 2009). AR5 assesses a collapse of the AMOC during this century as *very unlikely*, and *unlikely* that a collapse would occur in succeeding centuries under scenarios considered (AR5WGI SOD SPM-15).

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 forest to grassland as the dominant ecosystem (Jones *et al*., 2009; Lapola *et al*., 2009; Malhi *et al*., 2009). 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 role of CO_2 fertilisation being as strong as models project.

Risks to biological systems include species extinction (see 19.6.3.2), and regime shifts, which are sometimes classified as large-scale singular events. Such tipping points will occur in different ecosystems with different levels of warming (Warren *et al*., 2010). Although there is still uncertainty over when such points might be crossed, a significant increase in extinction rates is considered *likely* for GMT rise of more than 2°C above pre-industrial levels.

Based on the weight of the above evidence, we judge that the risk from large-scale singular events remains comparable to that assessed in AR4, as indicated by Smith *et al*. (2009) and Figure 19-5.

19.7. Assessment of Response Strategies to Manage Risks

The management of key and emerging risks of climate change can include mitigation that reduces the likelihood of climate changes and physical impacts and adaptation that reduces the 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 nature of Reasons for Concern (19.6). This section therefore assesses relationships between mitigation, adaptation, and the residual impacts that generate key and emerging 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 (19.6.3.6) are particularly important elements of key risks, and the section therefore assesses response strategies aimed at avoiding or adapting to them.

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

Evaluating the potential mixes of mitigation, adaptation, and impacts is made complicated by the fact that it requires joint consideration of alternative outcomes for both climate change and socio-economic development. Such an approach is further complicated because socio-economic development pathways will influence future emissions, land use change, and therefore climate change (WGIII, Chapter 5), and in turn climate change will influence development pathways through feedbacks on social and economic systems, including policy responses (AR5 WGII Chapter 2, Chapter 20).

One perspective on these relationships is provided by studies of the benefits of mitigation, i.e., the impacts avoided by mitigation, which sometimes also account for adaptation. Avoided impacts vary significantly across regions due to (a) differing levels of regional (as opposed to global) climate change, (b) differing numbers of people and levels of resources at risk in different regions (e.g. presence of unique ecosystems or the size of the human population exposed to impacts), and (c) differing sensitivities and adaptive capacities of humans, species or ecosystems in different regions. Similarly, residual impacts will differ between sectors due to (a) different levels of sensitivity and (b) differing levels of adaptive capacity. They will also differ over time depending on which aspect of the physical climate system is driving them. Benefits accrue most rapidly for impacts associated with ocean acidification, less rapidly for those associated with change in temperature and/or precipitation, and least rapidly for impacts associated with sea level rise such as coastal flooding, loss of mangroves and coastal wetlands (AR5 WGI SOD Figure 6.41). Sea level rise responds very slowly to mitigation efforts so that mitigation can reduce the rate of sea level rise but under most emissions scenarios, cannot halt it altogether (Meehl *et al*., 2012). Global temperature can be stabilized as a result of mitigation efforts, but even if anthropogenic CO_2 emissions were reduced to zero, global average temperature would not decline significantly from its peak over a century timescale (Matthews and Caldeira, 2008; Solomon *et al*., 2010). Ocean acidification responds more quickly to changes in emissions of CO_2 than does global temperature, with the rise in pH ceasing several decades after stringent emission reductions begin (Bernie *et al*., 2010).

Figure 19-9 gives an example of sectoral variation within three global analyses of the avoided impacts of climate change resulting from efforts to implement stringent mitigation (Arnell *et al*., 2013; Warren *et al*., in press; Warren *et al*., submitted). The figure shows the impacts avoided by reducing greenhouse gas emissions from either SRES A1B or SRES A1FI scenario, to one in which global greenhouse gas emissions peak in 2016 and are reduced thereafter at 5% annually, constraining global mean temperature rise to 2ºC above pre-industrial levels. In all three studies, global temperatures are simulated to reach between 4º and 5.6ºC above pre-industrial by 2100, consistent with WGI AR4, whilst under the pathways peaking in 2016 it reaches just above 2ºC. Global average sea level rises by 47-55cm by 2100 in the scenarios with no mitigation, with the increase reduced to 30 cm by the most aggressive mitigation pathway. Overall, the impacts avoided increase over time and by the end of the century range from 20-70% below SRES A1B base case impacts, or 30-80% below SRES A1FI base case impacts, across sectors (Figure 19-9). Specifically Arnell (2013) identified large benefits for crop productivity, exposure to coastal and fluvial flooding, and energy use for cooling, where impacts avoided relative to an A1FI baseline ranged from 60 to 80% by 2100 (Figure 19-9), whilst avoided impacts were smaller for water availability (20%). Similarly Warren *et al*. (2012) found that 60% of the impacts on biodiversity, in terms of projected loss in species range in 2100, can be avoided if warming can be limited to 2 degrees above pre-industrial levels (Figure 19-9). The proportion of impacts avoided *at the global scale* was relatively robust for most indicators across different climate model patterns, but the absolute magnitude of avoided impacts varied considerably.

[INSERT FIGURE 19-9 HERE
Figure 19-9: Climate change impacts avoided by a mitigation scenario compared to two no-mitigation cases (SRES A1B and A1FI scenarios), showing the uncertainty due to regional climate change impacts projection with 7 GCMs. 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*., in press, Warren *et al*., submitted.]

All three studies (Arnell *et al*. 2013; Warren *et al*., in press; Warren *et al*., submitted), which considered emission reduction rates of between 2 and 5% annually, showed that fewer impacts can be avoided when global emissions do not peak until 2030, even if emissions are reduced at 5% thereafter, than if emissions peak in 2016 and are reduced at 2% annually thereafter. A complementary economic analysis with the PAGE integrated assessment model showed that if global emissions peak in 2016, around one half of the economic impacts that would otherwise accrue by 2100 can be avoided, but if mitigation is delayed so that emissions peak in 2030, only around a third of the impacts can be avoided regardless of whether equity weightings are used in the economic model (Warren *et al*., submitted).

The above finding of the importance of an early peaking date for global emissions in avoiding climate change impacts, is consistent with an underlying independent finding that the later global emissions peak, the faster emissions must subsequently be reduced to obtain the same probability of meeting a given constraint on global temperature rise (Kalbekken and Rive, 2007; Vaughan *et al*., 2009; Huntingford *et al*., 2012). Example findings from these three studies are that (i) a 20 year delay in reducing emissions leads to a requirement of a 5-11 times greater emissions reduction to stay below identical levels of warming (ii) delaying the peaking date of global emissions from 2015 to 2025 leads to a requirement of more than doubling the post-peak emission reduction rate to maintain a 50% probability of constraining global temperature rise to 2°C above pre-industrial levels. The common finding of a tradeoff between emission reduction rate and the date at which global emission peak reflects the relatively fixed relationship between total cumulative CO_2 emissions and peak temperature change (WG1, Chapter 12).

Other studies have also quantified the benefits of mitigation. Taking the socioeconomic trends in the A2 scenario and exploring futures with and without climate change policy shows that mitigation can reduce by 80-95% the people additionally at risk of hunger in 2080 in the SRES A2 scenario (mostly in Africa), corresponding to a global saving of an estimated 23-34 billion US$ in terms of agricultural output (Tubiello and Fischer, 2007). Benefits varied regionally and were negative in some cases, for example in developed countries due to a positive, though uncertain, effect of CO_2 fertilisation. Similarly, mitigation was found to reduce overall potential welfare losses in the EU from 0.4-1% to 0.2-0.3%(Ciscar *et al*., 2011) with losses in the agricultural sector changing to gains, and the numbers of additional people affected by fluvial flooding decreasing from 318-396,000 annually to 251-276,000 annually. Fung *et al*. (2011) and Arnell *et al*. (2009) both found that projected climate change induced increases in water stress globally for a global temperature rise of 4°C above pre-industrial levels would be halved were global temperature rise to be constrained to 2°C.

Overall this suggests that early, stringent mitigation can avoid a large proportion of the impacts of climate change that would otherwise occur during the second half of the 21st century, irrespective of whether impacts are measured in physical or economic terms. Studies showed that because mitigation reduces the rate of temperature increase, stringent mitigation could increase by 3 to 4 decades the time available for adaptation to a particular level of global temperature rise and thus impacts (Arnell *et al*. 2013, Warren *et al*., in press). A limitation of all these studies, is the uneven treatment of adaptation, which has been explored thoroughly in the context of sea level rise (Nicholls *et al*., 2011) but less well in other contexts.

Mitigation scenarios in category 1 tend to constrain global temperature rise to between A and B degrees C above pre-industrial, significantly reducing the likelihood of occurrence of the following climate change impacts (list tbc) and the breaching of the following tipping points in the earth system (list tbc). Scenarios in category 2 on the other hand constrain global temperature rise to between C and D, also reducing these outcomes, but to a less significant extent. Scenarios in categories 4 to 6 are projected to result in temperature rise of above 4°C and would allow significant risks to persist in all the key areas listed in Table 19-3. Scenarios in category 3 produce modest reductions in the risks (Figure 19-10).

[INSERT FIGURE 19-10 HERE
Figure 19-10 (forthcoming): relates the categories of mitigation scenario considered in AR5 WGIII, to global temperature outcomes (consistent with the WGI calculations; data taken from Chapter 6 - WGIII). It also relates these temperature outcomes to some salient projected climate change impacts for the different levels of global temperature rise, focusing on those impacts which are less affected by the socioeconomic development pathway.]

19.7.2. Limits to Mitigation

Mitigation possibilities 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). Such scenarios lead to pathways in which global emissions peak within the next 1-2 decades and decline to 50-80% below 1990 levels by 2050, and in some cases exhibit negative emissions before the end of the century. In contrast, no 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 (UNEP, 2010; Ranger et al., 2012). The highest emission reduction rates 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 (den Elzen et al. 2010), whilst other studies highlight that for an additional cost higher rates may be achievable (Climate Change Committee, 2008, 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 energy, carbon capture and storage, and large-scale biomass energy. 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 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 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). Costs may also become unacceptably high; for example, if low carbon power plants and other infrastructure were limited to new installations (as opposed to replacement of existing stock), the maximum emissions reduction rate would be limited to about 3%/yr (Davis *et al*., 2010). Similarly, if the political will to implement coordinated mitigation policies within or across a large number of countries is limited, peak emissions and subsequent reductions would be delayed (Webster, 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 (van Vuuren and Stehfest, 2009; 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; WGI Chapters 6, 7).

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

Section 19.6.3 highlighted the reasons for concern related to non-linear changes in the Earth system, whereby anthropogenic forcings might cause irreversible and potentially rapid transitions. The risk of triggering these transitions generally increases with increasing anthropogenic climate forcings / climate change (Lenton *et al*., 2008; Kriegler *et al*., 2009; Levermann *et al*., 2011). Reducing greenhouse gas emissions is projected to reduce the risks of triggering such transitions. Adaptation (see 19.7.2.2) could reduce their potential consequences, but the efficacy of adaptation might be limited, for example for rapid transitions.

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*., 2008; Kriegler *et al*., 2009; Lenton *et al*., 2008). 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). A risk assessment based on expert elicitation (Lenton *et al*., 2008) finds that limiting global mean temperature increase to approximately 3°C above present values would considerably reduce the risks of triggering examples of potential climate threshold responses such as an Amazon rainforest dieback, a melting of the West Antarctic ice sheet (WAIS), a collapse of the thermohaline circulation / Atlantic meridional overturning circulation (THC/AMOC; see also 19.6.3.6), and disruptions of the Sahara/Sahel and West African monsoon and the El Niño-Southern Oscillation systems. Staying below this 3°C temperature limit does not entirely eliminate the risks of triggering these events (Hansen *et al*., 2008; Kriegler *et al*., 2009; Levermann *et al*., 2012; Zickfeld *et al*., 2010). In addition, this 3 ºC limit could still result in considerable risks of triggering threshold responses such as a disintegration of the Greenland Ice Sheet or a melting of the Arctic summer sea-ice (See 19.6.3.6; Lenton *et al*., 2008; Levermann *et al*., 2012). Past anthropogenic climate forcings may have already triggered some climate threshold responses (Lenton et al., 2008; Urban and Keller, 2010). In particular, evidence from the Last Interglacial suggests that 2°C may be a more appropriate indicator of high risk for a WAIS disintegration (Kopp *et al*., 2009; McKay *et al.,* 2011), a temperature limit that may be difficult to achieve with high probability (see section 19.7.2.1). 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, 1995). 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 (Lenton, 2011a; McAlpine *et al*., 2010; Steffen *et al*., 2011).

Several analyses have performed risk- and decision-analyses for specific thresholds, mostly focusing on a persistent weakening or collapse of the THC/MOC (Bahn *et al*., 2011; McInerney *et al*., 2012; Urban and Keller, 2010; Zickfeld and Bruckner, 2008). Experiencing a THC/MOC collapse has been assessed as *very unlikely* in this century and *unlikely* in subsequent centuries under scenarios considered in AR5 (AR5 WGI SOD SPM-15). However, due to the long response time of the THC/MOC, the probability of triggering an eventual collapse within a certain time period can be substantially higher than the probability of experiencing it (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 risk-management strategies are sensitive to factors such as the representation of the uncertainties and the decision-making frameworks (McInerney *et al*., 2012; Polasky *et al*., 2011). Other 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 *low confidence* in the feasibility and requirements for such systems due to the limited 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. They pose a particularly important risk because they can be initiated rapidly without warning, inducing a need for rapid response from human systems. 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 the social/economic networks are disrupted (Renaud *et al*., 2010). Climate change provides a stress on these services and networks that increases the potential for tipping points to 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 in a number of locations (Pimm, 2009).

The crossing of tipping points due to climate change can be avoided by preserving ecosystem services through (i) limiting the level of climate change and/or (ii) removing concomitant stresses such as overgrazing, fishing, habitat destruction, and pollution. Most of the literature currently focuses on strategy (ii), and there is limited information about the exact levels of climate change that specific coupled socio-economic systems can withstand. Examples of strategy (ii) include maintaining the resilience of coral reefs or pelagic cephalopod populations by the removal of stress from fishing (Andre *et al.,* 2010; Anthony *et al.,* 2011; section 6.3.5.1, section 30.6.3.1) or expanding protected area networks in the tropics (Brodie *et al.,* 2012). Similarly, risks to seabird populations due to climate change impacts on fish (prey) populations could be lessened by reducing concomitant fishing stress (Cury *et al*., 2011). In some cases, it is possible to use management to reverse the crossing of a tipping point, for example by adding an appropriately chosen amount of sediment to a submerged salt marsh (Stagg and Mendelssohn, 2010). However, strategy (ii) generally becomes ineffective once climate changes beyond a certain threshold that is not well known and varies across socio-ecological system. Furthermore, some systems may contain multiple thresholds (Renaud *et al*., 2010) that may be crossed as stresses increase.

Other literature focuses more generally on the need for adopting a resilence-based management approach in both marine and terrestrial ecosystems (Walker and Salt 2006; Lubchenko and Petes 2010; Allen *et al.* 2012; Selig *et al.,* 2012). For regime shifts in ecosystems, a high level of biodiversity increases ecosystems' resilience and can enable them to recover after crossing a tipping point (Brierley *et al*., 2009; Lubchenko and Petes, 2010). Regime shifts have already occurred in several marine food webs (Byrnes *et al*., 2007; Alheit *et al*., 2009, Green *et al.,* 2008, section 6.3.5.1) as a result of (observed) changes in sea surface temperature, changes in salinity due to change in runoff, and (separately) natural climate variability, and/or overfishing, showing how future climate change will analogously affect species composition and hence ecosystem functioning and potentially biogeochemical cycles. Removal of concomitant stress such as nutrient loading can reduce the chance of a regime shift (Jurgensone *et al*., 2011) for example in coral reef ecosystems (De'ath *et al*., 2012). Appropriate ecosystem monitoring that looks for a slowing down in the recovery of systems from small changes (Nes and Scheffer, 2007) or measures whether an appropriate indicator value is too low or too high, (Biggs *et al.,* 2008) may give warning that a system is a approaching a regime shift, allowing intervention of type (ii) above to be implemented (Brock and Carpenter, 2010; Cuttal and Jayaprakash, 2008). Indicators that could be used for such monitoring 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 of adaptation, including financial or economic limits to adapt, but also social and political or cognitive limits of adaptation. Limits of adaptation (see e.g. Adger, 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 of adaptation of urban agglomerations in low-laying coastal zones (see e.g. Birkmann, 2010b), or in relation to loss of water supplies as a result of glacier retreat (Orlove, 2009). Overall, limits of adaptation have a close link to key vulnerabilities and key risks, since limits of adaptation are influenced by key vulnerabilities, such as identified in the cross-chapter table 19.3, and contribute to the development of key risks.

Frequently Asked Questions

FAQ 19.1: How does climate change interact with and amplify pre-existing risks?

The size of a risk depends on the probability that people or societies will be exposed to a triggering weather or climate-related trend or event and their vulnerability to damage and loss occurring as a result. For example, people living near certain coastal areas are more likely to be exposed to storm surge from tropical cyclones than those living inland. Exposure to potentially damaging physical events and vulnerability to those damages taken together constitute risk.

Climate change can amplify climate risks by changing the likelihood that damaging physical events or trends will occur, altering patterns of exposure of vulnerable people and societies to such events, or increasing their vulnerability to a number of risks not directly related to climate change. For example, older populations are more vulnerable than younger ones to a variety of climate and non-climate stresses. The increased incidence of extreme heat as the climate warms will further raise the relatively high risk of death from heat stress in this vulnerable group and simultaneously make them yet more vulnerable to other stresses like air pollution (absent anticipatory adaptation measures like increased availability of air conditioning). An example of indirect effects of climate change on risk is provided by the interaction of vulnerability due to poverty and associated risk of malnutrition with climate change abatement policy. Poverty increases people's vulnerability to malnutrition during periods of rising grain prices. Climate change has already given rise to government policies encouraging expansion of biofuel production based on fermentation of corn. Resulting increases in demand for corn contribute to higher corn prices and may indirectly increase incidence of malnutrition in vulnerable populations.

FAQ 19.2: How can climate change at one location cause impacts at another, distant location?

Impacts of climate change are felt locally and directly where the events and trends related to a changing climate occur. However, such impacts may cause responses on the part of humans, societies, and ecosystems and species which reverberate elsewhere and cause important indirect impacts at great distance from the initial climate impact. For example, a changing climate may lead to reduced crop productivity in some regions, reducing agricultural commodities supplied from that region and increasing demand for and price of the same or substitute crops grown in distant regions. In that case, a distant, indirect impact is transmitted by price changes in the global commodities markets. In a second example, people may migrate in response to impacts of climate change such as drought, leading to potential for both positive and negative consequences at receiving regions that may be far from the point of origin of the migrants. (Chapter 19.3, 19.4)

[Placeholder for a schematic figure here illustrating distant, indirect impacts]

FAQ 19.3: Does science provide an answer to the question of how much warming is acceptable?

The question of how much warming is acceptable is raised in Article 2 of the UN Framework Convention on Climate Change (UNFCCC). The criteria for determining what constitutes, in the words of Article 2, "dangerous anthropogenic interference with the climate system" are based both on science and human values. Science can determine, within a range of uncertainty, how much monetary loss might occur if tropical cyclones grow more intense or heat waves more frequent, for example. But comparing damages across communities, countries, or larger regions depends on how each political, social, or cultural entity values the losses. Comparing loss of property to loss of life is even more difficult and controversial, particularly when damage to future generations is involved. The purpose of this chapter is to highlight key risks and vulnerabilities that science has identified; however it is up to people and governments to determine how these potential impacts should be valued. For example, 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).

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Table 19-1: Emergent risks related to biofuel production as a mitigation strategy.

Issue number	Issue description	Nature of emergent risk	Reference
(i)Biofuel production	Potential for enhancement of greenhouse gas emissions	Does not contribute to mitigation	Wise *et al.,* 2009 Mellilo *et al*., 2009 Khanna *et al.,* 2011
(ii) Policies targeting only fossil carbon	Competition for land, reducing natural forest and impacting on biodiversity	Emerging risk of biodiversity loss due to mitigation-driven land use change	Wise *et al*., 2009 Mellilo *et al*., 2009 Lapola *et al*., 2010 Fargione *et al*., 2010
(iii) Food/fuel competition for land	Competition for land driving up food prices and impacting on numbers of people at risk of hunger	Emerging risk of food insecurity due to mitigation-driven land use change	Hertel *et al.,* 2010, Searchinger *et al.,* 2008
(iv) Biofuels production effects water resources	Competition for water impacting on biodiversity and food cropping	Emerging risk of biodiversity loss and food insecurity due to mitigation-driven water stress	Fargione *et al*., 2010, Fingerman *et al*., 2010
(v) Land conversion causes air pollution	Potential for increased production of tropospheric ozone	Emerging risk of biodiversity loss and food insecurity due to mitigation-driven damage caused by tropospheric ozone	Hewitt *et al*., 2009, Cancado *et al*., 2006
(vi) 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
(vii) Invasive properties of biofuel crops	Potential to become an invasive species	Unintended consequences that damage agriculture and/or biodiversity	Barney and Ditomaso 2008, Council for Agricultural Science and Technology 2007, Raghu *et al*., 2006

NOTES:

(i) First-generation biofuel consumption has been projected to increase by up to 170-220% by 2020 and up to 250-620% by 2030 (IEA, 2009), with the larger numbers corresponding to the implementation of a limit of 450ppm for CO_2 concentrations. Second generation biofuels are thought not to be commercially viable for large scale production until after 2020. Biofuels presently occupy about 2.2% of global cropland (33 million ha), whilst the area under cultivation itself is expanding at some 3.4 million ha/yr (FAO, 2010) due to rising demand for food. Hence, such large projections for increase in biofuel production have profound implications for land use. If this biofuel induced land use change removes primary forest, the net contribution of the biofuel cropping towards climate change mitigation may be negative. The potential scope of the impact on a global scale is revealed in one study (Wise *et al*.,2009) that considers a scenario leading to conversion of more than 40% of global land area to biofuel production by 2095.

(ii) Large scale conversion of natural forest induced by a carbon tax that does not include terrestrial carbon would have a severe impact on biodiversity (see section 19.4.3.3.) through the destruction of most remaining natural ecosystems (Wise *et al*., 2009). In Brazil, the biofuel expansion resulting from such a scenario would be expected to impinge upon the Cerrado, the Amazon and the Atlantic rainforest all three of which have high biodiversity and high levels of endemism (Lapola *et al.,* 2010). Concessions of large areas for biofuel production have been made in the Brazilian Amazon, Papua New Guinea, and Madagascar, all of which are biodiversity hotspots (Koh et al. 2009). Biodiversity is reduced by about 60% in U.S. corn and soybean fields and by about 85% in Southeast Asian oil palm plantations compared to unconverted habitat (Fitzherbert *et al*., 2008; Fletcher *et al*., 2010; Fargione, 2010).

(iii)Displacement of agricultural land for biofuel crops would influence world food supply and prices (Hertel *et al*., 2010, Searchinger *et al*., 2008), as actually occurred during the food price crisis of 2007/2008 (Pimentel, 2009), thus increasing risks of malnutrition. A new assessment of agricultural land availability projects that by 2050, substantial areas of agricultural land will be lost to urbanization, desertification, sea level rise and increasing salt water intrusion (Foresight 2011) which will act to increase competition between cropping for food and biofuels. Mellilo *et al.* (2009) project that up to twice as much carbon loss can occur as result of this indirect land use change, than from the direct land use change associated with biofuel production. Some biofuel feedstocks such as wastes, residues, cover crops, and forest thinnings (Tilman *et al.,* 2009) are not in competition with cropland.

(iv) The water requirements of many biofuel crops are substantial (Fargione *et al*., 2010, Fingerman *et al*., 2010) and hence there would be potential for conflict with efforts to allocate water for domestic, industrial, agricultural and natural wetlands particularly where irrigation is required (Yang *et al*., 2012, Poudel *et al*., 2012).

(v) Where rainforest is converted to oil palm plantations, or where land is converted to sugarcane ethanol production, emissions of the precursors of tropospheric ozone increase (Hewitt *et al*., 2009, Cancado *et al*., 2006).

(vi) Where biofuels displace nitrogen-fixing crops such as soybean, fertiliser application will increase, leading to increased N_2O emissions and nitrogen runoff into rivers and oceans (Donner and Kucharik 2008). At the same time, displacement of food crops, in combination with reduced yields due to climate change impacts, would encourage farmers to increase yields through application of larger amounts of fertiliser, particularly in countries where there is a supply shortfall (Deryng *et al*., 2011) which in turn increases greenhouse gas emissions.

(vii) Land use change also has direct effects on local climate: for example, new urban developments caused an intensification and expansion of the area experiencing extreme temperatures, mainly increasing nighttime temperatures, by as much as 10 K. (Grossman and Clarke 2010).

(viii) Traits that make a plant a good candidate for biomass production also make it a potential invasive species (Barney and Ditomaso 2008; Council for Agricultural Science and Technology, 2007; Raghu *et al*., 2006). This could result in damage to nearby ecosystems or agricultural systems.

Table 19-2: Key risks from large temperature rise.

Sector	**Region**	**Key Risk**
Agriculture	Globe	Decline in agricultural production
Water	Globe	20-30% increase in exposure to water stress; 40-80% declines in runoff in Danube, Mississippi, Amazon and Murray-Darling rivers; Drought affected area 44+/-6% of earth's terrestrial surface
Ecosystems	Tropics	Widespread coral reef mortality
Ecosystems	Globe	Climate space is lost upon 10-48% earth's surface; 60% plants and 33% animals projected to lose >50% of climatic range;
Health	Globe, Urban Areas	To be provided with next draft

Table 19-3: A selection of the hazards/stressors, 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). Key risks are determined by hazards and stressors interacting with vulnerability and exposure of human systems, infrastructure, and ecosystems or species. The table underscores the complexity of risks determined by various climatic hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, demographic changes or tolerance limits of species and ecosystems 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. climate change, urbanization and demographic changes) in combination and in specific development context (e.g. in low-laying coastal zones), can generate new systemic risks that go far beyond existing adaptation and risk management capacities, particularly in highly vulnerable regions.

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)			
Hazard/ Stressor	**Key vulnerabilities**	**Key risks**	**Emergent risks**
Terrestrial and inland water systems (chapter 4)			
Rising air, soil, and water temperature	Exceedence of eco-physiological climate tolerance limits of species, increased viability of alien organisms	Loss of native biodiversity, increase in alien organism dominance	Cascades of native species loss due to interdependencies
	Epidemiological response to spread of temperature-sensitive vectors (insects)	Novel or much more severe pest and pathogen outbreaks	Interactions between pest, drought and fire interactions can lead to new risks and large negative impacts on ecosystems
Change in seasonality of rain	Vulnerability of plants and ecosystem services, due to mismatch of plant life strategy to growth opportunities	Changes in plant functional type mix leading to biome change with respective risks	Fire-promoting grasses and summer fuels in winter-rainfall areas
Ocean Systems (chapter 6)			
Rising water temperature, increase of (thermal and haline) stratification, and marine acidification [6.1.1] *(also Chapter 24)*	Tolerance limits of endemic species surpassed, increased abundance of invasive organism, high vulnerability of warm water coral reefs and respective ecosystem services for coastal communities [6.2.2, 6.2.5]	Loss of endemic species, mixing of ecosystem types, increased dominance of invasive organisms, loss of coral cover and associated ecosystem with reduction of biodiversity [6.3.2]	Enhancement of risk due to interactions, e.g., acidification and warming on calcareous organisms [6.3.5]
	Shifted productivity zones and species distribution ranges, largely from low to high latitudes [6.1.3], shifting fishery catch potential with species migration [6.5.2, 6.5.3]	Unknown productivity and services of new ecosystem types [6.4, 6.5.3]	Enhancement of risk due to interactions of drivers, 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]	Hypoxia tolerance limits of larger animals surpassed, habitat contraction and loss for midwater fishes and benthic invertebrates [6.2.5]	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 oceans [6.3.5]
Enhanced harmful algal blooms in coastal areas due to rising water temperature	Increasing vulnerability of important ecosystems and valuable services due to	Enhanced frequency of dinoflagellate blooms and respective losses and	Disproportionate enhancement of risk due to interactions of various

[6.4]	already existing multiple stresses [6.3.5, 6.4]	degradations of coastal ecosystems and ecosystem services [6.4]	stresses [6.3.5]
Food security and food production systems (chapter 7)			
Rising average temperatures and more frequent extreme temperatures.	All elements of the food system from production to consumption vulnerable for key grain crops.	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. [7.1, 7.2, 7.4, 7.5]
Urban areas (chapter 8)			
Inland flooding	Urban areas with large numbers of poor, uninsured people exposed to flood events including low-income informal settlements. Environmental health consequences from overwhelmed, aging, poorly maintained and inadequate urban drainage infrastructure and widespread impermeable surfaces. Inadequate local governance. Increased mosquito and water borne diseases.	Increasing urban flooding with increasing volume and velocity of flood waters on the one hand and increasing vulnerability on the other leads to key risks particularly in urban areas with large number of poor and exposed to flooding.	Larger and more frequent flooding impacting much larger population. Impacts reaching the limits of insurance; shift in the burden of risk management from the state to those at risk leading to greater inequality and property blight, abandonment of urban districts and the creation of high risk/high poverty spatial traps.
Coastal flooding (including sea level rise and storm surge)	High concentrations of people, businesses and physical assets including critical infrastructure in low-lying and unprotected coastal zones including low-elevation coastal zones in addition to vulnerability noted in previous example.	Flooding interacts with highly vulnerable people and areas that are likely lead to multiple negative consequences and hence key risks. Storm surges often causing the most serious floods	Sea level rise increasing risk over time, increasing concentration of population and economic activities on the coasts. Reaching the limits of insurance; shift in risk management from the state to those at risk leading to consequences noted above.
Heat and cold including Urban Heat Island (UHI)	Increasing urban population of infants, young children, older age groups, expectant mothers, people with compromised immune system at risk from 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.	In heat waves with higher or more prolonged high temperatures or cold spells - mortality and morbidity increasing, including shifts in seasonal patterns and concentrations.	Extension and variability of heat waves and less frequent and thus unexpected cold spells, increasing risks over time for most locations. Low-income groups often facing greatest difficulties avoiding risks
Water shortages and drought in urban regions	Urban dwellers lacking water piped to their premises. Urban areas with water	Loss of functionality to urban water provision services and industry with	Urban viability may be threatened by loss of freshwater sources –

	shortages and 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.	human and economic impacts. Damage to urban ecology and its utility including urban and peri-urban agriculture.	including many cities dependent on glacier meltwater
Changes in urban meteorological regimes lead to enhanced air pollution	Health impacts from increases in exposure to high pollution levels with impacts most serious among physiologically susceptible populations. Urban governments' not implementing pollution controls.	Mortality and morbidity, lowered quality of life. May undermine the competitiveness in global cities to attracting key workers and investment.	Complexity and compounding of health crises.
Geo-hydrological hazards (salt water intrusion, mud/landslides, subsidence)	Vulnerability of local structures and networked infrastructure impacted by systems-level environmental change. Inability of many low-income households to move to safer housing on safer sites	Increasing risk of damage to networked infrastructure (water, sanitation, drainage, communications. transport, energy), property and human loss due to geo-hydrological hazards and the vulnerability of people and local structures.	Potential for large local and aggregate impacts via knock on effects for urban activities and wellbeing.
Storms with higher wind speeds	Sub-standard buildings and physical infrastructure and the services and functions they support. Old and hard-to-retro-fit buildings and infrastructure in cities. Local government unable or unwilling to give attention to disaster risk reduction	Damage to dwellings, businesses and public infrastructure. 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 leading budgetary competition and potential for tensions between development and risk reduction investments.
Changing hazard profile including novel hazards and new multi-hazard complexes	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.	Risks from failures within coupled systems e.g., reliance of drainage systems on electric pumps, reliance of emergency services on roads and telecommunications, psychological shock from unanticipated risks.	Loss of faith in risk management institutions. Potential for large events that are magnified by a lack of preparation and capacity to respond.
Compound slow-onset hazards including rising temperatures and variability in temperature and water availability	Large sections of the urban population in low- and middle-income nations with livelihoods or food supplies dependent on urban and peri-urban agriculture.	Damage to or degradation of soils, water catchment capacity, fuel wood production, urban and peri-urban agriculture and other productive or protective eco-system services. 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 service provision and disaster risk reduction.
Changes in temperature and precipitation leading to	Large urban population at risk from food and	Increases in exposure to these diseases	Growing incapacity of public health system to

changed conditions for disease propagation	waterborne diseases and to malaria, dengue and other vector borne diseases		address this and simultaneous increase in exposure to other impacts such as flooding
Rural areas (chapter 9)			
Drought in pastoral areas, changes in rangeland composition [9.3.3.1, 9.3.5.3.1]	Encroachment on pastoral rangelands, inappropriate land policy, misperception and undermining of pastoral livelihoods, conflict over natural resources, all driven by remoteness and lack of voice.	Inability to cope with drought, leading to famine. Changes in herd dynamics. Loss of revenues from livestock trade.	Impacts on livelihoods through animal disease in pastoral areas.
Effects of climate change on fish stocks; impacts of tropical storms on settlements and fishing gear. [9.3.3.1, 9.3.5.3.3]	Artisanal fisheries affected by pollution, mangrove loss, competition from aquaculture, neglect of sector by governments and researchers, complex property rights.	Declining catches and incomes for artisanal fisherfolk.	Reduced dietary protein for those consuming artisanlly-caught fish.
Water shortages and drought in rural areas [9.3.5.2.1.]	Rural people lacking access to drinking and irrigation water. Lack of capacity and resilience in water management regimes (institutionally driven).	Reducing agricultural productivity and/or income of rural people, mostly those depending on irrigated agriculture or high-yield varieties. Food insecurity.	Impacts on livelihoods driven by interaction with other factors (water management institutions, water demand). Human health.
Human health (chapter 11)			
Increasing frequency and intensity of extreme heat *(also chapter 19)*	Older people living in cities are most vulnerable to heat waves, and their population projected to triple from 2010-2050.	Increased mortality and morbidity during heat waves, particularly in those with pre-existing conditions	Overloading of health and emergency services. Mortality, morbidity and productivity loss, particularly in manual workers in hot climates
Increasing temperatures, increased variability in precipitation	Food insecurity translates into malnutrition, which is among the largest disease burdens in poorer populations.	Progress in reducing mortality and morbidity from malnutrition may slow or reverse and constitutes a new key risk	Combined impacts of climate impacts, population growth, plateauing productivity gains, land demand for livestock, biofuels, persistent inequity, and on-going food insecurity for the poor
Increasing temperatures, changing patterns of precipitation	Water- and vector-borne disease highly sensitive to meteorological conditions	Changing spatial and temporal distribution hampers disease control, exposes non-immune populations	Rapid climate and other environmental change may promote emergence of new pathogens
Increased variability in precipitation	Diarrhoea facilitated by higher temperatures, unusually high or low precipitation	Progress in reducing diarrhoea morbidity is compromised	Increased rate of failure of water and sanitation infrastructure leading to higher diarrhoea risk
Livelihood and poverty (chapter 13)			
Changing rainfall patterns (temporally and spatially)	High dependence on rain-fed agriculture. Little access	Crop failure, food shortage, severe famine	May coincide with global food insecurity or periods of

	to alternative modes of income.		excessive global food prices which means that coping strategies may not work. Adaptation mechanisms such as crop insurance (risk spreading) may collapse.
Soaring demand (and prices) of biofuels due to climate change policies.	Unclear and/or insecure land tenure arrangements.	Risk of dispossession of land due to "land grabbing" in developing countries.	Creation of large groups of landless farmers unable to support themselves. Social unrest due to disparities between intensive energy production and neglected food production.
Increasing frequency of extreme events (droughts, floods). For example if 1:20 year drought/flood becomes 1:5 year flood/drought.	Livelihoods subject to damage to their productive assets (e.g. in case of droughts – herds of livestock; if floods – dykes, fences, terraces).	Risk of the loss of livelihoods and harm due to shorter time for recovery between extreme. 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 (degree of precipitation changes uncertain) [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, 19.3.2.2, 19.6.1.1, 19.7.5]	Risk of harm and loss due to livelihood degradation from systematic constraints on water resource use that lead to supply falling far below demand. In addition limited coping and adaptation options increase the risk of harm and loss. [19.3.2.2]	Negative outcomes to sending and/or receiving regions from migration of populations due to limits on agricultural productivity and livelihoods [19.3.2.2, 19.4.2.1]
Changes in regional and seasonal temperature and precipitation over land [AR5 WGI TS.5.3, WGI SPM, WGI 11.3, WGI 12.4]	Dependence of communities on ecosystem services [19.2.2.1, 19.3.2.1]	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 likely to lose ≥50% of their current climatic range by the 2080s leading to loss of services [19.3.2.1]	Widespread loss of ecosystem services: including *provisioning*, such as food and water; *regulating*, such as the control of climate and disease; *supporting*, such as 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	Health of exposed and vulnerable groups (increased exposure to heat, change in the transmission dynamics of vector-borne diseases)	Increase in disease burden – changes in the patterns of infection Decrease in outdoor worker productivity due to high temperature, increase in heat related morbidity and mortality	Emerging and re-emerging disease epidemics
	Vulnerability of aquatic	Loss of aquatic ecosystems	

	systems and vulnerability of aquatic ecosystem services due to increased water temperatures	and risks for people who might depend on these resources	
Extreme Events, e.g. floods and flash floods	Vulnerable and exposed urban areas, particularly in informal settlements	Increasing harm and losses due to water logging in terms of sudden volumes of rain	Due to water logging and contamination, compounded increase of the risk of epidemics
Europe (chapter 23)			
Extreme weather events *(also Chapter 19)*	Limited coping and adaptive capacity as well as high sensitivity of different sectors, e.g. transport, energy and health sector	Stress on multiple sectors can cause systemic risks due to interdependencies between the different sectors	Disproportionate intensification of risk due to increasing interdependencies
Climate change increases the spatial distribution and seasonality of pests and diseases	Vulnerability of plants and animals exposed to pests and diseases	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	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)			
Thawing of permafrost due to rising temperature in northern Asia.	Existence of structures and infrastructures on the permafrost and high dependences of civil life on them	Instability of or damages to the structures and infrastructures	Projected exacerbation of instability of residential buildings, pavements, pipelines used to transport petroleum and gas, pump stations and extraction facilities
Projected increase in frequency of various extreme events (heat-wave, floods and droughts) and sea level rise *(also Chapter 19)*	Convergence of livelihood and properties into coastal megacities, especially into area that is not protected against natural hazards sufficiently	Loss of human life and life stocks due to coastal floods accompanied by increasing vulnerabilities caused by occurrence of other extreme events like heat-wave and droughts	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)			
Warming and drying in southern Australia and parts of New Zealand (uncertain degree of precipitation change) [25.2, Table 25-1]	Increasing build-up of combustible material in CO_2-enriched environment, increased ignition rate and combustibility, increasing exposure of human systems to these changes [25.6.1,	Increased damages to ecosystems and settlements and risks to human life from wildfires [25.6.1, Box 25-6, 25.10.2]	Increasing risk from compound extreme events across time, space and governance scales, and cumulative adaptation [25.10.2, 25.10.3, Box 25-9]

	Box 25-6]		needs
Warming and increased temperature high extremes in Australia [25.2, Table 25-1, Figure 25-5]	Urbanization, aging of population and vital infrastructure [25.3, Box 25-9, 25.10.2]	Increase in morbidity, mortality and infrastructure failure during heat waves [25.8.1, 25.10.2]	
Potential for sea level rise beyond 2100 exceeding 1m [25.2, AR5 WGI Chapter 13]	Long lifetime of coastal infrastructure, concentration and further expansion of coastal population and assets; conflicting priorities and time preferences constraining adaptation options; limited scope for managed retreat in highly developed areas [25.3, Box 25-1]	Widespread damages to coastal infrastructure and low-lying ecosystems [Box 25-1, 25.10.2]	
North America (chapter 26)			
Increases in frequency and/or intensity of extreme events, such as hurricanes, river and coastal floods, heat waves and droughts [26.2] *(also Chapter 19)*	Declining state of physical infrastructures in urban areas as well as increases in income disparities [26.7]	Risk of serious harm and losses in urban areas, particularly in coastal environments due to enhanced vulnerabilities of social groups and physical systems combined with the increases of extreme weather events [26.8]	Inability to reduce vulnerability in many areas results in increase in risk greater than change in physical hazard [26.8]
Higher temperatures, decreases in runoff and lower soil moisture due to climate change [26.2, 26.3]	Increasing vulnerability of small landholders in agriculture [26.5]	Increased losses and decreases in agricultural production increase food and job insecurity for small landholders and social groups in that region [26.5]	Increasing risks of social instability and local economic disruption due to internal migration [26.2, 26.8]

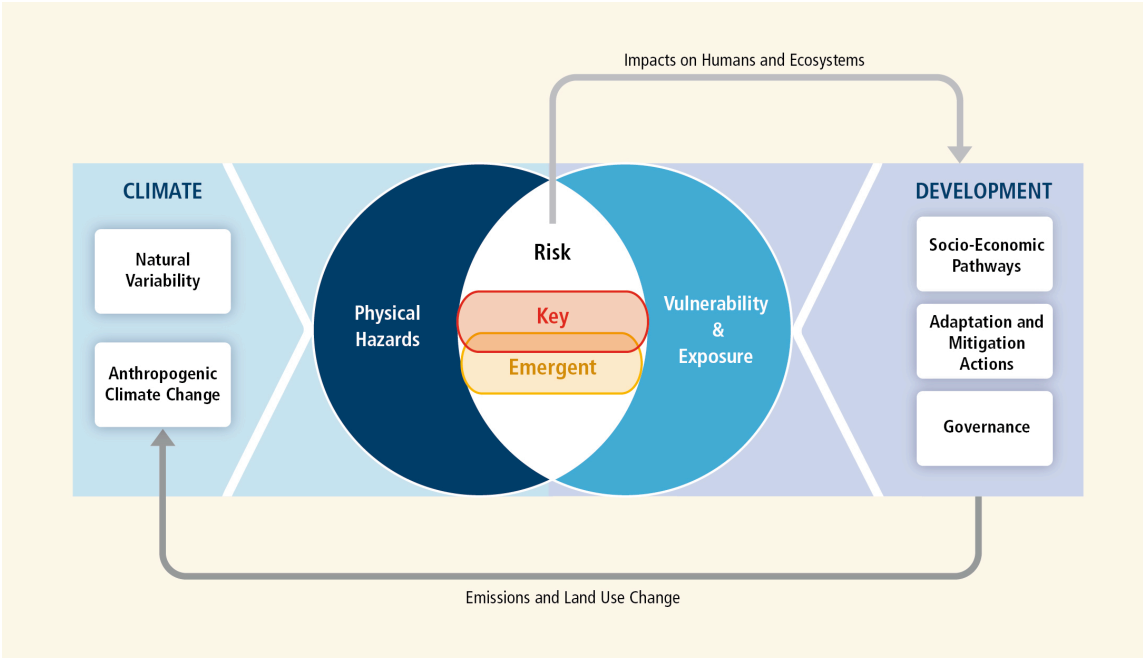

Figure 19-1: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. The figure visualizes the different terms and concepts discussed in this chapter. It underscores that risks are a product of a complex interaction between physical hazards associated 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" 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. Both the changes in the climate system (left side) and the development processes (right side) are key drivers of the different core components (vulnerability, exposure, and physical hazards) that constitute risk (modified version of Figure 1, IPCC, 2012.

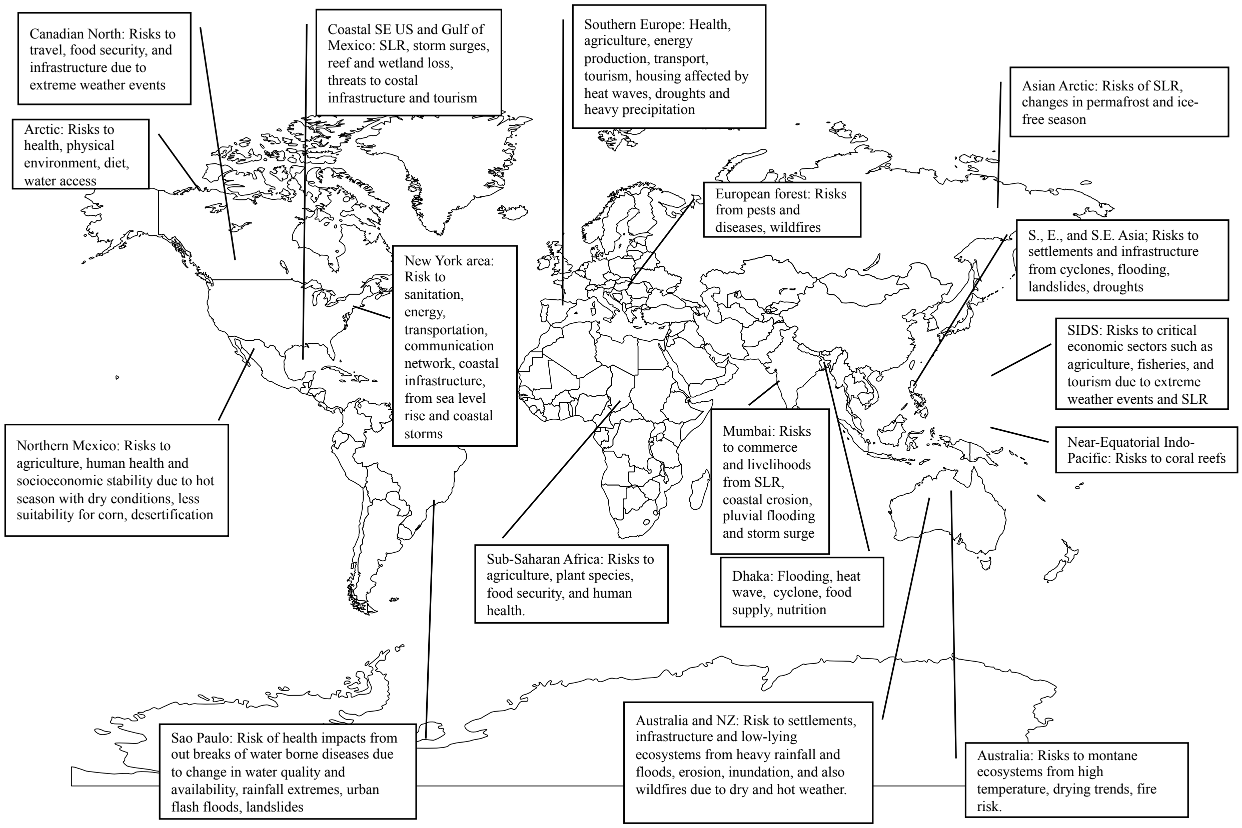

Figure 19-2: Some salient examples of multi-impacts hotspots identified in this assessment.

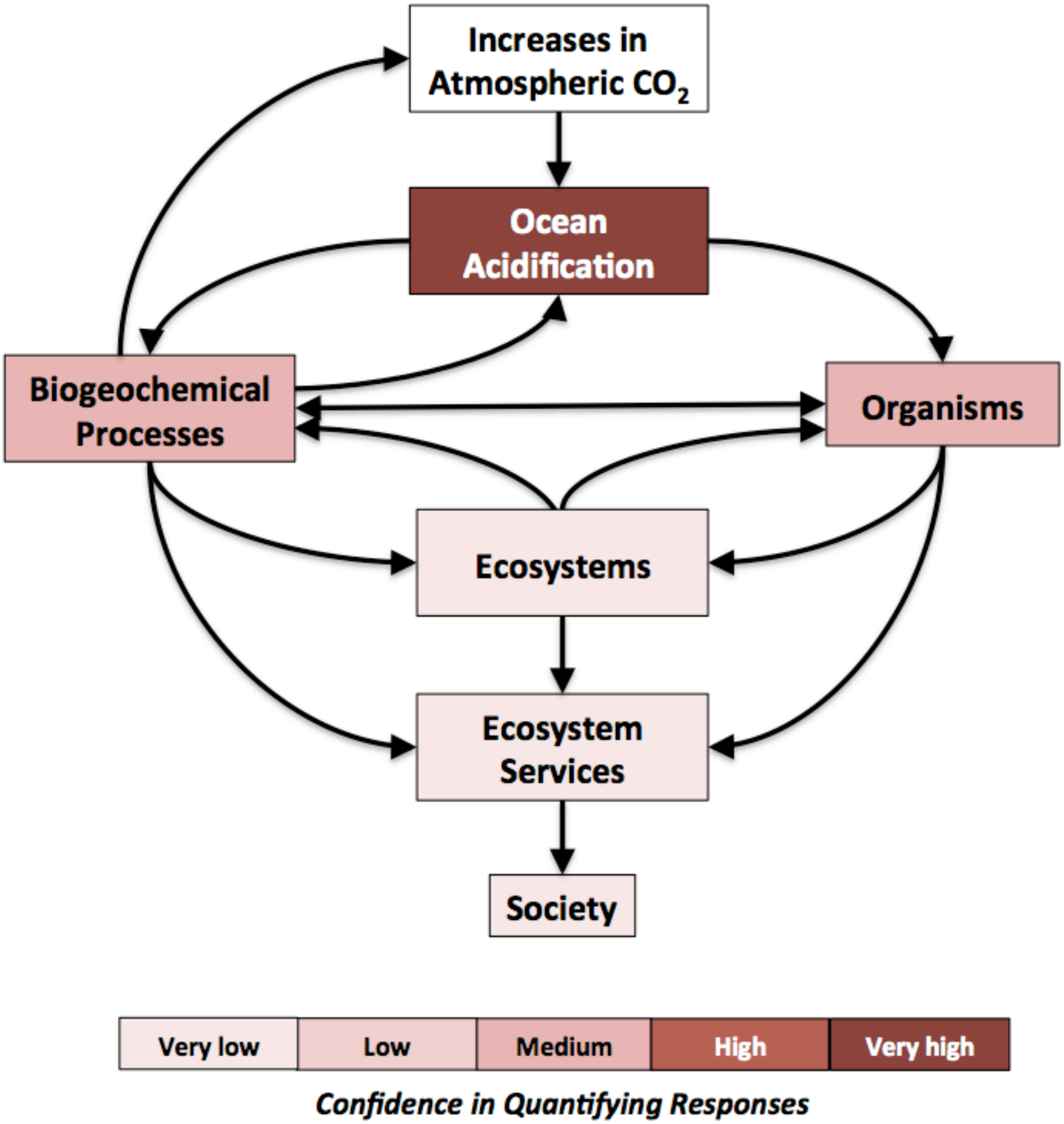

Figure 19-3: The pathways by which ocean acidification affects marine processes, organisms, ecosystems, and society. Confidence in quantifying these effects (as summarized from WG2 Chapter 6) decreases with each step along the pathway, and is very low for effects on ecosystems, ecosystem services, and society.

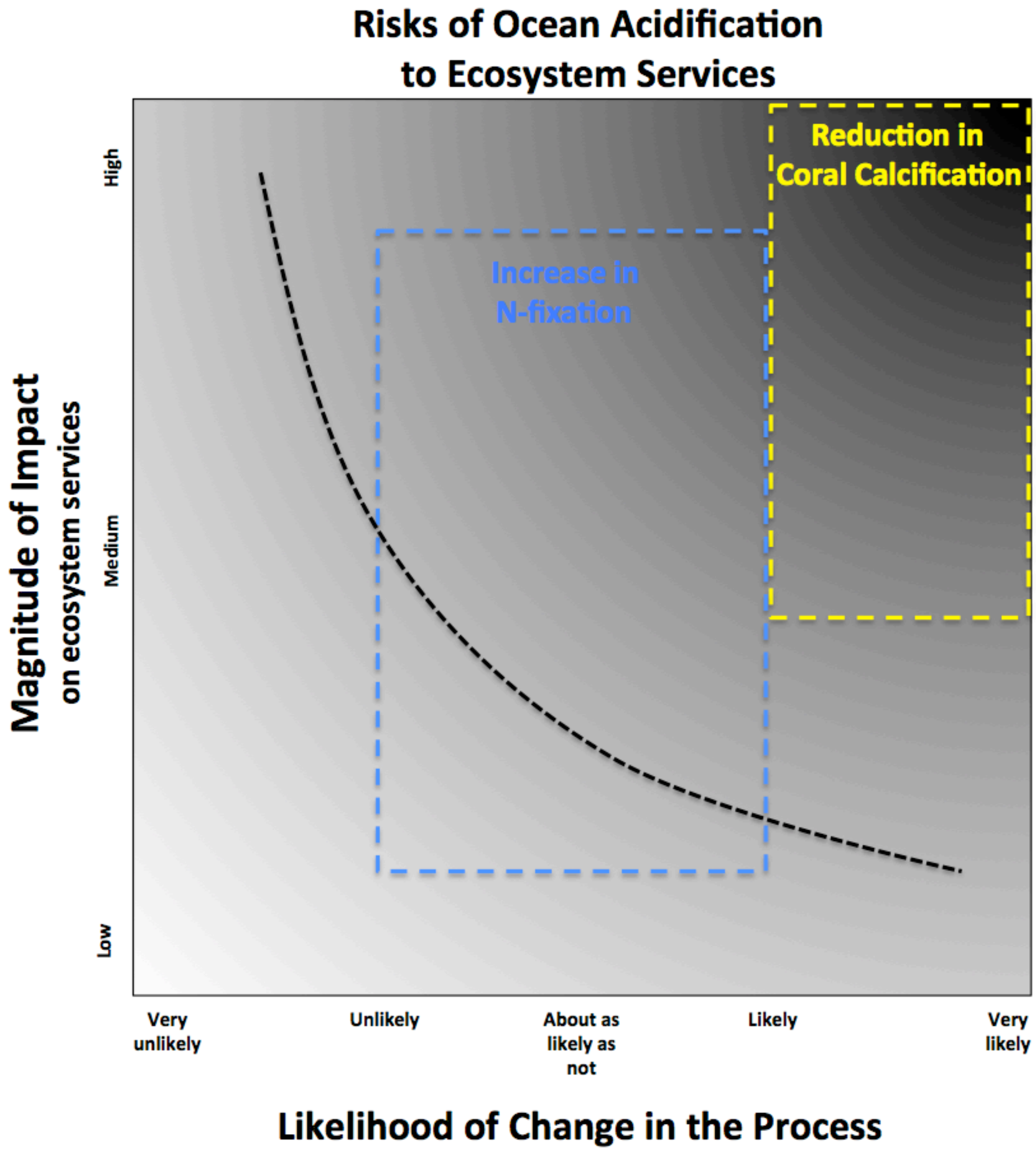

Figure 19-4: Risks of ocean acidification to ecosystems services through two effects on biogeochemical processes: (1) reductions in calcification rates (of corals) and (2) increases in nitrogen-fixation rates. Assessments are based on the estimated *likelihood* that the process will be affected by ocean acidification (horizontal axis) and the *magnitude* of the impacts on associated ecosystem services (vertical axis) should the process be affected. Heights and widths of boxes indicate the range of uncertainty in the magnitude of impacts on ecosystem services and likelihood of change in the process, respectively. Heights are greater than widths due to the lower confidence in responses of ecosystems and their services (Figure 19-3). Judgments are based on impacts expected with atmospheric CO_2 levels of 2-3x preindustrial levels (560-840 ppmv). This figure is meant to be broadly illustrative: with sufficient information Low, Medium, and High magnitudes of impacts would be defined quantitatively. The shading of the box represents the risk (*likelihood* x *magnitude*) to ecosystem services with the dashed contour showing the line of equal risk; the area above and to the right of this line is broadly indicative of key risks. Thus, the reduction in calcification due to ocean acidification is already considered a key risk to some ecosystem services, while the limited evidence regarding the nitrogen fixation response and its impacts implies that it may or may not become a key risk as uncertainty is reduced.

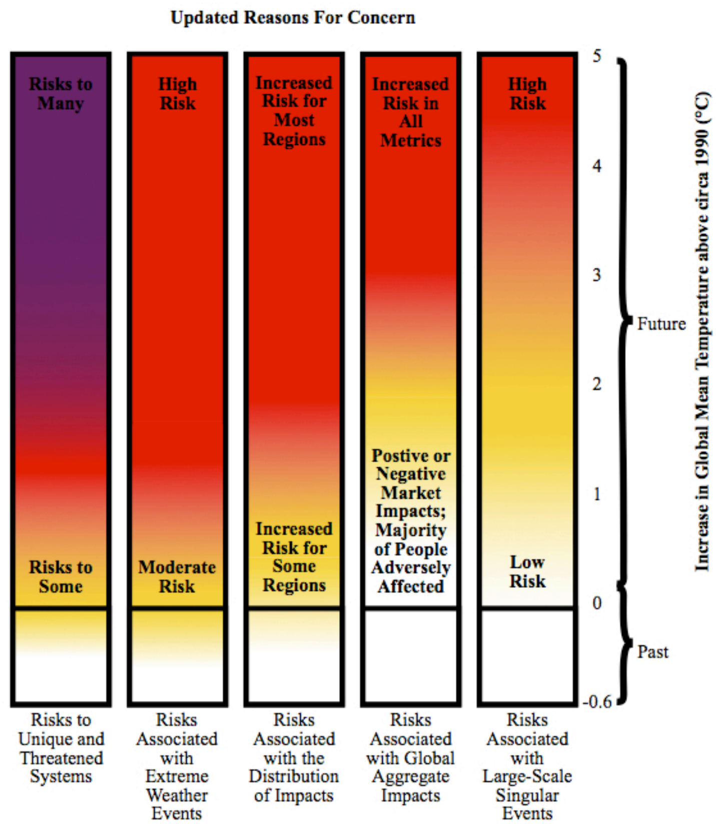

Figure 19-5: The dependence of risk associated with a Reason for Concern (RFC) on the level of climate change, updated from TAR and Smith *et al.* (2009). The color scheme indicates the additional risk due to climate change (with white to purple indicating the lowest to highest level of risk, respectively). The levels of risk illustrated reflect the judgments of Chapter 19 authors. Purple color, introduced here for the first time, reflects the assessment that unique human and natural systems tend to have very limited adaptive capacity (Chapters 4, 24), and hence we have *high confidence* that climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C were exceeded.

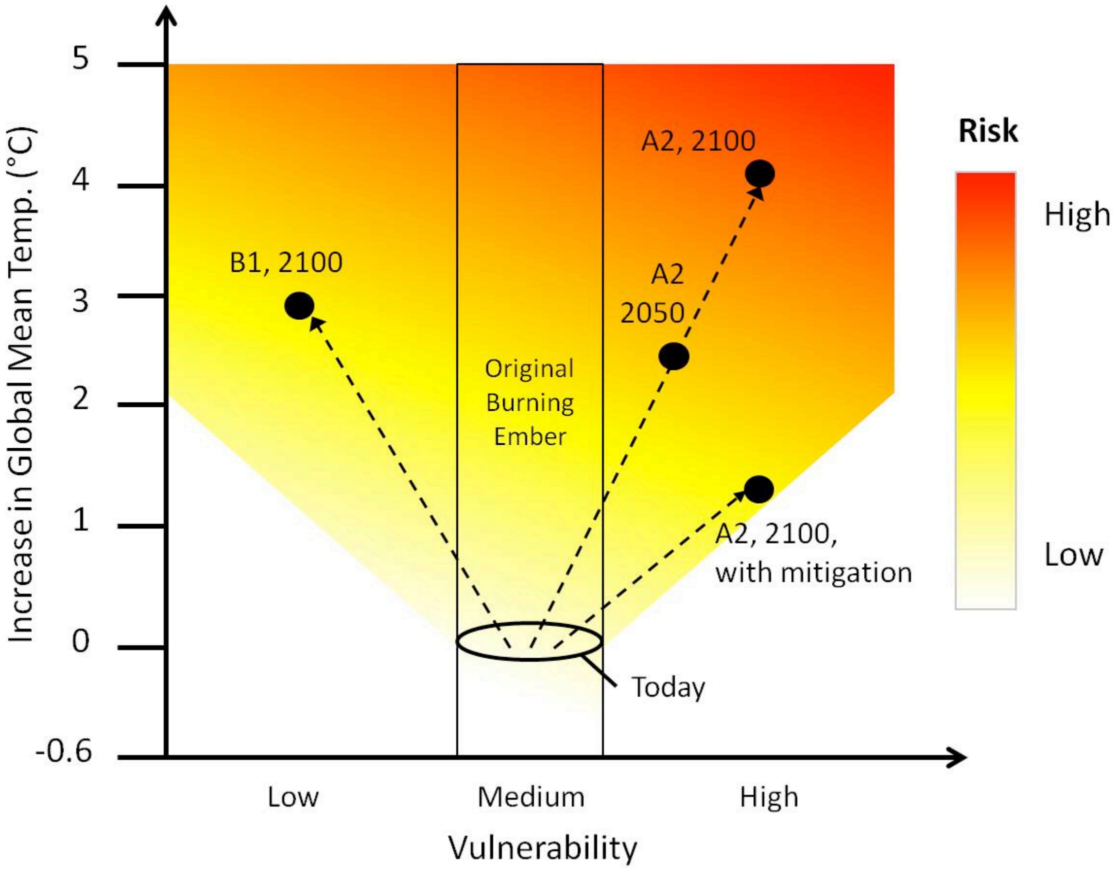

Figure 19-6: Illustration of the dependence of risk associated with a Reason for Concern (RFC) on the level of climate change and vulnerability of society. This figure is schematic; the degree of risk associated with particular levels of climate change or vulnerability has not been based on a literature assessment, nor associated with a particular RFC. The vulnerability axis is relative rather than absolute: "Medium" vulnerability indicates a future development path in which vulnerability changes over time driven by moderate trends in socio-economic conditions. "Low" and "High" vulnerability indicate futures that are substantially more optimistic or pessimistic, respectively, regarding vulnerability. We assume that judgments made in other burning ember diagrams of the RFCs (Smith *et al.*, 2001, 2009) including Figure 19-5, which do not explicitly take changes in vulnerability into account, are consistent with Medium future vulnerability. 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.

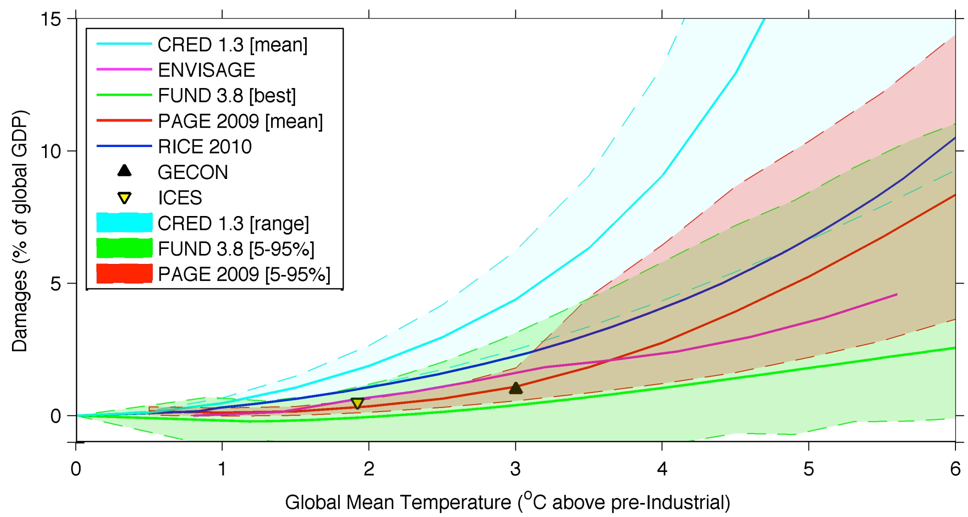

Figure 19-7: Representative global damage estimates, shown as a percentage loss of global output as a function of temperature, from integrated assessment models employing their own reference scenarios. PAGE 2009: (Hope, 2013a, 2013b). FUND 3.8: (Anthoff and Tol, 2010b; Anthoff et al., 2013; Waldhoff et al., 2013). RICE 2010: (Nordhaus, 2010). CRED: (Ackerman et al., 2011). ENVISAGE: (Roson and Mensbrugghe, 2012). GECON: (Nordhaus, 2006). ICES: (Bosello et al., 2012). For PAGE 2009 and FUND 3.8, the shaded region indicates the range spanned by the 5th and 95th percentile of outputs in Monte Carlo mode. The area of overlap between PAGE 2009 and FUND 3.8 is indicated in brown. For CRED 1.3, the shaded region indicates the range spanned by four alternative damage functions. In CRED at 6°C, mean damages are 32% of GDP and the largest of the four damage functions yields 50% loss of GDP.

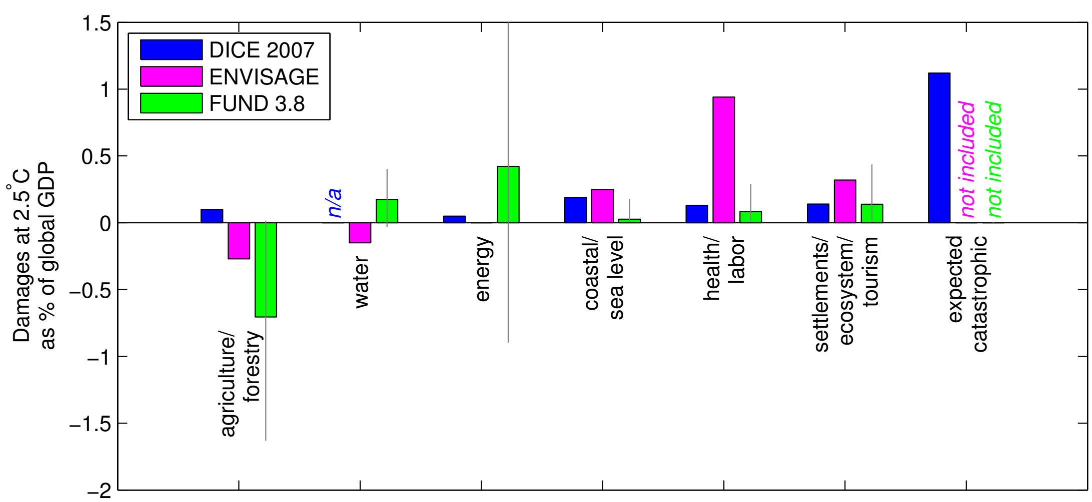

Figure 19-8: Breakdown of damages at 2.5°C above pre-industrial by sector in the DICE 2007 calibration (Nordhaus, 2007, 2008), FUND 3.8 (Anthoff and Tol, 2010b; Anthoff et al., 2013; Waldhoff et al., 2013) modal damages and ENVISAGE (Roson and Mensbrugghe, 2012), reflecting a *low level of agreement* among the integrated assessment models used to estimate global aggregate damages. Note that the DICE calibration does not include damages due to changes in water resources as distinct from temperature impacts on agriculture and forestry, and FUND and ENVISAGE do not include expected catastrophic damages. Representations of changes in energy demand, coastal/sea level impacts, health and labor productivity impacts, and impacts on settlements, ecosystem and tourism are included in all three models. Grey lines span the 5th to 95th percentile of estimates from FUND. The 95th percentile of energy sector damages in FUND is 2.2% of GDP.

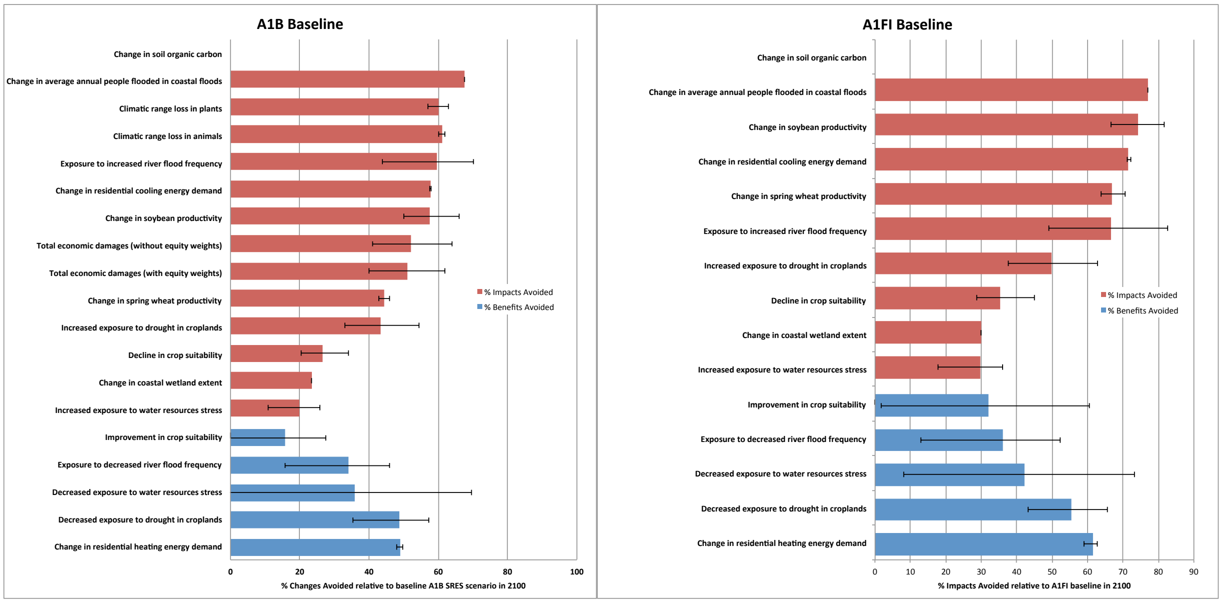

Figure 19-9: Climate change impacts avoided by a mitigation scenario compared to two no-mitigation cases (SRES A1B and A1FI scenarios), showing the uncertainty due to regional climate change impacts projection with 7 Global Circulation Models (GCMs). Since increases and decreases in water stress, flood risks and crop suitability are not co-located and affect different regions, these effects are not combined. From Arnell *et al.*, 2012, Warren *et al.*, in press, Warren *et al.*, submitted.

[Figure 19-10 provided in the next draft]

Figure 19-10: relates the categories of mitigation scenario considered in AR5 WGIII, to global temperature outcomes (consistent with the WGI calculations; data taken from Chapter 6 - WGIII). It also relates these temperature outcomes to some salient projected climate change impacts for the different levels of global temperature rise, focusing on those impacts which are less affected by the socioeconomic development pathway.