Chapter 16. Adaptation Opportunities, Constraints, and Limits

Coordinating Lead Authors
Richard J.T. Klein (Sweden), Guy F. Midgley (South Africa), Benjamin L. Preston (USA)

Lead Authors
Mozaharul Alam (Bangladesh), Frans G.H. Berkhout (Netherlands), Kirstin Dow (USA), Yu'e Li (China), Elena Mateescu (Romania), M. Rebecca Shaw (USA)

Contributing Authors
Wouter Botzen (Netherlands), Halvard Buhaug (Norway), Karl W. Butzer (USA), Carina Keskitalo (Sweden), Sarshen Marais (South Africa), Robert Muir-Wood (UK), Johanna Mustelin (Finland), Hannah Reid (UK), Lauren Rickards (Australia), Tim F. Smith (Australia)

Review Editors
Habiba Gitay (Australia), James Thurlow (South Africa)

Volunteer Chapter Scientists
Seraina Buob (Switzerland), Adelle Thomas (Bahamas)

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Executive Summary

Historical evidence from both natural and human-managed systems demonstrates the existence of limits to the extent to which systems can change and adapt in the face of challenges (*high agreement, robust evidence*). Such evidence illustrates the interactions between biophysical changes in the Earth system and socioeconomic and cultural factors that mediate societal responses to those changes and the likelihood of exceeding limits. While the risks of exceeding some limits have generally declined over time, such as those represented by epidemics or famine, others have increased. These dynamics are context-dependent and reflect the changing nature of the underlying constraints actors experience as they strive to achieve management and broader societal objectives. Economic development has enabled actors to deploy greater financial resources, technology, and human capital in managing the environment. However, the externalities of such development such as habitat degradation, resource depletion, and climate change have increased the constraints on actors in dealing with other challenges. The key factors driving whether or not limits are exceeded is the ability to anticipate the implications of unsustainable development trajectories and capitalize on opportunities to change behaviors. [16.3, 16.5, 16.5.1, 16.5.2, 16.8, Box 16-5]

The pursuit of adaptation policies and measures by actors is potentially constrained by multiple biophysical and socioeconomic factors (*high agreement, robust evidence*). The manner in which these constraints manifest and their implications for the capacity of an actor to achieve adaptation objectives vary significantly across different regions and sectors as well as among different social and temporal scales. The availability of resources for adaptation continues to feature strongly as a significant constraint on adaptation, as does uncertainty regarding future climate and disaster risk at national and regional scales. However, there is increasing awareness within the adaptation literature of the dynamics of social processes and governance that mediate the entitlements of actors to resources and promote social learning regarding adaptation. While many adaptation constraints are common across sectors and regions, the manner in which they manifest and the pathway by which they can be overcome are often highly context-dependent. [16.4, 16.6]

A diverse array of opportunities is available to actors in different geopolitical and development contexts to facilitate the implementation of adaptation policies and measures (*high agreement, moderate evidence*). Although evidence of increased societal resilience through adaptation remains limited, more structured and deliberate mechanisms for planning, implementation, and monitoring of adaptation suggest opportunities are

expanding across geopolitical scales. Recent research has increased attention on how actors and organizations create such enabling conditions for adaptation. Demand for adaptation is generated by growing knowledge of climate change and the potential benefits associated with adaptation. In addition, evidence of development deficits or, more specifically, adaptation deficits, encourage policy reform, infrastructure investment, and behavioral change. Meanwhile, pursuit of disaster risk reduction mechanisms and the engagement of post-disaster response and recovery processes create the potential for increased societal resilience to climate change. Opportunities for adaptation are also influenced by future policies and measures to mitigate anthropogenic greenhouse gas emissions. [16.3, 16.5.3, 16.5.4, 16.8]

Normative judgments and values are important in defining societal limits to adaptation and the underlying constraints by which they are determined (*high agreement, robust evidence*). Some examples of absolute biophysical limits to adaptation appear in the literature and are largely associated with large-scale singularities in the Earth system. The limits to adaptation of societal systems, including managed ecosystems, are defined by society or 'socially-constructed' and therefore potentially mutable. Levels of socioeconomic development, societal norms and values, as well as risk perceptions and tolerances all influence opportunities, constraints, and, therefore, limits to societal adaptation. Nevertheless, the more rapidly climate change progresses at global, regional and local scales, the greater the constraint on adaptation and the more likely limits will be exceeded, resulting in unacceptable risks to actors' objectives and the emergence of 'key vulnerabilities'. [16.2, 16.4, 16.5, 16.7]

The ability of adaptation research to inform strategies for managing the risks of climate change is constrained by the lack of a robust international policy framework to restrict the range of adaptation scenarios to be considered (*moderate agreement, moderate evidence*). The greater the magnitude of climate change to which actors must adapt, the greater the likelihood that such adaptation will encounter limits. Although a global mean temperature of 2°C above pre-industrial levels is the threshold used to define 'dangerous' anthropogenic interference in the international climate policy arena, for many regions and sectors, little analysis has been conducted to enable a determination regarding whether or not the regional expression of climate changes at this global threshold would exceed limits to adaptation. Delays in international mitigation efforts have triggered the adaptation research community to explore more severe scenarios of climate change, such as an increase in global mean temperature of 4°C by 2100. Such scenarios could necessitate system transformations, including modifications of management objectives, in order for adaptation to be successful. [16.4.2.4, 16.5.3, 16.5.4, 16.8]

Uncertainty regarding future biophysical and socioeconomic trajectories as well as the objectives and values of societal actors is a significant challenge to assessing the limits to adaptation (*high agreement, robust evidence*). Although there is evidence regarding the thresholds for the sustainability of a number of biophysical systems (Greenland Ice Sheet, the Amazon, coral reef ecosystems, and some iconic species), systematic understanding of biophysical and socioeconomic limits remains incomplete. Similarly, the effectiveness of different adaptation policies and measures for avoiding limits is often untested, and such assessments are subject to normative debates regarding what constitutes successful adaptation versus maladaptation. In many instances, additional research is required to better clarify system limits and the likelihood of their exceedance. Decision-support tools such as risk management, hedging, and preservation of real options provide mechanisms for coping with this uncertainty in adaptation process by promoting flexibility and minimizing the irreversibility of decisions. [16.3, 16.4, 16.5, 16.8]

16.1. Introduction and Context

Since the IPCC's *Fourth Assessment Report* (AR4), demand for knowledge and assessment regarding the planning and implementation of adaptation as a strategy for climate risk management has increased significantly (Preston *et al*., 2011a). This chapter assesses the literature on the circumstances that create opportunities for adaptation as well as the ancillary benefits that may arise from the implementation of adaptation policies and measures. It also assesses the latest literature on constraints on adaptation and the potential for such constraints to pose limits to adaptation, with an emphasis on both biophysical and socioeconomically-constructed constraints and their interactions. Given increasing interest in and evidence of fundamental limits to adaptation, the chapter also examines the literature on transformation as a response to limits on incremental adaptation.

This chapter expands upon the discussion of adaptation constraints and limits in the AR4 through engaging the considerable recent expansions to research on this topic.. To facilitate this literature assessment, this chapter provides an explicit framework for opportunities, constraints, and limits (see Section 16.2). In this framework, the core concepts including definitions of adaptation, vulnerability, and adaptive capacity are consistent with those used previously in the AR4. Given its focus, the material in this chapter should be considered in conjunction with that of other complementary AR5 WGII chapters. These include Chapter 14 (*Adaptation Needs and Options*) as well as Chapter 15 (*Adaptation Planning and Implementation*). As the financing and economic implications of adaptation are key considerations influencing adaptation opportunities and constraints, there are also important linkages between this chapter and Chapter 17 (*Economics of Adaptation*). Material from a range of other WGII chapters is also relevant to informing opportunities, constraints, and limits on adaptation, particularly Chapter 2 (*Foundations for Decision-Making*) and Chapter 19 (*Emergent Risks and Key Vulnerabilities*). Furthermore, while this chapter synthesizes material from each of the sectoral and regional chapters on adaptation opportunities, constraints, and limits, readers are encouraged to refer directly to those chapters for more detailed information.

In order to maximize the decision and policy relevance of the assessment of adaptation opportunities, constraints, and limits, this chapter takes as its entry point the perspective of actors as they consider adaptation response strategies over near, medium and longer terms. Actors may be individuals, communities, organizations, corporations, NGOs, governmental agencies, or other entities responding to real or perceived climate-related stresses or opportunities as they pursue their objectives (Blennow and Persson, 2009; Frank *et al.,* 2011; Patt and Schröter, 2008). These actors may seek to implement near-term adaptation policies and measures under constraining circumstances while simultaneously anticipating or working to alleviate those constraints to enable greater flexibility and adaptive capacity in the future. Therefore, it is necessary to consider diverse timeframes for possible social, institutional, technological and environmental changes. These timeframes also differ in the types of uncertainties that are relevant, ranging from those of climate scenarios and models, possible thresholds, nonlinear responses or irreversible changes in social or environmental systems, and the anticipated magnitude of impacts associated with higher or lower levels of climate change (Meze-Hausken, 2008; Hallegatte, 2009; Briske *et al.,* 2010).

The range of adaptation options available to actors to achieve their objectives vary with actor capacities, social context and the dynamics of climate-environment interactions. Hence, a robust understanding of adaptive capacity is necessary to evaluate adaptation needs and options (Chapter 14) and the challenges associated with their implementation (Chapter 15). The manner in which actors frame adaptation and their objectives also influences adaptation processes. Much of the dialogue on adaptation has focused on incremental adaptation, wherein actors aim to make adjustments to management practice and behavior to secure status quo values and objectives (Garrelts and Lange, 2011). Such adaptation may include portfolios of responses as it may not be possible to completely ‘climate proof’ a system, making insurance or other support mechanisms important means of building resilience. However, some adaptations may lead to future constraints or limits by promoting the lock-in to a technology or fostering path dependence around a set of strategies, which can lead to maladaptation (Berkhout, 2002; Chhetri *et al.,* 2010; Barnett and O'Neill, 2010; Eriksen *et al.,* 2011). Hence, the adaptation discourse has recently expanded to consider more transformational framings of adaptation associated with fundamental changes in actors’ objectives or values to shift from a position of increasing vulnerability to one of increasing opportunity (Pelling, 2011; Stafford Smith *et al*., 2011; Kates *et al*., 2012; O’Neill and Handmer, 2012; Park *et al*., 2012).

To provide further background and context, this chapter proceeds by revisiting relevant findings on adaptation opportunities constraints and limits within the AR4 and the more recent IPCC *Special Report on Managing the Risks of Extreme Events and. Disasters to Advance Climate Change Adaptation* (SREX; IPCC, 2012a). The chapter then presents a framework for assessment adaptation, opportunities, and limits with an emphasis on explicit definitions of these concepts to facilitate assessment of current knowledge. Key components of this framework are assessed in turn in subsequent chapter sections including the synthesis of how these components are treated among the different sectoral and regional chapters of the AR5 WGII report. The chapter concludes with an assessment of the ethical implications of adaptation constraints and limits and a synthesis of what the adaptation literature suggests are pathways forward for research and practice to capitalize on opportunities, reduce constraints, and avoid limits.

16.1.1. Summary of Relevant AR4 Findings

The AR4 *Summary for Policymakers* of Working Group II concluded that there are "*formidable environmental, economic, informational, social, attitudinal and behavioural barriers to the implementation of adaptation*" and that for developing countries, "*availability of resources and building adaptive capacity are particularly important*" (IPCC, 2007b). As the AR4 did not have a chapter dedicated specifically to adaptation opportunities, constraints and limits, these findings were based primarily on Chapter 17, *Assessment of Adaptation Practices, Options, Constraints and Capacity* (Adger *et al*., 2007). The key conclusion from Adger *et al*. (2007), as relevant to this chapter, was as follows: "*There are substantial limits and barriers to adaptation (very high confidence)*". The authors go on to identify a range of barriers including the rate and magnitude of climate change, as well as constraints arising from technological, financial, cognitive and behavioral, and social and cultural factors. The authors also noted both significant knowledge gaps associated with adaptation and impediments to the sharing of relevant information to alleviate those gaps.

These findings were further evidenced by the sectoral, and particularly, regional chapters in the AR4 WGII report which also provided additional information regarding the similarities and differences among regions with respect to the manner in which opportunities, constraints, and limits manifest. For example, the chapters assessing impacts and adaptation in Africa, Asia, and Latin America collectively emphasize the significant constraints on adaptation in developing nations. For Africa, Boko *et al*. (2007) suggest there is evidence of an erosion of coping and adaptive strategies as a result of varying land-use changes and socio-political and cultural stresses. For Asia, Cruz *et al*. (2007) note that the poor usually have very low adaptive capacity due to their limited access to information, technology and other capital assets, making them highly vulnerable to climate change. For Latin America, Magrin *et al*. (2007) find that socio-economic and political factors seriously reduce the capability to implement adaptation options. Meanwhile, the chapter on Small Islands by Mimura *et al*. (2007) identify several constraints to adaptation that are inherent to the nature of many small islands including limited natural resources and relative isolation. Furthermore, global economic processes such as market liberalization, together with global warming, sea-level rise and possibly increased frequency and intensity of extreme weather events, make it difficult for autonomous small islands to achieve an appropriate degree of sustainability. For all of these regions, adaptation challenges are linked to governance systems and the quality of national institutions as well as limited scientific capacity and ongoing development challenges (poverty, literacy, and civil and political rights).

The AR4 also provided evidence that constraints on adaptation are not limited to the developing world. For example, Hennessy *et al*. (2007) find that while adaptive capacity in Australia and New Zealand has been strengthened, a number of barriers remain including tools and methods for impact assessment as well as appraisal and evaluation of adaptation options. They also note weak linkages among the various strata of government, from national to local, regarding adaptation policy and ongoing skepticism among some populations regarding climate change science. Similarly for North America, Field *et al*. (2007) identify a range of social and cultural barriers, informational and technological barriers, and financial and market barriers. The chapter on Europe also mentions the limits faced by species and ecosystems due to lack of migration space, low soil fertility and human interventions (Alcamo *et al*. 2007). Finally, in the chapter on the Polar Regions, Anisimov *et al*. (2007) note that indigenous groups have developed resilience through sharing resources in kinship networks that link hunters with office workers, and even in the cash sector of the economy. However, they conclude that in the future, such responses may be constrained by social, cultural, economic and political communities externally and from within.

A few other AR4 chapters assessed literature relevant to this chapter. Chapter 18 (*Inter-Relationships between Adaptation and Mitigation*; Klein *et al*., 2007) discusses the possible effect of mitigation on adaptation (an issue also considered by Working Group III, in particular by Fisher *et al*., 2007 and Sathaye *et al*., 2007). Finally, Chapter 19 (*Assessing Key Vulnerabilities and the Risk from Climate Change*; Schneider *et al*., 2007) outlines how the presence of adaptation constraints and limits is a contributing factor to vulnerability, possibly resulting in significant adverse impacts. Chapters that address similar themes also appear in the AR5, and cross-references are provided in this chapter to this more recent material as appropriate.

16.1.2. Summary of Relevant SREX Findings

The IPCC's SREX report assesses a broad array of literature on climate change, extreme events, adaptation, and disaster risk reduction and management. A central framing concept for the SREX was the assertion that (Lavell *et al.*, 2012; pg. 37),

> *" . .while there is a longstanding awareness of the role of development policy and practice in shaping disaster risk, advances in the reduction of the underlying causes – the social, political, economic, and environmental drivers of disaster risk – remain insufficient to reduce hazard, exposure, and vulnerability in many regions (UNISDR, 2009, 2011) (high confidence)."*

As reductions in vulnerability can arise from either capitalizing on opportunities, relaxing constraints or removing limits to adaptation, this assessment of the relevant SREX material focuses specifically on how the key findings of the SREX provide insights relevant to the treatment of opportunities, constraints and limits in this chapter.

With respect to opportunities, the linkages between development and disaster risk reduction provide a number of avenues for facilitating adaptive responses toward enhanced societal resilience to natural disasters and climate change. For example, the SREX highlights the benefits to disaster risk management if disaster risk is considered in national development planning and strategies to adapt to climate change are adopted (Lal *et al.*, 2012). The observed dependence of disasters at national and regional scales upon underlying patterns of development are indicative of the opportunities for increasing societal resilience through sustainable development. In particular, incorporating adaptation into multi-hazard risk management may be an effective strategy for the efficient integrated management of natural hazards and future climate risk (O'Brien *et al.*, 2012). Disasters provide potential opportunities for reducing future weather- and climate-related risk through disaster response and recovery processes (Cutter *et al.*, 2012). Capitalizing on this opportunity often necessitates careful planning for the staging of response efforts to ensure the demand for near-term recover does not jeopardize opportunities for enhanced resilience over the long-term. There may also be opportunities for enhancing international assistance for climate adaptation through more robust finance mechanisms for mainstreaming adaptation into disaster risk management and sustainable development (Burton *et al.*, 2012).

Despite the range of opportunities identified in the SREX, the report also provides extensive discussion of the potential constraints associated with enhancing disaster risk reduction and management as well as climate adaptation. In particular, ongoing development deficits as well as inequality in capacities in coping and adaptive capacities pose fundamental challenges to disaster risk management and adaptation (Cardona *et al.*, 2012). Although such challenges can propagate from the bottom up, the SREX notes that national systems and institutions are critical to the capacity of nations to manage the risks associated with climate variability and change (Lal *et al.*, 2012). Yet capacity at one scale does not necessarily convey capacity at other scales (Burton *et al.*, 2012). Even in the presence of robust institutions, however, rates of socioeconomic and climate change can interact to constrain adaptation. For example, O'Brien *et al.* (2012) note that rapid socioeconomic development in vulnerable urban areas can increase societal exposure to natural hazards while simultaneously constraining the capacity of actors to implement policies and measures to reduce vulnerability. For many regions, such socioeconomic change may be a greater contributor to vulnerability than changes in the frequency, intensity, or duration of extreme weather events and natural hazards. The navigation of these constraints by actors toward development objectives is challenged by a paucity of disaster data at the local level as well as persistent uncertainties regarding the manifestation of extreme events in future decades (Cutter *et al.*, 2012; Seneviratne *et al.*, 2012).

The SREX also cautioned that there natural hazards, climate change and societal vulnerability can pose fundamental limits to sustainable development. Such limits can arise from the exceedence of biophysical and/or societal thresholds or tipping points (Lal *et al.*, 2012; O'Brien *et al.*, 2012; Seneviratne *et al.*, 2012). Accordingly, the SREX concludes that adaptation actions must include not only incremental adjustments to climate variability and climate change but also transformational changes that alter the fundamental attributes of systems of value. Such transformation may be aided by actors questioning prevailing assumptions, paradigms, and management objectives toward the development of new ways of managing risk and identifying opportunities (O'Brien *et al.*, 2012)

16.2. A Framework for Assessing Adaptation Opportunities, Constraints and Limits

Intrinsic to any definition of "*dangerous anthropogenic interference with the climate system*" (UNFCCC, 1992) are assumptions about the capacity of biophysical systems, social groups and societies to adapt to climatic change. The UNFCCC refers specifically to adaptation of ecosystems, threats to food production and the sustainability of economic development. There is evidence that while there are opportunities to adapt to climate change impacts in all natural and human systems, those opportunities are not unlimited or may not all be adopted. Climate change impacts, acting together with other factors and pressures, are therefore likely to result in 'residual damage', even following adaptation (Smit and Wandel, 2006; Stern, 2007; de Bruin *et al*., 2009a; Patt *et al*., 2009). Residual damage comprises loss of components and/or functions of the affected system, and increasing residual damage may indicate increasing risk of transgressing an adaptation limit. It is the extent of residual damages (following adaptation) that define whether anthropogenic interference with the climate is considered dangerous. Biophysical and human systems may have the capacity to cope with low residual damages. If residual damages are acceptable or do not threaten, for instance, ecosystems and food production, then climate risks will not be deemed dangerous. Only when climate risks or damages are deemed unacceptable (See Section 16.7), or lead to undesired discontinuities in natural or human systems, will they be perceived as dangerous. If these risks and discontinuities have global-scale consequences, they can be linked to 'key vulnerabilities' to climate change (see Chapter 19). It is important to understand adaptation opportunities, constraints and limits in this broader context of risk and sustainable development.

There are different reasons why adaptation fails to avoid residual damages due to climate change. First, there may be a lack of opportunity to adapt. For instance, along some coasts there are few plausible options to respond to sea-level rise of over a meter in a century (Tol at al., 2008; Nicholls *et al*., 2011). Second, there may be constraints on the deployment of available adaptation options (see Section 16.4). For instance, there are a host of perceptual, economic and institutional factors that determine whether or not organizations in the private or public sectors choose to adapt to reduce potential vulnerabilities to climate change impacts (Ivey *et al*., 2004; Naess *et al*., 2005; Moser *et al*., 2008; Storbjork, 2010; Farley *et al*., 2011; Berrang-Ford *et al*., 2011; Berkhout, 2012). In particular, the costs of adaptation may be perceived to outweigh the uncertain future benefits to the adapting actor. Third, there may be biophysical, technical, economic or other limits to adaptation. For instance, there may be physiological limits to heat-tolerance of certain key crops, such as wheat and maize (IPCC, 2007a) , or a climate-related shock may precipitate a regime shift in an ecosystem providing valued services (Peterson, 2008). Likewise, there are technical limits to artificial snow-making in response to less reliable snow conditions for skiing (Scott and McBoyle, 2007), or there may be economic limits to the insurability of disaster risks (see Box 16-4). Opportunities, constraints and limits to adaptation therefore need to be considered along a dynamic continuum, together conditioning the capacity of natural and human systems to adapt to climate change. New opportunities may emerge through time, constraints may be loosened, and many, although not all, limits may be shifted or removed altogether.

Unfortunately, the existing scientific literature on opportunities, constraints and limits to adaptation does not present a mature set of definitions, nor a consistent conceptual framework. A number of different meanings are ascribed to the terms and these have also worked to confuse an important scientific and policy debate. The AR4 for example used the terms constraints, barriers, and limits interchangeably to describe general impediments to adaptation (Adger *et al*., 2007), and similar confounding of meaning is evident across the literature (de Bruin *et al*., 2009a; Biesbroek *et al*., 2009; O'Brien, 2009). Here we present a set of linked definitions of opportunities, constraints and limits to adaptation (see Box 16-1) that draw on a number of literatures, in particular vulnerability assessment (Füssel and Klein, 2006; Füssel, 2006) and risk assessment (Jones, 2001; NRC, 2010) as well as climate adaptation (Hulme *et al.,* 2007; Adger *et al.,* 2009b).

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Box 16-1. Definitions of Limits, Opportunities, and Constraints to Adaptation

Adaptation Limit: *A situation in which an actor's objectives and values can no longer be secured from unacceptable risks through adaptive action, or where biophysical limits mean that a key component, attribute or* *service of an ecosystem is lost*. A limit to adaptation means that no adaptation options exist, or an unacceptable measure of adaptive effort is required to secure social objectives and values, or for a species or ecosystem to survive in an unaltered state. Social objectives include, for instance, standards of safety (*e.g.,* 1 in 500 year levees) or safe drinking water supplies. Values include attributes such as social equity, cultural cohesion, and preservation of livelihood practices. Key attributes of biophysical systems might include reproductive success of keystone species, or the pattern of precipitation in a region. An adaptation limit is a threshold at which social objectives or valued ecosystem services *are lost or must be abandoned*. In this sense, an adaptation limit is marked by a discontinuity in social behavior, or in the loss of a valued ecosystem service. This concept of a limit is distinct from discussions of barriers, constraints or limitations to adaptation (see Section 16.4). While adaptation limits may have a technical or an economic basis, they are often perceived and experienced by actors as normative or ethical limits (see Section 16.7). For example, greater drought risk may be a contributory factor in agricultural land abandonment, but the dominant perception of the farmer will be about the loss of livelihood and a valued way of life. For natural systems limits to adaptation will typically signify destruction of a species or ecosystem which in turn plays a role in the loss of a valued ecosystem service. Actors may live with these risks because they are unable to change or unwilling to pursue transformative adaptations that involve fundamental changes in objectives (Stafford-Smith *et al.,* 2012.)

Adaptation Opportunity: *An adaptation opportunity is a set of conditions that makes it possible or easier for an actor to maintain or increase the security of social objectives, values, or key attributes of an ecosystem.* Adaptation opportunities create new potential for an actor to secure their existing objectives and values, or for a biophysical system to retain productivity or functioning. New circumstances, such as public or private interventions, may make it possible or easier to pursue successful adaptation. Adaptation opportunities are not the same as opportunities arising from climate change, which would commonly be referred to as potential benefits of climate change (see chapter xx) or adaptation options (see Chapter 14 for further discussion).

Adaptation Constraints: *Constraints to adaptation exist when an actor lacks capabilities or resources for managing climate-related risks to social objectives and values, or a biophysical system faces resource constraints in responding to climate-related pressures. Additional effort is needed to keep risks within an acceptable range.* Actors regularly accept some measure of risk to their objectives and values. Biophysical systems also have resources and strategies for responding to environmental variability and risks. Through adaptation they will seek to manage new climate-related risks and pursue opportunities. To the extent that they lack capabilities or resources to manage new climate-related risks, they face adaptation constraints. The needed capabilities or resources may be provided by other actors, or become available in the future. This definition also assumes that actor objectives and values remain unaltered.

_____ END BOX 16-1 HERE _____

In developing a framework for defining adaptation opportunities, constraints and limits, we start with a definition of the objectives of adaptation. Füssel (2007) argues that 'valued attributes' of vulnerable systems, including human lives and health; the existence, income and cultural identity of a community; and the biodiversity, carbon sequestration potential and timber productivity of a forest ecosystem are threatened by exposure to climate change hazards. Here we make a distinction between *social objectives* and *valued qualities* for social systems, while we define *key system attributes* for biophysical systems. Social objectives include standards of safety (*e.g.,* 1 in 500 year levees), economic development, and food security. Valued qualities include traits such as equity in governance, and cultural preservation and cohesion. Key system attributes include the reproductive success in a given population or ecological community.

Climate variability and change generates new risks to the provision of these objectives, qualities and attributes. Such risks are modified through adaptation. Adaptation is therefore viewed as a response aimed at managing risks to valued attributes in social or natural systems. Adaptation opportunities, constraints and limits can also be defined in terms of their impacts on risks to valued attributes as a result of climate-related hazards. Opportunities make it easier to reduce risks to valued attributes, constraints make it more difficult, and limits represent a threshold at which risks can no longer be held at an acceptable or sustainable level. We make a distinction between acceptable and unacceptable risks (to objectives, values qualities and key attributes). An unacceptable risk is the exceedence of a socially-negotiated norm (*e.g.,* for flood protection), standard (*e.g.,* cost, harm, equity, taste, aesthetics) or biophysical limit (*e.g.,* reproductive success of a keystone species) *despite adaptive action*.

Although they each have specific impacts on risks to valued attributes, adaptation opportunities, constraints and limits are also shaped by similar factors. In social systems they are products of social and environmental context, as well as an actor's capacities. These may be physical, technological, economic, institutional, legal, cultural, or environmental conditions (Adger *et al*., 2009b; Meze-Hausken, 2008; Moser and Ekstrom, 2010; Patt and Schröter, 2008; Yohe and Tol, 2002). Some limits are mutable or flexible such that while they restrict the current decision, they may be overcome with time. Many processes work to alter these flexible limits including research and development to support the availability of a new technology, review of governance to direct changes in legal/regulatory rules, or creation of funds to support adaptation actions. We contrast these mutable/flexible limits with a set of absolute limits that cannot be altered. Examples of absolute limits include water supply in fossil aquifers, the range of a species, limits to retreat on islands, loss of genetic diversity, or the tolerance of coral species to temperature and ocean acidity. Many of these absolute limits will also be irreversible such that failure of mitigation or adaptation efforts to avoid them will result in permanent changes.

Figure 16-1 provides a simplified schematic view of the relationships between options, constraints and limits. Where constraints are higher, adaptation may be less effective or efficient (Moser and Ekstrom 2010), there may be fewer options available or tradeoffs maybe greater (Kasperson *et al*., 1995), and in the face of limits, there are no options that do not require giving up an important goal.

[INSERT FIGURE 16-1 HERE
Figure 16-1: An actor's view of adaptation constraints and limits at a given point in time.]

16.3. Opportunities for Adaptation

We take an adaptation opportunity to be a set of conditions that create the potential for actors to advance social objectives and values or for key system attributes of ecosystems to be secured. An opportunity is distinct from an adaptation option, which is a specific means of achieving a social adaptation objective (such as an early warning system as a means of reducing vulnerability to tropical cyclones) or a strategy for securing a key ecological attribute (see Chapter 14.3.2 for discussion).We also do not consider here potential benefits of climate change. Previous literature has focused especially opportunities (and constraints) to adaptive capacity and adaptation in national and international policy contexts. The AR4 argues that public policy has a growing role in reducing vulnerability of people and infrastructure, providing information on risks for private and public investments and decision-making, and protecting public goods such as habitats, species and culturally important resources (Adger *et al*., 2007). Such roles include the provision of adaptation options, creating the enabling environment for adaptation options to be implemented and to ensure that spillovers and externalities associated with adaptation options are managed for the public good. In a similar vein, the IPCC SREX report argues that (IPCC, 2012b; pg. 9),

> *"National systems are at the core of countries' capacity to meet the challenges of observed and projected trends in exposure, vulnerability, and weather and climate extremes. Effective national systems comprise multiple actors from national and sub-national governments, the private sector, research bodies, and civil society including community-based organizations, playing differential but complementary roles to manage risk, according to their accepted functions and capacities."*

In relation to ecosystem resilience, there is also a clear role for public policy (Vignola *et al*., 2009). Here too, common themes include information, mainstreaming, dialogue and participation. Special emphasis is placed on the transfer of power to local communities for adaptation decision-making. Given the great variability in social and ecosystem vulnerability, and the importance of local conditions and capacities in responding to these climate-related risks, there is often a rationale for local governance of adaptation. On the other hand, local resources, capacities and authority may not be sufficient to enable certain adaptation options to be realized. Such discussions often neglect the important role of the private sector in facilitating adaptation (Tompkins and Eaking, 2012).

16.3.1. Opportunities for Implementing Adaptation

There is evidence of public policy activity at the national and regional level in many parts of the world (see, for example, Chapter 15 for a discussion of National Action Plans for Adaptation (NAPAs)). Assessments of climate adaptation policies in Europe (Biesbroek *et al*., 2010; Massey and Bergsma, 2008) and North America (Luers and Moser, 2006; Moser and Luers, 2008; Moser *et al.,* 2008) show that governments at different levels have clearly recognized the importance of climate change and their potential role in adaptation. Accordingly, more structured policy frameworks and mechanisms to build capacity and advance adaptation are evident (16.8). Nevertheless, clear strategies for the implementation of substantive policies to reduce vulnerability to climate change and, subsequently, evaluate success are still lacking (Berrang-Ford et al., 2011; Ford et al., 2011; Preston et al., 2011a).

One of the primary strategies for enabling adaptation by private actors and securing public goods, such as ecosystem services, is through 'mainstreaming' climate vulnerability and adaptation into public policies (Urwin and Jordan, 2008; Ahmad, 2009). Mainstreaming involves a series of normative, organizational and procedural strategies that attempt to raise the profile of climate change at different stages of the policy cycle and to embed consideration of climate change impacts and adaptation in decision-making and policy evaluation (Mickwitz *et al*., 2009; Rayner and Jordan, 2010). Mainstreaming is not without its challenges. For instance, there will be a question about whether 'principled priority' (Lafferty and Hovden, 2003) should be given to climate adaptation goals over other goals, such as economic development. There is also a question over the extent of the coordination between policy domains that may be necessary. While key sectoral policy makers may accept the necessity for adaptive actions to ensure delivery of policy objectives into the long-term and adjust policies accordingly, they may fail to coordinate with efforts of other sectors. The result may be piecemeal approaches (Ellison, 2010) or incoherent, conflicting strategies (Pittock, 2011). For example, enhancing infrastructure for irrigation in arid areas to allow water-intensive agriculture to continue could hinder adaptation in other sectors, such as nature conservation.

A number of proposals have been made for public policy strategies that enable adaptation in the face of deep uncertainty. Hallegatte (2009) describes five approaches to management decisions under conditions of uncertainty: "*…(i) selecting 'no-regret' strategies that yield benefits even in absence of climate change; (ii) favouring reversible and flexible options; (iii) buying 'safety margins' in new investments; (iv) promoting soft adaptation strategies, including (a) long-term (perspective); and (v) reducing decision time horizons*." By applying these principles, policymakers are can create the conditions for better adaptation decisions by public agencies and in the private sector. In a similar vein, Stafford Smith *et al.* (2011) propose a number of decision-making strategies for public policymakers, matching these strategies to the nature of uncertainty being faced in the decision. They argue for a precautionary approach, risk-hedging against alternative futures and 'robust decision making' (see Chapter 2) where appropriate. In general, a focus on risk and the importance of flexibility, consistency and predictability, transparency and accountability in decision-making is stressed (Maddocks, 2011). More procedural proposals for creating the enabling conditions for adaptation have also been made. These include taking account of the full range of adaptation options available (including apparently unattractive ones); making resources available for chosen options (singly or in portfolios) to be implemented; getting the institutional setting right in terms of incentives and penalties; making human and social capital available; enabling risk-spreading; and providing information allowing for good public understanding of stresses, risks and trade-offs (Moser and Luers, 2008).

16.3.2. Ancillary Benefits of Adaptation

Adaptation in response to climate change vulnerabilities can achieve important co-benefits. While adaptation activities have often been developed and implemented in an *ad hoc* fashion (Ahmed and Fajber, 2009), increasingly adaptation efforts capitalize on complementarities by linking mainstreaming adaptation within existing policies and management activities (See section 16.8). Although existing options provide a foundation to normalize adaptation (Dovers, 2009), it is important that the assessment and selection processes consider a range of stressors and management options, given the presence of uncertainty and need for adaptive management. This broader heuristic for sectoral decision-making may generate new opportunities for welfare enhancement.

Co-benefits may arise in three main ways – through improved implementation of adaptation to current climate variability; through exploiting new opportunities that arise as a result of the provision of climate adaptation goods and services; and through more general impacts on sustainable development.

- *Stimulating adaptation to current climate variability*: While it is generally assumed that physical, ecological and social systems are well-adapted to current climatic conditions; this is frequently not the case (Smit, 1993; Heyd and Brooks, 2009; Dugmore *et al*., 2009). Changes in observed climate, as well as the attention to such change, may lead currently maladapted actors and organisations to make changes that bring net benefits.
- *Provision of climate adaptation goods and services*: Adaptation will generally require additional investment and effort. It therefore represents an economic opportunity for some producers of goods and services. For example, the market for snow machines will be influenced by growing concerns about snow cover in more marginal ski resorts (Scott *et al*., 2006). In Arizona's high elevation, low latitude ski resorts by 2050, temperatures will likely exceed technical thresholds in the shoulder seasons meaning that in years when natural snowfalls are poor the ski season may be curtailed. Higher elevation regions will see new opportunities as a result of snow resort shifts (Bark *et al*., 2010). Likewise, new and innovative railway track and drainage systems may develop a market for dealing with track buckling caused by higher summer temperatures (Bark *et al*., 2010). The Stern Review suggested that huge market opportunities exist for new infrastructure and buildings resilient to climate change in OECD countries, with a potential value of between £9.5bn and £94.8bn per year (Stern, 2006). New services related to climate prediction and insurance are also likely to develop. Rising damage caused by climate change could provide new markets for innovative insurance products. Insurance can play an important role managing risks associated with climate-related damages (Botzen *et al*., 2009, 2010).
- *Advancement of sustainability*: Economic development policies and strategies related to management of water and governance of natural resources, the development of water, transportation, and communication infrastructure, and the promotion of credit and insurance services can promote economic development, increase adaptive capacity and reduce the impacts of climate change on the poor (Hertel and Rosch, 2010).

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Box 16-2. Ecosystem-Based Approaches to Adaptation - Emerging Opportunities

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

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

EBA provides opportunities particularly in developing countries where economies depend more directly on the provision of ecosystem services (Vignola *et al.,* 2009). In these settings, ecosystem-based adaptation projects may be readily developed by enhancing existing initiatives, such as community-based adaptation and natural resource management approaches (*e.g.,* Midgley *et al.,* 2012).

Examples of ecosystem based approaches to adaptation include:

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

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

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16.4. Adaptation Capacities and Constraints

There is *high agreement and robust evidence* that different actors, sectors, and geographic regions have differential capacities to adapt to climate variability and change, although those capacities can be difficult to measure (Tol *et al.*, 2008). Research regarding adaptive capacity to climate change dates to the mid- to late-1990s (Smit *et al.*, 2001), and the concept featured prominently in both the IPCC TAR and AR4 (Smit *et al.*, 2001; Adger *et al.*, 2007). Since the AR4, the literature on adaptive capacity and the various constraints on adaptation has deepened (Adger *et al.*, 2009b; Moser and Ekstrom, 2010). This literature continues to evolve along two pathways. The first focuses on adaptation constraints as generally discrete determinants that are often represented as tangible stocks of resources or capital that can be deployed in pursuit of adaptation (Yohe and Tol, 2002; Paavola, 2008; Osbahr *et al.*, 2010). As such, deficiencies in the availability of, or entitlement to, those resources constrain the planning and implementation of adaptation policies and measures. However, Adger *et al.* (2007) caution that high adaptive capacity in terms of resources for adaptation does not necessarily translate into vulnerability reduction. Hence, a second pathway focuses on adaptation constraints as dynamic processes involving complex interactions that may span multiple actors across different spatial or temporal scales. Such dynamic constraints mediate access to and the disposition of resources for adaptation. Each of these categories of constraints as well as specific examples are discussed further in the following sections. Nevertheless, it should be noted that adaptation in practice may be constrained by interactions among multiple constraints (Dryden-Cripton *et al.*, 2007; Smith *et al.*, 2008b; Moser and Ekstrom, 2010; Shen *et al.*, 2011; Section 16.4.6).

16.4.1. Discrete Constraints

16.4.1.1. Knowledge and Information

The generation and dissemination of knowledge regarding climate change and adaptive responses are important components of adaptation processes. The various types of knowledge most frequently examined in adaptation studies include a) information regarding future biophysical and socioeconomic states and associated uncertainties (Keller *et al.*, 2008; Moss *et al.*, 2010; Wilby *et al.*, 2009); b) information regarding adaptation options and their associated costs and benefits (Prato, 2008; de Bruin *et al.*, 2009b; Patt *et al.*, 2010); and c) information regarding the various constraints on, or limits to, the implementation of those options and how they can be ameliorated (Mitchell *et al*., 2006; Moser, 2009; Smith *et al*., 2008b; Moser and Ekstrom, 2010; Conway and Schipper, 2011). Although the pursuit of adaptation has been linked to education and awareness of climate change among actors (Deressa *et al*., 2011), the adaptation literature reflects different perspectives on the manner in which knowledge constraints adaptation. Adaptation practitioners and stakeholders continue to identify a deficit of information as a major constraint on adaptation (Adger *et al*., 2009b; Jones and Preston, 2011; Preston *et al*., 2011a). This is evidenced by surveys and case studies in both developed (Jantarasami *et al*., 2010; Gardner, 2010; see also Tribbia and Moser, 2008; Ford *et al*., 2011) and developing nations (Bryan *et al*., 2009; Deressa *et al*., 2009). Nevertheless, the AR4 concluded that knowledge in itself is not sufficient to drive adaptive responses (Adger *et al*., 2007). Recent literature has questioned the extent to which uncertainty and/or lack of information about future climate change is a constraint on adaptation (Hulme *et al*., 2009; Dessai *et al*., 2009; Wilby and Dessai, 2010). Other authors have also questioned the utility of vulnerability metrics and assessments for informing adaptation decision-making (Barnett *et al*., 2009; Preston *et al*., 2009, 2011b; Hinkel, 2011). Hence, the extent to which knowledge acts to constrain or enable adaptation is ultimately dependent upon how that knowledge is generated, shared and used to achieve desired adaptation objectives (Patt *et al*., 2007; Nelson *et al*., 2008; Tribbia and Moser, 2008; Moser, 2010).

16.4.1.2. Natural Resources

Constraints on natural resource supply and quality can significantly constrain the adaptation measures that are available as well the cost and effectiveness of those measures (Barnett and Adger, 2007). This constraint is particularly relevant in developing nations and small island states where livelihoods are closely linked to ecosystem services. Since the AR4, a number of livelihood analyses in different regional and sectoral contexts have explored the role of access to natural capital and resources in influencing vulnerability and the capacity to adapt to climate change (Paavola, 2008; Thornton *et al*., 2008; Iwasaki *et al*., 2009; Badjeck *et al*., 2010; Nelson *et al*., 2010a,b). A particular focus in the literature is on risk to water resource security. For example, demand for fresh water for human consumption is increasingly encroaching upon the sustainable yield of surface and groundwater systems in a number of global regions (Shah, 2009). As a consequence, such systems have reduced flexibility to cope with reductions in water supply. This in turn influences the effective portfolio of adaptation actions that can be implemented and, subsequently, agriculture and food security (Hanjra and Qureshi, 2010). The degradation of resource quality is another source of constraints on adaptation to climate change (Côté and Darling, 2010). Non-climatic stresses to ecological systems can reduce their resilience to climate change as evidenced by studies on coral reefs and marine ecosystems, tropical forests, and coastal wetlands (Malhi *et al*., 2009a,b; Diaz and Rosenberg, 2008; Kapos and Miles, 2008; Afreen *et al*., 2011). Ecological degradation also influences the goods and services provided by those systems to humans (Nkem *et al*, 2010; Tobey *et al*., 2010). For example, degradation of coastal wetlands and coral reef systems may reduce their capacity to buffer coastal systems from the effects of tropical cyclones (Das and Vincent, 2009; Tobey *et al*., 2010; Gedan *et al*., 2011; Keryn *et al*., 2011; Box 16-2). Meanwhile, soil degradation and desertification reduce crop yields and the resilience of agricultural and pastoral livelihoods to climate stress (Iglesias *et al*., 2011; Lal, 2011). These consequences of degraded natural capital reduce coping capacity and resilience and thus can increase the demand for adaptation.

16.4.1.3. Financial Resources

Constraints on the capacity to finance priority adaptation measures are widely recognized as a potential impediment to adaptation. At the international scale, despite the development of a number of mechanisms to finance financing adaptation in developing nations, the demand for adaptation finance is significantly larger than the current availability of resources represented through these funds (Flåm and Skjærseth, 2009; Hof *et al*., 2009). Furthermore, the challenge of developing a framework for the equitable and effective allocation of adaptation funds to developing nations is non-trivial (Barr *et al*., 2010; Smith *et al*., 2009b). Alternative funding mechanisms such as overseas development assistance (ODI) have been discussed as ways of subsidizing the adaptation funds, yet the reallocation of ODI may undermine adaptive capacity by diverting resources away from programs and projects targeting development goals (Ayers and Huq, 2009). A range of finance challenges have been identified at other scales. Investigations of farming communities in Africa, for example, have identified finance as a key determinant of vulnerability and adaptive capacity of farmers to climate variability and change (Nhemachena and Hassan, 2007; Hassan and Nhemachena, 2008; Deressa *et al*., 2009, 2011). Such case studies often examine the issue of finance as just one component of a broader livelihoods framework (Paavola, 2008; Osbahr *et al*., 2010). Meanwhile, despite traditional assumptions regarding the high adaptive capacity of developed nations, institutions in such nations may still face challenges in funding adaptation measures, although financial constraints are often discussed in the broader context of resource limitations (Jantarasami *et al*., 2010; Moser and Ekstrom, 2010). Jantarasami *et al*. (2010) observe that staff from federal land management agencies identified resource constraints as a key barrier to adaptation. Similarly, surveys and interviews with state and local government representatives in Australia indicate that the costs of investigating and responding to climate change are perceived to be significant constraints on adaptation at these levels of governance (Gardner *et al*., 2010; Smith *et al*., 2008b; Measham *et al*., 2011).

16.4.1.4. Technology and Infrastructure

The adaptation literature recognizes technology as a critical driver of and constraint on both adaptation to climate change as well as economic development and sustainability more broadly (UNFCCC, 2006; Adger *et al*., 2007). The AR4 noted the role of technology in contributing to spatial and temporal heterogeneity in adaptive capacity and the potential for technology to constrain adaptation or create opportunities (Adger *et al*., 2007). Meanwhile, the economics literature indicates that impacts to existing infrastructure and the needsfor new infrastructure to manage emerging climate risks dominate adaptation costs (see Chapter 17, World Bank, 2006; Nicholls, 2007; UNDP, 2007; UNFCCC, 2007; Parry *et al*., 2009). Technology and infrastructure have been identified as one factor associated with the so called ‘adaptation deficit’ of particular regions and sectors (Burton 2004, 2005; Burton and May 2004). Key considerations with respect to technology and infrastructure include a) availability; b) access (including the capacity to finance, operate and maintain); c) acceptability to users and affected stakeholders; and d) effectiveness in managing climate risk (Adger *et al*., 2007; Dryden-Cripton *et al*., 2007; van Aalst *et al*. 2008). The adaptation literature explores these issues in the context of specific sectors, particularly agriculture, water resources management and coastal management (Howden *et al*., 2007; Bates *et al*., 2008; van Koningsveld *et al*., 2008; Parry *et al*., 2009; Zhu *et al*., 2010). For example, Howden *et al*. (2007) note the importance of technology options for facilitating adaptation including applications of existing management strategies as well as introduction of innovative solutions such as bio- and nanotechnology (see also Hillie and Hlophe, 2007; Bates *et al*., 2008; Fleischer *et al*., 2011;). Several studies from Africa have explored how different factors drive awareness, uptake and use of adaptation technologies for agriculture (Nhemachena and Hassan, 2007; Hassan and Nhemachena, 2008; Deressa *et al*., 2009, 2011). Meanwhile, Nicholls (2007) and van Koningsveld *et al*. (2008) note the range of technologies that have been deployed for managing coasts and sea-level rise. While such literature identifies adaptation technologies and in some cases the costs of their implementation, quantitative understanding of the extent to which technology will enhance adaptive capacity (Piao *et al*., 2010).

16.4.1.5. Human Resources

The effectiveness societal efforts to adapt to climate change are dependent upon the humans who are the primary agents of change. Hence, human resources provide the foundation for intelligence gathering, the uptake and use of technology, as well as leadership regarding the prioritization of adaptation policies and measures and their implementation. Although the AR4 and subsequent adaptation literature identify human resources as one of the factors influencing adaptive capacity (Adger *et al*., 2007), there has been little attention given specifically to human resources as a constraint on adaptation by adaptation researchers. Rather the literature mentions human resources in two principle contexts. First, it highlights the linkages between the development of human resources and adaptive capacity more broadly. For example, Ebi and Semenza (2008) treat human resources as part of the portfolio of resources that can be harnessed to facilitate adaptation in the public health arena. A number of recent studied call attention to the role of leadership in enabling or constraining organisational adaptation (Gupta *et al*., 2010; Tompkins *et al*., 2010; Termeer *et al.,* 2012; van der Berg *et al*., 2010). Murphy *et al*. (2009) discuss the emergence of institutions to build human resources in the climate change arena, including expanded higher education opportunities to build climate expertise as well as professional societies. Second, the literature highlights the finite nature of human resources as a need to prioritize adaptation efforts including the extent of engagement in participatory processes (van Aalst *et al*., 2008) as well as the selection of adaptation actions for implementation (Millar *et al*., 2007).

16.4.2. Dynamic Constraints

16.4.2.1. Framing of Adaptation

Adaptation processes are influenced by the manner in which individuals and institutions perceive climate change risks and the mental models employed to structure decision-making regarding adaptation. Several studies point to differences between risk perception and problem definition at the individual level versus at the organizational level (Patt and Schröter, 2008). For example, Wolf *et al.* (2010) find that elderly individuals in the UK generally have low perceptions of their own vulnerability to heat waves, and Whitmarsh (2008) finds that perceptions of climate risk were mediated indirectly through individual, environmental values rather than through overt experience with climate impacts. However, van der Berg *et al.* (2010) note that drivers of climate adaptation in nine Dutch municipalities had little to do with risk perception, but rather was driven by local leadership and normative motivations to take action. Framing also influences the manner in which actors pursue adaptation including preferred adaptation options and the timing of their implementation (Kuruppu and Liverman, 2011). Pielke (2005) notes that institutional definitions of climate change have had significant implications for adaptation policy and the eligibility of adaptation efforts to receive funding through mechanisms such as the Global Environment Facility (GEF). A number of authors have observed that methods for the assessment of vulnerability and adaptation have changed over time and different methods lead to different understandings of vulnerability and appropriate adaptation (Füssel and Klein, 2006; Jones and Preston, 2011; Preston *et al.,* 2011b). Such challenges are prompting research into the characteristics, evolution and implications of different framings of adaptation (McGray *et al*., 2007; McEvoy *et al*., 2010; Fünfgeld and McEvoy, 2011) as well as efforts to map relations between adaptation and associated concepts like vulnerability and resilience (Cork, 2010; Gallopin, 2006; Miller *et al*., 2010; O'Brien *et al*., 2007; Young, 2009). Concerns have been raised that framing adaptation in terms of available or dominant tools, paradigms and institutions such as climatic predictions, risk management and economic development, may obfuscate the need for and desirability of alternative approaches (Eriksen and Brown, 2011; Eriksen *et al*., 2011; Hulme *et al*., 2009; O'Brien *et al*., 2007; Pelling, 2011). Perceptions of what the goal of adaptation is, what constraints obstruct its realization, and what constraints may be inadvertently created by certain adaptation efforts, are also products of how adaptation is framed (Fünfgeld and McEvoy, 2011).

16.4.2.2. Rates of Change

There is *high agreement, robust evidence* that future rates of global change will have a significant influence on the demand for and costs of adaptation. Since, the AR4, new research has confirmed the commitment of the Earth system to future warming (Lowe *et al*., 2009; Armour and Roe, 2011) and elucidated a broad range of tipping points or ‘key vulnerabilities’ in the Earth system that would result in significant adverse consequences should they be exceeded (Lenton *et al*., 2008; Rockström, 2009; Chapter 19). While the specific rate of climate change to which different ecological communities or individual species can adapt remains uncertain (Section 16.5), there is *high agreement, robust evidence* that more rapid rates of change constrain adaptation of natural systems (Hoegh-Guldberg, 2008; Gilman *et al*., 2008; Allen *et al*., 2009; Lemieux *et al*., 2011; Maynard *et al*., 2008; Malhi *et al*., 2009a,b; Thackeray *et al*., 2010), particularly in the presence of other environmental pressures (Brook *et al*., 2008). Rapid socioeconomic change, including economic development and technological innovation and diffusion, can enhance adaptive capacity, but can also pose constraints to adaptation. Globally, rates of economic losses from climate extremes are doubling approximately every one to two decades due to increasing human exposure (Pielke *et al*., 2008; Baldassarre *et al*., 2010; Bouwer, 2011; Munich Re, 2011; IPCC, 2012a). These trends are projected to continue in future decades (Pielke *et al*., 2007; Montgomery, 2008; O’Neill *et al*., 2010; UN, 2011; Preston, submitted). In addition, larger populations can lead to greater resource consumption, which can constrain adaptation in regions that are resource-limited. Global trends toward population aging can increase vulnerability by increasing net population sensitivity to climate extremes (O’Brien *et al*., 2008; Wolf *et al*., 2010; Bambrick *et al*., 2011). The adaptation literature also suggests that successful adaptation will be dependent in part upon the rate at which institutions can learn to adjust to the challenges and risks posed by climate change and implement effective responses (Adger *et al*., 2009b; Moser and Ekstrom, 2010; Stafford Smith *et al*., 2011).

16.4.2.3. Governance and Institutional Arrangements

Governance and institutional arrangements, though needed to enable adaptation, can act as potential constraints. Decision-making is often undertaken within a context of multi-level governance including governmental administration at local to international as well as market actors and non-governmental organizations (*e.g.,* Rosenau, 2005). As a result, coordination among actors is important for facilitating adaptation decision-making and implementation. Studies of the development of adaptation planning and policy at different levels of governance largely center on case studies (*e.g.,* van Nieuwaal *et al.,* 2009; Hunt and Watkiss 2011), often by level or issue (*e.g.,* Gagnon-Lebrun and Agrawala, 2006; Swart *et al*., 2009; Keskitalo, 2010; Biesbroeck *et al.,* 2010; Ford and Berrang-Ford, 2011; Preston *et al.,* 2011a; Corfee-Morlot *et al.,* 2009). Multi-level governance of adaptation is challenged by the different regulatory and legal systems – including differing levels of decentralization – that exist across different geopolitical scales as well as differential authorities and power relationships. As national and subnational governments have the ability to establish legislatively binding policy directives, adaptation to climate change cannot entirely be determined or steered from local level, but will be dependent on legislation and often also policy at higher levels (Measham *et al*., 2011; Westerhoff *et al.,* 2011; Box 16-3). A study of adaptation policy initiatives in the UK, Sweden, Finland and Italy showed that central governments may play a significant role in supporting the development of adaptation policies at the local level. Pittock (2011) notes, however, that national policies for water management can impede rather than enable adaptation (see also Urwin and Jordan, 2008). In cases where there is limited top down leadership on adaptation, less centralized state structures could create opportunities for local initiatives (Keskitalo, 2010; Measham and Preston, 2012). In addition, in some cases in the EU region, EU investments have enabled local actions on adaptation even in the absence of funding by EU member states (Keskitalo, 2010). McDonald (2011) also notes that bodies of law may not be adequate for addressing adaptation challenges. For example, the need for adaptation may create new challenges for the complex multi-national governance of transboundary resources, particularly where there are ongoing disputes or conflicts (see Section 16.4.4). To include the relevant scope of institutions and social actors in adaptation strategies, it has been noted that communication and coordination between different groups is important (van Nieuwaal *et al.,* 2009; Grothmann, 2011,). While some attention has been given quite recently to role of the private sector in adaptation governance (CDP, 2012; Taylor *et al*. 2012; Tomkins and Eakin, 2012), adaptation research and practice to date has largely focused on the public components of governance.

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Box 16-3. Constraints on Adaptation in Australian Local Governments: A Case Study of Sydney, Australia

A study of adaptation among coastal local governments in Sydney, Australia identified a number of constraints on local adaptation associated with organizational capacities, the structure of Australian governance, and the role of science and assessment in supporting local decision-making. The study rationale and methodology was based on an acceptance that climate adaptation is an uncertain and complex policy challenge, which thereby creates a need for participatory approaches (Smith *et al*., 2008b). The study was organized around three stages including: (i) mapping local government vulnerabilities; (ii) participatory systems modeling and prioritization of adaptation opportunities and constraints; and (iii) an institutional analysis of adaptive capacity and multi-criteria assessment of potential options for overcoming adaptation constraints (Smith *et al*., 2008b). While the vulnerability mapping highlighted the challenges associated with changing climatic and socioeconomic conditions in Sydney, subsequent discussions with stakeholders revealed gaps in local government knowledge about climate risk as well as the potential difficulty in operationalizing abstract concepts such as adaptive capacity within existing local government practice (Preston *et al*., 2008; Preston *et al*., 2009). The three most commonly-cited constraints on local government adaptation included (i) perceptions, expectations, and behaviors of residents; (ii) challenges in managing community infrastructure; and (iii) the inadequacy of planning frameworks for local adaptation (Smith *et al*., 2008a). In particular, infrastructure and planning processes within local government are closely linked to state government legislation and investment priorities. Therefore, while local government can pursue capacity building activities unilaterally (e.g., community education and intelligence gathering), more substantive policy reforms for adaptation must be sanctioned by State government (Smith *et al*., 2008b). The study also revealed that adaptation is a fairly new consideration for this level of governance, particularly relative to greenhouse gas mitigation (Smith *et al*., 2008b; Measham *et al*., 2011). Furthermore, the perception within local government of climate change being an environmental issue has led to it being compartmentalized within the environmental departments of local government. Collectively, the study suggests the need for both ongoing social learning about climate change and adaptation as well as concerted and coordinated efforts among local and state government to develop adaptive policy responses (Yuen *et al*., 2012; Smith *et al*., 2008b).

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16.4.2.4. Social and Cultural Dimensions

Adaptation can be constrained by social and cultural factors which are based on, and correspond with, broader held ideals of how a society should function and what is valued (Hartzell-Nichols, 2011; Moser and Ekstrom, 2010; O'Brien, 2009; O'Brien and Wolf, 2010). Values underlie practices, beliefs and worldviews and are the normative dimension of adaptation (O'Brien, 2009). New studies on these constraints since the AR4 have focused on communities (Kuruppu, 2009; Nielsen and Reenberg, 2010) or specific groups such as farmers (Codjoe *et al*., 2011; Patt and Schröter, 2008) and the elderly (Wolf *et al*., 2009). These studies demonstrate that existing social and cultural norms have a major role in determining what kind of adaptation can take place, when and by whom. Such norms include gender roles and identity, traditionally acceptable livelihoods, caste, land ownership systems and religion which can hinder adaptive actions at individual, household and community levels (Ahmed and Fajber, 2009; Bryan *et al*., 2009; Jones and Boyd, 2011). Women in particular are often constrained by social practices such as not being able to own land and lack of access to decision-making structures (Jones and Boyd, 2011) and hazard information (Ahmed and Fajber, 2009). Cultural constraints include lack of oral history of disasters and risks, a prominent phenomenon in developed countries where highly vulnerable environments are built upon without adequate understanding of the landscape and its history (Heyd and Brooks, 2009). The lack of perception of vulnerability has left for example elderly people unprepared for heatwaves in the UK (Wolf *et al*., 2009). Social constraints can come in the form of governance arrangements which, for example, in the Arctic constrain individual's and communities' hunting and fishing practices and adaptation opportunities (Loring *et al*., 2011; Section16.4.2.3).

Religious beliefs can constrain adaptation as they reduce the perceived necessity and opportunities for adaptation while contributing to increase in vulnerability. In Kiribati, for example, constraints have emerged through religious institutions that have placed extensive financial commitments on their members, which has displaced individual agency to undertake adaptation as resources are spent on the collective 'good' (*e.g.,* church buildings) (Kuruppu, 2009). In both Kiribati and Zanzibar, natural hazards are viewed as events controlled by God to which nothing can be done (Kuruppu and Liverman, 2011; Mustelin *et al*., 2010). In Tuvalu, God is attributed responsibility to take care of the people (Mortreux and Barnett, 2009) while in Ecuador, some religious groups believe that even the impacts accruing from natural hazards are dictated by God (Schipper, 2008). In Mozambique, attributing disasters to supernatural forces, such as God, angry ancestral spirits or witches reinforces existing power structures and social control (Artur and Hilhorst, 2012). Further ethnographic explorations are needed at local level to better grasp how and to what extent global climatic processes alter culture, values, and identity (Crate, 2011). Improved understanding is also needed how gender, religious beliefs and land-use and rights can decrease vulnerability and enable individual, household and community adaptation.

16.4.2.5. Monitoring and Evaluation

The AR4 provided little discussion of the role of monitoring and evaluation (M&E) of adaptation responses as a component of building adaptive capacity (Adger *et al*., 2007). Nevertheless, adaptation guidance, such as the guidelines for the preparation of National Adaptation Programmes of Action (UNFCCC, 2002), the United Nations Development Programme's *Adaptation Policy Framework* (Lim *et al*., 2005), and a range of climate change risk management frameworks (Jones *et al*., 2001; Willows and Connell, 2003; NZCCO, 2004a,b; AGO, 2006; US AID, 2007; World Bank, 2008) all emphasize the importance of M&E for adaptation planning and implementation. The ability to implement adaptation policies and measures that achieve objectives is dependent upon the capacity of actors to develop robust adaptation practice through learning from policy successes and failures (GIZ, 2011a, b). Nevertheless, the long time scales associated with climate change and adaptation responses as well as uncertainty about the future pose significant challenges for evaluating success (GIZ, 2011b), particularly when there is a lack of consensus with respect to adaptation objectives (de França Doria *et al*., 2009; Osbahr *et al*., 2010). Recent evidence suggests adaptation guidance on M&E is increasingly being translated into practice (GIZ, 2011a,b). However, Preston *et al*. (2011a) argue that adaptation M&E is more advanced in the developing world due to the close linkages between adaptation and development assistance, which has a long history of M&E. In contrast, the limited evidence from developed nations suggests that many organizations have yet to engage on adaptation (Wheeler, 2008); have yet to turn adaptation planning into practice (Berrang-Ford *et al*. 2011; Ford *et al*., 2011); or are limiting adaptation actions to capacity building efforts (Preston *et al*., 2011a). Yet, the UK (2008) Climate Change Act and U.S. Executive Order 13514 (CEQ, 2011) contain reporting provisions with respect to adaptation planning and implementation. This suggests that the policy foundation for M&E in developed nations is emerging, but additional development of objectives, methods, and metrics for M&E will be required.

16.4.3. Generic versus Context-Specific Constraints

Many of the adaptation constraints identified in Section 16.4.1 and 16.4.2 are common to multiple regions, sectors and communities. Internationally, awareness of, and investments in, climate adaptation have generally lagged those associated with greenhouse gas mitigation (Pielke *et al*., 2007; Wheeler *et al*., 2008; Measham *et al*., 2011). The availability of and access to information on future climate change (See Section 16.4.2.2), vulnerability and risk remains challenging for some institutions and stakeholders in both the developing and developed world, with adverse implications for progressing adaptation (Tribbia and Moser, 2008; Preston and Kay, 2010; Campbell-Lendrum and Woodruff, 2010; Tarnoczi and Berkes, 2010; Ziervogel *et al*., 2010). The adaptation literature indicates that the costs of adapting to future climate change will be significant (see Chapter 17) for both the developed and developing world, and would be higher given faster rates and/or higher magnitudes of climate change (Pittock, 2006; Joos and Sphani, 2008; Kriegler *et al*., 2008; Lenton *et al*., 2008; Lowe *et al*., 2009; Smith *et al*., 2009a). Yet financial resources for adaptation are finite, necessitating reallocation of existing resources (Collier *et al*., 2008; von Braun, 2009; Mechler *et al*., 2010; Beckman, 2011), the pursuit of 'low' or 'no regrets' adaptation measures (Heltberg *et al*., 2008), and the development of innovative financing mechanisms (Müller, 2008). Institutional weaknesses and complex systems of governance are a common constraint on the timely and effective delivery of adaptation solutions (see Section 16.4.2.3; Adger *et al*., 2009b; Smith *et al*., 2009b; Bisaro *et al*., 2010; Burch *et al*., 2010; Jantarasami *et al*., 2010; Pidgeon and Butler, 2011). Despite some degree of universality with respect to these constraints, the manner in which they manifest is context dependent and thus varies among sectors, regions, actors, as well as spatial and temporal scales (16.4.4). Therefore, one must be cautious in applying generic assumptions regarding adaptation constraints in assessments of vulnerability and adaptive capacity or in the identification of appropriate adaptation responses (Adger and Barnett, 2009; Barnett and Campbell, 2009; Mortreux and Barnett, 2009). The recent adaptation literature suggests significant work remains in understanding such context-specific determinants of vulnerability and adaptive capacity (Tol and Yohe, 2007; Smith *et al*., 2010; Hinkel *et al*., 2011; Preston *et al*., 2011b) and in effectively using the diversity of knowledge gained from the multitude of available case studies to facilitate adaptation more broadly.

16.4.4. Constraints across Spatial and Temporal Scales

Despite a strong emphasis in the adaptation literature on place-based adaptation, adaptation can be constrained by processes that transcend multiple spatial scales (Adger *et al*., 2005; Eakin *et al*., 2009; Adger *et al*., 2009a; Preston and Stafford Smith, 2009). International efforts to reduce greenhouse gas emissions, for example, influence the magnitude and rate of change in climate at national, regional, and local scales (see Section 16.5.4). Adaptation constraints can also propagate from the bottom up. For example, global food commodity prices increased sharply in 2006–2008 and again in 2010–2011 due in part to the impacts of extreme weather events on food producing regions.

The resulting global increase in food prices benefited some producers in developed nations, but undermined food security in developing nations (FAO, 2011). The bulk of the literature on adaptation and spatial scales, however, focuses on climate impacts and adaptive responses that pose trans-boundary challenges, such as water resources management in multi-national river basins (Iglesias *et al*., 2007; Goulden *et al*., 2010; Huntjens *et al*., 2010; Krysanova *et al*., 2010; Timmerman *et al*., 2011; Wilby and Keenan, 2012).

Constraints on adaptation can also transcend temporal scales. Development of water management and allocation systems in both Australia and the U.S. Southeast occurred during periods of relatively favorable rainfall (Jones, 2011; Pederson, 2012), resulting in systems that have been challenged to cope with persistent drought in recent decades. Similarly, Libecap (2011) suggests that water infrastructure developed in the U.S. West in the late-19th and early 20th centuries has resulted in path dependence that constrains management choice regarding water allocation in the present. Cherti *et al*. (2010) suggest similar challenges may exist for the U.S. agricultural industry in the future due to constraints on farmers' capacity to alter management practices and technology in response to a changing climate. Preston (submitted) illustrates how the continuation of historical patterns of U.S. population growth and wealth accumulation will contribute to significant increases in future societal exposure to extreme events and associated economic losses. Attempts to rectify such path dependence come at significant costs. For example, the Australian Government has committed AUS$3.1 billion to purchase water entitlements in an attempt to restore water usage in the Murray Darling basin to sustainable levels (Commonwealth of Australia, 2010).

16.4.5. Constraints and Competing Values

Constraints on adaptation arise from the fundamental values of actors within society, conflicts among values, and the trade-offs associated with prioritizing adaptation objectives (Haddad, 2005; UNEP, 2011). For some actors, investments in climate adaptation, particularly over the near-term, represent an opportunity cost (Tomkins and Eakin, 2012). At international scales, for example, deliberation over how the adaptation needs of least developed countries will be financed has become central to the UNFCCC policy agenda (UNFCCC, 2007; Ayers and Huq, 2009; Dellink *et al*., 2009; Flåm and Skjærseth, 2009; Denton, 2010; Patt *et al*., 2010). Yet the extent to which the developed world bears responsibility for compensating the developing world for climate impacts has been a contentious issue (Hartzell-Nichols, 2011). Even at local scales, Measham *et al*. (2011) report that some Local Government stakeholders in Australia find it difficult to elevate adaptation on the policy agenda given other responsibilities and the absence of a legislative mandate. The real or perceived trade-offs associated with adaptation may vary depending on actors' objectives and underlying values (Haddad, 2005; UNEP, 2011; Table 16-1). Such trade-offs may result in some actions being simultaneously perceived as adaptive and maladaptive (Bardsley and Hugo, 2010), depending on the perspective of stakeholders. Alternatively, whether an adaptation option represents an opportunity or a constraint may depend upon the manner in which it's implemented (see Box 16-4 for a discussion in the context of insurance). Recognizing the potential for values conflicts to constrain adaptation, researchers and practitioners have advocated for so-called 'no regrets' or 'low regrets' adaptation strategies (Heltberg *et al*, 2009). However, Preston *et al*. (2011a) suggest such no regrets actions may reduce investments in more substantive adaptations necessary to protect highly vulnerable systems or avoid irreversible consequences. Meanwhile, Adger *et al*. (2009a) question whether incremental adaptation is sufficient to avoid consequences that directly impact human values and cultural identities that cannot be readily compensated. Addressing such risks through adaptation may necessitate deliberation among stakeholders regarding adaptation objectives and the manner in which competing or conflicting values can be reconciled to achieve outcomes (de Bruin *et al*., 2009b; McNamara *et al*., 2009, 2011; UNEP, 2011).

[INSERT TABLE 16-1 HERE
Table 16-1: Examples of potential trade-offs among adaptation objectives.]

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Box 16-4. Opportunities, Constraints, and Limits to Insurance for Adapting to Climate Change

The insurance sector provides coverage for a considerable part of weather-related damage, principally covering wind-related damage and, to varying degrees, flood risks in developed countries. Insurers have experienced steadily increasing losses from natural disasters during the last decades (Munich Re, 2012) as a result of rapid increases in exposure, and these losses may in the future also increase as a result of climate change (IPCC, 2012a). Several studies have assessed the risks and opportunities for the insurance sector associated with climate change (Vellinga *et al.*, 2001; Dlugolecki, 2000, 2008; Mills, 2005, 2009; Kunreuther and Michel-Kerjan, 2007; Daily *et al.*, 2009; Botzen *et al.*, 2010).

Insurance against extreme weather events can be an important instrument for adapting to some of the consequences of climate change. Insurance can help an individual homeowner adapt to more extreme weather events by spreading these risks, although this comes at a cost of paying higher insurance premiums. However, on a macro (societal) level, risk spreading does not reduce aggregate risks, and additional incentives and policies need to be put in place to achieve adaptation through risk reduction. Insurance arrangements can, in theory, provide policyholders with pricing incentives for reducing their exposure and vulnerability to natural hazards (Botzen at al., 2009), although there are few successful examples of such systems in practice (Warner *et al.*, 2009). Incentivizing actions through price requires charging the full technical rate for the risk, without the inherent subsidization of those at greater risk and price regulation that is a feature of many insurance systems, such as hurricane insurance in the USA (Kunreuther *et al.*, 2011).

The experience of the insurance sector in modelling the costs of weather risks will be employed to determine whether those risk costs have altered, potentially as a result of climate change. The insurance sector mostly writes annual contracts, giving the insurer flexibility to raise premiums, or reduce coverage in the face of evidence for an increase in risk, although this freedom may be constrained in practice by the inherent ‘societal contract’ for insurers to serve consumer interests. For example, in situations where insurance has been withdrawn or rates have increased, as after the 2004-2005 hurricane season in Florida, insurers have found themselves under significant political and regulatory pressure (Grace and Klein, 2009). On the demand side, the ability of insurers to raise premiums is constrained by consumers’ willingness-to-pay for insurance (Botzen and van den Bergh, 2012).

There are clear limits to the use of insurance for all situations where climate change is altering risks of extreme weather events. On a local level, insurability of properties will be impaired if it becomes certain that large damages will occur more frequently as a certain result of sea level rise. In free market situations, insurance may be withdrawn for those at greatest risk, which may leave them unable to obtain mortgages. This happened in parts of Grand Bahama for flood insurance (IPCC, 2007a). Where levels of risk are rising, the option to break the insurance contract may be asymmetric, as the insured may be unable to find a replacement insurer. On a more aggregate level, climate change may increase the ‘fat tails’, and correlation between tails, of natural disaster loss distributions (Kousky and Cooke, 2009), requiring the purchase of additional reinsurance or alternative risk transfer instruments at relatively high cost (Charpentier, 2008). Public-private insurance arrangements in which the government provides some form of coverage against the extreme part of risk may be a solution, even though existing schemes do not provide adequate incentives for risk reduction because, for reasons of social risk sharing, premiums are not risk-based (Paudel *et al.*, 2012). Several government-backed insurance systems, such as for flood insurance in the US, are already in persistent debt (Michel-Kerjan, 2010), and currently there is little appetite for financing disaster insurance from public budgets. In summary, while insurance can support climate change adaptation, it does so at a cost to the property owner and has limits of insurability that are already being tested and exceeded. An important condition for insurance to contribute to adaptation is that it provides adequate incentives for risk reduction and should be embedded in broader adaptation policies that limit natural disaster risks.

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16.4.6. Interactions among Constraints

Deconstruction of adaptation constraints into discrete factors assists with their identification and diagnosis, but, such constraints rarely act in isolation. Rather actors are challenged to navigate multiple, interactive constraints in order to achieve a given adaptation objective (Adger *et al*., 2007, 2009; Smith *et al*., 2008b; Jantarasami *et al*., 2010; Moser and Ekstrom, 2010). For example, while the cost of adaptation is frequently cited as a constraint on action, cost is a function of rates of climate change and greenhouse gas mitigation efforts (16.4.2.2), the availability of finance (16.4.1.3), and available technologies (16.4.1.4). Meanwhile, the perceived costs and benefits of a given adaptation option have strong intersections with governance as well as social and cultural preferences (Dryden-Cripton *et al*., 2007; Smith *et al*., 2009b; Engle, 2011; Shen *et al*., 2011). Multiple constraints can significantly reduce the range of adaptation options and opportunities and therefore may pose fundamental limits to adaptation (Section 16.5), and/or drive actors toward responses that may ultimately prove to be maladaptive (Barnett and O'Neill, 2012). As such, removing various constraints on adaptation, which in turn increases adaptation options and flexibility, is fundamental to the facilitation of adaptation processes (Smith *et al*., 2008b; Moser and Eckstrom, 2010). Bottom up approaches have been credited with making adaptation constraints explicit and stimulating social learning (Preston *et al*., 2009; Yuen *et al*., 2012), but have yielded less evidence of substantive adaptation. Meanwhile, top down, index-based approaches have come under criticism due to concerns about robustness and relevance to adaptation decision-making (Hinkel, 2010; Preston *et al*., 2011b). Ongoing advances in comprehensive understanding of multiple, interacting constraints as well as the manner in which they influence adaptation and outcomes are needed to facilitate adaptation practice (Engle, 2011).

16.5. Limits to Adaptation

Although constraints increase the challenges associated with implementing adaptation policies and measures, they do not necessarily pose a limit to adaptation. A limit is reached when adaptation efforts are unable to provide an acceptable level of security from risks to the existing objectives and values and prevent the loss of the key attributes, components or services of ecosystems (see Box 16-1). In some instances, those limits are mutable and may be removed over time by new technologies, institutional arrangements, economic or fiscal change. Other limits are absolute and there is no identified process of change that might be expected to alter them over time. While terms such as barriers, limits, and constraints are sometimes used interchangeably, this discussion builds on recent efforts refining the distinction between a constraint and limit (Hulme *et al*., 2007; Adger *et al*., 2009b; Section 16.2; Box 16-1).

16.5.1. Types and Sources of Limits

Limits may arise due to constraints associated with technology, institutional capacity, economic and financial resources, ecological, social, political, and cultural circumstances as well as inability to generate resources needed to meet the magnitude, scale, and/or rates of change (Adger *et al.,* 2009b; Meze-Hausken, 2008; O'Brien, 2009; Moser and Eckstrom, 2010; Section 16.4). There is a variety of circumstances and associated terminology in the literature that relate to adaptation limits including 'thresholds' (Meze-Hausken, 2008; Briske *et al.,* 2010; Washington-Allen et al., 2010); 'regime shifts' (Washington-Allen *et al*., 2010); 'tipping points' (Lenton *et al*., 2008; Kriegler *et al*., 2008; 'dangerous climate change' (Mastrandrea and Schneider, 2004; Ford, 2009); 'reasons for concern' (Smith *et al*., 2009a); 'planetary boundaries' (Rockstrom *et al.,* 2009); or 'key vulnerabilities' (Schneider *et al*., 2007; Johannessen and Miles, 2011; Hare *et al*., 2011; Chapter 19).

The literature on limits to adaptation distinguishes between limits that arise from biophysical characteristics and processes and those that are socioeconomically constructed. Biophysical limits equate to thresholds in physical or ecological systems that, if exceeded, would lead to irreversible changes or the loss of critical structure or function (Hulme *et al*., 2007; Lenton *et al*., 2008). There is *high agreement and much evidence* that climate change can trigger such irreversible changes in biophysical systems (IPCC, 2012a; Chapter 19). Such limits arise from the magnitude and/or rate of change (16.4.2.2). For example, a number of physical thresholds in the Earth system have been proposed as posing potential limits to adaptation, particularly large-scale events such as irreversible melting of the Greenland or Antarctic Ice Sheets as well as collapse of the Atlantic Thermohaline Circulation (Schneider and Lane, 2006; Sheehan et al., 2008; Travis, 2010). Such physical thresholds, however, though relevant to understanding adaptation limits, are not necessarily limits in themselves. Rather, the limiting nature of changes in the physical environment is dependent upon the nature of ecological and societal systems exposed to such changes. Lenton et al. (2008) comment, for example, on the need to examine tipping points in socioeconomic systems as well as in the Earth system. In contrast with purely physical limits, ecological limits reflect a more direct connection with the adaptive capacity of natural systems. Ecological limits to adaptation are often associated with exceedences of the physiological capacity of individual organisms to cope with and/or adapt to changes in the climate (i.e., temperature, rainfall, and/or disturbance regimes; Peck et al., 2009). Such systems tend to be those that persist at the upper limit of climate tolerances (e.g., Sheehan et al., 2008; Evans *et al*., 2011); or latitudinal/altitudinal ranges (Dirnböck et al., 2010; Benito et al., 2011); those for which sustainability is closely tied to vulnerable physical systems (Johannessen and Miles, 2011); or those that are under significant pressure from non-climatic forces (Evans et al., 2011; Jenkins et al., 2011).

Since the AR4, the literature on socioeconomically-constructed limits has enriched understanding of adaptation limits beyond the purely biophysical dimension. Human choice and action create significant opportunities for adaptation (Section 16.2), reducing the likelihood that limits will be encountered. Nevertheless, there is *high agreement and moderate evidence* that socioeconomic constraints can pose limits to adaptation. The key socioeconomically-constructed limits discussed in the literature are material in nature – specifically economic resources and technology (Adger et al., 2009b; de Bruin et al., 2009; Flåm and Skjærseth, 2009). More recently, however, other factors such as complexities of multi-level governance, values, and social processes have been discussed (Adger et al., 2009b; O'Brien, 2009). This dependence of socioeconomically-constructed limits upon human agency and normative factors distinguishes them from biophysical sources of limits, which are purely objective in origin (O'Brien *et al*., 2009). The distributional aspects of climate impacts and adaptive capacity hinder the definition of socioeconomic limits. For example, 'losers' in one global region may be compensated by winners in other regions through, for example, global trade or development assistance (Hare *et al*., 2011).

Understanding the potential for adaptation limits to arise in practice is an area of ongoing research. Investigators have posited that biophysical feedbacks due to climate changes could lead to tipping points, but these are not well integrated with understanding of social systems (Leary *et al.,* 2009). In ecosystem science, substantial questions regarding the significance, identification, and interpretation of thresholds remain (Meze-Hausken, 2008; Briske *et al.* 2010). Similarly, specifying species- and location-specific climate thresholds that represent limits to adaptation remains challenging as does assessing the likelihood of exceeding such thresholds (Akçakaya et al., 2006; Ragen *et al.,* 2008; Fordham *et al*., 2012). As the Millennial Ecosystem Assessment demonstrated, there are large gaps in our knowledge of the relationships between environmental conditions and human well-being (Millennium Ecosystem Assessment, 2005; Raudsepp-Hearne *et al.,* 2010). There is not a standard methodology to assess adaptive capacity or anticipate what societal resources might become available as perceptions of risk change. Therefore, judgments of whether a tipping point or threshold will exceed an adaptation limit tend to rely on assessments of past experience and normative judgment. Natural disasters inform those judgments as they demonstrate shortcomings in current adaptation and challenges to effective response (IPCC, 2012a). In other cases, factors that may influence the feasibility of a strategy have been identified but not systematically evaluated. For instance, maintaining current yields of some perennial crops in California may require shifting production locations, although topography, soils, competing land uses and irrigation infrastructure may limit feasibility (Lobell *et al.,* 2006).

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Box 16-5. Historical Perspectives on Approaching and Exceeding Limits to Adaptation

Increasingly sophisticated archeological and environmental reconstruction techniques are providing useful perspectives on the role of environmental change in cases of significant societal change (sometimes termed 'collapse'). These may help to illuminate how adaptation limits were either exceeded, or where this was avoided to a greater or lesser degree. Great care is necessary to avoid over-simplifying cause and effect, or over-emphasizing the role of environmental change, in triggering significant societal change, and the societal response itself. Coincidence does not demonstrate causality, such as in the instance of matching climatic events with social crises through the use of simple statistical tests (*e.g.,* Zhang *et al.,* 2011), or through derivative compilations of historical data (*e.g.,* de Menocal, 2001, Thompson *et al.,* 2002, Drysdale *et al.,* 2006, versus Butzer, 2012).

Application of social theories may not explain specific cases of human behavior and community decision-making, and diminishes the singular importance of the roles of leaders, elites and ideology (e.g., Hunt, 2007; McAnany and Yoffee, 2010; Butzer, 2012; Butzer and Endfield, 2012). Resilience itself is much more than a bundle of environmental processes, and involves complex political and socio-cultural factors and feedbacks, that define vulnerabilities critical to adaptation and constraints.

There are now roughly a dozen case studies of historical societies under stress, from different time ranges and several parts of the world, that are sufficiently detailed (based on field, archival, or other primary sources) for relevant analysis (*e.g.,* Butzer and Endfield, 2012). These include Medieval Greenland and Iceland (Dugmore *et al.,* 2012; Streeter *et al.,* 2012); Ancient Egypt (Butzer, 2012); Colonial Cyprus (Harris, 2012); the prehistoric Levant (Rosen and Rivera, 2012); Islamic Mesopotamia and Ethiopia (Butzer, 2012); the Classic Maya (Dunning *et al.,* 2012; Luzzadder-Beach *et al.,* 2012); and Colonial Mexico (Endfield, 2012). Seven such civilizations underwent drastic transformation in the wake of multiple inputs, triggers, and feedbacks, with unpredictable outcomes. These can be seen to have exceeded adaptation limits. Five other examples showed successful adaptation through the interplay of environmental, political and socio-cultural resilience, which responded to multiple stressors (e.g., insecurity, environmental or economic crises, epidemics, famine). Climatic perturbations are identified as only one of many ‘triggers’ of potential crisis, with preconditions necessary for such triggers to stimulate transformational change. These preconditions include human-induced environmental decline mainly through over-exploitation. Avoidance of limits to adaptation requires buffering feedbacks that encompass social and environmental resilience. Exceedance of limits occurred through cascading feedbacks that were characterized by social polarization and conflict that ultimately result in societal disruption. Political simplification undermined traditional structures of authority to favor militarism, while breakdown was accompanied or followed by demographic decline. Although climatic perturbations did contribute to triggering many cases of breakdown, the most prominent driver at an early stage was institutional failure. Environmental degradation seldom played a pivotal role. Collapse was neither abrupt nor inevitable, often playing out over centuries.

These historical insights cannot be directly applied to contemporary problems of sustainability without adjustment for cumulative information and increasing social possibilities for grassroots participation. For example, from the 14th to 18th centuries AD, Western Europe responded to environmental crises at great societal cost, with high nutritional stress and long-wave demographic fluctuations. This occurred through the consideration of traditional knowledge and the localized evaluation of new information to emphasize innovation, experimentation and intensification, sometimes under the stress of fresh environmental perturbations or social unrest. Resilience and adaptation depended on experience, communications, identification of alternative options, and a measure of consensus. Effective change in recent historical societies involved both the grassroots and the elites, with the key questions increasingly cybernetic, structural, and cultural.

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16.5.2. Absolute versus Mutable Limits

The observation that limits to adaptation can be socially-constructed suggests that such limits are amenable to being shifted or muted entirely. Therefore, it is important to distinguish between mutable and absolute limits, as they have different implications for the success of adaptation, particularly over long time scales. For example, adaptation in ski resorts faces some limits related to the efficiency of snowmaking equipment at different temperatures as well as the design and location of lifts and runs, which could be overcome with redesign and relocation (Bark *et al.,* 2010). Other mutable limits may be in the capacity to respond at a particular rate or scale. A local area may not have the money, equipment, or expertise to adapt but they may overcome such a limit by drawing in resources from regional, national, or international entities. Laws, regulations, funding programs, and other potentially limiting factors can be changed, although some efforts are likely to be more difficult, expensive, and time-consuming than others.

Adger *et al.* (2009; pg. 338) argue that many 'limits' to adaptation are dependent on the changing goals, values, risk and social choices of society which may make limits "*mutable, subjective, and socially constructed*." Similarly, Meze- Hausken (2008) views adaptation as being triggered in part by subjective thresholds including perceptions of change; choices, needs, options and economic capacity; and expectations of the future and wants (see also O'Brien, 2009). The influence of cognitive factors, culture and ideology on judgment about risks is a well-documented element of risk management (IPCC, 2012a; Section 14.4.2.1). Plans are often constructed and designed to meet multiple goals and determining the acceptable or tolerable balance will reflect potential tradeoffs and risks. These value choices have significant implication for other analyses. For example, estimates of the engineering capacity to manage flood risk on the Themes were based on the assumption society would maintain the standard of a 1 in 1000 year level of protection over time (Reeder *et al.,* 2009). Societal assessment of risk and willingness to invest in risk management is subject to many influences some of which can result in rapid changes (Kasperson *et al.* 1996).

Despite the theoretical potential for changes in society to mute adaptation limits, some researchers caution that institutions may not be able to achieve all that is desired of them. In the USA, institutions across scales lack the mandate, information, and/or professional capacity to select and implement adaptations for risk reductions (NRC, 2009). In addition, America's Climate Choices reports that new institutions and bridging organizations will be needed to facilitate integration of complex planning processes across scales (NRC, 2010). Zinn (2007) points to cases of persistent difficulties in environmental management in suggesting that climate change would require levels of integrated environmental planning and management that U.S. institutions have not been able to achieve consistently. In a related vein, Brikmann *et al.* (2010) observe that many urban adaptation plans depend on the involvement and interplay of formal and informal organizations, but these plans rarely address how this integration might be achieved (also see Chapter 15 on implementation). Therefore, while limits to adaptation may be mutable in principle, in practice they can be highly persistent.

A critical uncertainty affecting the prospects for adaptation to manage climate risk is the circumstances that cause adaptation limits to become absolute (see, for example, Box 16-6 on climate change and conflict). Even for unmanaged ecological systems, where there is robust evidence that limits exist, defining those limits remains challenging due to system complexity and lack of information regarding responses across different scales of biological organization (Wookey *et al*., 2009; Lavergne *et al*., 2010). For human systems, defining absolute limits is even more challenging due to the aforementioned normative aspects that interact with biophysical conditions. The challenge is perhaps most evident in considering human migration as a potential adaptive response to climate risk. Migration can be viewed as adaptive in that it often has a positive influence on livelihoods as it provides diversified incomes and opportunities for a household as well as a response to deteriorating conditions. For example, on some Torres Strait Islands, adaptation to rising seas through retreat is not an option due to the limited land or lack of high land (Green *et al*., 2009), suggesting some degree of displacement or migration may eventually be needed to maintain human security. Yet, Adger et al. (2009b) and O'Brien et al.'s (2009) emphasis on actors' values suggests that migration can carry adverse consequences, even when initiated in response to a real hazard. Objectives such as preservation of health and safety are met, but others such as maintenance of sense of place experience an absolute limit. On the other hand, staying in place when the security of objectives and values continue to deteriorate can, in some instances, reflect a profound inability to pursue more positive adaptive options (Foresight, 2011). This unwillingness or inability to pursue migration as an adaptation option may be as significant a policy concern as migration (Foresight, 2011). The inability to retreat from highly vulnerable coastal areas due to the inherent lack of physical land is also suggestive of an absolute limit to adaptation. Hence, both remaining in place and migrating to avoid risk can be adaptive or reflect limits to adaptation depending on the socioecological context, the objectives of actors, and the trade-offs they are willing to make.

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Box 16-6. Climate and Conflict

Recent years have seen a surge of academic interest into possible causal linkages between climate variability and armed conflict. Most of this work concentrates on the extent to which short-term changes in meteorological conditions correlate with the outbreak or occurrence of intrastate armed conflicts and civil wars. Some studies report that civil war risk increases in unusually dry periods, either directly (Hendrix and Glaser, 2007; Raleigh and

Kniveton, 2012) or as an indirect consequence of economic shocks (Miguel and Satyanath, 2011). Similarly, Burke *et al*. (2009) report that civil wars are more frequent in warmer years, and Hsiang *et al*. (2011) find civil war risk in the tropics to covary with El Niño/La Niña-Southern Oscillation (ENSO) cycles. Other studies fail to uncover a robust link between specific climatic conditions and armed conflict (Buhaug, 2010; Ciccone, 2011; Koubi *et al*., 2012; Theisen *et al*., 2011, 2012) or report results that are in direct opposition to earlier findings (Hendrix and Salehyan, 2012) whereby conflict risk is found to increase with excess rainfall. A related set of studies focuses specifically on climate-related natural disasters and conflict. Nel and Righarts (2008) find a positive effect of disasters on civil war risk, while more recent investigations conclude that climatic disasters are largely unrelated to civil war risk (Bergholt and Lujala, 2012; Slettebak, 2012) and to political instability more generally (Omelicheva, 2011).

Research exploring climate impacts on lesser forms of organized political violence appears more supportive of a relationship. For example, Theisen (2012) report that violent communal events in Kenya are more frequent following unusually wet years, corroborating similar observations by Witsenburg and Adano (2009) and Raleigh and Kniveton (2012). Hendrix and Salehyan (2012), studying the entire African continent, conclude that precipitation anomalies in either direction are associated with an increase in social conflict. Other studies are less supportive of a climate-conflict dynamic. Benjaminsen *et al*. (2012), Kevane and Gray (2008), and Raleigh (2010) all dispute a significant causal role of climate-induced environmental degradation in driving communal violence in various parts of Africa, whereas Bohlken and Sergenti's (2010) analysis of Hindu-Muslim riots in India suggests a negative association between rainfall and conflict. A commonality among many of these studies is the important role ascribed to traditional and local political institutions in facilitating or mitigating communal conflict (see, e.g., Adano *et al*., 2012). Moreover, to the extent there is a temporal pattern in intergroup conflict, it appears to be driven more by material opportunity conditions than by competition over dwindling resources, which dominates environmental security thinking (e.g., Homer-Dixon, 1999).

Taken together, this body of literature provides mostly weak, inconsistent, and inconclusive evidence for a systematic impact of climate variability on armed conflict (Bernauer *et al*., 2012; Gleditsch, 2012). Empirical findings appear most congruent for the least severe and organized forms of conflict. Reflecting the empirical uncertainty in the field, research thus far has been unable to identify key causal mechanisms connecting climate variability and extremes with armed conflict, although economic shocks in response to agricultural underperformance and food insecurity and inflation of food prices constitute the main narratives motivating this research.

_____ END BOX 16-6 HERE _____

16.5.3. Effects of Mitigation Practice on Adaptation Opportunities, Constraints, and Limits

In Chapter 15, three major themes are identified where adaptation and mitigation responses are expected to show interactions, being agriculture, the built environment and carbon sequestration through re-vegetation. Here, we consider more broadly which mitigation practices may affect adaptation opportunities, constraints and limits. Nine practices are identified with potential for interactions, some much stronger than others (Table 16-2). Only one mitigation practice, carbon sequestration through Carbon Capture and Storage, shows no obvious potential interaction. One of the strongest and most common interactions relates to impacts on biodiversity and ecosystems, and therefore also on ecosystem based approaches to adaptation and human livelihoods. The next most common interaction relates to sustainability of natural resources such as water.

[INSERT TABLE 16-2 HERE
Table 16-2: Summary of potential interactions between mitigation practices and adaptation opportunities, constraints and limits.]

Energy efficiency gains through demand side management have strong potential to reduce water use in energy production (e.g., Hardy *et al.,* 2012) and are relevant to many energy production systems . Increased energy efficiency would therefore enhance adaptation opportunities in the water sector especially in water constrained countries. Energy efficiency gains through shifting transportation modes have the potential to allow the development of more climate resilient transportation systems, but also could increase vulnerability if the planning and implementation of new transportation systems ignores climate risks (e.g., Eisenack *et al*., 2012). Energy de-carbonisation could increase vulnerabilities if risks to natural resources are not taken into account. For example, hydraulic fracturing for shale gas extraction is a process that may both require large amounts of water and contaminate ground water supplies (e.g., Coman, 2012) and thus reduce the long term adaptation options associated with groundwater abstraction.

Fossil fuel substitution has several potentially strong interactions with land use, biodiversity and ecosystem impacts (e.g., Tscharntke *et al*., 2012). These may translate to adaptation opportunities, as in the case of using lands that are aridifying, degraded or abandoned due to climatic shifts for the production of biofuels or biomass energy, or land allocated to wind turbines to sustainable use of ecosystem goods and services. However, expanding land allocations to biofuel production may strongly inhibit adaptive responses to increase the resilience of food supply under climate change (Ilaboya *et al.,* 2012). Inappropriate biofuel plantings can also result in ecosystem degradation and the loss of future climate resilience supplied by ecosystem goods and services (Sinkala and Johnson, 2012). Such outcomes would also reduce the potential for conservation adaptation responses and ecosystem based adaptation opportunities. Finally, agricultural production allocations to biofuel (e.g., Madramootoo and Fyles, 2012) could reduce the regional or global climate change limit for sustainable food production, although there appears to be no regional or global calculation currently available to assess this risk.

Fossil fuel substitution through renewable energy provides opportunities to enhance ecosystem climate resilience in the footprints of solar and wind plants, and hydrological schemes may also provide additional water security or increase potential for irrigation for food production and food security. Such schemes pose uncertain risks to biodiversity and ecosystems and thus have unclear potential impacts on the effectiveness of adaptation responses to climate change (e.g., Pearce-Higgins *et al*., 2012; Witt *et al*., 2012). Well-supported adverse effects on biodiversity include those on migrating bird species of wind energy (e.g., Saidur *et al.,* 2011), and the disruption of ecosystems and destruction of their goods and services for adaptation by hydrological schemes (e.g., Poff *et al.,* 2007).

Carbon sequestration schemes involving forests and sustainable agriculture are promising for enhancing adaptation opportunities, especially for biodiversity conservation (*e.g.,* Harvey *et al*., 2010) and ecosystem based adaptation, though not without risk (*e.g.,* Huettner, 2012). While reforestation shows few if any constraint interactions, afforestation may reduce ecosystem service flows (*e.g.,* catchment water yields) especially if invasive alien forest species are employed (Van Wilgen *et al*., 2007). Approaches towards reducing emissions from deforestation and degradation (REDD+) may compromise the potential for indigenous peoples use of ecosystem goods and services (Phelps *et al.,* 2010).

16.5.4. Limits and Transformational Adaptation

Adaptation has traditionally been viewed as a process of incremental adjustments to climate variability and change in order to continue to maintain existing management objectives and values (Burton *et al*., 2001). Reliance upon incremental adaptation, however, though initially adaptive, can create path dependence that ultimately leads to adaptation limits (Folke, 2006; Gallopin, 2006; Nelson *et al*., 2010; Pelling and Manuel-Navarrete, 2011).Once this point is reached, continuing to maintain those objectives and values can prove maladaptive resulting in chronic system underperformance or, in more severe instances, irreversible losses and system collapse (Box 16-5). Encountering an adaptation limit, however, does not necessarily result in the end of the adaptive process. Since the AR4, the adaptation and resilience literatures have suggested that climate change may drive actors toward transformational changes, which represent fundamental changes in underlying objectives and values (Pelling, 2011; Kates *et al*., 2012; Stafford Smith *et al*., 2011; O'Neill *et al*., 2012; Park *et al*., 2012; see also Chapter 20). This may involve accepting the loss of lower-order objectives (e.g., protection of existing vulnerable coastal property, or continuation of an agricultural practice in a given location) in order to continue to meet higher order objectives (e.g., resilient coastal communities or sustainable rural economies) (Pelling and Manuel-Navarrete, 2011). This suggests there are hierarchies of limits within systems and thus a need for a more dynamic understanding of limits than what has appeared in the literature to date. Park *et al*. (2012) discuss transformational adaptation within the Australian wine industry, including the speculative acquisition of land in regions that may become suitable for grape varieties in a future climate. In addition, O'Neill *et al*. (2012) suggest that managing the risks associated with wildfire events in Australia may necessitate transformational change regarding assessments of the suitability of land for development. Transformational adaptation, however, isn't without risks (Kates *et al*., 2012). The development of new management objectives and business models in anticipation of a changing climate creates opportunity costs and there are inherent uncertainties associated with the timing and magnitude of investment returns. Hence, the same factors that constrain incremental adaptation also constrain transformation. Transformational change may therefore be most feasible when it is perceived as creating new opportunities consistent with existing values (e.g., expansion of an industry into new locations) as opposed to a reaction to loss (e.g., retreat from vulnerable locations).

16.6. Sectoral and Regional Syntheses of Adaptation Opportunities, Constraints, and Limits

THIS SECTION SYNTHESIZES MATERIAL AVAILABLE AT THE TIME OF WRITING FROM SECTORAL AND REGIONAL ZERO-ORDER DRAFTS – UPDATES WILL BE MADE WITH SUBSEQUENT INTERATIONS THOSE CHAPTERS

16.6.1. Cross-Sectoral Synthesis

16.6.1.1. Opportunities, Constraints, and Limits within Sectors

Opportunities, constraint and limits depend on how adaptation been framed (Section 16.4.2.1), the scale at which adaptation been planed and the types of adaption options that have been identified, which vary among different sectors and regional contexts. Integration or mainstreaming and adaptive management have been frequently identified as relevant frameworks for adaptation policy implementation. Meanwhile, Integrated Water Resource Management (IWRM), and Integrated Coastal Zone Management (ICZM) represent multi-sectoral adaptation options for the management of natural resources that are viewed as more effective than standalone efforts to reduce climate-related risks (Bijlsma *et al*., 1996; Chapter 3.6.; Chapter 5.9). IWRM, for example, is an ideal overarching framework in which to evaluate, design, implement and monitor adaptation strategies for climate impacts on water resources. Building communities of practice around IWRM can facilitate the mainstreaming of climate adaptation strategies into sustainable development efforts, providing synergy in awareness-raising, capacity-building and in the creation of social, political, and institutional environments receptive to technological innovation (UNFCCC, 2006).

Mainstreaming climate change into national, sectoral and local development has emerged over time as several adaptation measures happening now support the argument that adaptation is taking place in response to multiple stresses and are reinforcing the importance of mainstreaming adaptation (Dovers and Hezri, 2010; Tompkins *et al*., 2010). Several studies reveal that there is a mismatch between national statements on adaptation and local action to address climate change impacts meaningfully. Adaptation intervention addressing short term risks over long term strategic planning potentially increasing vulnerability and make future adaption more difficult. Institutional barriers along with limited consideration of future climate change scenarios in adaptation planning and intervention create potential maladaptation (Berrang-Ford *et al*., 2011). Ecosystem based adaptation has also emerged as key adaptation measure along with other options (Box 16-2).

The degree of adaptation depends on the adaptive capacity of each country, region, or exposed sector and adaptive capacity relies on various factors, such as financial and human resources, scientific knowledge, access to information, technology, social institutions and infra-structure. Barriers to adaptation are distinct in nature between developed and developing countries. Institutional challenges are widely noted as common barriers to adaption faced by developed countries, often involving significant time to negotiate and consult with various interested parties. Changing and creating institutions and present political short-sightedness also often limit planning for long term risk. However, financial barriers, lack of information on the necessity to adapt, knowledge about available options and the ability to implement most suitable ones appear to be lesser problems for developed countries relative to developing countries (Berrang-Ford *et al*., 2011). Table 16-3 provides summary of opportunities, constraints and limits to adaptation in the context of sectors.

[INSERT TABLE 16-3 HERE
Table 16-3: Cross-sectoral synthesis.]

16.6.1.2. Opportunities, Constraints, and Limits arising from the Interaction among Sectors

Engineering of protective structures such as seawalls and dikes protect the population and productive systems, but can generate adverse externalities on natural systems by limiting sediment discharge and subsequently causing erosion at the river mouths (Nunn *et al*., 2006) and may also eliminate valuable natural wetlands in future. The collapse of seawalls is also very common in many Pacific Islands. A cheaper and more effective long-term solution is planting mangroves along affected shorelines (Nunn *et al*., 2006).

16.6.2. Cross-Regional Synthesis

16.6.2.1. Opportunities, Constraints, and Limits within Regions

Adaptation is a trans-national and a cross-sectoral issue. Therefore a key organizational framework for addressing adaptation is the mainstreaming of an interdependent mix of strategies at regional and sub-regional levels by encouraging organizations to integrate climate change into their policies and economic management systems. Many countries and region consider mainstreaming and integrating climate change into development plans as overarching goal. Outcomes of MEAs, particularly several decisions of the UNFCCC, also provide opportunities for integrating climate change into development planning and processes. The key examples are a) formulation of National Adaptation Programmes of Action (NAPA); b) the National Adaptation Plans (NAPs), and c) the Technology Mechanism under which a Climate Technology Centre and Network have been launched to facilitate technology transfer. Black Carbon abatement is an opportunity to achieve both climate mitigation and health benefits, and a new initiative has been launched recently by the United Nations Environment Programme (UNEP, 2012). Table 16-4 provides a summary of opportunities, constraints and limits to adaptation in the context of different regions.

[INSERT TABLE 16-4 HERE
Table 16-4: Cross-regional synthesis.]

16.6.2.2. Opportunities, Constraints, and Limits arising from the Interaction among Regions

Common constrains in developing countries are lack of technical and human capacity, financial resources, social and cultural, political and legal framework. In addition, spatial and temporal uncertainties associated with forecasts of regional climate, lack of socio-economic scenarios and data at the required scale as well as limited national capacities for monitoring climate and forecasting extreme events and natural hazards also impede climate and disaster risk management. Lack of institutional co-ordination in the formulation of responses as well as engagement and participation of stakeholders are types of constraints. Mainstream climate change into policy is also constrained by multiple factors including institutional capacity. While financial and technical capacity do not seems key constraint in developed countries rather availability of natural resources is key constraint such as water availability for expansion of agriculture, and maintenance of key infrastructure or upgrade those by local council or authority.

16.7. Ethical Dimensions of Adaptation Constraints and Limits

Hartzell-Nichols (2011, pg. 690) argues that "*Adaptation is fundamentally an ethical issue because the aim of adaptation is to protect that which we value*." This underlines the ethical dimensions of the framing of adaptation opportunities, constraints and limits adopted in this chapter as being concerned with risks to social objectives and values, and to valued attributes of biophysical systems. However, defining what these values are and untangling the ethical issues is not straightforward, such that defining moral principles to clarify choices between alternative courses of action remains difficult. According to Gardiner (2006, pg. 407), "*Even our best theories face basic and often severe difficulties addressing basic issues … such as scientific uncertainty, intergenerational equity, contingent persons, nonhuman animals, and nature. But climate change involves all of these matters and more"*. Complicating this picture further is the observation that social and personal values are not universal nor are they static (O'Brien, 2009; O'Brien and Wolf, 2010). There may be different, equally well-founded values about something that is being put at risk by climate change. These are not limited to economic values, but include intangible cultural or spiritual values as well. Berkes (2008; pg. 163) documents that in Inuit culture, the loss of sea ice in summer months leaves some people 'lonely for the ice.' Whether the risk of such a loss would be seen as unacceptable remains a complicated question and raises ethical issues that remain unresolved.

One ethical principle that is widely applied in ethical discussions of climate is 'equity' (Gardiner, 2010). It is now well-established that nations, peoples and ecosystems are differentially vulnerable to current and future projected climate change impacts, which themselves are also almost certain to be unequally distributed across the world (Füssel, 2009; IPCC, 2007a; Füssel, 2010;). This inequity is exacerbated by the fact that exposure to adverse impacts is involuntary for many societies (Dellink *et al*., 2009; Fussel, 2010; Paavola and Adger, 2006; Patz *et al*., 2007). Therefore, adaptation capacity and implementation constraints have the potential to create or exacerbate inequitable consequences due to climate change (*high agreement, robust evidence*).

Inequity resulting from adaptation constraints and limits emerge across several dimensions; namely inter-country equity, inter-generational equity, inter-pecies equity (Schneider and Lane, 2005), and intra-country or sub-national equity (Thomas and Twyman, 2005). Adger *et al*. (2009b) propose that adaptation limits are endogenous to society and thus dependent on ethics, knowledge, attitudes to risk and culture. Inter-generational equity considerations are dominated by discussions of discount rate (Nordhaus, 2001;Stern *et al*., 2006; Beckerman and Hepburn, 2007). This debate largely ignores the challenge of irreversible damages associated with limits to adaptation, especially those that may result from non-linear damage functions (Hanemann, 2008). Inter-species equity is a complex topic and still the subject of evolving ethics unrelated to climate change considerations – value to human society increasingly serves as the most common metric for determining interventions affecting species (Balmford *et al*., 2002). Clearly, differential ecosystem vulnerability is an important determinant of most species' vulnerability to climate change, with some species and ecosystems already severely threatened (IPCC, 2007a). Support for climate change adaptation interventions for species increasingly invokes human and societal benefits as a primary motivation (CBD, 2009). Intra-country or subnational equity issues have emerged due to the impacts of recent climate extreme events, clearly this is a wide disparity in vulnerability at subnational level in almost all countries, with extreme climatic conditions highlighting previously concealed limits.

The complexity of international law comprises a significant barrier to making the case for addressing the breaching of adaptation limits (Koivurova, 2007). At national and sub-national levels, cultural attitudes can contribute to stakeholder marginalization from adaptation processes, thus preventing some constraints and limits from being identified (such as gender issues and patriarchal conventions).

16.7.1. Ethics and the Externalities of Adaptation

There is a wide variety of potential positive and negative externalities associated with adaptation to climate change, and some of these have relevance in the context of constraints and limits. Externalities are important because they may allow 'free-riding' on the one hand, or, on the other hand, unintended adverse consequences that are not considered in achieving optimal adaptation outcomes. Positive externalities can be projected at all levels of scale from international to local. Positive externalities may be most closely associated with investments in public goods, but they may also arise from private investments in adaptation. Investments in health, food security and disaster risk reduction adaptive strategies may benefit neighbours most through reducing risks of social instability and resource demands. Negative externalities relate most obviously to adaptive strategies that reduce resource availability to neighbours, such as through water security strategies that may reduce availability to downstream neighbours (Eckstein, 2009), or generate new risks to neighbours, such as changing downstream flood risks as a result of raising river levees (te Linde *et al*., 2011).

Positive distributional spill-overs of adaptation that aim to avoid limits are many and would benefit society through their monetization (Jack *et al.*, 2008). An example is the enhancement of ecosystem functions for local adaptation benefits (*e.g.,* restoration of wetlands to avoid the permanent loss of ecosystem services such as food and water security). The downstream externalized benefits would include a reduction in flood risk. Emerging concepts in the form of payments for ecosystem services would internalize these and provide further motivation for more integrated and equitable sharing of the burden and benefits of adaptation, but their implementation faces constraints relating to valuation and verification. There are few agreed international procedural arrangements for addressing or resolving these externalities, compounded by complex international law (Koivurova, 2007).

16.7.2. Ethics at the Limits of Adaptation

Historical reconstructions of societies that approach limits to adaptation involving a climate driver show that endogenous responses may determine whether limits are exceeded or avoided (Box 16-5). Ethical considerations are central to these endogenous responses. As real or perceived national or local limits to adaptation are approached, strategies may be encouraged that deprive neighbors of resources (FAO, 2011). Adaptation to water resource limitations may be particularly pernicious (Eckstein, 2009), with local strategies involving water table reductions that affect entire regions, and national strategies that impound water that would have previously flowed between or across political boundaries. Intergenerational concerns are important for considering the ethics relating to avoiding adaptation limits. This is because several generations in the twenty-first century, at least, will experience progressively changing climates (Adger *et al.* 2009), which could expose them to greater probabilities of exceeding adaptation limits.

16.8. Seizing Opportunities, Overcoming Constraints and Avoiding Limits

There is a growing body of knowledge, including tools and guidelines, on the implementation of climate change adaptation responses which is addressing information and knowledge constraints on adaptation. This information provides a very wide range of views on how constraints may be overcome and opportunities taken. One of the important early initiatives in this area was the 'Assessment of Impacts and Adaptation to Climate Change' project under the START Program, which prompted an increase in research and policy interest and engagement in implementation (e.g., Mataki *et al.* 2006). In general, the information remains largely fragmented, although there is a major international effort underway to extract value from this knowledge through several actions of the Nairobi Work Program of the UNFCCC.

Opportunities for advancing implementation are becoming increasingly available through policies, tools and guidelines that are emerging throughout the developed and developing world addressing national, sub-national and local urban scales. For example, there is growing recognition of the potential for using disaster response and recovery processes as a means of increasing resilience to future extreme events (Lavell *et al.,* 2012), although such opportunities require awareness and procedures to allow them to be taken. Examples of national responses include the USA '*Instructions for Implementing Climate Change Adaptation Planning in Accordance with Executive Order 13514*' (CEQ, 2011) and South Africa's '*National Climate Change Response White Paper*' (Government of South Africa, 2011). Many similar initiatives have been launched at sub-national and local levels with some early lessons about overcoming constraints to implementation being learned. For example Pickets (2012) states that many opportunities exist to incorporate adaptation-related principles and objectives into 'Official Community Plans', referring to storm-water management, water supply management, infrastructure planning, ecosystem mapping, and flood risk mitigation. Pickets (2012) also reports that incorporating climate change adaptation into existing plans and policies (i.e. mainstreaming) is effective in prioritizing implementation. However, there is far less information to assess how the theoretical body of adaptation knowledge has been applied, and the outcomes that have resulted, International networks of local governments (*e.g.,* Local Governments for Sustainability, ICLEI) will provide an important source of potential information on the effectiveness of implementation, and how constraints are being overcome and opportunities taken.

At present, the study of limits to adaptation is immature, with very few published data and little robust information available. As stated by the Australian National Climate Change Adaptation Research Facility (Jenkins *et al*., 2011; McNamara *et al*., 2011), the study of adaptation concerns mainly what adaptation can achieve, and not what is unachievable. Because limits to adaptation may be determined by a mix of physical, economic, technological and socially-related factors, and because history suggests behavioral responses affect the outcome of exceeding or avoiding limits, there is an urgent need to identify the social context that increases the chance of avoiding limits to adaptation.

Frequently Asked Questions

[answers forthcoming]

FAQ 16.1: Given the range of constraints and limits, what is the potential for adaptation effectively to address impacts of climate change?

FAQ 16.2: How does uncertainty about climate change and climate policy affect adaptation opportunities, constraints and limits?

FAQ 16.3: What would be the effect on adaptation of exceeding the 2°C global goal?

FAQ 16.4: How can adaptation opportunities be seized, adaptation constraints be overcome and adaptation limits be avoided? (And what would it cost? Do the benefits outweigh the costs?)

References

Aaheim, A., F. Berkhout, D. McEvoy, R. Mechler, H. Neufeldt, A. Patt, P. Watkiss, A. Wreford, Z. Kundezwicz, C. Lavalle, and C. Egenhofer, 2008: Adaptation to climate change: Why is it needed and how can it be implemented? *CEPS Policy Brief,* **No 161**.

Abel, N., R. Gorddard, B. Harman, A. Leitch, J. Langridge, A. Ryan, and S. Heyenga, 2011: Sea level rise, coastal development and planned retreat: Analytical framework, governance principles, and an australian case study. *Environmental Science & Policy,* **14**, 279-288.

Adano, W.R., T. Dietz, K. Witsenburg, and F. Zaal, 2012: Climate change, violent conflict and local institutions in Kenya's drylands. *Journal of Peace Research,* **49(1)**, 65-80.

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwart, B. Smit, and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. In: *Climate change 2007: Impacts, adaptation and vulnerability*. [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson(eds.)]. Cambridge University Press, Cambridge, UK, pp. 717-743.

Adger, W.N., N.W. Arnell, and E.L. Tompkins, 2005: Successful adaptation to climate change across scales. *Global Environmental Change,* **15**, 77-86.

Adger, W.N. and J. Barnett, 2009: Four reasons for concern about adaptation to climate change. *Environment and Planning A,* **41(12)**, 2800-2805.

Adger, W.N., J. Barnett, F.S. Chapin III, and H. Ellemor, 2011: This must be the place: Underrepresentation of identity and meaning in climate change decision-making. *Global Environmental Politics,* **11(2)**, 1-25.

Adger, W.N., H. Eakin, and A. Winkels, 2009a: Nested and teleconnected vulnerabilities to environmental change. *Frontiers in Ecology and the Environment,* **7(3)**, 150-157.

Adger, W.N. and P.M. Kelly, 1999: Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change,* **4**, 253-266.

Adger, W.N., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D.R. Nelson, L.O. Naess, J. Wolf, and A. Wreford, 2009b: Are there social limits to adaptation to climate change? *Climatic Change,* **93(3-4)**, 335-354.

Afreen, S., N. Sharma, R.K. Chaturvedi, R. Gopalakrishnan, and N.H. Ravidranath, 2011: Forest policies and programs affecting vulnerability and adaptation to climate change. *Mitigation and Adaptation Strategies for Global Change,* **16(2)**, 177-197.

AGO, 2006: Climate Change Impacts and Risk Management: A Guide for Business and Government, Australian Greenhouse Office, Department of Environment and Heritage, Canberra, Australia.
Agrawal, A. and N. Perrin, 2009: Climate adaptation, local institutions and rural livelihoods. In: *Adapting to climate change: Thresholds, values, governance*. [Adger, W.N., I. Lorenzoni, and K.L. O'Brien(eds.)]. Cambridge University Press, Cambridge University Press, pp. 350-367.
Ahmad, I.H., 2009: Climate Policy Integration: Towards Operationalization, United Nations, New York, NY, USA, 1-16 pp.
Ahmed, S. and E. Fajber, 2009: Engendering adaptation to climate variability in gujarat, india. *Gender & Development,* **17(1)**, 33-50.
Akçakaya, H.R., S.H.M. Butchart, G.M. Mace, S.N. Stuart, and C. Hilton-Taylor, 2006: Use and misuse of the IUCN red list criteria in projecting climate change impacts on biodiversity. *Global Change Biology,* **12(11)**, 2037-2043.
Alcamo, J., J.M. Moreno, B. Nováky, M. Bindi, R. Corobov, R.J.N. Devoy, C. Giannakopoulos, E. Martin, J.E. Olesen, and A. Shvidenko, 2007: Europe. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 541-580 pp.
Allen, C.D., C. Birkeland, F.S. Chapin III, P.M. Groffman, G.R. Guntenspergen, A.K. Knapp, A.D. McGuire, P.J. Mulholland, D.P.C. Peters, D.D. Roby, and G. Sugihara, 2009: Thresholds of Climate Change in Ecosystems. Final Report. U.S. Global Change Research Program and the Subcommittee on Global Change Research, Reston, Virginia, USA, 1-70 pp.
Alston, M. and R. Mason, 2008: Who turns the taps off? introducing social flow to the australian water debate. *Rural Society,* **18(2)**, 131-139.
Anisimov, O.A., D.G. Vaughan, T.V. Callaghan, C. Furgal, H. Marchant, T.D. Prowse, H. Vilhjálmsson, and J.E. Walsh, 2007: Polar Regions (Artic and Antarctica). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 653-685 pp.
Armour, K.C. and G.H. Roe, 2011: Climate commitment in an uncertain world *Geophysical Research Letters,* **38(L01707)**, DOI:10.1029/2010GL045850.
Arnell, N.W. and E.K. Delaney, 2006: Adapting to climate change: Public water supply in england and wales. *Climatic Change,* **78(2-4)**, 225-227.
Arnell, N.W., D.P. van Vuuren, and M. Isaac, 2011: The implications of climate policy for the impacts of climate change on global water resources. *Global Environmental Change,* **21(2)**, 592-603.
Artur, L. and D. Hilhorst, 2012: Everyday realities of climate change adaptation in mozambique. *Global Environmental Change,* **22(2)**, 529-536.
Ayers, J.M. and S. Huq, 2009: Supporting adaptation to climate change: What role for official development assistance? . *Development Policy Review,* **27(6)**, 675-692.
Badjeck, M.C., E.H. Allison, A.S. Halls, and N.K. Dulvy, 2010: Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy,* **34(3)**, 375-383.
Baldassarre, G., A. Montanari, H. Lins, D. Koutsoyiannis, L. Brandimarte, and G. Blöschl, 2010: Flood fatalities in africa: From diagnosis to mitigation. *Geophysical Research Letters,* **37(L22402)**, DOI:10.1029/2010GL045467.
Balmford, A., A. Brunner, P. Cooper, R. Costanza, S. Farber, R.E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and K. Turner, 2002: Science. In: *Economic reasons for conserving wild nature* pp. 950-953.
Bambrick, H.J., A.G. Capon, G.B. Barnett, R.M. Beaty, and A.J. Burton, 2011: Climate change and health in the urban environment: Adaptation opportunities in australian cities. *Asia Pacific Journal of Public Health,* **2**, 79S.
Bardsley, D.K. and G.J. Hugo, 2010: Migration and climate change: Examining thresholds of change to guide effective adaptation decision-making. *Population and Environment,* **32(2-3)**, 238-262.
Bark, R.H., B.G. Colby, and F. Dominguez, 2010: Snow days? snowmaking adaptation and the future of low latitude, high elevation skiing in arizona, USA. *Climatic Change,* **102(3-4)**, 467-491.
Barnett, J. and W.N. Adger, 2007: Climate change, human security and violent conflict *Political Geography,* **26(6)**, 639-655.
Barnett, J. and J. Campbell, 2009: *Climate change and small island states: Power, knowledge and the south pacific*. Earthscan, London, UK, .

Barnett, J., S. Lambert, and I. Fry, 2009: The hazards of indicators: Insights from the environment vulnerability index. *Annals of the Association of American Geographers,* **98(1)**, 102-119.
Barnett, J. and S. O'Neill, 2010: Maladaptation. *Global Environmental Change,* **20**, 211-213.
Barr, R., S. Fankhauser, and K. Hamilton, 2010: Adaptation investments: A resource allocation framework. *Mitigation and Adaptation Strategies for Global Change,* **15**, 843-858.
Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof (eds.), 2008: *Climate change and water. technical paper of the intergovernmental panel on climate change*. IPCC Secretariat, Geneva, Switzerland.
Becker, N., D. Lavee, and D. Katz, 2010: Desalination and alternative water-shortage mitigation options in israel: A comparative cost analysis. *Journal of Water Resource and Protection,* **2**, 1042-1056.
Beckerman, W. and C. Hepburn, 2007: Ethics of the discount rate in the stern review on the economics of climate change. **8(1)**, 187-210.
Beckman, M., 2011: Converging and conflicting interests in adaptation to environmental change in central vietnam. *Climate and Development,* **3**, 32-41.
Benito, B., J. Lorite, and J. Peñas, 2011: *Simulating potential effects of climatic warming on altitudinal patterns of key species in mediterranean-alpine ecosystems* Springer Netherlands, pp. 471-483.
Benjaminsen, T.A., K. Alinon, H. Buhaug, and J.T. Buseth, 2012: Does climate change drive land-use conflicts in the sahel? *Journal of Peace Research,* **49(1)**, 97-111.
Bergholt, D. and P. Lujala, 2012: Climate-related natural disasters, economic growth, and armed civil conflict. *Journal of Peace Research,* **49(1)**, 147-162.
Berkes, F., 2008: *Sacred ecology*. Routledge, New York, NY, USA, pp. 336.
Berkhout, F.G.H., 2012: Adaptation to climate change by organizations. *WIRES Climate Change,* **3(1)**, 91-106.
Berkhout, F., 2002: Technological regimes, path dependency and the environment. *Global Environmental Change-Human and Policy Dimensions,* **12(1)**, 1-4.
Bernauer, T., T. Bohmelt, and V. Koubi, 2012: Environmental change and conflict. *Environmental Research Letters,* **7(1)**.
Bernazzani, P., B.A. Bradley, and J.J. Opperman, 2012: Integrating climate change into habitat conservation plans under the U.S. endangered species act. *Environmental Management,* .
Berrang-Ford, L., J.D. Ford, and J. Paterson, 2011: Are we adapting to climate change? *Global Environmental Change,* **21**, 25-33.
Biesbroek, G.R., K. Termeer, P. Kabat, and J.E.M. Klostermann, 2009: Institutional governance barriers for the development and implementation of climate adaptation strategies. In: Proceedings of International human dimensions programme (IHDP) conference "Earth system governance people places and the planet", 2-4 December, 2009, Amsterdam, Netherlands, pp. 1-14.
Biesbroek, G.R., R.J. Swart, T.R. Carter, C. Cowan, T. Henrichs, H. Mela, M.D. Morecroft, and D. Rey, 2010: Europe adapts to climate change: Comparing national adaptation strategies. *Global Environmental Change,* **20(3)**, 440-450.
Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Pérez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick, 1996: *Climate Change 1995—Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Coastal Zones and Small Islands, Cambridge University Press, Cambridge, UK, 289-324 pp.
Birkmann, J., M. Garschagen, F. Kraas, and Q. Nguyen, 2010: Adaptive urban governance: New challenges for the second generation of urban adaptation strategies to climate change. *Sustainability Science,* **5(2)**, 185-206.
Bisaro, A., S. Wolf, and J. Hinkel, 2010: Framing climate vulnerability and adaptation at multiple levels: Addressing climate risks or institutional barriers in lesotho? *Climate and Development,* **2(2)**, 161-175.
Blennow, K. and J. Persson, 2009: Climate change: Motivation for taking measure to adapt. *Global Environmental Change-Human and Policy Dimensions,* **19(1)**, 100-104.
Bohlken, A.T. and E.J. Sergenti, 2010: Economic growth and ethnic violence: An empirical investigation of Hindu—Muslim riots in india. *Journal of Peace Research,* **47(5)**, 589-600.
Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, and P. Yanda, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Africa, Cambridge University Press, Cambridge, UK, 433-467 pp.

Botzen, W.J.W., J.C.J.H. Aerts, and J.C.J.M. van den Bergh, 2009: Willingness of homeowners to mitigate climate risk through insurance. *Ecological Economics,* **68(8-9)**, 2265-2277.
Botzen, W.J.W. and J.C.J.M. van den Bergh, 2012: Monetary valuation of insurance against flood risk under climate change. *International Economic Review,* **In Review**.
Botzen, W.J.W., J.C.J.M. van den Bergh, and L.M. Bouwer, 2010: Climate change and increased risk for the insurance sector: A global perspective and an assessment for the netherlands. *Natural Hazards,* **52(3)**, 577-598.
Bouwer, L.M., 2011: Have disaster losses increased due to anthropogenic climate change? *Bulletin of the American Meteorological Society,* **92**, 46.
Boxall, A.B.A., A. Hardy, S. Beulke, T. Boucard, L. Burgin, P.D. Falloon, P.M. Haygarth, T. Hutchinson, R.S. Kovats, G. Leonardi, L.S. Levy, G. Nichols, S.A. Parsons, L. Potts, D. Stone, E. Topp, D.B. Turley, K. Walsh, E. Wellington M.H., and R.J. Williams, 2009: Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. *Environmental Health Perspectives,* **117(4)**, 508-514.
Bran, F., I. Ioan, and C.V. Radulescu, 2009: Climate change action readiness in oil industry. *Metalurgia International,* **14**, 86-90.
Briske, D.D., R.A. Washington-Allen, C.R. Johnson, J.A. Lockwood, D.R. Lockwood, T.K. Stringham, and H.H. Shugart, 2010: Catastrophic thresholds: A synthesis of concepts, perspectives, and applications. *Ecology and Society,* **15(3)**, 37.
Brook, B.W., N.S. Sodhi, and J.A. Bradshaw, 2008: Synergies among extinction drivers under global change. *Trends in Ecology & Evolution,* **23(8)**, 453-460.
Bryan, E., T.T. Deressa, G.A. Gbetibouo, and C. Ringler, 2009: Adaptation to climate change in ethiopia and south africa: Options and constraints. *Environmental Science & Policy,* **12(4)**, 413-426.
Buhaug, H., 2010: Climate not to blame for african civil wars. *Proceedings of the National Academy of Sciences,* **107(38)**, 16477-16482.
Burch, S., S.R.J. Sheppard, A. Shaw, and D. Flanders, 2010: Planning for climate change in a flood-prone community: Municipal barriers to policy action and the use of visualizations as decision-support tools. *Journal of Flood Risk Management,* **3(2)**, 126-139.
Burke, M.B., E. Miguel, S. Satyanath, J.A. Dykema, and D.B. Lobell, 2009: Warming increases the risk of civil war in africa. *Proceedings of the National Academy of Sciences,* **106(49)**, 20670-20674.
Burton, I., 2004: Climate Change and the Adaptation Deficit, Adaptation and Impacts Research Group, Meteorological Service of Canada, Downsview, Ontario, Canada, .
Burton, I., 2005: Adapt and thrive: Policy options for reducing the climate change adaptation deficit. *Policy Options,* **December**, 38.
Burton, I., O.P. Dube, D. Campbell-Lendrum, I. Davis, R.J.T. Klein, J. Linnerooth-Bayer, A. Sanghi, and F. Toth, 2012: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Managing the Risks: International Level and Integration Across Scales, Cambridge University Press, Cambridge, UK and New York, NY, USA, 393-435 pp.
Burton, I. and E. May, 2009: The adaptation deficit in water resource management. *IDS Bulletin-Institute of Development Studies,* **35**, 31-37.
Butzer, K.W., 2012: Collapse, environment, and society. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3632-3639.
Butzer, K.W. and G.H. Endfield, 2012: Critical perspectives on historical collapse. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3628-3631.
Campbell, A., V. Kapos, J. Scharlemann, P. Bubb, A. Chenery, L. Coad, B. Dickson, N. Doswald, M. Khan, F. Kershaw, and M. Rashid, 2009: Review of the Literature on the Links between Biodiversity and Climate Change: Impacts, Adaptation and Mitigation. Technical Series no. 42, Secretariat of the Convention on Biological Diversity (CBD), Montreal, Canada, 124pp.
Campbell-Lendrum, D. and R. Woodruff, 2007: *WHO Environmental Burden of Disease Series* Climate Change: Quantifying the Health Impact at National and Local Levels, World Health Organization, Geneva, Switzerland.
Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Determinants of Risk: Exposure and Vulnerability, Cambridge University Press, Cambridge, UK and New York, NY, USA, 65-108 pp.
Carmichael, L. and C. Lambert, 2011: Governance, knowledge and sustainability: The implementation of EU directives on air quality in southampton. *Local Environment,* **16(2)**, 181-191.

CBD, 2009: Ad Hoc Technical Expert Group: Climate Change and Biodiversity, Secretariat of the Convention on Biological Diversity, Montreal, Canada .
CDP, 2012: Insights into Climate Change Adaptation by UK Companies, Carbon Disclosure Project, London, UK, 1-53 pp.
CEQ, 2011: Federal Agency Climate Change Adaptation Planning: Implementing Instructions, Council on Environmental Quality, Washington, DC, USA, 1-4 pp.
Charpentier, A., 2008: Insurability of climate risks. *The Geneva Papers on Risk and Insurance-Issues and Practice,* **33(1)**, 91-109.
Chhetri, N.B., W.E. Easterling, A. Terando, and L. Mearns, 2010: Modeling path dependence in agricultural adaptation to climate variability and change. *Annals of the Association of American Geographers,* **100(4)**, 894-907.
Chiew, F.H.S., J. Teng, J. Vaze, D.A. Post, J.M. Perraud, D.G.C. Kirono, and N.R. Viney, 2009: Estimating climate change impact on runoff across southeast australia: Method, results, and implications of the modeling method. *Water Resources Research,* **45(W10414)**.
Ciccone, A., 2011: Economic shocks and civil conflict: A comment. *American Economic Journal: Applied Economics,* **3(4)**, 215-227.
Clark, D.A., D.S. Lee, M.M.R. Freeman, and S.G. Clark, 2008: Polar bear conservation in canada: Defining the policy problems. *Arctic,* **61(4)**, 347-360.
Codjoe, S.N.A., L.K. Atidoh, and V. Burkett, 2011: Gender and occupational perspectives on adaptation to climate extremes in the afram plains of ghana. *Climatic Change,* **110(1-2)**, 431-454.
Collier, P., G. Conway, and T. Venebles, 2008: Climate change and africa. *Oxford Review of Economic Policy,* **24(2)**, 337-353.
Colls, A., N. Ash, and N. Ikkala, 2009: Ecosystem-Based Adaptation: A Natural Response to Climate Change, IUCN, Gland, Switzerland, 16pp pp.
Coman, H., 2012: Balancing the need for energy and clean water: The case for applying strict liability in hydraulic fracturing suits. **39(1)**, 131-160.
Conway, D. and E.L.F. Schipper, 2011: Adaptation to climate change in africa: Challenges and opportunities identified from ethiopia. *Global Environmental Change,* **21**, 227-237.
Corfee-Morlot, J., I. Cochran, S. Hallegatte, and P.J. Teasdale, 2009: Multilevel risk governance and urban adaptation policy. *Climatic Change,* **104(1)**, 169-197.
Cork, S., 2010: Resilience of social-ecological systems. In: *Resilience and transformation: Preparing australia for uncertain futures*. [Cork, S. (ed.)]. Australia 21 and CSIRO, Melbourne, Victoria, Australia, pp. 142.
Côté, I.M. and E.S. Darling, 2010: Rethinking ecosystem resilience in the face of climate change. *PLoS Biology,* **8(7)**, e1000438.
Crate, S., 2011: Climate and culture: Anthropology in the era of contemporary climate change. *Annual Review of Anthropology,* **40(1)**, 175-194.
Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li, and N. Huu Ninh, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Asia, Cambridge University Press, Cambridge, UK, 469-506 pp.
Cutter, S., B. Osman-Elasha, J. Campbell, S.-. Cheong, S. McCormick, R. Pulwarty, S. Supratid, and G. Ziervogel, 2012: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Managing the Risks from Climate Extremes at the Local Level, Cambridge University Press, Cambridge, UK and New York, NY, USA, 291-338 pp.
Dailey, P., M. Huddleston, S. Brown, and D. Fasking, 2009: The Financial Risks of Climate Change. Examining the Financial Implications of Climate Change using Climate Models and Insurance Catastrophe Risk Models. Association of British Insurers, London.
Das, S. and J.R. Vincent, 2009: Mangroves protected villages and reduced death toll during indian super cyclone. *Proceedings of the National Academies of Sciences,* **106(18)**, 7357-7360.
Davis, J.R. and C. Tan, 2010: Tackling climate change through adaptation finance in the least developed countries: Is the LDC fund still fit for purpose? .
de Bruin, K., R. Dellink, and S. Agrawala, 2009a: Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits, OECD Publishing, Paris, France, .

de Bruin, K., R.B. Dellink, A. Ruijs, L. Bolwidt, A. van Buuren, J. Graveland, R.S. de Groot, P.J. Kuikman, S. Reinhard, R.P. Roetter, V.C. Tassone, A. Verhagen, and E.C. van Ierland, 2009b: Adapting to climate change in the netherlands: An inventory of climate adaptation options and ranking of alternatives. *Climatic Change,* **95(1-2)**, 23-45.

de Franca Doria, M., E. Boyd, E.L. Tompkins, and W.N. Adger, 2009: Using expert elicitation to define successful adaptation to climate change. *Environmental Science & Policy,* **12(7)**, 810-819.

Dellink, R., M. den Elzen, H. Aiking, E. Bergsma, F. Berkhout, T. Dekker, and J. Gupta, 2009: Sharing the burden of adaptation financing. *Global Environmental Change,* **19**, 411-421.

deMenocal, P.B., 2001: Cultural responses to climate change during the late holocene. *Science,* **292(5517)**, 667-673.

Denton, F., Financing adaptation in least developed countries in west africa: Is finance the 'real deal'? *Climate Policy,* **10(6)**, 655-671.

Deressa, T.T., R.M. Hassan, and C. Ringler, 2011: Perception of and adaptation to climate change by farmers in the nile basin of ethiopia. *Journal of Agricultural Science,* **149**, 23-31.

Deressa, T.T., R.M. Hassan, C. Ringler, T. Alemu, and M. Yesuf, 2009: Determinants of farmers' choice of adaptation methods to climate change in the nile basin of ethiopia *Global Environmental Change,* **19(2)**, 248-255.

Dessai, S., M. Hulme, R. Lempert, and R.A. Pielke Jr., 2009: Do we need more precise and accurate predictions in order to adapt to a changing climate. *Eos,* **90(13)**, 111-112.

Diaz, R.J. and R. Rosenberg, 2008: Spreading dead zones and consequences for marine ecosystems. *Science,* **321(5891)**, 926-929.

Dirnböck, T., F. Essl, and W. Rabitsch, 2011: Disproportional risk for habitat loss of high-altitude endemic species under climate change. *Global Change Biology,* **17(2)**, 990-996.

Dlugolecki, A., 2008: Climate change and the insurance sector. *The Geneva Papers on Risk and Insurance-Issues and Practice,* **33(1)**, 71-90.

Dlugolecki, A.F., 2000: Climate change and the insurance industry. *The Geneva Papers on Risk and Insurance-Issues and Practice,* **25(4)**, 582-601.

Dolcinar, S., A. Hurlimann, and B. Grun, What affects public acceptance of recycled and desalinated water? *Water Research,* **45(2)**, 933-943.

Donohew, Z., 2009: Property rights and western united states water markets. *The Australian Journal of Agricultural and Resource Economics,* **53**, 85-103.

Dovers, S., 2010: Normalizing adaptation. *Global Environmental Change,* **19**, 4-6.

Dovers, S. and R. Hezri, 2010: Institutions and policy processes: The means to the ends of adaptation. *Wiley Interdisciplinary Reviews Climate Change,* **1**, 212-231.

Dryden-Cripton, S., J. Smithers, R. de Loë, and R. Kreutzwiser, 2007: An Evaluation of Options for Responding to Agricultural Droughts and Water Shortages in Canada, Guelph Water Management Group, University of Guelph, Guelph, Ontario, Canada.

Drysdale, R., G. Zanchetta, J. Hellstrom, R. Maas, A. Fallick, M. Pickett, I. Cartwright, and L. Piccini, 2006: Late holocene drought responsible for the collapse of old world civilizations is recorded in an italian cave flowstone. *Geology,* **34(2)**, 101-104.

Dugmore, A.J., C. Keller, T.H. McGovern, A.F. Casely, and K. Smiarowski, 2009: Norse greenland settlement and limits to adaptation. In: *Adapting to climate change: Thresholds, values, governance*. [Adger, W.N., I. Lorenzoni, and K.L. O'Brien(eds.)]. Cambridge University Press, Cambridge, UK, pp. 96-113.

Dugmore, A.J., T.H. McGovern, O. Vesteinsson, J. Arneborg, R. Streeter, and C. Keller, 2012: Cultural adaptation, compounding vulnerabilities and conjunctures in norse greenland. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3658-3663.

Dunning, N.P., T.P. Beach, and S. Luzzadder-Beach, 2012: Kax and kol: Collapse and resilience in lowland maya civilization. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3652-3657.

Ebi, K.L. and J.C. Semenza, 2008: Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine,* **35(5)**, 501-507.

Eckstein, G., 2009: Water scarcity, conflict and security in a climate change world: Challenges and opportunities for international law and policy. **27(3)**, 410-461.

Eisenack, K., R. Stecker, D. Reckien, and E. Hoffmann, 2012: Adaptation to climate change in the transport sector: A review of actions and actors. **17(5)**, 451-469.

Ellison, D., 2010: Addressing adaptation in the EU policy framework. In: *Developing adaptation policy and practice in europe: Multi-level governance of climate change*. [Keskitalo, E.C.H. (ed.)]. Springer, Dordrecht, The Netherlands, pp. 39-96.
Endfield, G.H., 2012: The resilience and adaptive capacity of social-environmental systems in colonial mexico. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3676-3681.
Engle, N.L., 2011: Adaptive capacity and its assessment. *Global Environmental Change,* **21**, 647-656.
Eriksen, S., P. Aldunce, C.S. Bahinipati, R.D. Martins, J.I. Molefe, C. Nhemachena, K. O'Brien, F. Olorunfemi, J. Park, L. Sygna, and K. Ulsrud, 2011: When not every response to climate change is a good one: Identifying principles for sustainable adaptation. *Climate and Development,* **3**, 7-20.
Eriksen, S. and K. Brown, 2011: Sustainable adaptation to climate change *Climate and Development,* **3**, 3-6.
FAO, 2011: Food Security in the World. how does Food Price Volatility Affect Domestic Economies and Food Security? Food and Agriculture Organisation of the United Nations, Rome, Italy, 1-50 pp.
Farley, E.V., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C. Guthrie, L. Eisner, and J.R. Guyon, 2011: Implications of a warming eastern bering sea for bristol bay sockeye salmon. *ICES Journal of Marine Science: Journal Du Conseil,* **68(6)**, 1138-1146.
Fedoroff, N.V., D.S. Battisti, R.N. Beachy, P.J.M. Cooper, D.A. Fischhoff, C.N. Hodges, V.C. Knauf, D. Lobell, B.J. Mazur, D. Molden, M.P. Reynolds, P.C. Ronald, M.W. Rosegrant, P.A. Sanchez, A. Vonshak, and J.-. Zhu, 2010: Radically rethinking agriculture for the 21st century. *Science,* **327**, 833-834.
Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott, 2007: North America. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.Cambridge University Press, Cambridge, UK, 617-652 pp.
Fisher, B.S., N. Nakicenovic, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J.-. Hourcade, K. Jiang, M. Kainuma, E. La Rovere, A. Matysek, A. Rana, K. Riahi, R. Richels, S. Rose, D. van Vuuren, and R. Warren, 2007: Issues Related to Mitigation in the Long-Term Context. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 169-250 pp.
Flåm, K.H. and J.B. Skjærseth, 2009: Does adequate financing exist for adaptation in developing countries? *Climate Policy,* **9(1)**, 109-114.
Fleischer, A., R. Mendelsohn, and A. Dinar, 2011: Bundling agricultural technologies to adapt to climate change . *Technological Forecasting and Social Change,* **78(6)**, 982-990.
Folke, C., 2006: Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change,* **16(3)**, 253-267.
Ford, J.D. and L. Berrang-Ford (eds.), 2011: *Climate change adaptation in developed nations: From theory to practice*. Springer, Dordrecht, The Netherlands, pp. 490.
Ford, J.D., L. Berrang-Ford, and J. Paterson, 2011: A systematic review of observed climate change adaptation in developed nations. A letter. *Climatic Change,* **160**, 237-336.
Ford, J.D., T. Pearce, B. Smit, J. Wandel, M. Allarut, K. Shappa, H. Ittusujurat, and K. Qrunnut, 2007: Reducing vulnerability to climate change in the arctic: The case of nunavut, canada. *Arctic,* **60(2)**, 150-166.
Ford, J.D., 2009: Dangerous climate change and the importance of adaptation for the arctic's inuit population. *Environmental Research Letters,* **4(2)**.
Fordham, D.A., H. Resit Akçakaya, M.B. Araújo, J. Elith, D.A. Keith, R. Pearson, T.D. Auld, C. Mellin, J.W. Morgan, T.J. Regan, M. Tozer, M.J. Watts, M. White, B.A. Wintle, C. Yates, and B.W. Brook, 2012: Plant extinction risk under climate change: Are forecast range shifts alone a good indicator of species vulnerability to global warming? *Global Change Biology,* **18(4)**, 1357-1371.
Foresight, 2011: Migration and Global Environmental Change. Final Project Report, The Government Office for Science, London.
Frank, S., C. Fürst, L. Koschke, and F. Makeschin, 2011: A contribution toward the transfer of the ecosystem service concept to lanscape planning using landscape metrics. *Ecological Indicators,* **21**, 30-38.
Friis, C., 2010: *Land grab in africa: Emerging land system drivers in a teleconnected world* GLP-IPO No.1, Copenhagen, pp. 47.
Fünfgeld, H. and D. McEvoy, 2011: Framing Climate Change Adaptation, Victorian Centre for Climate Change Adaptation Research and RMIT University Climate Change Adaptation Program, Melbourne, Victoria, Australia, .

Füssel, H., 2006: Reducing the risk of a collapse of the atlantic thermohaline circulation: A comment. *The Integrated Assessment Journal,* **6(3)**, 51-58.
Füssel, H., 2007: Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change,* , 167.
Füssel, H., 2009: Ranking of national-level adaptation options. an editorial comment. *Climatic Change,* **95(1-2)**, 47-51.
Füssel, H., 2010: How inequitable is the global distribution of responsibility, capability, and vulnerability to climate change: A comprehensive indicator-based assessment. **20(4)**, 597-611.
Füssel, H. and R.J.T. Klein, 2006: Climate change vulnerability assessments: An evolution of conceptual thinking *Climatic Change,* **75(3)**, 329.
Gagnon-Lebrun, F. and S. Agrawala, 2006: Progress on Adaptation to Climate Change in Developed Countries: An Analysis of Broad Trends, Organization for Economic Cooperation and Development, Paris, France, .
Gallopin, G.C., 2006: Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change,* **16**, 293-303.
Gardiner, S.M., 2010: A perfect moral storm. climate change, intergenerational ethics, and the problem of corruption. In: *Climate ethics: Essential readings.* [Gardiner, S.M., S. Caney, D. Jamieson, and H. Shue(eds.)]. Oxford University Press, Oxford, pp. 87-100.
Gardner, J., R. Parsons, and G. Paxton, 2010: Adaptation Benchmarking Survey: Initial Report, CSIRO Climate Adaptaiton Flagship, Kenmore, Queensland, Australia,.
Garrelts, H. and H. Lange, 2011: Path dependencies and path change in complex fields of action: Climate adaptation policies in germany in the realm of flood risk management. *Ambio,* **40(2)**, 200-209.
Gedan, K.B., M.L. Kirwan, E. Wolanski, E.B. Barbier, and B.R. Silliman, 2011: The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm *Climatic Change,* **106**, 7-29.
Gilman, E.L., J. Ellison, N.C. Duke, and C. Field, 2008: Threats to mangroves from climate change and adaptation options: A review. *Aquatic Botany,* **89(2)**, 237-250.
GIZ, 2011a: Adaptation to Climate Change: New Findings, Methods and Solutions, Deutsche Gesellschaft für Internationale Zusammenarbeit, Eschborn, Germany, 1-35 pp.
GIZ, 2011b: Making Adaptation Count: Concepts and Options for Monitoring and Evaluation of Climate Change Adaptation, Deutsche Gesellschaft für Internationale Zusammenarbeit, Eschborn, Germany, 1-92 pp.
Gleditsch, N.P., 2012: Whither the weather? climate change and conflict. *Journal of Peace Research,* **49(1)**, 3-9.
Goulden, M., D. Conway, and A. Persechino, 2009: Adaptation to climate change in international river basins in africa: A review. *Hydrological Sciences Journal,* **54(5)**, 805-828.
Government of South Africa, 2011: National Climate Change Response White Paper, The Government of the Republic of South Africa, Pretoria, South Africa, 1-48 pp.
Grace, M.F. and R.W. Klein, 2009: The perfect storm: Hurricanes, insurance, and regulation. *Risk Management and Insurance Review,* **12(1)**, 81-124.
Green, D., L. Alexander, K. McLnnes, J. Church, N. Nicholls, and N. White, 2009: An assessment of climate change impacts and adaptation for the torres strait islands, australia. *Climatic Change,* **102(3-4)**, 405-433.
Gregory, P.J., J.S.I. Ingram, and M. Brklacich, 2005: Climate change and food security. *Philosophical Transactions of the Royal Society B,* **360**, 2139-2148.
Grothmann, T., 2011: Governance recommendations for adaptation in european urban regions: Results from five case studies and a european expert survey. In: *Resilient cities: Cities and adaptation to climate change.* [Otto-Zimmermann, K. (ed.)]. Springer, Dordrecht, The Netherlands, pp. 167-176.
Gupta, J., C. Termeer, J. Klostermann, S. Meijerink, M. van den Brink, P. Jong, S. Nooteboom, and E. Bergsma, 2010: The adaptive capacity wheel: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy,* **13(6)**, 459-471.
Haddad, B.M., 2005: Ranking the adaptive capacity of nations to climate change when socio-political goals are explicit. *Global Environmental Change,* **15**, 165-176.
Hallegatte, S., 2009: Strategies to adapt to an uncertain climate change. *Global Environmental Change-Human and Policy Dimensions,* **19(2)**, 240-247.
Hanemann, W.M., 2008: *What is the economic cost of climate change?* Department of Agricultural & Resource Economics, Paper 1071, University of California, Berkeley.

Hanjra, M.A. and M.E. Qureshi, 2010: Global water crisis and future food security in an era of climate change. *Food Policy,* **35(5)**, 365--377.
Hardy, L., A. Garrido, and L. Juana, 2012: Evaluation of spain's water-energy nexus. **28(1)**, 151-170.
Hare, W.L., W. Cramer, M. Schaeffer, A. Battaglini, and C.C. Jaeger, 2011: Climate hotspots: Key vulnerable regions, climate change and limits to warming. *Regional Environmental Change,* **11(Supplement 1)**, S1-S13.
Harris, S.E., 2012: Cyprus as a degraded landscape or resilient environment in the wake of colonial intrusion. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3670-3675.
Hartley, T.W., 2006: Public perception and participation in water reuse. *Desalination,* **187(1-3)**, 115-126.
Hartzell-Nichols, L., 2011: Responsibility for meeting the costs of adaptation. *Wiley Interdisciplinary Reviews: Climate Change,* **2(5)**, 687-700.
Harvey, C.A., B. Dickson, and C. Kormos, 2010: Opportunities for achieving biodiversity conservation through REDD. **3(1)**, 53-61.
Hassan, R. and C. Nhemachena, 2008: Determinants of african farmers' strategies for adapting to clmate change: Multinomial choice analysis. *AfJARE,* **2(1)**, 83-104.
Hayward, B., 2008: 'Nowhere far from sea': Political challenges of coastal adaptation to climate change in new zealand. *Political Science,* **60(1)** , 47-59.
Heltberg, R., P.B. Siegel, and S.L. Jorgensen, 2009: Addressing human vulnerability to climate change: Toward a 'no-regrets' approach. *Global Environmental Change,* **(1)**, 89-99.
Hendrix, C.S. and S.M. Glaser, 2007: Trends and triggers: Climate, climate change and civil conflict in sub-saharan africa. *Political Geography,* **26(6)**, 695-715.
Hendrix, C.S. and I. Salehyan, 2012: Climate change, rainfall, and social conflict in africa. *Journal of Peace Research,* **49(1)**, 35-50.
Hennessy, K., B. Fitzharris, B.C. Bates, N. Harvey, S.M. Howden, L. Hughes, J. Salinger, and R. Warrick, 2007: Australia and New Zealand. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 507-540 pp.
Hertel, T.W. and S. Rosch, 2010: Climate change agriculture and poverty. *Applied Economic Perspectives and Policy,* **32(3)**, 355-385.
Hess, J.J., J.N. Malilay, and A.J. Parkinson, 2008: Climate change: The importance of place. *American Journal of Preventive Medicine,* **(5)**, 468-478.
Heyd, T. and N. Brooks, 2009: Exploring cultural dimensions of adaptation to climate change. In: *Adapting to climate change: Thresholds, values, governance,* [Adger, W.N., I. Lorenzoni, and K.L. O'Brien(eds.)]. Cambridge University Press, Cambridge, 269-282 pp.
Hillie, T. and M. Hlophe, 2007: Nanotechnology and the challenge of clean water. *Nature Nanotechnology,* **2**, 663-664.
Hinkel, J., 2011: Indicators of vulnerability and adaptive capacity: Towards a clarification of the science. *Global Environmental Change,* **21**, 198-208.
Hodgson, J.A., C.D. Thomas, B.A. Wintle, and A. Moilanen, 2009: Climate change, connectivity and conservation decision making: Back to basics. *Journal of Applied Ecology,* **46(5)**, 964-969.
Hoegh-Guldberg, O., 2008: Climate change and coral reefs: Trojan horse or false prophecy? *Coral Reefs,* **28**, 569-575.
Hof, A.F., K.C. de Bruin, R.B. Dellink, M.G.J. den Elzen, and D.P. van Vuuren, 2009: The effect of different mitigation strategies on international financing of adaptation. *Environmental Science & Policy,* **12(7)**, 832-843.
Hof, A.F., M.G.J. den Elzen, and D.P. van Vuuren, 2010: Including adaptation costs and climate change damages in evaluating post-2012 burden-sharing regimes. *Mitigation and Adaptation Strategies for Global Change,* **15(1)**, 19-40.
Homer-Dixon, T.F., 1999: *Environment, scarcity, and violence*. Princeton University Press, Princeton, NJ, USA, .
Howden, S.M., J.F. Soussana, F.N. Tubiello, N. Chhetri, M. Dunlop, and H. Meinke, 2007: Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America,* **104(50)**, 19691-19696.
Hsiang, S.M., K.C. Meng, and M.A. Cane, 2011: Civil conflicts are associated with the global climate. *Nature,* **476(7361)**, 438-441.

Huang, C.R., P. Vaneckova, X.M. Wang, G. FitzGerald, Y.M. Guo, and S.L. Tong, 2011: Constraints and barriers to public health adaptation to climate change A review of the literature. *American Journal of Preventive Medicine,* **40(2)**, 183-190.
Huettner, M., 2012: Risks and opportunities of REDD+ implementation for environmental integrity and socio-economic compatibility. **15(1)**, 4-12.
Hulme, M., W.N. Adger, S. Dessai, M. Goulden, I. Lorenzoni, D. Nelson, L.O. Naess, J. Wolf, and A. Wreford, 2007: *Tyndall Briefing Note*. Limits and Barriers to Adaptation: Four Propositions, Tyndall Centre for Climate Change Research, Norwich, 1-7 pp.
Hulme, M., S. Dessai, I. Lorenzoni, and D.R. Nelson, 2009: Unstable climates: Exploring the statistical and social constructions of 'normal' climate. *Geoforum,* **40(2)**, 197-206.
Hulme, M., R.A. Pielke Jr., and S. Dessai, 2009: Keeping prediction in perspective. *Nature,* **3**, 2.
Hunt, A. and P. Watkiss, 2011: Climate change impacts and adaptation in cities: A review of the literature. *Climatic Change,* **104(1)**, 13-49.
Hunt, T.L., 2007: Rethinking easter island's ecological catastrophe. *Journal of Archaeological Science,* **34(3)**, 485-502.
Huntjens, P., C. Pahl-Wostl, and J. Grin, 2010: Climate change adaptation in european river basins. *Regional Environmental Change,* **10**, 263-284.
Iglesias, A., R. Mougou, M. Moneo, and S. Quiroga, 2011: Towards adaptation of agriculture to climate change in the mediterranean. *Regional Environmental Change,* **11(Supplement 1)**, 166.
Iglesias, A., L. Garrote, F. Flores, and M. Moneo, 2007: Challenges to manage the risk of water security and climate change in the mediterranean. *Water Resources Management,* **21**, 775-788.
Ilaboya, I.R., E. Atikpo, F.E. Omofuma, F.F. Asekhame, and L. Umukoro, 2012: Causes, effects and way forward to food insecurity. *Iranica Journal of Energy & Environment,* **3(1)**, 35-43.
IPCC, 2007a: *Climate change 2007 - impacts, adaptation and vulnerability*. In: Contribution of working group II to the assessment report four of the intergovernmental panel on climate change (IPCC) [Parry, M., O. Canziani, J. Palutikof, and P. van der Linden(eds.)]. Cambridge University Press, Cambridge, UK.
IPCC, 2007b: Summary for Policymakers. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
IPCC, 2012a: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. *A Special Report of the Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
IPCC, 2012b: Summary for policymakers. *A Special Report of the Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
Ivey, J.L., J. Smithers, R.C. de Loë, and R.D. Kreutzwiser, 2004: *Community capacity for adaptation to climate-induced water shortages: Linking institutional complexity and local actors* Springer New York, pp. 36-47.
Iwasaki, S., B.H.N. Razafindrabe, and R. Shaw, 2009: Fishery livelihoods and adaptation to climate change: A case study of chilika lagoon, india. *Mitigation and Adaptation Strategies for Global Change,* **14(4)**, 339-355.
Jack, B.K., C. Kousky, and K.R.E. Sims, 2008: Payments for ecosystem services: Lessons from previous experience with incentive-based systems. *Proceedings of the National Academy of Sciences of the United States of America,* **105(28)**, 9465-9470.
Jantarasami, L.C., J.J. Lawler, and C.W. Thomas, 2010: Institutional barriers to climate change adaptation in U.S. national parks and forests. *Ecology and Society,* **15(4)**, 33.
Jenkins, K.M., R.T. Kingsford, B.J. Wolfenden, S. Whitten, H. Parris, C. Sives, and R. Rolls, 2011: Limits to Climate Change Adaptation in Floodplain Wetlands: The Macquarie Marshes, National Climate Change Adaptation Research Facility, Gold Coast, Queensland, Australia, 1-159 pp.
Johannessen, O.M. and M.W. Miles, 2011: Critical vulnerabilities of marine and sea ice-based ecosystems in the high arctic. *Regional Environmental Change,* **11(Supplement 1)**, S239-S248.
Jones, R.N., 2001: An environmental risk assessment/management framework for climate change impact assessments. *Natural Hazards,* **23**, 197-230.
Jones, R.N. and B.L. Preston, 2011: Adaptation and risk management. *Wiley Interdisciplinary Reviews Climate Change,* **2(2)**, 292-308.

Jones, L. and E. Boyd, 2011: Exploring social barriers to adaptation: Insights from western nepal. *Global Environmental Change,* **21(4)**, 1262-1274.
Joos, F. and R. Spani, 2008: Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years. *Proceedings of the National Academies of Sciences,* **105(5)**, 1430.
Kapos, V. and L. Miles, 2008: Reducing greenhouse gas emissions from deforestation and forest degradation: Global land-use implications. *Science,* **320(5882)**, 1454-1455.
Kasperson, J.X., R.E. Kasperson, and B.L. Turner II (eds.), 1995: *Regions at risk: Comparisons of threatened environments*. United Nations University Press, Tokyo, pp. 588.
Kasperson, R.E. and J.X. Kasperson, 1996: The social amplification and attenuation of risk. *Annals of the American Academy of Political and Social Science,* **545**, 95-105.
Kates, R.W., W.R. Travis, and T.J. Wilbanks, 2012: Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences of the United States of America,* in press.
Keller, K., G. Yohe, and M. Schlesinger, 2008: Managing the risks of climate thresholds: Uncertainties and information needs *Climatic Change,* **91**, 5-10.
Keryn, B., M.L. Kirwan, E. Wolanski, E.B. Barbier, and B.R. Silliman, 2011: The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. *Climatic Change,* , 7-29.
Keskitalo, E.C.H. (ed.), 2010: *The development of adaptation policy and practice in europe: Multi-level governance of climate change*. Spring, Dordrecht, The Netherlands, pp. 376.
Kevane, M. and L. Gray, 2008: Darfur: Rainfall and conflict. *Environmental Research Letters,* **3**, 034006.
Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, and F.L. Toth, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Inter-Relationships between Adaptation and Mitigation, Cambridge University Press, Cambridge, UK, 745-777 pp.
Koivurova, T., 2007: International legal avenues to address the plight of victims of climate change: Problems and prospects. **22**, 267-299.
Koubi, V., T. Bernauer, A. Kalbhenn, and G. Spilker, 2012: Climate variability, economic growth, and civil conflict. *Journal of Peace Research,* **49(1)**, 113-127.
Kousky, C. and R.M. Cooke, 2009: Climate change and risk management: Challenges for insurance, adaptation, and loss estimation. *RFF Discussion Paper no.09-03-REV*, Resources for the Future, Washington, DC, USA.
Kriegler, E., J.W. Hall, H. Held, R. Dawson, and H.J. Schellnhuber, 2008: Imprecise probability assessment of tipping points in the climate system. *Proceedings of the National Academies of Science,* **106(13)**, 5041-5046.
Krosby, M., J. Tewksbury, N.M. Haddad, and J. Hoekstra, 2010: Ecological connectivity for a changing climate. *Conservation Biology,* **24(6)**, 1686-1689.
Krysanova, V., C. Dickens, J. Timmerman, C. Varela-Ortega, M. Schlüter, K. Roest, P. Huntjeans, F. Jaspers, H. Buiteveld, E. Moreno, J. de Pedraza Carrera, R. Slámová, M. Martínková, I. Blanco, P. Esteve, K. Pringle, C. Pahl-Wostl, and P. Kabat, 2010: Cross-comparison of climate chagne adaptation strategies across large river basins in europe, africa and asia. *Water Resources Management,* **24**, 4121-4160.
Kunreuther, H. and E. Michel-Kerjan, 2009: *At war with the weather: Managing large-scale risks in a new era of catastrophes*. The MIT Press, Cambridge, Massachusetts, USA.
Kunreuther, H., E. Michel-Kerjan, and N. Ranger, 2011: Insuring Climate Catastrophes in Florida: An Analysis of Insurance Pricing and Capacity Under various Scenarios of Climate Change and Adaptation Measures, Centre for Climate Change Economics and Policy and The Grantham Research Institute on Climate Change and the Environment, London, UK, 1-24 pp.
Kunreuther, H.C. and E.O. Michel-Kerjan, 2007: Climate change, insurability of large-scale disasters and the emerging liability challenge. *University of Pennsylvania Law Review,* **155(6)**, 1795-1842.
Kuruppu, N. and D. Liverman, 2011: Mental preparation for climate adaptation: The role of cognition and culture in enhancing adaptive capacity of water management in kirabati. *Global Environmental Change,* **21(2)**, 657-669.
Kuruppu, N., 2009: Adapting water resources to climate change in kiribati: The importance of cultural values and meanings. *Environmental Science & Policy,* **12(7)**, 799-809.
Lafferty, W. and E. Hoyden, 2003: Environmental policy integration: Towards and analytical framework. *Environmental Politics,* **12(3)**, 1-22.

Lal, P.N., P. Mitchell, P. Aldunce, H. Auld, R. Mechler, A. Miyan, L.E. Romano, and S. Zakaria, 2012: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. National Systems for Managing the Risks from Climate Extremes and Disasters, Cambridge University Press, Cambridge, UK and New York, NY, USA, 339-392 pp.
Lal, R., 2011: Soil degradation and food security in south asia. In: [Lal, R., M.V.K. Sivakumar, S.M.A. Faiz, A.H.M. Mustafizur Rahman, and K.R. Islam(eds.)]. Springer, Dordrecht, Netherlands, pp. 137-152.
Lavell, A.M., M. Oppenheimer, C. Diop, J. Hess, R. Lempert, J. Li, R. Muir-Wood, and S. Myeong, 2012: *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Climate Change: New Dimensions in Disaster Risk, Expoure, Vulnerability, and Resilience, Cambridge University Press, Cambridge, UK and New York, NY, USA, 25-64 pp.
Lavergne, S., N. Mouquet, W. Thuiller, and O. Ronce, 2010: Biodiversity and climate change: Integrating evolutionary and ecological responses of species and communities. *Annual Review of Ecology, Evolution, and Systematics,* **41(1)**, 321-350.
Leary, N., K. Averyt, B. Hewitson, and J. Marengo, 2009: Crossing thresholds in regional climate research: Synthesis of the IPCC expert meeting on regional impacts, adaptation, vulnerability, and mitigation. *Climate Research,* **40(2-3)**, 121-131.
Lemieux, C.J., T.J. Beechey, and P.A. Gray, 2011: Prospects for canada's protected areas in an era of rapid climate change. *Land use Policy,* **28(4)**, 928-941.
Lenton, T., H. Held, E. Kriegler, J. Hall, W. Lucht, S. Rahmstorf, and S. Hoachim, 2008: Tipping points in the Earth's climate system. *Proceedings of the National Academies of Science,* **(6)**, 1793.
Levin, K. and B. Petersen, 2011: Tradeoffs in the policy process in advancing climate change adaptation: The case of australia's great eastern ranges initiative. *Journal of Natural Resources Policy Research,* **3(2)**, 145-162.
Libecap, G.D., 2010: Institutional Path Dependence in Climate Adaptation: Coman's "some Unsettled Problems of Irrigation", National Bureau of Economic Research, Cambridge, Massachusettes, USA, 1-27 pp.
Lim, B., E. Spanger-Siegfried, I. Burton, E. Malone, and S. Huq (eds.), 2005: *Adaptation policy frameworks for climate change: Developing strategies, policies and measures*. Cambridge University Press, New York, pp. 258.
Lobell, D.B., C.B. Field, K.N. Cahill, and C. Bonfils, 2006: Impacts of future climate change on california perennial crop yields: Model projections with climate and crop uncertainties. *Agricultural and Forest Meteorology,* **141(2-4)**, 208-218.
Loring, P.A., S.C. Gerlach, D.E. Atkinson, and M.S. Murray, 2011: Ways to help and ways to hinder: Governance for effective adaptation to an uncertain climate. *Arctic,* **64(1)**, 73-88.
Lovejoy, T.E., 2005: Conservation with a changing climate. In: *Climate change and biodivesity*. [Lovejoy, T.E. and L.J. Hannah(eds.)]. Yale University Press, New Haven, Connecticut, pp. 325-328.
Lovejoy, T.E., 2006: Protected areas: A prism for a changing world. *Trends in Ecology & Evolution,* **21**, 329-333.
Lowe, J.A., S.C.B. Raper, S.K. Liddicoat, and L.K. Gohar, 2009: How difficult is it to recover from dangerous levels of global warming? *Environmental Research Letters,* **4(1)**, DOI: 10.1088/1748-9326/4/1/014012.
Luers, A.L. and S.C. Moser, 2006: Preparing for the Impacts of Climate Change in California: Advancing the Debate on Adaptation, Public Interest Energy Research Program and the California Environmental Protection Agency, Sacramento, California.
Luzzadder-Beach, S., T.P. Beach, and N.P. Dunning, 2012: Wetland fields as mirrors of drought and the maya abandonment. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3646-3651.
Maddocks, 2012: The Role of Regulation in Facilitating Or Constraining Adaptation to Climate Change for Australian Infrastructure, Department of Climate Change and Energy Efficiency, Canberra, ACT, Australia, 1-153 pp.
Madramootoo, C. and H. Fyles, 2012: Synthesis of findings from the four McGill conferences on global food security: 2008 - 2011. *Food Security,* , 1-11.
Magrin, G., C. Gay García, D. Cruz Choque, J.C. Giménez, A.R. Moreno, G.J. Nagy, C. Nobre, and A. Villamizar, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Latin America, Cambridge University Press, Cambridge, UK, 581-615 pp.

Malhi, Y., L.E.O.C. Aragao, D. Galbraith, C. Huntingford, R. Fisher, P. Zelazowski, S. Sitch, C. McSweeney, and P. Meir, 2009a: Exploring the likelihood and mechanism of a climate-change-induced dieback of the amazon rainforest. *Proceedings of the National Academies of Sciences,* **106**, 20615.
Malhi, Y., J.T. Roberts, R.A. Betts, T.J. Killeen, W. Li, and C.W. Nobre, 2009b: Climate change, deforestation, and the fate of the amazon. *Science,* **319(5860)**, 169-172.
Massey, E. and E. Bergsma, 2008: Assessing Adaptation in 29 European Countries, Institute for Environmental Studies, Amsterdam, Netherlands, 1-84 pp.
Mastrandrea, M.D. and S.H. Schneider, 2004: Probabilistic integrated assessment of "dangerous" climate change. *Science,* **304(5670)**, 571-575.
Mataki, M., K. Koshy, and V. Nair, 2006: Implementing Climate Change Adaptation in the Pacific Islands: Adapting to Present Climate Variability and Extreme Weather Events in Navua (Fiji), International START Secretariat, Washington, DC, USA, 1-30 pp.
Maynard, J., A. Baird, and M. Pratchett, 2008: Revisiting the cassandra syndrome; the changing climate of coral reef research. *Coral Reefs,* **27**, 745-749.
McAnany, P.A. and N. Yoffee, 2010: Questioning how different societies respond to crises. *Nature,* **464(7291)**, 977-977.
McDonald, J., 2011: The role of law in adapting to climate change. *WIRES Climate Change,* **2**, 283-295.
McEvoy, D., P. Matczak, I. Banaszak, and A. Chorynski, 2010: Framing adaptation to climate-related extreme events. *Mitigation and Adaptation Strategies for Global Change,* **15(7)**, 779-795.
McGray, H., H. Hammill, R. Bradley, E.L. Schipper, and J.E. Parry, 2007: Weathering the Storm: Options for Framing Adaptation and Development, World Resources Institute, Washington, DC, USA.
McNamara, K.E., S.G. Smithers, R. Westoby, and K. Parnell, 2011: Limits to Climate Change Adaptation for Low-Lying Communities in the Torres Strait, National Climate Change Adaptation Research Facility, Gold Coast, Queensland, Australia, 1-87 pp.
McNamara, K.E. and C. Gibson, 2009: 'We don't want to leave our land': Pacific ambassadors to the united nations resist the category of 'climate refugees'. *Geoforum,* **40**, 475-483.
Measham, T.G., B.L. Preston, C. Brooke, T.F. Smith, C. Morrison, G. Withycombe, and R. Gorddard, 2011: Adapting to climate change through local municipal planning: Barriers and opportunities. *Mitigation and Adaptation Strategies for Global Change,***16(8)**, 889- 909.
Measham, T.G. and B.L. Preston, 2012: Vulnerability analysis, risk and deliberation: The sydney climate change adaptation initiative. In: *Risk and social theory in environmental management*. CSIRO Publishing, Collingwood, Victoria, Australia.
Mechler, R., S. Hochrainer, A. Aaheim, H. Salen, and A. Wreford, 2010: Modelling economic impacts and adaptation to extreme events: Insights from european case studies. *Mitigation and Adaptation Strategies for Global Change,* **15**, 762.
Meze-Hausken, E., 2008: On the (im-)possibilities of defining human climate thresholds. *Climatic Change,* **89(3-4)**, 299-324.
Michel-Kerjan, E.O., 2010: Catastrophe economics: The national flood insurance program. *The Journal of Economic Perspectives,* **24(4)**, 165-186.
Mickwitz, P., F. Aix, S. Beck, D. Carss, N. Ferrand, C. Görg, A. Jensen, P. Kivimaa, C. Kuhlicke, W. Kuindersma, M. Máñez, M. Melanen, S. Monni, A.B. Pedersen, H. Reinert, and S. van Bommel, 2009: Climate Policy Integration, Coherence, and Governance, Partnership for European Environmental Research, Helsinki, Finland, 1-91 pp.
Midgley, G., Sarshen,M., M. Barnett, and K. Wågsæther, 2012: Biodiversity, Climate Change and Sustainable Development – Harnessing Synergies and Celebrating Successes. Final Technical Report, The Adaptation Network.
Miguel, E. and S. Satyanath, 2011: Re-examining economic shocks and civil conflict. *American Economic Journal: Applied Economics,* **3(4)**, 228-232.
Millar, C.I., N.L. Stephenson, and S.L. Stephens, 2007: Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Applications,* **17(8)**, 2145-2151.
Millennium Ecosystem Assessment, 2005: *Ecosystems and human well-being: General synthesis*. Island Press, .
Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. van der Leeuw, J. Rockstrom, J. Hinkel, T. Downing, C. Folke, and D. Nelson, 2010: Resilience and vulnerability: Complementary or conflicting concepts? *Ecology and Society,* **15(3)**, 11.

Mills, E., 2005: Insurance in a climate of change. *Science,* **309(5737)**, 1040-1044.
Mills, E., 2009: A global review of insurance industry responses to climate change. *Geneva Papers on Risk and Insurance-Issues and Practice,* **34(3)**, 323-359.
Mimura, N., L. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet, and G. Sem, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Small Islands, Cambridge University Press, Cambridge, UK, 687-716 pp.
Mitchell, T., T. Tanner, and E. Wilkinson, 2006: Overcoming the Barriers: Mainstreaming Climate Change Adaptation in Developing Countries, Institute for Development Studies, Brighton, UK, .
Montgomery, M.R., 2008: The urban transformation of the developing world. *Science,* **(5864)**, 761-764.
Mortreux, C. and J. Barnett, 2009: Climate change, migration and adaptation in funafuti, tuvalu. *Global Environmental Change,* **19**, 105-112.
Moser, S.C., 2009: Governance and the art of overcoming barriers to adaptation. *IHDP Update,* **3**, 31-36.
Moser, S.C., 2010: Now more than ever: The need for more societally-relevant research on vulnerability and adaptation to climate change. *Applied Geography,* **30(4)**, 464-474.
Moser, S.C., R.E. Kasperson, G. Yohe, and J. Agyeman, 2008: Adaptation to climate change in the northeast united states: Opportunities, process, constraints. *Mitigation and Adaptation Strategies for Global Change,* **13**, 643-659.
Moser, S.C. and J.A. Ekstrom, 2010: A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences of the United States of America,* **107(51)**, 22026-22031.
Moser, S.C. and A.L. Luers, 2008: Managing climate risks in california: The need to engage resource managers for successful adaptation to change. *Climatic Change,* **87**, S309-S322.
Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant, and T.J. Wilbanks, 2010: The next generation of scenarios for climate change research and assessment. *Nature,* **463**, 747-756.
Müller, B., 2008: International Adaptation Finance: The Need for an Innovative and Strategic Approach, International Adaptation Finance: The Need for an Innovative and Strategic Approach, Oxford, UK, .
Muller, M., 2007: Adapting to climate change: Water management for urban resilience. *Environment and Urbanization,* **19(1)**, 99-113.
Munich Re, 2011: Great Natural Catastrophes Worldwide 1950 – 2010, Münchener Rückversicherungs Gesellschaft, Geo Risks Research, NatCatService, Munich, Germany.
Munich Re, 2012: Topics Geo- Natural Catastrophes 2011: Analysis, Assessments, Positions, Munich Re, Munich, Germany.
Munroe, R., N. Doswald, D. Roe, H. Reid, A. Giuliani, I. Castelli, and I. Moller, 2011: Does EbA Work? A Review of the Evidence on the Effectiveness of Ecosystem-Based Approaches to Adaptation. Nairobi, Kenya, .
Murphy, C.F., D. Allen, B. Allenby, J. Crittenden, C.I. Davidson, C. Hendrickson, and H.S. Matthews, 2009: Sustainability in engineering education and research at U.S. universities. *Environmental Science & Technology,* **43**, 5564.
Mustelin, J., R. Klein, B. Assaid, T. Sitari, M. Khamis, A. Mzee, and T. Haji, 2010: Understanding current and future vulnerability in coastal settings: Community perceptions and preferences for adaptation in zanzibar, tanzania. *Population & Environment,* **31(5)**, 371-398.
Naess, L.O., G. Bang, S. Eriksen, and J. Vevatne, 2005: Institutional adaptation to climate change: Flood responses at the municipal level in norway. *Global Environmental Change,* **15(2)**, 125-138.
National Research Council, 2009: *Informing decisions in a changing climate*. The National Academies Press, Washington, D.C.
National Research Council, 2010: *Adapting to the impacts of climate change*. The National Academies Press, Washington, DC.
Nel, P. and M. Righarts, 2008: Natural disasters and the risk of violent civil conflict. *International Studies Quarterly,* **52(1)**, 159-185.
Nelson, R., M. Howden, and M. Stafford Smith, 2008: Using adaptive governance to rethink the way science supports australian drought policy *Environmental Science & Policy,* **11(7)**, 588-601.

Nelson, R., P. Kokic, S. Crimp, P. Martin, H. Meinke, S.M. Howden, P. DeVoil, G. McKeon, and U. Nidumolu, 2010: The vulnerability of australian rural communities to climate variability and change: Part II—integrating impacts with adaptive capacity. *Environmental Science & Policy,* **13**, 18-27.

Nelson, R., P. Kokic, S. Crimp, H. Meinke, and S.M. Howden, 2010: The vulnerability of australian rural communities to climate variability and change: Part I—conceptualising and measuring vulnerability. *Environmental Science & Policy,* **11(7)**, 642-654.

Nhemachena, C. and R. Hassan, 2007: Micro-Level Analysis of Farmers' Adaptation to Climate Change in Southern Africa, International Food Policy Research Institute, Washington, DC, USA, .

Nicholls, R., 2007: Adaptation Options for Coastal Zones and Infrastructure. Financial and Technical Support Division, Bonn, Germany.

Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. De Gusmao, J. Hinkel, and R.S.J. Tol, 2011: Sea-level rise and its possible impacts given a 'beyond 4 degrees C world' in the twenty-first century. *Philosophical Transactions of the Royal Society A,* **369(1934)**, 161-181.

Nielsen, J.O. and A. Reenberg, 2010: Cultural barriers to climate change adaptation: A case study from northern burkina faso. *Global Environmental Change-Human and Policy Dimensions,* **20(1)**, 142-152.

Nisbet, M.C. and D.A. Scheufele, 2009: What's next for science communication? promising directions and lingering distractions. *American Journal of Botany,* **96(10)**, 1767-1778.

Nkem, J., F.B. Kalame, M. Idinoba, O.A. Somorin, O. Ndoye, and A. Awono, 2010: Shaping forest safety nets with markets: Adaptation to climate change under changing roles of tropical forests in congo basin *Environmental Science & Policy,* **13**, 498-508.

Nordhaus, W.D., 2001: Global warming economics. **294(9)**, 1283-1284.

NRC, 2010: *America's Climate Choices*. Adapting to the Impacts of Climate Change, National Research Council, Washington, DC, USA, 1-272 pp.

Nunn, P.D., C.T. Keally, C. King, J. Wijaya, and R. Cruz, 2006: Human responses to coastal change in the asia-pacific region. In: *Global change and integrated coastal management*. [Harvey, N. (ed.)]. Springer, Dordrecht, The Netherlands, pp. 117-161.

NZCCO, 2004a: Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand, New Zealand Ministry for the Environment, Wellington, New Zealand.

NZCCO, 2004b: Preparing for Climate Change: A Guide for Local Government in New Zealand, Wellington, New Zealand.

O'Brien, K., S. Eriksen, L. Nygaard, and A. Schjolden, 2007: Why different interpretations of vulnerability matter in climate change discourses. *Climate Policy,* **7**, 73-88.

O'Brien, K., M. Pelling, A. Patwardhan, S. Hallegatte, A. Maskrey, T. Oki, U. Oswald-Spring, T. Wilbanks, and P.Z. Yanda, 2012: Toward a Sustainable and Resilient Future. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 437-486 pp.

O'Brien, K., L. Syngna, R. Leichenko, W.N. Adger, J. Barnett, T. Mitchell, L. Schipper, T. Tanner, C. Vogel, and C. Mortreaux, 2008: Disaster Risk Reduction, Climate Chaneg Adaptation and Human Security, Report Prepared for the Norwegian Ministry of Foreign Affairs by the Global Environmental Change and Human Security (GECHS) Project, Oslo, Norway, 1-76 pp.

O'Brien, K., 2009: Do values subjectively define the limits to climate change adaptation? In: *Adapting to climate change: Thresholds, values, governance*. [Adger, N.W., I. Lorenzoni, and K. O'Brien(eds.)]. Cambridge University Press, Cambridge, pp. 164-180.

O'Brien, K.L. and J. Wolf, 2010: A values-based approach to vulnerability and adaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change,* **1(2)**, 232-242.

O'Hara, J.K., 2012: Ensuring the Harvest: Crop Insurance and Credit for a Healthy Farm and Food Future, Union of Concerned Scientists, Cambridge, Massachusettes, 1-30 pp.

Omelicheva, M.Y., 2011: Natural disasters: Triggers of political instability? *International Interactions,* **37(4)**, 441-465.

O'Neill, B.C., M. Dalton, R. Fuchs, L. Jiang, S. Pachauri, and K. Zigova, 2010: Global demographic trends and future carbon emissions. *Proceedings of the National Academies of Sciences,* **(41)**, 17521-17523.

O'Neill, S. and J. Handmer, 2012: Responding to bushfire risk: The need for transformative adaptation. *Environmental Research Letters,* **7**.

Opperman, J.J., G.E. Galloway, J. Fargione, J.F. Mount, B.D. Richter, and S. Secchi, 2009: Sustainable floodplains through large-scale reconnection to rivers. *Science,* **326(5959)**, 1487-1488.
Osbahr, H., C. Twyman, W.N. Adger, and D.S.G. Thomas, 2010: Evaluating successful livelihood adaptation to climate variability and change in southern africa. *Ecology and Society,* **(2)**, 27.
Paavola, J., 2008: Livelihoods, vulnerability and adaptation to climate change in morogoro, tanzania *Environmental Science & Policy,* **11(7)**, 642-654.
Paavola, J. and W.N. Adger, 2006: Fair adaptation to climate change. **56(4)**, 594-609.
Park, S.E., N.A. Marshall, E. Jakku, A.M. Dowd, S.M. Howden, and A. Fleming, 2011: Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change,* **22(1)**, 115-126.
Parry, M., N. Arnell, P. Berry, D. Dodman, S. Fankhauser, C. Hope, S. Kovats, R. Nicholls, D. Satterthwaite, R. Tiffin, and T. Wheeler, 2009: Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates, International Institute for Environment and Development and Grantham Institute for Climate Change, London, UK.
Parry, M.L., O.F. Canziani, and J.P. Palutikof, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Technical Summary, Cambridge University Press, Cambridge, UK, 23-78 pp.
Patt, A.G., L. Ogallo, and M. Hellmuth, 2007: Learning from 10 years of climate outlook forums in africa. *Science,* **318(5847)**, 49-50.
Patt, A.G. and D. Schröter, 2008: Perceptions of climate risk in mozambique: Implications for the success of adaptation strategies. *Global Environmental Change,* **(3)**, 467.
Patt, A.G., D.P. van Vuuren, F. Berkhout, A. Aaheim, A.F. Hof, M. Isaac, and R. Mechler, 2010: Adaptation in integrated assessment modeling: Where do we stand? . *Climatic Change,* **99**, 383-402.
Patt, A.G., M. Tadross, P. Nussbaumer, Asante Kwabena, M. Metzger, J. Rafael, A. Goujon, and G. Brundri, 2010: Estimating least-developed countries' vulnerability to climate-related extreme events over the next 50 years. *Proceedings of the National Academy of Sciences of the United States of America,* **107(4)**, 1333-1337.
Patt, A.G. and D. Schröter, 2008: Perceptions of climate risk in mozambique: Implications for the success of adaptation strategies. *Global Environmental Change,* **18(3)**, 458-467.
Patz, J.A., H.K. Gibbs, J.A. Foley, J.V. Rogers, and K.R. Smith, 2007: Climate change and global health: Quantifying a growing ethical crisis. *EcoHealth,* **DOI: 10.1007/s10393-007-0141-1**, 397-405.
Paudel, Y., 2012: A comparative study of Public—Private catastrophe insurance systems: Lessons from current practices. *The Geneva Papers on Risk and Insurance-Issues and Practice,* **37(2)**, 257-285.
Pearce-Higgins, J., L. Stephen, A. Douse, and R.H.W. Langston, 2012: Greater impacts of wind farms on bird populations during construction than subsequent operation: Results of a multi-site and multi-species analysis. *Journal of Applied Ecology,* **49(2)**, 386-394.
Peck, L.S., M.S. Clark, S.A. Morley, A. Massey, and H. Rossetti, 2009: Animal temperature limits and ecological relevance: Effects of size, activity and rates of change. *Functional Ecology,* **23(2)**, 248-256.
Pederson, N., A.R. Bell, T.A. Knight, C. Leland, N. Malcomb, K.J. Anchkaitis, K. Tackett, J. Scheff, A. Brice, B. Catron, W. Blozan, and J. Riddle, 2012: A long-term perspective on a modern drought in the american southwest. *Environmental Research Letters,* **7**.
Pelling, M., 2011: *Adaptation to climate change: From resilience to transformation*. Routledge, London, UK, .
Persson, Å., R.J.T. Klein, C.K. Siebert, A. Atteridge, B. Müller, J. Hoffmaister, M. Lazarus, and T. Takama, Adaptation Finance Under a Copenhagen Agreed Outcome, Stockholm Environment Institute, Stockholm, Sweden.
Petersen, J.K., J.W. Hansen, M.B. Laursen, P. Clausen, J. Carstensen, and D.J. Conley, Regime shift in a coastal marine ecosystem. *Ecological Applications,* **(- 2)**, - 497-510.
Phelps, J., E.L. Webb, and A. Agrawal, 2010: Does REDD+ threaten to recentralize forest governance? *Science,* **328(5976)**, 312-313.
Piao, S., P. Ciais, Y. Huang, Z. Shen, S. Peng, J. Li, L. Zhou, H. Liu, Y. Ma, Y. Ding, P. Friedlingstein, C. Liu, K. Tan, Y. Yu, T. Zhang, and J. Fang, 2010: The impacts of climate change on water resources and agriculture in china. *Nature,* **467**, 43-51.
Picketts, I.M., A.T. Werner, T.Q. Murdock, J. Curry, S.J. Déry, and D. Dyer, 2012: Planning for climate change adaptation: Lessons learned from a community-based workshop. *Environmental Science & Policy,* **17(0)**, 82-93.
Pidgeon, N. and C. Butler, 2009: Risk analysis and climate change. *Environmental Politics,* **18(5)**, 670-688.

Pielke Jr., R.A., 2005: Misdefining "climate change": Consequences for science and action. *Environmental Science and Policy,* **8**, 548-561.
Pielke Jr., R.A., 2007: Future economic damage from tropical cyclones: Sensitivities to societal and climate changes. *Philosophical Transactions of the Royal Society A,* **365**, 2717-2729.
Pielke Jr., R.A., J. Gratz, C.W. Landsea, D. Collins, M.A. Saunders, and R. Musulin, 2008: Normalized hurricane damages for the united states: 1900-2005. *Natural Hazards Review,* **9(1)**, 29-42.
Pielke Jr., R.A., G. Prins, and S. Rayner, 2007: Climate change 2007: Lifting the taboo on adaptation. *Nature,* **445**, 597-598.
Pittock, A.B., 2006: Are scientists underestimating climate change? *Eos,* **(34)**, 340-341.
Pittock, J., 2011: National climate change policies and sustainable water management: Conflicts and synergies. *Ecology and Society,* **16(2)**, 25.
Poff, N.L., J.D. Olden, D.M. Merritt, and D.M. Pepin, 2007: Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences,* **104(14)**, 5732-5737.
Prato, T., 2008: Accounting for risk and uncertainty in determining preferred strategies for adapting to future climate change. *Mitigation and Adaptation Strategies Fro Global Change,* **13**, 47-60.
Preston, B.L., Submitted: Path dependence in socioeconomic exposure to climate extremes and the 'vulnerability commitment'. *Global Environmental Change,* .
Preston, B.L. and CSIRO, 2008: *Mapping climate change vulnerability in the sydney coastal councils group*. Sydney Coastal Councils Group Incorporated, Sydney, NSW.
Preston, B.L. and R.C. Kay, 2010: Managing climate risk in human settlements. In: *Greenhouse 2009*. [Jubb, I., P. Holper, and W. Cai(eds.)]. CSIRO Publishing, Collingwood, Victoria, Australia, pp. 185.
Preston, B.L. and M. Stafford Smith, 2009: Framing Vulnerability and Adaptive Capacity Assessment, Climate Adaptation National Research Flagship, Canberra, 1-52 pp.
Preston, B.L., R.M. Westaway, and E.J. Yuen, 2011a: Climate adaptation planning in practice: An evaluation of adaptation plans from three developed nations. *Mitigation and Adaptation Strategies for Global Change,* **16(4)**, 407-438.
Preston, B.L., E.J. Yuen, and R.M. Westaway, 2011b: Putting climate vulnerability on the map: A critical look at approaches, benefits, and risks. *Sustainability Science,* **6(2)**, 177-202.
Preston, B.L., C. Brooke, T.G. Measham, T.F. Smith, and R. Gorddard, 2009: Igniting change in local government: Lessons learned from a bushfire vulnerability assessment. *Mitigation and Adaptation Strategies for Global Change,* **14(3)**, 251-283.
Productivity Commission, 2009: *Productivity Commission Inquiry Report*. Government Drought Support, Commonwealth of Australia, Canberra, Australian Commonwealth Territory, 1-486 pp.
Ragen, T.J., H.P. Huntington, and G.K. Hovelsrud, 2008: Conservation of arctic marine mammals faced with climate change. *Ecological Applications,* **18(2)**, S166-S174.
Raleigh, C., 2010: Political vulnerability to climate change in the african sahel states. *International Studies Review,* **12(1)**, 69-89.
Raleigh, C. and D. Kniveton, 2012: Come rain or shine: An analysis of conflict and climate variability in east africa. *Journal of Peace Research,* **49(1)**, 51-64.
Raudsepp-Hearne, C., G.D. Peterson, M. Tengo, E.M. Bennett, T. Holland, K. Benessaiah, G.K. MacDonald, and L. Pfeifer, 2010: Untangling the environmentalist's paradox: Why is human well-being increasing as ecosystem services degrade? *Bioscience,* **60(8)**, 576-589.
Rayner, T. and A. Jordan, 2010: Adapting to climate change: An emerging european policy? In: *Climate change policy in the european union: Confronting the dilemmas of mitigation and adaptation*. [Jordan, A., D. Huitema, H. van Asselt, T. Rayner, and F. Berhout(eds.)]. Cambridge University Press, Cambridge, UK, .
Reeder, T., J. Wicks, L. Lovell, and O. Tarrant, 2009: Protecting london from tidal flooding: Limits to engineering adaptation. In: *Adapting to climate change*. [Adger, W.N., I. Lorenzoni, and K.L. O'Brien(eds.)]. Cambridge University Press, Cambridge, pp. 54-78.
Rockstrom, J., W. Steffen, K. Noone, A. Persson, F.S. Chapin , E.F. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sorlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J.A. Foley, 2009: A safe operating space for humanity. *Nature,* **461(7263)**, 472-475.

Rosen, A.M. and I. Rivera-Collazo, 2012: Climate change, adaptive cycles, and the persistence of foraging economies during the late Pleistocene/Holocene transition in the levant. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3640-3645.
Rosenau, J.N., 2005: Strong demand, huge supply: Governance in an emerging epoch. In: *Multi-level governance*. [Bache, I. and M. Flinders(eds.)]. Oxford University Press, Oxford, UK, pp. 31-48.
Rowley, R.J., J.C. Kostelnick, D. Braaten, X. Li, and J. Meisel, 2007: Risk of rising sea level to population and land area. *Eos,* **88**, 105-116.
Rupp-Armstrong, S. and R.J. Nicholls, 2007: Coastal and estuarine retreat: A comparison of the application of manage realignment in england and germany. *Journal of Coastal Research,* **236**, 1418-1430.
Rygaard, M., P.J. Binning, and H. Albrechtsen, 2011: Increasing urban water self-sufficiency: New era, new challenges. *Journal of Environmental Management,* **92**, 185-194.
Sathaye, J., A. Najam, C. Cocklin, T. Heller, F. Lecocq, J. Llanes-Regueiro, J. Pan, G. Petschel-Held, S. Rayner, J. Robinson, R. Schaeffer, Y. Sokona, R. Swart, and H. Winkler, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Sustainable Development and Mitigation, Cambridge University Press, Cambridge, UK, 691-743 pp.
Schipper, E.L.F., 2008: Religion and risk: The challenge of harnessing faith and reducing exposure. In: Proceedings of Living with climate change: Are there limits to adaptation? 7-8 February 2008, Royal Geographical Society, London.
Schneider, S.H. and J. Lane, 2006: An overview of 'dangerous' climate change. In: *Avoiding dangerous climate change*. [Schellnhuber, H.J., W. Cramer, N. Nakicenovic, T. Wigley, and G. Yohe(eds.)]. Cambridge University Press, Cambridge, UK, pp. 159-176.
Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez, and F. Yamin, 2007: Assessing Key Vulnerabilities and the Risk from Climate Change. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 779-810 pp.
Schneider, S.H. and J. Lane, 2005: Dangers and thresholds in climate change and the implications for justice. In: *Justice in adaptation to climate change*. [Adger, W.N. (ed.)]. Cambridge University Press, Cambridge, .
Scott, D., G. McBoyle, A. Minogue, and B. Mills, 2006: Climate change and the sustainability of ski-based tourism in eastern north america: A reassessment. *Journal of Sustainable Tourism,* **14(4)**, 376-398.
Scott, D. and G. McBoyle, 2007: *Climate change adaptation in the ski industry* Springer Netherlands, pp. 1411-1431.
Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-. Huang, N. Harnik, A. Leetmaa, N.-. Lau, C. Li, J. Velez, and N. Naik, Model projections of an imminent transition to a more arid climate in southwestern north america. *Science,* **316**, 1181-1184.
Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in Climate Extremes and their Impacts on the Natural Physical Environment. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, 109-230 pp.
Shah, T., 2009: Climate change and groundwater: India's opportunities for mitigation and adaptation. *Environmental Research Letters,* **4**.
Sheehan, P., R.N. Jones, A. Jolley, B.L. Preston, M. Clarke, P.J. Durack, S.M.N. Islam, and P.H. Whetton, 2008: Climate change and the new world economy: Implications for the nature and timing of policy responses. *Global Environmental Change,* **18(3)**, 380-396.
Shen, L.Y., J.J. Ochoa, M.N. Shah, and X. Zhang, 2011: The application of urban sustainability indicators - A comparison between various practices. *Habitat International,* **35**, 17-29.
Shen, Y., T. Oki, N. Utsumi, S. Kanae, and N. Hansaki, 2008: Projection of future world water resources under SRES scenarios: Water withdrawal. *Hydrological Sciences Journal,* **53(1)**, 11-33.
Sinkala, T. and F.X. Johnson, 2012: Small-scale production of jatropha in zambia and its implications for rural development and national biofuel policies. bioenergy for sustainable development in africa. In: [Janssen, R. and D. Rutz(eds.)]. Springer Netherlands, pp. 41-51.

Slettebak, R.T., 2012: Don't blame the weather! climate-related natural disasters and civil conflict. *Journal of Peace Research,* **49(1)**, 163-176.
Smit, B., 1993: *Occasional Paper, Canadian Climate Program Board, Department of Geography, University of Guelph*. Adaption to Climatic Variability and Change: Report of the Task Force on Climate Adaptation, Environment Canada, Ontario .
Smit, B., I. Burton, R. Klein, and J. Wandel, 2000: An anatomy of adaptation to climate change and variability. *Climatic Change,* **45**, 223-251.
Smit, B., O. Pilifosova, I. Burton, B. Challenger, S. Huq, R.J.T. Klein, and G. Yohe, 2001: Adaptation to climate change in the context of sustainable development and equity. *Climate Change 2001: Impacts, Adaptation, Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, 876-912 pp.
Smith, J.B., S.H. Schneider, M. Oppenhimer, G.W. Yohe, W. Haref, M.D. Mastrandrea, A. Patwardhang, I. Burton, J. Corfee-Morloti, C.H.D. Magadzaj, H. Füssel, A.B. Pittock, A. Rahman, A. Suarez, and J.-. van Yperselen, 2009a: Assessing dangerous climate change through an update of the intergovernmental panel on climate change (IPCC) ''reasons for concern''. *Proceedings of the National Academies of Science,* , 4137.
Smith, T.F., Preston, B., R. Goordard, C. Brooke, T.G. Measham, G. Withycombe, B. Beveridge, and C. Morrison, 2008a: Regional Workshop Synthesis Report: Sydney Coastal Councils' Vulnerability to Climate Change Part 1, Sydney Coastal Councils Group, Sydney, Australia.
Smith, T.F., C. Brooke, T.G. Measham, B.L. Preston, R. Gorddard, G. Withycombe, B. Beveridge, and C. Morrison, 2008b: Case Studies of Adaptive Capacity: Systems Approach to Regional Climate Change Adaptation Strategies, Sydney Coastal Councils Group, Inc., Sydney, New South Wales, Australia, .
Smith, T.F., R.W. Carter, P. Daffara, and N. Keys, 2010: The Nature and Utility of Adaptive Capacity Research, National Climate Change Adaptation Research Facility, Gold Coast, Queensland, Australia.
Smith, J.B., J.M. Vogel, and J.E. Cromwell, 2009b: An architecture for government action on adaptation to climate change. an editorial comment. *Climatic Change,* **95(1-2)**, 53-61.
Stafford Smith, M., L. Horrocks, A. Harvey, and C. Hamilton, 2011: Rethinking adaptation for a 4°C world. *Philosophical Transactions of the Royal Society A,* **369**, 196-216.
Stern, N., S. Peters, V. Bakhshi, A. Bowen, C.S. Cameron, C.D. Catovsky, S. Cruickshank, S. Dietz, N. Edmondson, S. Garbett, L. Hamid, G. Hoffman, D. Ingram, B. Jones, N. Patmore, H. Radcliffe, R. Sathiyarajah, M.C. Stock, V.T. Taylor, H. Wanjie, and D. Zenghelis, 2006: Stern Review on the Economics of Climate Change, Cambridge University Press, Cambridge, UK, 579 pp.
Storbjork, S., 2010: 'It takes more to get a ship to change course': Barriers for organizational learning and local climate adaptation in sweden. *Journal of Environmental Policy & Planning,* **12(3)**, 235-254.
Streeter, R., A.J. Dugmore, and O. Vesteinsson, 2012: Plague and landscape resilience in premodern iceland. *Proceedings of the National Academy of Sciences of the United States of America,* **109(10)**, 3664-3669.
Swart, R.J., G.R. Biesbroek, S. Binnerup, T.R. Carter, C. Cowan, T. Henrichs, S. Loquen, H. Mela, M. Morecroft, M. Reese, and D. Rey, 2009: Europe Adapts to Climate Change: Comparing National Adaptation Strategies, Partnership for European Environmental Research, Helsinki, Finland, 440-450 pp.
Tal, A., 2011: The desalination debate - lessons learned thus far. *Environment: Science and Policy for Sustainable Development,* **53(5)**, 34-48.
Tan, P.-., K.H. Bowmer, and J. Mackenzie, 2012: Deliberative tools for meeting the challenges of water planning in australia. *Journal of Hydrology,* in press.
Tarnoczi, T.J. and F. Berkes, 2010: Sources of information for farmers' adaptation practices in Canada's prairie agro-ecosystem. A letter. *Climatic Change,* **98(1-2)**, 299-305.
Taylor, B.M., B.P. Harman, S. Heyenga, and R.R.J. McAllister, 2012: Property developers and urban adaptation: Conceptual and empirical perspectives on governance. *Urban Policy and Research,* in press.
te Linde, A.H., P. Bubeck, J.E.C. Dekkers, H. de Moel, and J.C.J.H. Aerts, 2011: Future flood risk estimates along the river rhine. *Natural Hazards and Earth Systems Sciences,* **11**, 459-473.
Termeer, C., R. Biesbroek, and M. van den Brink, 2012: Institutions for adaptation to climate change: Comparing national adaptation strategies in europe. *Eupean Political Science,* **11**, 41-53.
Thackeray, S.J., T.H. Sparks, M. Frederiksen, S. Burthe, P.J. Bacon, J.R. Bell, M.S. Botham, T.M. Brereton, P.W. Bright, L. Carvalho, T. Clutton-Brock, A. Dawson, M. Edwards, J.M. Elliott, R. Harrington, D. Johns, I.D. Jones, J.T. Jones, D.I. Leech, D.B. Roy, W.A. Scott, M. Smith, R.J. Smithers, I.J. Winfield, and S. Wanless,

2010: Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. *Global Change Biology,* **116(2)**, 3304-3313.
Theisen, O.M., 2012: Climate clashes? weather variability, land pressure, and organized violence in kenya, 1989–2004. *Journal of Peace Research,* **49(1)**, 81-96.
Theisen, O.M., H. Holtermann, and H. Buhaug, 2012: Climate wars? assessing the claim that drought breeds conflict. *International Security,* **36(3)**, 79-106.
Thomas, D.S.G. and C. Twyman, 2005: Equity and justice in climate change adaptation amongst natural-resource-dependent societies. **15(2)**, 115-124.
Thompson, L.G., E. Mosley-Thompson, M.E. Davis, K.A. Henderson, H.H. Brecher, V.S. Zagorodnov, T.A. Mashiotta, P.N. Lin, V.N. Mikhalenko, D.R. Hardy, and J. Beer, 2002: Kilimanjaro ice core records: Evidence of holocene climate change in tropical africa. *Science,* **298(5593)**, 589-593.
Thornton, P.K., P.G. Jones, T. Owiyo, R.L. Kruska, M. Herrero, V. Orindi, S. Bhadwal, P. Kristjanson, A. Notenbaert, N. Bekele, and A. Omolo, 2008: Climate change and poverty in africa: Mapping hotspots of vulnerability. *AfJARE,* **2(1)**, 24-44.
Timmerman, J.G., S. Koeppel, F. Bernardini, and J.J. Buntsma, 2011: Adaptation to climate change: Challenges for transboundary water management. In: *The economic, socal, and political elements of climate change*. [Filho, W.L. (ed.)]. Springer-Verlag, Berlin, pp. 523-541.
Tobey, J., P. Rubinoff, D. Robadue Jr., G. Ricci, R. Volk, J. Furlow, and G. Anderson, 2010: Practicing coastal adaptation to climate change: Lessons from integrated coastal management. *Coastal Management,* **38(3)**, 317-335.
Tol, R.S.J., R.J.T. Klein, and R.J. Nicholls, 2008: Toward successful adaptation to sea-level rise along europe's coast. *Journal of Coastal Research,* **242**, 432-442.
Tol, R.S.J. and G.W. Yohe, 2007: The weakest link hypothesis for adaptive capacity: An empirical test. *Global Environmental Change,* **17(2)**, 227.
Tompkins, E.L. and H. Eakin, 2012: Managing private and public adaptation to climate change. *Global Environmental Change,* **22**, 3-11.
Tompkins, E.L., W.N. Adger, E. Boyd, S. Nicholson-Cole, K. Weatherhead, and N. Arnell, 2010: Observed adaptation to climate change: UK evidence of transition to a well-adapting society. *Global Environmental Change-Human and Policy Dimensions,* **20(4)**, 627-635.
Trærup, S.L.M., 2012: Informal networks and resilience to climate change impacts: A collective approach to index insurance. *Global Environmental Change,* **22**, 255-267.
Travis, W.R., 2010: Going to extremes: Propositions on the social response to severe climate chagne. *Climatic Change,* **98**, 1-19.
Tribbia, J. and S.C. Moser, 2008: More than information: What coastal managers need to plan for climate change. *Environmental Science & Policy,* **11(4)**, 315-328.
Tscharntke, T., Y. Clough, T.C. Wanger, L. Jackson, I. Motzke, I. Perfecto, J. Vandermeer, and A. Whitbread, 2012: Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation,* in press.
UK Government, 2008: *Climate change act 2008* London, UK.
UN, 2011: *World Population Prospects: The 2010 Revision. CD-ROM Edition - Extended Dataset in Excel and ASCII Formats*. Department of Economic and Social Affairs, Population Division, United Nations, New York, New York, USA.
UNDP, 2007: Human Development Report 2007/08, Palgrave McMillan, New York, USA, .
UNEP, 2011: A Practical Framework for Planning Pro-Development Climate Policy, Untied Nations Environment Programme, Nairobi, Nigeria, 1-143 pp.
UNEP, 2012: Protecting climate, health, and crops: New coalition callas time on short-lived pollutants. *Black Carbon e-Bulletin,* **4(1)**, 1-6.
UNFCCC, 1992: United Nations Framework Convention on Climate Change, UNFCCC Secretariat, Bonn, Germany.
UNFCCC, 2002: Annotated Guidelines for the Preparation of National Adaptation Programs of Action, Least Developed Countries Expert Group, United Nations Framework Convention on Climate Change, New York, New York, USA.
UNFCCC, 2006: Application of Environmentally-Sound Technologies for Climate Change Adaptation, Climate Change Secretariat, United Nations Framework Convention on Climate Change, Bonn, Germany, .

UNFCCC, 2007: Investment and Financial Flows to Address Climate Change, Climate Change Secretariat, United Nations Framework Convention on Climate Change, Bonn, Germany.
UNISDR, 2009: Global Assessment Report on Disaster Risk Reduction: Risk and Poverty in a Changing Climate - Invest Today for a Safer Tomorrow, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.
Urwin, K. and A. Jordan, 2008: Does public policy support or undermine climate change adaptation? exploring policy interplay across different scales of governance. *Global Environmental Change,* **18**, 180-191.
USAID, 2007: Adapting to Climate Variability and Change: A Guidance Manual for Development Planning, Bureau for Economic Growth, Agriculture and Trade, US Agency for International Development, Washington, DC, USA.
van Aalst, M.K., T. Cannon, and I. Burton, 2008: Community level adaptation to climate change: The potential role of participatory community risk assessment. *Global Environmental Change,* **18**, 165-179.
van den Berg, M.M., W.M. Lafferty, and F.H.J.M. Coenen, 2010: Adaptation to climate change induced flooding in dutch municipalities. In: *The social and behavioural aspects of climate change: Linking vulnerability, adaptation and mitigation*. [Martens, W.J.M. and C.T. Chang(eds.)]. Greenleaf, Sheffield, UK.
van Koningsveld, M., J.P.M. Mulder, M.J.F. Stive, L. Vandervalk, and A.W. Vanderweck, 2008: Living with sea-level rise and climate change: A case study of the netherlands. *Journal of Coastal Research,* **24**, 367-379.
van Nieuwaal, K., P. Driessen, T. Spit, and C. Termeer, 2009: A State of the Art Governance Literature on Adaptation to Climate Change: Towards a Research Agenda, National Research Programme Knowledge for Climate, Utrecht, Netherlands, 1-43 pp.
Van Wilgen, B.W., J.L. Nel, and M. Rouget, 2007: Invasive alien plants and south african rivers: A proposed approach to the prioritization of control operations. *Freshwater Biology,* **52(4)**, 711-723.
Vellinga, P., E. Mills, G. Berz, L. Bouwer, S. Huq, L. Kozak, J. Palutikof, and B. Schanzenbächer, 2001: *Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Insurance and Other Financial Services, Cambridge, UK, 417-450 pp.
Vermeulen, S.J., P.K. Aggarawal, A. Ainslie, C. Angelone, B.M. Campbell, A.J. Challinor, J.W. Hansen, J.S.I. Ingram, A. Jarvis, P. Kristjanson, C. Lau, G.C. Nelson, P.K. Thornton, and E. Wollenberg, 2012: Options for support to agriculture and food security under climate change. *Environmental Science & Policy,* **15**, 136-144.
Vignola, R., B. Locatelli, C. Martinez, and P. Imbach, 2009: Ecosystem-based adaptation to climate change: What role for policymakers, society and scientists? *Mitigation and Adaptation Strategies for Global Change,* **14(8)**, 691-696.
von Braun, J., 2009: Addressing the food crisis: Governance, market functioning, and investment in public goods *Food Security,* **(1)**, 9-15.
Walther, G., 2010: Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society B,* **365**, 2019-2024.
Warner, K., N. Ranger, S. Surminski, M. Arnold, J. Linnerooth-Bayer, E. Michel-Kerjan, P. Kovacs, and C. Herweijer, 2009: *Adaptation to Climate Change: Linking Disaster Reduction and Insurance*, United Nations International Strategy for Disaster Reduction Secretariat (UNISDR), Geneva, Switzerland.
Washington-Allen, R.A., D.D. Briske, H.H. Shugart, and L.F. Salo, 2010: Introduction to special feature on catastrophic thresholds, perspectives, definitions, and applications. *Ecology and Society,* **15(3)**.
West, J.M., S.H. Julius, P. Kareiva, C. Enquist, J.J. Lawler, B. Petersen, A.E. Johnson, and M.R. Shaw, 2009: U.S. natural resources and climate change: Concepts and approaches for management adaptation. *Environmental Management,* **44**, 1001-1021.
Westerhoff, L., E.C.H. Keskitalo, and S. Juhola, 2011: Capacities across scales: Local to national adaptation policy in four european countries. *Climate Policy,* **11(4)**, 1071-1085.
Wheeler, S.M., 2008: State and municipal climate change plans. *Journal of the American Planning Association,* **74(4)**, 481-496.
Whitmarsh, L., 2008: Are flood victims more concerned about climate change than other people? the role of direct experience in risk perception and behavioural response. *Journal of Risk Research,* **11(3)**, 351-374.
Wilby, R.L. and S. Dessai, 2010: Robust adaptation to climate change. *Weather,* **65(7)**, 180-185.
Wilby, R.L. and R. Keenan, 2012: Adapting to flood risk under climate change. *Progress in Physical Geography,* **29**, in press.
Wilby, R.L., J. Troni, Y. Biot, L. Tedd, C. Hewitson, D.M. Smith, and R.T. Sutton, 2009: A review of climate risk information for adaptation and development planning. *International Journal of Climatology,* **29(9)**, 1193-1215.

Willows, R. and R. Connell, 2003: Climate Adaptation: Risk, Uncertainty, and Decision-Making, UK Climate Impacts Programme, Oxford, UK.
Witsenburg, K.M. and W.R. Adano, 2009: Of rain and raids: Violent livestock raiding in northern kenya. *Civil Wars,* **11(4)**, 514-538.
Witt, M.J., E.V. Sheehan, S. Bearhop, A.C. Broderick, D.C. Conley, S.P. Cotterell, E. Crow, W.J. Grecian, C. Halsband, D.J. Hodgson, P. Hosegood, R. Inger, P.I. Miller, D.W. Sims, R.C. Thompson, K. Vanstaen, S.C. Votier, M.J. Attrill, and B.J. Godley, 2012: Assessing wave energy effects on biodiversity: The wave hub experience. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* **370(1959)**, 502-529.
Wolf, J., W.N. Adger, I. Lorenzoni, V. Abrahamson, and R. Raine, 2010: Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two UK cities. *Global Environmental Change,* **(1)**, 44-52.
Wolf, J., I. Lorenzoni, R. Few, V. Abrahamson, and R. Raine, 2009: Conceptual and practical barriers to adaptation: Vulnerability and responses to heat waves in the UK. In: *Adapting to climate change: Thresholds, values, governance*. [Adger, N.W., I. Lorenzoni, and K. O'Brien(eds.)]. Cambridge University Press, Cambridge, pp. 181-196.
Wookey, P.A., R. Aerts, R.D. Bardgett, F. Baptist, K.A. Bråthen, J.H.C. Cornelissen, L. Gough, I.P. Hartley, D.W. Hopkins, S. Lavorel, and G.R. Shaver, 2009: Ecosystem feedbacks and cascade processes: Understanding their role in the responses of arctic and alpine ecosystems to environmental change. *Global Change Biology,* **15(5)**, 1153-1172.
World Bank, 2006: Investment Framework for Clean Energy and Development, The World Bank, Washington, DC, USA.
World Bank, 2008: Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters, The World Bank, Washington, DC, USA.
Yohe, G. and K. Strzepek, 2007: Adaptation and mitigation as complementary tools for reducing the risk of climate impacts. *Mitigation and Adaptation Strategies for Global Change,* **12(5)**, 727-739.
Yohe, G.W. and R.S.J. Tol, 2002: Indicators for social and economic coping capacity – moving towards a working definition of adaptive capacity. *Global Environmental Change,* **12(1)**, 25-40.
Young, O.R., 2009: Institutional dynamics: Resilience, vulnerability and adaptation in environmental and resource regimes. *Global Environmental Change,* **20**, 378-385.
Younger, M., H. Morrow-Almeida, S.M. Vindigni, and A.L. Dannenberg, 2008: *The built environment, climate change, and health: Opportunities for co-benefits* Elsevier Science, pp. 517-526.
Yuen, E.J. and S. Stone Jovicich, 2012: Climate change vulnerability assessments as catalysts for social learning: Four case studies in south-eastern australia. *Mitigation and Adaptation Strategies for Global Change*, in press.
Zhang, D.D., H.F. Lee, C. Wang, B.S. Li, Q. Pei, J. Zhang, and Y.L. An, 2011: The causality analysis of climate change and large-scale human crisis. *Proceedings of the National Academy of Sciences of the United States of America,* **108(42)**, 17296-17301.
Zhu, X., M.M. Linham, and R.J. Nicholls, 2010: *TNA Guidebook Series*. Technologies for Climate Change Adaptation -Coastal Erosion and Flooding, UNEP Risø Centre on Energy, Climate and Sustainable Development, Roskilde, Denmark, .
Ziervogel, G., P. Johnston, M. Matthew, and P. Mukheibir, 2010: Using climate information for supporting climate change adaptation in water resource management in south africa *Climatic Change,* **(3-4)**, 537-554.
Zinn, M.D., 2007: Adapting to climate change: Environmental law in a warmer world. *Ecology Law Quarterly,* **34(1)**, 61-105.

Table 16-1: Examples of potential trade-offs among adaptation objectives.

Sector	Strategy	Adaptation Objective	Real or Perceived Externality	References
Agriculture	Biotechnology and genetically modified crops	Enhance drought and pest resistance; enhance yields	Perceived risk to public health and safety; ecological risks associated with introduction of new genetic variants to natural environments	Howden *et al*. (2007); Nisbet and Scheufele (2009); Fedoroff *et al*. (2010)
	Subsidized drought assistance; crop insurance	Provide financial safety net for farmers to ensure continuation of farming enterprises	Creates moral hazard and inequality if not appropriately administered	Productivity Commission (2009); Pray *et al*. (2011); Trærup (2011); O'Hara (2012); Vermeulen *et al*. (2012)
	Increased use of chemical fertilizer and pesticides	Maintain or enhance crop yields; suppress opportunistic agricultural pests and invasive species	Increased discharge of nutrients and chemical pollution to the environment; increased emissions of greenhouse gases; increased human exposure to pollutants	Gregory *et al*. (2005); Howden *et al*. (2007); Boxall *et al*. (2009)
Biodiversity	Migration corridors; expansion of conservation areas	Enable natural adaptation and migration to changing climatic conditions	Unknown efficacy; concerns over property rights regarding land acquisition; governance challenges	Hodgson *et al*. (2009); West *et al*. (2009); Krosby *et al*. (2010); Levin and Petersen (2011)
	Anticipatory endangerment listings	Enhance regulatory protections for species potentially at-risk due to climate change	Addresses secondary rather than primary pressures on species; concerns over property rights; regulatory barriers to economic development	Clark *et al*. (2008); Ragen *et al*. (2008); Bernanzzani *et al*. (2012)
	Assisted migration	Facilitate conservation of valued species	Potential for externalities for ecological and human systems due to species relocation	Lovejoy (2005, 2006); McLachlan *et al*. (2007); Dunlop and Brown (2008)
Coasts	Sea walls	Protect assets from inundation and/or erosion	High direct and opportunity costs; equity concerns; ecological impacts to coastal wetlands	Nicholls (2007); Hayward (2008); Hallegatte (2009); Zhu *et al*., (2010)
	Managed retreat	Allow natural coastal and ecological processes; reduce long-term risk to property and assets	Undermines private property rights; significant governance challenges associated with implementation	Rupp-Armstrong and Nicholls (2007); Hayward (2008); Abel *et al*. (2011); Titus (2011)
	Migration out of low-lying areas	Preserve public health and safety; minimize property damage and risk of stranded assets	Loss of sense of place and cultural identify; erosion of kinship and familial ties; impacts to receiving communities	Hess *et al*. (2008); Helberg *et al*. (2009); McNamara and Gibson (2009); Adger *et al*. (2011)
Water resources management	Desalination	Increase water resource reliability and drought resilience	Ecological risk of saline discharge; high energy demand and associated carbon emissions; creates disincentives for conservation	Adger and Barnett (2009); Barnett and O'Neill (2010); Becker *et al*. (2010); Rygaard *et al*. (2011); Tal *et al*. (2011)
	Water trading	Maximize efficiency of water management and use; increases flexibility	Undermines public good/social aspects of water	Alston and Mason (2008); Bourgeon *et al*. (2008); Donohew (2008); Mooney and Tan (2012); Tan *et al*. (2012)
	Water recycling/reuse	Enhance efficiency of available water resources	Perceived risk to public health and safety;	Hartley, 2006; Dolcinar *et al*., 2011

Table 16-2: Summary of potential interactions between mitigation practices and adaptation opportunities, constraints, and limits.

Mitigation practice	**Adaptation Opportunity**	**Adaptation Constraint**	**Adaptation limit**
Energy efficiency (demand side)	Water use efficiency; Climate resilient transportation systems	Current vulnerability of transport infrastructure	--
Energy decarbonisation	Identification of new technologies and sources for natural gas	Some strategies may involve hydraulic fracturing and unsustainable impacts on ground water resource	--
Fossil fuel substitution - biofuel	Use of aridifying/degraded/abandoned croplands	May lead to unsustainable land use change, food security impacts, adverse conservation/EBA outcomes	Food security
Fossil fuel substitution – renewable energy	Conservation/Ecosystem Based Adaptation (EBA)/Livelihoods Hydro power also provides irrigation Sea level control through tidal power production systems?	May pose risk to natural ecosystems (birds/bats due to solar; all hydro; tide and wind may have unacceptable impacts on marine species and ecosystems)	Exceeding species or systems thresholds at a local level
Carbon sequestration CCS	Emerging carbon markets encourage investment	Status of research and development of technologies	--
Carbon sequestration Reforestation	Conservation/EBA/Livelihoods	Competing land uses	Wildfire/drought/thermal limits
Carbon sequestration – afforestation	Conservation/Fire suppression	Ecosystem conversion; sustainable water supply; invasiveness	Wildfire/drought/thermal limits
Carbon sequestration – REDD	Conservation/EBA/Livelihoods	Indigenous use of goods and services; design of institutions	Wildfire/drought/thermal limits
Land-use change sustainable agriculture	Conservation/EBA/Livelihoods	--Ability to adopt new agricultural practices	Drought/thermal limits

*Ecosystem-based approaches to adaptation

Table 16-3: Cross-sectoral synthesis.

Sector	Framing	Rate of change	Opportunities	Constraint	Limits	Synthesis
Freshwater resources	Integration of water-related adaptation options into planning and implementation, enhance adaptive water management techniques. IWRM joined with SEA is a major instrument to explore water-related adaptation measures. Successful IWRM strategies capture several elements. [3.6.1, 3.6.3]. Adaptation involves measures to alter hydrological characteristics to suit human demands, and measures to alter demands to fit conditions of water availability [3.6.6]	*[To be completed post-FOD]*	Climate change is frequently cited as a key motivation for the adoption of adaptive water management [3.6.3]	Failure to estimate actual costs for many reasons [3.6.2], very little guidance on precisely how the adaptive water management approach works when addressing climate change over the next few decades, institutional structures that limit stakeholder engagement and the uncertainty in how climate change may affect the water management system [3.6.3] Uncertainty in the projected future changes makes it impossible for practical purposes to construct quantitative probability distributions of climate change impacts [3.6.5]	Four different types of limits on adaptation to changes in water quantity and quality in UK identified by Arnell and Delaney, 2006.	*[To be completed post-FOD]*
Terrestrial and inland water systems	Autonomous adaptation by ecosystem (capacity to migrate) and human assisted adaptation including adaptive management and, migration and restoration [4.4.1, 4.4.2]	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Autonomous adaptation constrained by physical or topographic barriers (*e.g.*, valleys, mountain ranges and water bodies), human-created (fences, roads, croplands or settled areas), increasing habitat fragmentation of ecosystem. [4.4.3] Social and institutional factors including poor ecological understanding are constraints for successful adaptive management. [4.4.2]	A clear consensus that climate change will result in shifts in species ranges, and that range contractions and constraints on migration for many species, especially in the context of highly fragmented habitats and other global change pressures, will greatly increase extinction risk over the coming century. [4.3.3]	*[To be completed post-FOD]*

Coastal systems and low-lying areas	Adaptation occurs in the context of existing governance and social-ecological systems, regardless of types of adaptation i.e. proactive and planned or reactive and ad hoc, approach is integrative and adaptive management [5.9.1] Different constraints typically do not act as barriers in isolation, but come in interacting bundles. [5.9.4]	*[To be completed post-FOD]*	Many approaches on integration, better social, ecological, and economic outcomes have been developed over time including Integrated Coastal Management, Community-Based Adaptation, Ecosystem-Based Adaptation, and Disaster Risk Reduction and Management. [5.9.1]	Technological feasibility, resources, institutional barriers (existing laws, regulations, procedural requirements or ineffective governance), social and psychosocial (place attachment, social support, social norms, identity), cultural-cognitive (beliefs, worldviews, values, awareness, education) and economic (livelihood, job mobility, investment), lack of awareness, knowledge or location-specific information, social justice concerns, or negative interactions between different policy goals. [5.9.4]	Studies published after AR4 reinforcing finding and producing a better understanding on "there are limits to the extent to which natural and human coastal systems can adapt even to the more immediate changes in climate variability and extreme events, including in more developed countries"	*[To be completed post-FOD]*
Ocean systems	Ecosystem resilience and marine ecosystem based adaptation [6.4]	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Constraints are related to ocean temperature, acidification, etc that limit functions of ocean and supply of primary elements to living organism such as oxygen [6.4]. Knowledge gap on whether and to what extent species can undergo adaptation to progressive ocean acidification over generations [6.2].	There have been reports on climate-induced changes in species abundances but not on climate-induced extinctions in the oceans [6.3].	*[To be completed post-FOD]*
Food production and food systems	Reductions in risk and vulnerability by adjusting practices, processes and capital in response to current climate or threat of climate change [7.5.1].	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Inadequate information on climate, climate impacts, risks and benefits of options, lack of adaptive capacity, technical options, inadequate extension, institutional inertia, financial resources, infrastructure, functioning markets and insurance systems [7.5.1]	Physiological limits to performance and crop yields requirement to sustain critical backward and forward link infrastructure. [7.5.1]	*[To be completed post-FOD]*

Urban areas	Integrate/mainstream climate change adaptation in city planning and implementation.	*[To be completed post-FOD]*	Growing attention to cities and urban areas in middle-income and low-income countries. Recognition of important relation between adaptation to climate change and development.	Institutional constraints, resource limitations, limited adaptive capacity with limited resources, weak institutions, poor/inadequate infrastructure and poor governance in global south. Capacity constraints including limited technical expertise and ill-designed institutional mechanisms, uncertainty as to what climate change will bring (and when) in each locality, city government priorities are often driven by short term priorities and nearer term concerns about economic growth and competitiveness.	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Rural Areas	Economic and institutional development, improvements in health, education and infrastructure, growing interconnectedness and technology transfers	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Prevailing development constraints, physical, financial, social and cultural barriers, lack of access to credit and water, better access to markets, extension and credit services, technology and farm assets, lack of access to technologies and markets.	There are limits to the role of social capital in resilience which also context specific.	*[To be completed post-FOD]*
Key economic sectors and services	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*

Human health	*[To be completed post-FOD]*	[*[To be completed post-FOD]*	Black Carbon abatement is an opportunity to achieve both climate mitigation and health benefits (UNEP, 2012). Cross sectoral adaptation opportunities exists (transportation, building, landuse, forestry and agriculture (Younger et al., 2008)	Uncertainties of future climate and socioeconomic conditions, financial, technologic, institutional, social capital and individual cognitive limits, different knowledge and conceptual understanding by different actors/stakeholders, governance arrangements and the way institutions works (Huang, C, et al., 2010; Carmichael and Lambert, 2011)	*[To be completed post-FOD]*	[*[To be completed post-FOD]*
Synthesis	[*[To be completed post-FOD]*	[*[To be completed post-FOD]*	*[To be completed post-FOD]*	[*[To be completed post-FOD]*	*[To be completed post-FOD]*	[*[To be completed post-FOD]*

Table 16-4: Cross-regional synthesis.

Region	**Framing**	**Rate of change**	**Opportunities**	**Constraint**	**Limits**	**Synthesis**
Africa [22.3.4: adaptation section is forthcoming]	Mainstreaming climate change into national development policies. Sub-regional organizations integrate climate change in their policies and economic management.	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Lack of capacity, data and integrated analysis,	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Asia	Adaptive management and mainstreaming climate change into development planning at all scales, levels and sectors.	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Ecological, social and economic, technical and political are key constraints for developing countries in Asia. Spatial and temporal uncertainties associated with forecasts of regional climate, limited national capacities in climate monitoring and forecasting, and lack of co-ordination in the formulation of responses are other constraints. Absence of involvement of upstream and downstream stakeholder, using inaccurate or incomplete impact forecasts has potential to increase maladaptation.	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Europe	Adaptation is a trans-national and a cross-sectoral issue.	*[To be completed post-FOD]*	Policy makers are responding to the need to develop climate adaptation strategies. There are some evidences that adaptation are already occurring in Europe.	There is no integrated coastal zone management or climate change adaptation for the Baltic Sea Region.	There are limits to how far communities can adapt to rapid and large sea-level rise. Studies have examined such impacts in the UK.	*[To be completed post-FOD]*
Australasia	Policy reforms for mainstreaming climate change that comprises an interdependent mix of strategies.	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Water availability for expansion of agriculture, individual and collective social and cultural values, councils with limited resources, community level adaptation is constraints by financial resources, social and institutional capital, limited vertical and horizontal integration of governance.	*To be completed post-FOD]*	*[To be completed post-FOD]*

North America	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Climate change offers many adaptation opportunities in water scarce areas. Relationships also exist between urban development and adaptations. Some urban authorities in North America are starting to acknowledge the local implications of climate change and are adapting.	High cost, energy and time required to construct, develop and maintain Infrastructures and services, warning systems and emergency preparedness, low social capital and limited economic resources, regional-to-local spatial scales climate scenarios, decision priority on extreme events than changes in long-term average conditions, many cities that are developing adaptation actions have existing deficits in infrastructure (e.g., insufficient coverage, need of major upgrades and climate proofing), services (health, education), and institutional capacity. Other cities lack of willingness to address adaptation issues.	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Central and South America	*[To be completed post-FOD]*	*[To be completed post-FOD]*	Heavily constrained by limited funding available from central governments for this purpose.	Limited fund, responses to disaster mainly, lack of capacity to response to early warning system, institutional capacity to mainstream climate change into policy.	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Polar Region [will add later]	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Small Islands	Mainstreaming and integrating climate change into development plans is seen as a goal. The importance of community-based adaptation actions are seen as being critical to successful adaptation in small islands.		*[To be completed post-FOD]*	Lack of technology and human resource capacity, financial limitations, lack of cultural and social acceptability and uncertain political and legal frameworks, lack of climate change and socio-economic scenarios and data at the required scale.	*[To be completed post-FOD]*	*[To be completed post-FOD]*
Synthesis	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*	*[To be completed post-FOD]*

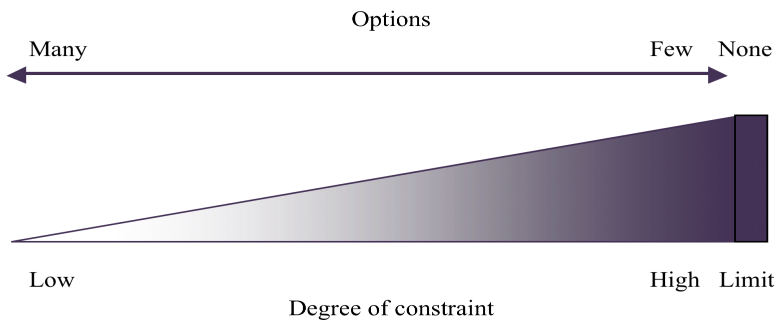

Figure 16-1: An actor’s view of adaptation constraints and limits at a given point in time.