Chapter 16. Adaptation Opportunities, Constraints, and Limits

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Contents

Executive Summary

A range of factors constrain the planning and implementation of adaptation actions and potentially reduce their effectiveness (*high agreement, robust evidence*). The availability of resources for adaptation continues to feature strongly in the adaptation literature as a significant constraint on adaptation, as does uncertainty regarding future climate and disaster risk at national and regional scales. However, there is increasing awareness within the literature of the dynamics of social processes and governance that mediate the entitlements of actors to resources and promote social learning regarding adaptation. The manner in which these constraints manifest and their implications for the capacity of an actor to achieve adaptation objectives vary significantly across different regions and sectors as well as across different social and temporal scales. Some constraints to adaptation are a consequence of inherent trade-offs among different perceptions of risk and the allocation of finite resources, and therefore, adaptation efficiency and effectiveness may often be less than optimal. [16.2, 16.3]

Evidence from both natural and human-managed systems demonstrates the existence of limits to adaptation to climatic and other related environmental and socio-economic risks (*high agreement, robust evidence*). Archeological and historical evidence is providing growing insights into periods of societal change, including catastrophic societal failures, in which climate change or variability may have been a contributory factor. Such evidence indicates that socioeconomic and cultural factors mediate societal responses to emergent risks such as changes in climate and influence the likelihood of limits to adaptation being reached and exceeded. [16.3, 16.5, 16.5.1, 16.5.2, 16.8, Box16-3]

Limits to adaptation emerge as a result of the interaction between climate change and other biophysical and socioeconomic constraints (*high agreement, robust evidence*). Recent studies have provided valuable insights regarding the presence of so-called ‘tipping points’, ‘key vulnerabilities’, or ‘planetary boundaries’ for the Earth system. While these biophysical thresholds represent an important determinant of limits to adaptation, particularly for natural systems, socioeconomic conditions and trends also contribute to the definition of limits in social systems. In particular, demographic change as well as economic development will influence future human vulnerability and adaptive capacity, but the externalities of these processes may reduce the resilience of natural systems to adapt to a changing climate. [16.2, 16.3, 16.4]

Much of the literature identifying limits to adaptation for specific systems and/or management objectives are associated with biophysical systems, particularly ecosystems and/or individual species that are dependent upon specific biophysical regimes (*high agreement, robust evidence*). Those species that already persist at the

edge of their thermal and/or hydrological limits are likely to be most vulnerable to a changing climate. Species do have the capacity to adapt through phenotypic and genetic responses. The physiological and/or ecological thresholds imposed by climate effectively represent 'hard' limits in that no adaptation options can be implemented to enable sustainability once thresholds are exceeded. As a broad range of human values and managed systems are dependent upon ecosystems goods and services, 'hard' limits in ecological systems have the potential to constrain or limit adaptation in socioeconomic systems. [16.4.1]

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

The greater the magnitude of climate change, the greater the likelihood that adaptation will encounter limits (*high agreement, low evidence*). Mitigation and adaptation are complementary strategies. Greater adaptation efforts will be required to achieve the objectives of actors if mitigation efforts are not successful in avoiding high magnitudes of climate change. There are, however, limits to the extent to which adaptation could reduce the impacts not avoided by mitigation, and residual loss and damage is may occur despite adaptive action. Knowledge about limits to adaptation could therefore inform the level and timing of mitigation and might justify early mitigation action. However, as the future capacity of actors in different sectoral and regional contexts to adapt to climate change remains uncertain, the implications of adaptation for mitigation demand will be contingent upon economic development pathways and investments made to enhance the adaptive capacity of vulnerable actors. [16.3.1.2, 16.5, 19.6, 19.7, 20.5.3]

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

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

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

16.1. Introduction and Context

Since the IPCC's *Fourth Assessment Report* (AR4), demand for knowledge regarding the planning and implementation of adaptation as a strategy for climate risk management has increased significantly ((Park *et al*., 2011; Preston *et al*., 2011a). This chapter assesses the latest literature on biophysical and socioeconomic constraints on adaptation and the potential for such constraints to pose limits to adaptation. It also examines the circumstances that create opportunities for adaptation and the ancillary benefits that may arise from the implementation of adaptation policies and measures. Given increasing evidence of potential limits to adaptation, the chapter also examines the literature on transformation as a consequence of, or response to, adaptation limits.

To facilitate this literature assessment, this chapter provides an explicit framework for conceptualizing opportunities, constraints, and limits (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. However, 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*), Chapter 15 (*Adaptation Planning and Implementation*), and Chapter 17 (*Economics of Adaptation*). Material from a range of other WGII chapters is also relevant to informing adaptation opportunities, constraints, and limits, 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, readers are encouraged to refer directly to those chapters for more detailed information.

In order to enhance the 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 (Dow *et al*., 2013; Dow *et al*., In Press). 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 (Patt and Schröter, 2008a; Blennow and Persson, 2009; Frank *et al*., 2011). 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, 2009a; Briske *et al*., 2010).

The range of adaptation options available to actors to achieve their objectives vary with 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 encounter future constraints or limits by promoting lock-in to a technology or fostering path dependence around a set of strategies, which can lead to maladaptation (Berkhout, 2002; 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 (Stafford Smith *et al*., 2011; Pelling, 2011; Park *et al*., 2011; Kates *et al*., 2012; O'Neill and Handmer, 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, 2012). The chapter then presents a framework for adaptation, opportunities, and limits with an emphasis on explicit definitions of these concepts to facilitate assessment. Key components of this framework are assessed 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, 2007a). 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 and impediments to the sharing of relevant information to alleviate those gaps.

These findings were further evidenced by the sectoral, and particularly, regional chapters of the AR4 WGII report which provided information regarding the similarities and differences among regions with respect to the manner in which adaptation 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) identifies several constraints to adaptation including limited natural resources and relative isolation. 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 (e.g., 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 regarding adaptation policy and skepticism among some populations toward 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 mentions the limits faced by species and ecosystems due to lack of migration space, low soil fertility and human alternations of the landscape (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 factors.

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 ablso 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. 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 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 of considering disaster risk in national development planning and if 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).

The report also provides discussion of the constraints associated with enhancing disaster risk reduction as well as climate adaptation. In particular, ongoing development deficits as well as inequality 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, 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. Overcoming these constraints to achieve 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 (Seneviratne *et al*., 2012; Cutter *et al*., 2012).

The SREX also cautioned that natural hazards, climate change and societal vulnerability can pose fundamental limits to sustainable development. Such limits can arise from the exceedance 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 Risk-Based Framework for Assessing Adaptation Opportunities, Constraints, and Limits

Risk is an intrinsic element of any understanding of "*dangerous anthropogenic interference with the climate system*" (UNFCCC, 1992) and the associated 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. While there is evidence that there are opportunities to adapt to climate change impacts in natural and human systems, there is also evidence that the potential to adapt is constrained, or more difficult, in some situations, and faces limits in others (e.g. Adger *et al*., 2009b; Dow *et al*., In Press).

Consistent with for the development of risk management approaches to guide adaptation response to climate change (IPCC, 2012) this chapter utilizes a risk-based framework and a set of linked definitions of opportunities, constraints and limits to adaptation (see Box 16-1). A number of different meanings are ascribed to these key terms and these have 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 ambiguities are evident across the literature (O'Brien, 2009; Biesbroek *et al*., 2009; de Bruin *et al*., 2009a). The integrated set of definitions employed here aims to clarify discussions in this realm. The framework and definitions draw on a number of literatures (Dow *et al*., In Press), in particular vulnerability assessment (Füssel, 2006; Füssel and Klein, 2006a) and risk assessment (Jones, 2001; Klinke and Renn, 2002; Renn, 2008; NRC, 2010) as well as climate adaptation (Hulme *et al*., 2007; Adger *et al*., 2009b; Hall *et al*., 2012).

Building on the risk management approach, we present a set of definitions of opportunities, constraints and limits to adaptation. An explicit focus on risk is particularly useful to understanding climate adaptation. Adaptation is intended to reduce the risk to things we value (Adger *et al*., 2012b). The concept of risk integrates the dimensions of probability and uncertainty with the material and normative dimensions that shape societal response to threats. The framing is grounded in an actor-based perspective which acknowledges that social actors from individuals to agencies or governments, and biophysical entities from species to habitats to ecosystems have different objectives and resources with respect to adaptation.

Figure 16-1 relates judgement about risk and the ability to maintain risks at a tolerable level to the concept of adaptation and adaptation opportunities, constraints, and limits (Box 16-1). Drawing on the work of Klinke and Renn (2002)(2002), we view individual actors as addressing risks in one of three categories. Acceptable risks are risks deemed so low that additional efforts at risk reduction, in this case climate adaptation efforts, are not justified. Tolerable risks relate to situations where adaptive, risk reduction efforts are required and effective for risks to be kept within reasonable levels. The scope of risks that fall within the tolerable area is influenced by adaptation opportunities and constraints. As discussed further in sections 16.3 and 16.7, these opportunities and constraints may be physical, technological, economic, institutional, legal, cultural, or environmental conditions(Yohe and Tol, 2002; Meze-Hausken, 2008; Patt and Schröter, 2008a; Adger *et al*., 2009b; Moser and Ekstrom, 2010; Adger *et al*., 2012a; Adger *et al*., 2012b). Constraints may limit the range of adaptation options leaving the potential for 'residual damages' which nevertheless are deemed to remains at a tolerable level. There are also 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 or avoid 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) (Also see AR5 2.2; 14.4; 16.3.1.1; 17.3). In particular, the economic and other costs of adaptation may be perceived to outweigh the uncertain future benefits of adaptation. Within this category, some level of residual damage following adaptation may be tolerable (Stern *et al*., 2006; de Bruin *et al*., 2009a)

[INSERT FIGURE 16-1 HERE
Figure 16-1: Conceptual model of the determinants of acceptable, tolerable and intolerable risks and their implications for limits to adaptation (Dow *et al*., 2013); based on (Klinke and Renn, 2002).]

Intolerable risks to existing objectives and needs are those which, despite adaptive actions, pose threats of such combined frequency and intensity that an actor would avoid them or, if feasible and appropriate, act in the societal interest to prohibit them. Whether it is an individual's decision to relocate, an insurance company's decision to withdraw coverage, or a lack of managed adaption strategies for a species, these actions represent a discontinuity in behaviour symptomatic of reaching an adaptation limit. The alternative to such discontinuities of disposition or behaviour is escalating risk of losses (16.4.2). While actors have their own judgements of what are acceptable, tolerable or intolerable risks, collective responses often shape the constraints and opportunities to adaptation and responses to risk through the distribution of resources, institutional design, and support of capacity development (16.3). If these risks and discontinuities have global-scale consequences, they can be linked to 'key vulnerabilities' to climate change (see Chapter 19). Consistent with our framing of adaptation limits as being actor-centered, such key vulnerabilities would need to be assessed in terms of the adaptation limits which they imply for specific social actors, species and ecosystems.

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

Adaptation Limit: *The point at which an actor's objectives (or biophysical system needs) cannot be secured from intolerable risks through adaptive actions* (Dow *et al*., 2013).
A limit to adaptation means that no adaptation options exist, or an unacceptable measure of adaptive effort is required to secure objectives, or to allow for a species or ecosystem to survive in an unaltered state. Examples of objectives include, for instance, standards of safety codified in laws, regulations, or engineering design standards (*e.g.,* 1 in 500 year levees), security of drinking water supplies as well as equity, cultural cohesion, and preservation of livelihoods. Requirements of biophysical systems might include a maximum temperature or precipitation levels. That ability to avoid adaptation limits is shaped by adaptation opportunities and constraints.

Adaptation Opportunity: *factors that make it easier to plan and implement adaptation actions*.
Opportunities are the opposite of constraints. Adaptation opportunities create new potential for an actor to secure their existing objectives, 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 distinct from co-benefits and from opportunities arising from climate change (e.g., longer growing seasons), which would commonly be referred to as potential benefits of climate change (see chapter 17) or adaptation options (see Chapter 14).

Adaptation Constraints: *factors that make it harder to plan and implement adaptation actions*.
Adaptation constraints restrict options for an actor to secure their existing objectives, or for a biophysical system to maintain productivity or functioning. These constraints commonly include lack funding, technology or knowledge, or institutional traits that restrict some actions (see 16.3) or lack of connectivity for ecosystems. The terms "barriers" and "obstacles" are frequently used as synonyms.

_____ END BOX 16-1 HERE _____

It is essential to evaluate opportunities, constraints, and limits with respect to the rate and magnitude of climate change and within the relevant time horizon for an actor, a species or an ecosystem. Opportunities, constraints and limits to adaptation develop 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 some, although not all, limits may be shifted or removed altogether. Climate variability and change and associated patterns of impacts are also changing at diverse and non-linear rates. For a given social actor, the timeframe for adaptation decisions usefully bounds an analysis of opportunities, constraints and limits. Each year, for example, US Great Plains farmers chooses if, when, and what to plant and how much insurance to purchase. While more drought-resistant crop varieties might become available in future, the choice in any given year is limited to the varieties currently available. A community that has suffered severe storm damage must act urgently to restore homes and infrastructure using the technologies, financial resources and institutions then available. Changing institutional relationships may make greater amounts of disaster recovery aid available to support other adaptation choices in future, but if there are immediate safety needs, delay in expectation of these changes would be hard to justify. For natural ecosystems, the rate of species responses relative to change in environmental conditions bounds the capacity to adapt. The observed rate of evolutionary and other species responses ranges from rapid to inadequate to allow persistence (Hoffmann and Sgro, 2011), but the knowledge base is insufficient to permit clear general conclusions for ecosystem adaptation capacity.

Because adaptation limits relate to adaptation resources and attitudes to risk and threat which may change over time, some limits may be viewed as "soft". While a given adaptation option may not be available today or require impracticable levels of effort, it may become available through innovation or changes in attitudes in time. Soft limits may be shifted investments in research and development, changes in regulatory rules or funding arrangements, or by changing social or political attitudes. Other limits are "hard" in that there is no known process to change them. Examples of fixed 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.

16.3. 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 (Adger *et al*., 2007; IPCC, 2012), although those capacities can be difficult to measure (Tol *et al*., 2008; Hinkel, 2011). Since the AR4, the literature on adaptive capacity and adaptation constraints has deepened (Adger *et al*., 2009b; Moser and Ekstrom, 2010). This literature can be divided into two general categories of constraints (Figure 16-2). One focuses on interactions among biophysical and socioeconomic processes that may span multiple actors across different spatial or temporal scales. These processes evolve constantly over time and establish the context in societal context for adaptation. The second category focuses on the entitlements of actors to the assets and capital necessary for the implementation of specific adaptation policies and measures (Yohe and Tol, 2002; Paavola, 2008; Osbahr *et al*., 2010). These two categories of constraints as well as specific examples are discussed further in the following sections.

[INSERT FIGURE 16-2 HERE
Figure 16-2: Identification of key adaptation constraints considered in this chapter, which are categorized into two groups. One reflects constantly evolving biophysical and socio-economic processes that influence the societal context for adaptation. These processes subsequently influence the implementation of specific adaptation policies and measures that could be deployed to achieve a particular objective.]

Specific constraints associated with these two categories are common to multiple regions, sectors, communities, and actors. Nevertheless, the manner in which they manifest is context-dependent (Adger *et al*., 2007; Kasperson and Berberian, 2011; Weichselgartner and Breviere, 2011; IPCC, 2012). 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; Klein, 2009; Smith *et al*., 2010; Hinkel, 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.

16.3.1. Constraints Affecting the Context for Adaptation

16.3.1.1. Framing of Adaptation

Adaptation processes are influenced by the manner in which individuals and institutions frame adaptation including the perception of climate change risks and the mental models employed to structure decision-making regarding adaptation (Nisbet and Scheufele, 2009; Fünfgeld and McEvoy, 2011; Preston and Mustelin, 2013) (see also 15.4.3.1). Framing elements include definitions of adaptation and to what actors must adapt; objectives and responsibilities of actors; the role of knowledge; appropriate adaptation responses; and constraints and limits associated with implementation (Smith *et al*., 2000; Nelson *et al*., 2008; Meinke *et al*., 2009; Preston and Stafford Smith, 2009; Fünfgeld and McEvoy, 2011; Gifford, 2011; Klein and Juhola, 2013; Arbuckle Jr. *et al*., 2013; Preston and Mustelin, 2013). In particular, recent literature identifies risk perception as a constraint on adaptation by conveying over-confidence in the ability of actors to manage risk (Wolf *et al*., 2010; Kuruppu and Liverman, 2011) or creating differences in the perception of climate risk between actors and governing institutions (Patt and Schröter, 2008a). However, Whitmarsh (2008) finds that motivation for adaptation is mediated indirectly through individual, environmental values rather than direct perceptions of climate risk. Meanwhile, van der Berg *et al*. (2010) suggest local leadership and normative values may be more critical drivers of adaptation than risk perception. The inconsistency among such case studies suggests risk perception may interact with other factors to shape adaptation responses and/or that other factors take precedence. A number of authors have commented on the potential constraints associated with the framing of adaptation as strictly a top down (i.e., government-led) or bottom up (i.e., community-based) process. Orlove (2009), for example, notes that indigenous herders in Peru frame adaptation differently than those working within NGOs and government agencies. Hence, there may be value in more integrated views of risk governance (16.3.1.4).

Recent studies have also investigated the science/policy interface with respect to how vulnerability and adaptation assessment shape understanding of adaptation (Füssel and Klein, 2006b; McGray *et al*., 2007; McEvoy *et al*., 2010; Eakin and Patt, 2011; Fünfgeld and McEvoy, 2011; Jones and Preston, 2011; Preston *et al*., 2011b; Yuen *et al*., 2012). Concerns have been raised in the literature that assessment tools and paradigms such as climatic prediction, risk management, cost/benefit analysis may obfuscate the need for and desirability of alternative approaches to adaptation (O'Brien *et al*., 2007; Hulme *et al*., 2009a; Eriksen and Brown, 2011; Eriksen *et al*., 2011; Pelling, 2011). Eisenack and Stecker (2012) and Klein and Juhola (2013) comment on the disconnect between adaptation research and policy that arises from limited consideration for the role of actors in shaping adaptation responses. Meanwhile, multiple authors have raised questions regarding the utility and legitimacy of vulnerability metrics for prioritizing adaptation interventions (Klein, 2009; Hinkel, 2011; Preston *et al*., 2011b). Greater incorporation of actors and communities into assessment processes and education interventions may be a pathway for increasing their potential to trigger effective adaptation responses(Kuruppu and Liverman, 2011; Klein and Juhola, 2013).

16.3.1.2. 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; Rockstrom *et al*., 2009); Chapter 19). While the specific rate of climate change to which different ecological communities or individual species can adapt remains uncertain (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; Maynard *et al*., 2008; Allen *et al*., 2009; Malhi *et al*., 2009a; Malhi *et al*., 2009b; Thackeray *et al*., 2010; Lemieux *et al*., 2011), particularly in the presence of other environmental pressures (Brook *et al*., 2008). Therefore, if greenhouse gas mitigation policy is unable to reduce the rate of climate change, the effectiveness of some adaptation options may be reduced and higher costs for adaptation may be incurred (New *et al*., 2011; Stafford Smith *et al*., 2011; Peters, G.P., Andrew, R.M. *et al*., 2013).

Meanwhile, although rapid socioeconomic change, including economic development and technological innovation and diffusion, can enhance adaptive capacity, they 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 Jr. *et al*., 2008; Baldassarre *et al*., 2010; Bouwer, 2011; Gall *et al*., 2011; Munich Re, 2011; IPCC, 2012). These trends in losses are projected to continue in future decades (Pielke Jr., 2007; Montgomery, 2008; O'Neill *et al*., 2010; UN, 2011; Preston, Submitted);10.7.3). In addition, population growth and economic development can lead to greater resource consumption and ecological degradation (Alberti, 2010; Chen *et al*., 2010; Raudsepp-Hearne *et al*., 2010; Liu *et al*., 2012), which can constrain adaptation in regions that are dependent on natural resources (Badjeck *et al*., 2010; Marshall, 2010; Warner *et al*., 2010); CC-EA). 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).

16.3.1.3. Social and Cultural Dimensions

Adaptation can be constrained by social and cultural factors that are based on societal ideals regarding how a society should function and what is valued (O'Brien, 2009; Moser and Ekstrom, 2010; O'Brien and Wolf, 2010; Hartzell-Nichols, 2011). These social and cultural factors are the normative dimension of adaptation (O'Brien, 2009) (O'Brien, 2009), which determines what kind of adaptation is considered useful and feasible as well as when and by whom (Grothmann and Patt, 2005; Weber, 2006; Patt and Schröter, 2008b; Kuruppu, 2009; Adger *et al.*, 2009b; Nielsen and Reenberg, 2010; Wolf and Moser, 2011; Wolf *et al.*, 2013). Gender roles and identity, traditionally acceptable livelihoods, caste or class, land ownership systems, and religion can influence adaptation processes and hinder adaptive actions at individual, household and community levels (Ahmed and Fajber, 2009; Bryan *et al.*, 2009; Codjoe *et al.*, 2011; Jones and Boyd, 2011). Yet, values are not homogenous across society, which results in differential preferences for adaptation that can contribute to societal conflict (Wolf *et al.*, 2013). Women in particular are often constrained by cultural and institutional pressures that favor male land ownership (Jones and Boyd, 2011) and constrain access to hazard information (Ahmed and Fajber, 2009). The lack of perception of vulnerability has left for example elderly people unprepared for heat waves in the UK (Sheridan, 2007; Wolf *et al.*, 2009). Meanwhile, evidence suggests that chronic stresses such as poverty affect cognition and behavior, which influence adaptive capacity (Dias-Ferreira *et al.*, 2009; Spears, 2011). Cultural constraints also 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). Studies indicate that cultural preferences regarding the value of traditional versus more formal scientific forms of knowledge influences that types of knowledge are considered legitimate (Jones and Boyd, 2011) and thus the way in which knowledge is used in adaptation (Box 16-2). Furthermore, social constraints can arise from governance arrangements which, for example, in the Arctic constrain individual's and communities' hunting and fishing practices and adaptation opportunities (Loring *et al.*, 2011); 16.4.2.3).

Perceptions of the need for adaptation are also shaped by religion and sense of place. Religious beliefs can constrain adaptation as they reduce the perceived necessity and opportunities for adaptation while contributing to increase in vulnerability. Such constraints have emerged, for example, through religious institutions that have placed extensive financial commitments on their members reducing available capital for adaptation (Kuruppu, 2009). In Kiribati, Zanzibar, Tibet, Ecuador, and Mozambique, natural hazards are viewed as events controlled by God, supernatural forces, or ancestral spirits about which nothing can be done (Schipper, 2008; Byg and Salick, 2009; Mustelin *et al.*, 2010; Kuruppu and Liverman, 2011; Artur and Hilhorst, 2012). In Tuvalu, God is attributed responsibility to take care of the people (Mortreux and Barnett, 2009). Adger *et al.* (2011; 2012a) and Fresque-Baxter and Armitage (2012) argue that sense of place, tied intimately to identity, shapes adaptation responses through sense of belonging, security, social connections, self-esteem, and emotional attachment. For example, Park *et al.* (2011) note that sense of place attachment among wine grape growers in Australia precludes consideration for migration to other growing areas. Further ethnographic explorations are needed to better grasp how and to what extent global climatic processes alter culture, values, and identity (Crate, 2011). Improved understanding is also needed regarding how gender, religious beliefs, land-use and rights can decrease vulnerability and enable individual, household and community adaptation.

16.3.1.4. Governance and Institutional Arrangements

Governance and institutional arrangements may both enable adaptation and act as potential constraints. Decision-making regarding adaptation is often undertaken within a context of multi-level governance including governmental administration at local to international levels as well as market actors and non-governmental organizations

(Rosenau, 2005). As a result, coordination or interplay among actors is crucial for facilitating adaptation decision-making and implementation (Young, 2006; 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; Tompkins and Eakin, 2012), adaptation research and practice to date has largely focused on the public components of governance, particularly formal government institutions. Studies of the development of adaptation planning and policy at different levels of governance largely center on case studies (van Nieuwaal *et al*., 2009; Hunt and Watkiss, 2011), often by issue or level of government (Gagnon-Lebrun and Agrawala, 2006; Swart *et al*., 2009; Corfee-Morlot *et al*., 2009; Keskitalo, 2010; Biesbroek *et al*., 2010; Ford and Berrang-Ford, 2011; Preston *et al*., 2011a).

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. The NRC (2009) argued that U.S. institutions across scales lack the mandate, information, and/or professional capacity to select and implement adaptations for risk reductions. Similarly, Zinn (2007) and Preston (2009) suggest that effective responses to climate change would require levels of integrated environmental planning and management that governance systems have not been able to achieve consistently. Adger *et al*. (2009b), attribute such deficiencies to the complexity of governance systems that pose challenges to coordinating adaptation efforts, due in part to different objectives among actors (Preston *et al*., 2013). Similarly, Birkmann *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). As binding legislation at national and in some cases subnational levels may create disincentives or potentially limit adaptation even in cases where adaptation per se is not the focus of legislation, adaptation decision-making at local level is partly shaped by higher levels as well as by the distribution of authority within the state (Urwin and Jordan, 2008; Huntjens *et al*., 2010a; Measham *et al*., 2011; Pittock, 2011; Westerhoff *et al*., 2011; Mukheibir *et al*., 2012; Amaru and Chhetri, 2013). The literature notes the challenges of changing legal principles to accommodate more forward-looking adaptation responses (Craig, 2010; McDonald, 2011). Preston *et al*. (2013), for example, identify cases in Australia and the United States where state government policies have impeded local governments from anticipatory adaptation for sea-level rise. A study of adaptation policy initiatives in the UK, Sweden, Finland and Italy, concluded that while initiatives at the central government level may play a significant role in supporting the development of adaptation policies at the local level, in cases where there is limited top down leadership or prioritization on adaptation, less centralized state structures could allow opportunities for local initiatives (Keskitalo, 2010). Transnational governance also influences adaptive capacity. For instance, in some cases in the European Union, funding programs have enabled local action on adaptation even in the absence of funding from the relevant EU member state (Keskitalo, 2010). The need for adaptation thus creates new challenges for the complex multi-national and multi-level governance of resources, particularly where there are ongoing disputes or conflicts (16.3.5). New institutions and bridging organizations will be needed to facilitate integration of complex planning processes across scales (National Research Council, 2010).

16.3.1.5. 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. 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, 2001; Willows and Connell, 2003; NZCCO, 2004a; NZCCO, 2004b; AGO, 2006; USAID, 2007; World Bank, 2008) all emphasize the importance of M&E for adaptation planning and implementation. The UK's Adaptation Sub-Committee, for example, recommends the monitoring of the implementation of the National Adaptation Programme and several agencies already have M&E protocols in place to track the effectiveness of responses to climate-related risks (Adaptation Sub-Commitee, 2012). In particular, M&E enables practitioners to develop robust adaptation practice through learning from policy successes and failures (GIZ, 2011a; GIZ, 2011b). 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 Franca Doria *et al*., 2009; Osbahr *et al*., 2010). The literature on participatory M&E may offer guidance for how to overcome such conflicts by enhancing the incorporation of tacit and local knowledge into M&E and the prioritization of management interventions (Brown *et al*., 2012; Harvey *et al*., 2012; Stringer and Dougill, 2013). Recent evidence suggests guidance on climate adaptation M&E is increasingly being translated into practice (GIZ, 2011a; GIZ, 2011b). 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 (Global Environmental Facility, 2006), 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 Climate Change Act (2008) 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 may be required.

16.3.2. Constraints Affecting the Implementation of Adaptation Policies and Measures

The various socioeconomic processes that influence the context for adaptation ultimately influence the entitlements of actors to the capacity and resources needed to support the implementation of adaptation policies and measures (Figure 16-2). The literature on vulnerability and adaptive capacity, for example, has traditionally focused on the availability of such resources and differential availability and access across different sectors, regions, and actors (Jantarasami *et al*., 2010; Moser and Ekstrom, 2010). For example, multiple studies have assessed adaptive capacity in sectors and communities using sustainable livelihoods framework (Paavola, 2008; Osbahr *et al*., 2010; Nelson *et al*., 2010a; Nelson *et al*., 2010b), which deconstructs adaptive capacity into five types of capital: financial, physical, natural, social, and human. Hence, adaptation efforts can be constrained by various factors including knowledge regarding climate change and adaptation (Deressa *et al*., 2011); Box 16-2); availability of adaptation finance (Hof *et al*., 2009; Smith *et al*., 2009b; Barr *et al*., 2010; Schultz, 2012); degradation of natural resources (Humphreys *et al*., 2007; Paavola, 2008; Thornton *et al*., 2008; Iwasaki *et al*., 2009; Badjeck *et al*., 2010; Côté and Darling, 2010; Nkem *et al*., 2010; Tobey *et al*., 2010); effectiveness of technology (UNFCCC, 2006; Adger *et al*., 2007; Dryden-Cripton *et al*., 2007; van Aalst *et al*., 2008); the degree of public engagement in adaptation (van Aalst *et al*., 2008; Burton and Mustelin, 2013); and the quality of human capital and leadership (Ebi and Semenza, 2008; Termeer *et al*., 2012). Such constraints have been identified and discussed in previous IPCC reports (Adger *et al*., 2007; IPCC, 2012), and are closely aligned to the discussion of adaptation needs in Chapter 14. Therefore, this chapter focuses on providing illustrative examples from the literature of how such constraints affect adaptation implementation (Table 16-1) and synthesizing key constraints across the regional and sectoral chapters (16.5). However, debates appear within the adaptation literature regarding the extent to which some types of resources constrain adaptation (Box 16-2).

[INSERT TABLE 16-1 HERE
Table 16-1: Constraints affecting the implementation of adaptation policies and measures.]

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Box 16-2. Is Knowledge a Constraint on Adaptation?

The generation and dissemination of knowledge regarding climate change and adaptive responses are important components of adaptation processes and, in particular, the effective implementation of specific policies and measures. The various types of knowledge most frequently examined in adaptation studies include a) knowledge regarding future biophysical and socioeconomic conditions and associated uncertainties (Keller *et al*., 2008; Wilby *et al*., 2009; Moss *et al*., 2010); b) knowledge regarding adaptation options and their associated costs and benefits (Prato, 2008; de Bruin *et al*., 2009b; Patt *et al*., 2010a); and c) knowledge regarding the various constraints on, or limits to, the implementation of those options and how they can be ameliorated (Mitchell *et al*., 2006; Smith *et al*., 2008; Moser, 2009; 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 (Tribbia and Moser, 2008; Jantarasami *et al*., 2010; Gardner *et al*., 2010; Ford *et al*., 2011) and developing nations (Bryan *et al*., 2009; Deressa *et al*., 2009). Discussions of knowledge deficits in the literature are often closely associated with the broader issue of uncertainty and its implications for adaptation. Key sources of uncertainty include scientific understanding of biophysical processes that influence future climate change; understanding of socioeconomic processes that influence the impacts of, and responses to, climate change; and understanding of the costs and benefits of different adaptation policies (Congressional Budget Office, 2005; Fankhauser, 2009; Hallegatte, 2009b; Arnell, 2010; Patt *et al*., 2010a; UNFCCC, 2011). Nevertheless, the AR4 concluded that knowledge in itself is not sufficient to drive adaptive responses (Adger *et al*., 2007). Recent literature has questioned, for example, the extent to which uncertainty and/or lack of information about future climate change is a constraint on adaptation (Dessai *et al*., 2009; Hulme *et al*., 2009b; Wilby and Dessai, 2010), particularly over the near-term. Approaches such as robust decision-making and so-called ‘no regrets’ or ‘win-win’ strategies may identify adaptation options that are insensitive to uncertainty (Lempert and Collins, 2007; Hallegatte, 2009a; Adger *et al*., 2009b; 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 and Stafford Smith, 2009; Klein, 2009; Hinkel, 2011; Preston *et al*., 2011a).

Studies also indicate that the role of knowledge in adaptation is closely tied to culture. For example, cultural preferences regarding the value of traditional versus more formal scientific forms of knowledge influence what types of knowledge are considered legitimate (Jones and Boyd, 2011). In the Arctic, however, Inuit traditional knowledge (*Inuit Qaujimajatuqangit,* IQ) encompasses all aspects of traditional Inuit culture including values, world-view, language, life skills, perceptions and expectations (Nunavut Social Development Council, 1999; Wenzel, 2004). While declining especially among youth (Pearce *et al*., 2011), IQ includes, for example, weather forecasting, sea ice safety, navigation, hunting and animal preparation skills that link together Inuit perception, knowledge, and values and are essential for managing climate risk. On the other hand, evidence suggests that increasing reliance on non-traditional forecasting (national weather office forecasts) and other technologies (GPS) in Arctic communities is in part responsible for increased risk taking when travelling on the land and sea ice (Aporta and Higgs, 2005; Ford *et al*., 2006; Pearce *et al*., 2011). As a result, the implications of relying upon traditional forecasting and skills are place and context-dependent. These various studies, and the inconsistency of conclusions that arise, indicates that 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).

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16.3.3. Constraints across Spatial and Temporal Scales

Despite an 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 and Wehbe, 2009; Preston and Stafford Smith, 2009; Adger *et al*., 2009a; Preston and Mustelin, 2013); 16.4.1.4). International efforts to reduce greenhouse gas emissions, for example, influence the magnitude and rate of change in climate at national, regional, and local scales (16.7). 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 increase in food prices benefited some producers in developed nations, but undermined food security in developing nations (FAO, 2011). Much 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 or multi-state river basins (Iglesias *et al*., 2007; Goulden *et al*., 2009; Krysanova *et al*., 2010; Huntjens *et al*., 2010b; 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, 2010; Pederson *et al*., 2012), resulting in systems that have been challenged to cope with persistent drought in recent decades. Similarly, Libecap (2010) 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 (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). Hence, the literature on flexible adaptation pathways emphasizes the implementation of reversible and flexible options (Stafford Smith *et al.*, 2011; Haasnoot *et al.*, In Press) as well as 'real options' that recognize that there may be value in delaying adaptation decisions until additional information is available (Dobes, 2008).

16.3.4. Constraints and Competing Values

Constraints on adaptation arise from the differential values of societal actors and the trade-offs associated with prioritizing and implementing adaptation objectives (Haddad, 2005; UNEP, 2011); Table 16-2). 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.*, 2010b). 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). Brouwer *et al.*, (2013) report that policy-makers in the EU may be reluctant to pursue climate adaptation, because such efforts may conflict with existing objectives with respect to maintain water quality. Even at local scales, Measham *et al.* (2011) report that some Local Government stakeholders in Australia find it difficult to pursue adaptation efforts to due perceived conflicts with an adaptation agenda with community values. Such differences among stakeholders with respect to the need for adaptation and appropriate adaptation responses may result in some actions being simultaneously perceived as adaptive and maladaptive (Bardsley and Hugo, 2010). Alternatively, whether an adaptation option represents an opportunity or a constraint may depend upon the manner in which it's implemented. 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 (McNamara and Gibson, 2009; de Bruin *et al.*, 2009b; McNamara *et al.*, 2011; UNEP, 2011).

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

16.3.5. Interactions among Constraints

Deconstruction of adaptation constraints into discrete factors assists with their identification and diagnosis, but, such constraints rarely act in isolation (Dryden-Cripton *et al.*, 2007; Smith *et al.*, 2008; Moser and Ekstrom, 2010; Shen *et al.*, 2011); 16.4.6). Rather actors are challenged to navigate multiple, interactive constraints in order to achieve a given adaptation objective(Adger *et al.*, 2007; Dryden-Cripton *et al.*, 2007; Smith *et al.*, 2008; Shen *et al.*, 2008; Adger *et al.*, 2009b; Jantarasami *et al.*, 2010; Moser and Ekstrom, 2010; Shen *et al.*, 2011). 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 (16.5), and/or drive actors toward responses that may ultimately prove to be maladaptive (Barnett and O'Neill, 2010). 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*., 2008; Moser and Ekstrom, 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, 2011; Preston *et al*., 2011a). 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).

16.4. Limits to Adaptation

There is *high agreement and much evidence* that there are limits to the capacity of actors to adapt to climate change (Meze-Hausken, 2008; O'Brien, 2009; Adger *et al*., 2009b; Moser and Ekstrom, 2010; Dow *et al*., 2013); 16.4). Although constraints increase the challenges associated with implementing adaptation policies and measures, they do not necessarily pose a limit to adaptation in themselves. 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). 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, 2009a); ‘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). In addition, terms such as barriers, limits, and constraints are sometimes used interchangeably. Due to this diversity in language, this discussion builds on recent efforts to develop a common lexicon to facilitate research and practice (Hulme *et al*., 2007; Adger *et al*., 2009b; Dow *et al*., 2013; Dow *et al*., In Press); 16.2; Box 16-1).

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Box 16-3. Historical Perspectives on Approaching and Exceeding Limits to Adaptation

Does human history provide insights into societal resilience and vulnerability under conditions of environmental change? Archeological and environmental reconstruction provides useful perspectives on the role of environmental change in cases of significant societal change (sometimes termed ‘collapse’ (Diamond, 2005)). 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 (Zhang *et al*., 2011), or through derivative compilations of historical data (deMenocal, 2001; Thompson *et al*., 2002; Drysdale *et al*., 2006; Butzer, 2012). Application of social theories may not explain specific cases of human behavior and community decision-making, especially because of the singular importance of the roles of leaders, elites and ideology (Hunt, 2007; McAnany and Yoffee, 2010; Butzer and Endfield, 2012; Butzer, 2012).

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 (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-Collazo, 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 evolving developments such as 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.

Recent work on resilience and adaptation synthesizes lessons from extreme event impacts and responses in Australia (Kiem *et al.*, 2010). This further emphasizes an institutional basis for resilience, finding that government intervention through the provision of frameworks to enable adaptation is beneficial. Furthermore, it was found that a strong government role may be necessary to absorb a portion of the costs associated with natural disasters. On the other hand, community awareness and recognition of novel conditions were also found to be critical elements of effective responses.

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16.4.1. Hard versus Soft Limits

Although limits to adaptation are at times described in the literature as fixed thresholds(Adger *et al.*, 2009b), recent studies have emphasized the need to consider the perspective of actors in defining adaptation limits (Adger *et al.*, 2009b; Dow *et al.*, 2013; Dow *et al.*, In Press) as well as the dynamic nature of both biophysical and socioeconomic processes that influence adaptation decision-making and implementation (Dow *et al.*, 2013; Dow *et al.*, In Press). Informed by the distinctions drawn in the work of Meze-Hausken (2008), Adger *et al.* (2009b), and Moser and Eckstrom (2010), one can distinguish between “hard” limits, those that will not change, and "soft" limits, which could change over time. For human actors, whether a limit is hard or soft is usefully evaluated with respect to whether the capacity to implement an adaptation response to manage an intolerable risk could emerge in the future, even if that capacity is not immediately available in the present. For natural ecosystems, whether a limit is hard or soft is defined by the rate and capacity of species and ecosystem responses relative to environmental changes (Shaw and Etterson, 2012).

Discussions of hard limits in the literature are often associated with thresholds in physical systems that, if exceeded, would lead to irreversible changes or the loss of critical structure or function (Lenton *et al.*, 2008; Adger *et al.*, 2009b; IPCC, 2012; Preston *et al.*, 2013). Such limits arise from the magnitude and/or rate of climate change (16.3.1.2). 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, or 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 as they neglect consideration for the adaptive capacity of natural and human systems(Leary *et al.*, 2009; Adger *et al.*, 2009b; Dow *et al.*, 2013; Klein and Juhola, 2013; Preston *et al.*, 2013; Dow *et al.*, In Press).

For species and ecosystems, hard limits to adaptation are often associated with exceedances of the physiological capacity of individual organisms or communities to adapt to changes in the climate (i.e., temperature, rainfall, and/or disturbance regimes; (Peck *et al*., 2009)) or to climate-induced changes in the abiotic environment (e.g., ocean circulation and stratification, (Harley *et al*., 2006; Doney *et al*., 2012)). Such systems tend to be those that persist at the upper limit of climate tolerances (Sheehan *et al*., 2008; Dirnböck *et al*., 2011; 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 (Jenkins *et al*., 2011). For example, many species, including humans (Sherwood and Huber, 2010) and key food crops (e.g., wheat, maize, and rice) are known to have thermal limits to survival (IPCC, 2007a). Similarly, increased ocean acidity is expected to reduce the ability of some marine organisms, such as corals, to grow posing threats of significant ecosystem damage (CC-OA; CC-CR). However, 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 (Steffen *et al*., 2009; Wookey *et al*., 2009; Lavergne *et al*., 2010; Preston *et al*., 2013). Furthermore, species have mechanisms for coping with climate change including phenotypic plasticity (Charmantier *et al*., 2008; Matesanz *et al*., 2010) genetic (evolutionary) responses (Gienapp *et al*., 17; Bradshaw and Holzapfel, 2006; Visser, 2008; Wang *et al*., 2013), and range shifts (Colwell *et al*., 2008; Thomas, 2010; Chen *et al*., 2011). Such mechanisms influence adaptation limits by extending the range of climate conditions with which individual organisms can cope in situ and/or enabling species to migrate over time to more suitable climates. Recent evidence suggests that range shifts and phenotypic plasticity, rather than evolutionary adaptation, may be a more common response to climate change (Merilä, 2012). Yet, more comprehensive assessments of such adaptive mechanisms are needed to develop robust understanding of ecological limits.

In contrast, limits within social systems are often soft as they are influenced by exogenous climate change as well as endogenous processes such as societal choices and preferences (Adger *et al*., 2009b). Various authors have noted that adaptation limits are socially-constructed by human agency in that economics, technology, infrastructure, laws and regulations, or broader social and cultural considerations can limit adaptation (Flåm and Skjærseth, 2009; O'Brien, 2009; Adger *et al*., 2009b; de Bruin *et al*., 2009b; Wilbanks and Kates, 2010; McNamara *et al*., 2011; Morrison and PICKERING, 2012). All of these factors, however, are dynamic and change over time. The Shared Socioeconomic Pathways, for example reflect different perspectives on future changes in the capacity of actors to adapt (Kriegler *et al*., 2012). Given rising incomes and advances in knowledge and technology, a greater number of adaptation options may become available to a greater number of actors over time. In contrast, impediments to development, constraints on investments in adaptation, or rapid escalations in risk may create more challenges for adaptation. Societal assessments of risk and willingness to invest in risk management are subject to many influences, such as experience of a recent disaster, some of which can result in rapid changes (Ho *et al*., 2008; Breakwell, 2010; Renn, 2011). Hence, Adger *et al*. (2009b; pg. 338), argue that many limits to adaptation are dependent on the changing goals, values, risk tolerances and social choices of society which may make them "*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, and values; and expectations about the future (see also O'Brien, 2009). The influence of cognitive factors, culture, and ideology on judgments about risk is a well-documented element of risk management (Renn, 2008; IPCC, 2012); 14.3.1.1). Cost-benefit analyses and associated discount rates, for example, reflect a social value on investment returns (17.3.7.2). Yet, Morgan (2011) notes that adaptation planning based on cost-benefit analysis can pose limits to adaptation by discounting the future economic benefits of adaptation actions and excluding non-market benefits. Meanwhile, increasing loss and damage from societal exposure and climate change may pose economic limits to the insurability of disaster risks (10.7.3), which ultimately influences what activities can occur in certain locations.

Limits also have scale-dependent properties. A local community may not have the necessary resources to adapt but these constraints may be overcome by drawing in resources from regional, national, or international authorities as well as from NGOs. Adaptation finance and capacity building activities more broadly, for example, enable resources for adaptation to be transferred from developed nations to developing nations in order to overcome soft limits to adaptation. Nevertheless, the demand for adaptation finance is significantly larger than the current availability of resources represented through international adaptation funds (Flåm and Skjærseth, 2009; Hof *et al*., 2009), and there are challenges associated with developing a framework for the equitable and effective allocation of adaptation funds

(Barr *et al*., 2010; Smith *et al*., 2009b). Scale-dependence also manifests among different actors within sectoral supply chains. For example, climate change that poses limits to the sustainability of an individual farm enterprise may have little impact on a national or international agribusiness (Park *et al*., 2011). Such scale dynamics invariably arise within any complex networked system (e.g., energy, water resources, health), and they create inequities among actors with respect to who encounters limits and when.

When all options for managing a risk are exhausted, shifting or removing a soft limit can only occur through granting actors new entitlements to resources or technology (16.3.2); reform to governance systems and policies (16.3.1.4); and/or changes in values and risk tolerance (16.3.1.3). While some changes, such as global economic development, will occur autonomously, other changes are a function of social processes and human choice. In some instances, limits may arise from humans explicitly avoiding what would seem to be adaptive behaviors. Different communities and populations, for example, have different attitudes toward migration as a response to climate vulnerability (Acosta-Michlik and Espaldon, 2008; Locke, 2009; Mortreux and Barnett, 2009; Ford, 2009b). Yet, for some locations, such as low-lying islands in Torres Strait, adaptation in place is not a feasible option (Green *et al*., 2009), and thus sea-level rise poses a hard limit to those who view relocation as an intolerable risk. Foresight (2011) observes that staying in place when security continues to deteriorate can reflect a profound inability to pursue more positive adaptive options, which may be as significant a policy concern as migration. Therefore, while limits to adaptation may be soft in principle, in practice they can pose highly persistent obstacles to adaptation if the necessary societal changes to remove the limit are not forthcoming.

16.4.2. Limits and Transformational Adaptation

Adaptation has traditionally been viewed as a process of incremental adjustments to climate variability and change to maintain existing objectives and values (Burton *et al*., 2001). Reliance upon incremental adaptation, however, 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 16-3). Encountering an adaptation limit, however, does not necessarily result in the end of the adaptive process.Since the AR4, the adaptation and resilience literature has suggested that climate change may drive actors toward transformational changes (Dow *et al*., 2013), which include scaling-up of management efforts; introduction of new technologies or practices; geographic shifts in the location of activities, or fundamental changes in underlying objectives and values governing human and natural systems (Pelling, 2011; Stafford Smith *et al*., 2011; Kates *et al*., 2012; O'Neill *et al*., 2012; Park *et al*., 2012; 20.3). While transformational change is one pathway by which soft limits can be removed (16.4.1), they are also a means of adapting to hard limits. For example, transformation 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 (Park *et al*., 2012).Transformational adaptation, however, isn't without risks (Orlove, 2009; Kates *et al*., 2012), such changes can involve significant transaction costs and there are inherent uncertainties associated with the timing and magnitude of investment returns. Hence, the factors that constrain incremental adaptation also constrain transformation, but the greater scale of investment and/or shift in fundamental values and expectations required for transformational change may create greater resistance. Yet, the question of whether or not an adaptive response is in fact transformational is dependent how it is perceived by actors. Following on Davies and Hossain (1997), Preston and Stafford Smith (2009) argue that the feasibility of transformational change may be dependent upon whether it is perceived as a positive outcome (e.g., expansion of an industry into new locations; Park *et al*., 2012) or a negative (e.g., retreat from vulnerable locations; Kates *et al*., 2012).

16.4.3. Effects of Mitigation on Adaptation Constraints and Limits

Klein *et al*. (2007) in IPCC AR4 identified four ways in which adaptation and mitigation can inter- relate, one of which are mitigation actions that have consequences for adaptation. It follows that mitigation actions could have consequences for adaptation constraints and limits. This section discusses the effects of alternative mitigation pathways on adaptation potential.

Klein *et al*. (2007) concluded that without mitigation, a magnitude of climate change may be reached that makes adaptation impossible for some natural systems, while for most human systems it would involve very high social and economic costs (see also Chapter 19). However, the literature aiming to establish at which magnitude of climate change, or at which levels of mitigation, such adaptation constraints and limits emerge, is scattered and inconclusive. Uncertainty about the location of both hard and soft limits is to a large extent due to the fact that these limits are determined not only by the degree and rate of climate change (and are therefore a function of mitigation pathways), but also by the degree and rate of non-climatic stresses affecting the resilience or adaptive capacity of natural and human systems. Little empirical information is available on the functional relationships between climate change, non-climatic stresses and the emergence of limits to adaptation, offering scant support to the idea that the 2°C global goal represents a limit.

Analysis by Christensen *et al*. (2011) shows that all emission scenarios – whether aggressive mitigation scenarios consistent with a 2°C stabilization pathway or medium-high emission scenarios such as SRES A1B or A1Fi – are very similar in terms of projected climate up to 2040. The effects of mitigation on overall adaptation potential will therefore arise in the medium to long term. Integrated assessment models (IAMs) can assess the relative damage-reducing effect of mitigation and adaptation, but in doing so these models assume the two strategies to be substitutes. However, mitigation and adaptation create benefits on different spatial, institutional and temporal scales and involve different actors with different interests. At the global level it requires the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. As highlighted in Chapter 17, defining the costs and benefits of adaptation is particularly difficult, limited by data, and depends on value judgments.

Furthermore, since AR4 the literature on tipping elements (Lenton *et al*., 2008; Kriegler *et al*., 2009; Levermann *et al*., 2012) has provided a greater separation of mitigation and adaptation, because only mitigation can avoid these discontinuities. These concerns have also been picked up in the economic literature, notably in relation to the plausible, if unknown, probability of catastrophic climate change (Weitzman, 2009) and 'fat tails', where uncertainty is so large that the tails of the probability distribution tend to dominate. Against this background, mitigation insures against catastrophic climate change, and thus mitigation has an additional objective to adaptation. While there could be potential for mitigation and adaptation substitutability under scenarios where catastrophic climate change is avoided, the thresholds for the onset of any tipping elements are not known.

[INSERT FIGURE 16-3 HERE]
Figure 16-3. Adaptation policy space as a function of mitigation pathways (Watkiss *et al*., 2013).]

Nonetheless, several studies using IAMs have investigated tradeoffs between mitigation and adaptation (De Bruin *et al*., 2009; Bosello *et al*., 2010), treating the two strategies as substitutes in order to find a balance or even an optimal mix. De Bruin *et al*. (2009) report that short-term optimal policies need to consist of a mixture of substantial investments in adaptation measures, coupled with investments in mitigation, even though the latter will only decrease damages in the longer term. They also find that the relative mix of the two depends critically on the assumptions, notably in relation to the discount rate and the parameterization of damages.

Such findings are preliminary, because the representation of adaptation in IAMs is very simple (Ackerman *et al*., 2009; Patt *et al*., 2010): the models adopt a highly aggregated and theoretical approach without considering any real-world constraints on adaptation. They also often assume perfect foresight, no uncertainty and no maladaptation (see also Watkiss, 2011; Berkhout, 2012). More recent models have attempted to address some of these issues. The PAGE09 model (Hope, 2011), for example, has less positive assumptions about adaptation than PAGE02 (assuming it to be about half as effective), which along with other factors leads to a strong increase in the economic costs of climate change.

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

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

The adaptation literature since the AR4 reflects *high agreement and much evidence* that adaptation efforts can and will be constrained by multiple factors (16.3), and, in some cases, such constraints may effectively limit adaptation (16.4). However, there is also *high agreement and much evidence* that opportunities, constraints, and limits for adaptation vary significantly among different sectors and regional contexts (Adger *et al.*, 2007). This heterogeneity arises from a range of sources including regional differences with respect to the rate and magnitude of climate change that is experienced, differential exposure and sensitivity of sectors or ecological systems, and differential capacity to adapt. In particular, a robust funding from the literature is the differential adaptive capacity of developed versus developing nations (Adger *et al.*, 2007). Nevertheless, while developing nations face potential challenges for adaptation arising from development and adaptation deficits (2.3.2.2.; 15.4.3.1.; 15.6), challenges for adaptation planning and implementation have been reported for developed countries as well (NRC, 2009, 2010; Berrang-Ford *et al.*, 2011; Preston *et al.*, 2011a). Given this diversity in adaptation opportunities, constraints, and limits, it is important that they be considered in the specific context in which they arise. Therefore, this section draws on the various assessments of adaptation presented in the sectoral (Chapters 3-13) and regional (Chapters 22-30) chapters of the Working Group II report to synthesize knowledge regarding opportunities, constraints, and limits across these contexts.

16.5.1. Sectoral Synthesis

Each of the sectoral chapters in the Working Group II report addresses the opportunities for, and challenges associated with, the pursuit of adaptation (Table 16-3). Collectively, this represents a rich body of knowledge regarding understanding of adaptation processes and how they are evolving among different human and natural systems. Although each sectoral chapter assesses the relevant literature on adaptation somewhat independently, a common emphasis among these chapters is a need for integrated approaches to adaptation planning and implementation. For example, Integrated Water Resource Management (IWRM), Integrated Coastal Zone Management (ICZM), Community-Based Adaptation, and Ecosystem-Based Adaptation (CC-EA) are identified as cross-sectoral adaptation options, which are viewed as more effective than standalone efforts to reduce climate-related risks(Bijlsma *et al.*, 1996); 3.6; 5.9). Such integration is important as many sectors experience threats not from by climate change, but also from a range of existing or emerging threats. The sectoral chapters also reflect the distinction between autonomous adaptation, which is particularly important for natural systems such as freshwater, terrestrial, and ocean ecosystems, and planned adaptation, which features strongly in the literature associated with human systems. Common constraints arise among different sectors, which resemble those addressed previously (16.3). These include institutional challenges, barriers to accessing resources for adaptation, as well as lack of or uncertain information (3.6.1). As such, many chapters emphasize the various opportunities for building capacity through development and increasing resilience to climate change by addressing other stresses to human and natural systems. While the sectoral chapters offer few explicit definitions of adaptation limits, they reflect the potential for soft limits to arise and the potential for them to be persistent due to interactions among multiple constraints (16.3.5). Meanwhile, the sustainability of individual species or ecosystems may experience hard limits in a change climate, as may ecosystem services for humans such as food crops and fisheries.

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

16.5.2. Regional Synthesis

While the regional chapters assess the relevant literature on key sectors affected by climate change, those discussions are specific to the various regional contexts (Table 16-4). Mainstreaming climate change into national development policies as well as regional and local planning and economic development has emerged as a unified theme across regions for addressing multiple, interacting, stresses (Dovers and Hezri, 2010; Tompkins *et al*., 2010). Most regional chapters reveal there is a significant mismatch between national adaptation planning on adaptation and local implementation to achieve substantive reductions in vulnerability. Just as there is a scale disconnect in adaptation planning and implementation, there is also a temporal disconnect. Adaptation interventions largely emphasize short-term risk management over long-term strategic planning, which potentially increases vulnerability and therefore the costs associated with future adaption efforts. Such short-sighted decision-making can also create the potential for maladaptation (Berrang-Ford *et al*., 2011). The regional chapters also reveal the fundamental disparities between developing and developed nations with respect to adaptive capacity. For example, Asia, Central and South America, and Africa reveal consistent weaknesses with respect to information on climate change and adaptation, access to other resources, and effective institutions for facilitating adaptation planning and implementation. Nevertheless, governance frameworks for incorporating adaptation are also identified in global regions such as North America and Europe, which are largely comprised of developed nations. A shift to risk-based approaches to adaptation offer opportunities for the development of approaches, tool and guidelines for the construction of adaptation plans with a long-term focus (16.7.2). In addition, ecosystem based adaptation (CC-EA) appears as another one adaptation opportunity to address short and long-term adaptation vulnerabilities in several regions (Africa, Australasia, Central and South America) (CC-EA).

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

16.6. 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 needs of biophysical systems. However, defining what these values are and untangling the ethical issues is not straightforward. Defining general moral principles to clarify how to handle risks to objectives, values and needs, including where they are unavoidable and catastrophic, is 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 and nor are they static (O'Brien, 2009; O'Brien and Wolf, 2010). There may be different, equally well-founded values about an activity or value 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 an irreversible cultural loss would be seen as intolerable remains a complicated question. The loss of traditional cosmologies and ways of seeing the world is a common occurrence throughout history. The ethical question is whether such non-material losses need to be acknowledged and whether there is a right to restitution.

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 (IPCC, 2007b; Füssel, 2009; Füssel, 2010). This inequity is exacerbated by the fact that exposure to adverse impacts is involuntary for many societies (Paavola and Adger, 2006; Patz *et al*., 2007; Dellink *et al*., 2009; Füssel, 2010). Therefore, adaptation capacity and implementation constraints have the potential to create or exacerbate inequitable consequences due to climate change (*high agreement, robust evidence*). Linked to this is the complex question of the attribution of risks to anthropogenic forcing of climate change and whether there could be grounds for redress or compensation (Verheyen, 2005). Where limits to adaptation lead to catastrophic losses there are may be a strong need for humanitarian responses.

Inequity resulting from adaptation constraints and limits emerge across several dimensions; namely inter-country equity, inter-generational equity, inter-species 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 complex technical discussions about the time 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, 2007b). Support for climate change adaptation interventions for species increasingly invokes human and societal benefits as a primary motivation (CBD, 2009).

Law codifies principles, norms and procedures for dealing with problems of risk and loss, including intolerable losses. National and international law will play a role in managing and sharing climate-related risks. 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).

16.6.1. 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 implementing adaptation actions. Positive externalities can be projected at all levels of scale from international to local. Positive externalities may be 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 neighbors most through reducing risks of social instability and resource demands. Negative externalities relate to adaptive strategies that reduce resource availability to neighbors, such as through water security strategies that may reduce availability to downstream neighbors (Eckstein, 2009), or generate new risks to neighbors, 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).

16.6.2. Ethics at the Limits of Adaptation

Historical reconstructions of societies that approach limits to adaptation involving a climate driver show that endogenous capabilities may determine whether limits are exceeded or avoided (Box 16-3). 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*., 2009b), which could expose them to greater probabilities of exceeding adaptation limits.

16.7. Seizing Opportunities, Overcoming Constraints, and Avoiding Limits

16.7.1. Opportunities for Adaptation

We take adaptation opportunities to be factors that make it easier to plan and implement adaptive actions, or which ease adaptive responses to climate-related risks in ecosystems. 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, an issue addressed to varying degrees among the various sectoral and regional chapters.

Previous literature has focused especially on opportunities (and constraints) to build adaptive capacity and adaptation in national (Tompkins *et al*., 2010) and international policy contexts, while tending to neglect the important role of the private sector in facilitating adaptation (Tompkins and Eakin, 2012). 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 research and innovation support for adaptation options, creating the enabling environment for adaptation options to be implemented and ensuring that spillovers and externalities associated with adaptation options are managed. 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 resilience, 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.

16.7.1.1. 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 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 evaluate success are still lacking (Berrang-Ford *et al*., 2011; Ford *et al*., 2011; Preston *et al*., 2011a; Brouwer *et al*., 2013).

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; Dovers and Hezri, 2010). 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 Hoyden, 2003) should be given to climate adaptation goals over other goals, such as economic development or environmental protection. 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 (2009b) 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 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 decision-making strategies for public policymaking, matching these strategies to the nature of uncertainty being faced in a specific decision context. They argue for a precautionary approach, risk-hedging against alternative futures and 'robust decision making' (see Chapter 2), where appropriate. Moser and Leurs (2008) suggest a series of enabling conditions for adaptation. 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-off. In summary, adaptation opportunities are an outcome of an emphasis on flexibility, consistency and predictability, transparency and accountability in decision-making (Maddocks, 2012).

16.7.1.2. 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), adaptation efforts increasingly capitalize on complementarities by mainstreaming adaptation into existing policies and management activities (16.7.2). Although existing options provide a foundation to normalize adaptation (Dovers, 2010), it is important that the assessment and selection of adaptation responses consider a range of stressors, and, the need for adaptive management given future uncertainty.

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 may 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 *et al.*, 2006). New services related to climate prediction and insurance also may emerge. 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; Botzen *et al.*, 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).

16.7.2. Approaches to 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 (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

FAQ 16.1: Are there limits to adaptation to climate change?

Climate variations in the past sometimes went beyond what communities and societies at the time were able to cope with. Climate change during this century is also very likely to go beyond the limits of some of those needing to adapt. The greater the magnitude of climate change, the greater the likelihood that adaptation will encounter these limits. Limits exist both in the natural world and in society; some limits are hard while other ones are soft. For example, the rate of sea-level rise determines whether or not healthy coastal ecosystems can adapt by growing landwards or upwards. Beyond a certain rate these ecosystems will not be able to keep pace; this is a hard limit. Soft limits are reached when adaptation can no longer avoid a situation in which people's needs and values are compromised due to adverse effects of climate change. The location of both hard and soft limits is determined both by the degree and rate of climate change (and is therefore a function of mitigation pathways) and by the degree and rate of non-climatic stresses affecting the resilience or adaptive capacity of natural and human systems. Little empirical information is available on the functional relationships between climate change, non-climatic stresses and the emergence of limits to adaptation, offering scant support to the idea that the 2°C global goal represents a limit.

FAQ 16.2: To what extent can sustainable economic development, innovation, and technological change reduce adaptation constraints and contribute to the avoidance of limits?

There is a strong perception that economic development has enabled actors to deploy greater financial resources, technology, and human capital in managing risks due to climate change. However, the role of externalities of such development such as habitat degradation and, resource depletion, and climate change in increasing these risks has not been well quantified. A portfolio of local, national, and international strategies will be needed to facilitate sustainable development that expands the range of climate to which socio-ecological systems can adapt.

FAQ 16.3: Are limits to adaptation predictable?

Knowledge about limits to adaptation could inform the level and timing of mitigation and might justify early mitigation action. There is high confidence that limits to adaptation exist, but detailed understanding of the level at which climate change exceeds a limit is available only for a small number of natural systems and crop species. Research on adaptation by people often considers, explicitly or implicitly, technological change, financial resource availability, and other factors determining adaptive capacity, as well as physical and ecological impacts of climate change. However, any assessment of limits to adaptation in human systems is preliminary and of little use in decision-making, because of uncertainty about the existence and level of adaptation limits, and the soft nature of these limits. Furthermore, non-climatic trends and conditions, including uncertainty regarding actors' objectives and values and how they evolve over time, interact with climate change to further challenge the prediction of limits.

FAQ 16.4: What are the consequences of exceeding adaptation limits?

The exceedance of a socio-ecological system's limits to adaptation unavoidably results in a transformational change. This transformation may be adaptive through changes in management objectives, policy instruments, institutions and attitudes that enhance sustainability. Alternatively, transformation may be destructive resulting in loss and damage. As multiple values and objectives are often attached to biophysical and socioeconomic systems, transformation may involve trade-offs whereby some values are preserved while others are lost. As such, the exceedance of adaptation limits may raise ethical questions regarding how trade-offs are managed among different actors and, particularly, public versus private goods.

Cross-Chapter Box

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

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

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

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

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

Examples of ecosystem based approaches to adaptation include:

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

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

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

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Table 16-1: Constraints affecting the implementation of adaptation policies and measures.

Constraint	Examples
Knowledge and Information	• Uncertainty regarding future climate change (Hulme *et al*., 2009; Dessai *et al*., 2009; Wilby and Dessai, 2010) • Uncertainty regarding future socioeconomic states and associated uncertainties (Preston et al., 2011b) • Lack of information regarding adaptation options and their costs and benefits (Prato, 2008; de Bruin *et al*., 2009b; Patt *et al*., 2010) • Incomplete information regarding the various constraints on, or limits to, the effectiveness of adaptation options (Mitchell *et al*., 2006; Moser, 2009; Smith *et al*., 2008b; Moser and Ekstrom, 2010; Conway and Schipper, 2011) • Lack of consensus regarding the appropriate balance between traditional and formal scientific knowledge (Box 16-2)
Natural Resources	• Growing consumption of water by humans is threatening the sustainable yield of surface and groundwater systems in a number of global regions (Bates *et al*., 2008; Shah, 2009; Goulden et al., 2009; Gober and Kirkwood, 2010; MacDonald, 2010; Taylor et al., 2012) • Non-climatic stresses to ecological systems can reduce their resilience to climate change (Malhi *et al*., 2009a,b; Diaz and Rosenberg, 2008; Kapos and Miles, 2008; Afreen *et al*., 2011). • 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; CC-EA). • Soil degradation and desertification reduce crop yields and the resilience of agricultural and pastoral livelihoods to climate stress (Iglesias *et al*., 2011; Lal, 2011).
Financial Resources	• Financial capital is a key determinant of vulnerability and adaptive capacity of farmers and land managers to climate variability and change (Nhemachena and Hassan, 2007; Hassan and Nhemachena, 2008; Deressa *et al*., 2009, 2011; Jantarasami *et al*., 2010). • The costs of investigating and responding to climate change are perceived to be significant constraints on adaptation for local governments (Gardner *et al*., 2010; Smith *et al*., 2008b; Measham *et al*., 2011) • The reallocation of overseas development assistance to adaptation may divert resources away from programs and projects targeting development goals (Ayers and Huq, 2009) • Availability of adaptation finance through the clean development mechanism is declining (AFB, 2012)
Technology and Infrastructure	• Climate impacts to existing infrastructure and the needs for new infrastructure dominate aggregate estimates of adaptation costs (see Chapter 17, World Bank, 2006; Nicholls, 2007; UNDP, 2007; UNFCCC, 2007; Parry *et al*., 2009). • Inadequate technology and infrastructure is a key determining factor of the ‘adaptation deficit’ of particular regions and sectors (Burton 2004, 2005; Burton and May 2004). • Technological innovation and deployment is important for facilitating adaptation in agriculture (Hillie and Hlophe, 2007; Howden et al., 2007; Bates *et al*., 2008; Fleischer *et al*., 2011). • Technology is important for managing the risks of climate change and sea-level rise to coastal communities (Nicholls, 2007; van Koningsveld *et al*., 2008). • Awareness, uptake and use of technology is determined by multiple factors including education, financial resources, and cultural attitudes (Nhemachena and Hassan, 2007; Hassan and Nhemachena, 2008; Deressa *et al*., 2009, 2011).
Human Resources	• Lack of leadership on adaptation is a key constraint to adaptation planning and implementation (Gupta *et al*., 2010; Tompkins *et al*., 2010; Termeer *et al*., 2012; van der Berg *et al*., 2010) • Human resources influence the capacity of public health systems to manage climate risk (Ebi and Semenza, 2008) • Multiple stressors to mental health can impair cognition and effective decision-making around adaptation (Dias-Ferreira *et al*., 2009; Spears, 2011)

Table 16-2: 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 16-3: Sectoral synthesis.

Sector	***Framing***	***Adaptation Objective***	***Rate of change***	***Opportunities***	***Constraint***	***Limits***	***Synthesis***
Freshwater resources [Chapter 3]	Major emphasis needs to be given to governance reform to build the capacity for climate change adaptation and design and implementation of resilient system. 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]. Therefore, there is a concerted effort away from "predict and provide" to enhancement of adaptive water management techniques including Integrated Water Resource Management (IWRM) joined with Strategic Environmental Assessment (SEA)[3.6.1, 3.6.3].	Avoid adverse impacts (e.g. floods and droughts) to the economy (e.g. economic losses) and the society (e.g. affected population) through strategic water resource management by incorporating adaptation options in planning and implementation of best practices, and enhance adaptive water management techniques [3.6.1]. Move from "predict and provide" approach towards adaptive water management and the adoption of 'resilient' approaches [3.6.3], and investments in risk-based actions [3.6.4].	Intense precipitation events will become more frequently and droughts will be more severe [3.3.1.4] and rates of mass loss of glaciers is likely to increase [3.4.4.2]	Climate change is frequently cited as a key motivation for the adoption of adaptive water management [3.6.3 and Table 3.3] provides a list of Adaptation Options including improve information, improve water management practices, improve the design and operations of water services, reduce water demand and waste, increase water supply and reliability, prevent pollution, reduce impacts of natural disasters, IWRM. Opportunities for improvements include "no regret" actions - those that generate net social and/or economic benefits regardless of whether climatic change occurs [3.6.3 and FAQ 3.6].	Specific constraints include: Structural: Long-lived infrastructure and the prevailing of large infrastructure as prevailing design [3.6.1]. Governance/Institutional: Sectoral fragmentation, lack of reform to manage uncertainty and surprise [3.6.1]. Institutional structures that limit stakeholder engagement and the uncertainty in how climate change may affect the water management system [3.6.3]. Economic (Human and financial capital) constraints include high economic costs and the failure to estimate actual costs [3.6.2], the high cost of implementation. Lack of financial resources. Technological, Information and Science: Uncertainty in the projected future changes makes it impossible for practical purposes to construct quantitative probability distributions of climate change impacts [3.6.5]. Lack of guidance on how the adaptive water management approach works when addressing climate change over the next few decades [3.6.3]. Access constraints including technology, information, capacity, institutions and capital, particularly in the developing countries [Table 3.4]. Lack of technical capacity, financial resources, awareness, and communication in developing countries [3.6.4]. Social/Psychological/Cultural: *[Need specifics/update from SOD]* Other: *[Need specifics/update from SOD]*	Nothing mentioned explicitly; the subsection on limits to adaptation (3.6.4) discusses constraints.	Changes in precipitation patterns and reduction in glacier volume may lead to reductions in river flows and falling groundwater tables, and cause saline intrusion in rivers and groundwater in coastal areas and that reduction in local water sources will lead to increased demand on regional water supplies [3.5.1] and significant declines in freshwater species globally [3.5.5]. Costs will be ca. USD 531 billion through 2030 to provide a sufficient water supply, given present and future projected water demands and supplies in more than 200 countries, the adaptation (Kirshen 2007, [3.6.2].

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
Terrestrial and inland water systems [Chapter 4]	There is a potential for autonomous adaptation by ecosystems and species including the capacity to migrate and human assisted adaptation including adaptive management, assisted, migration and restoration [4.4.1, 4.4.2]	Increasing the capacity of target organisms, ecosystem or Social-Ecological System to survive and function at an acceptable level, in the presence of climate change [4.4.2].	Capacity of autonomous adaptation for ecosystem and their constituent organisms is insufficient to cope with the rate and magnitude of change under moderate and high climate change scenarios for this century [4.4.1-4.4.1.2, 4.4.3]	Opportunities to facilitate adaptation stems from the implementation of planned or "human-assisted" adaptation including reduction of non-climatic stresses [4.4.2.1], strategic number, location and connectedness of protected areas [4.4.2.2], landscape and watershed management [4.4.2.3], assisted migration and restoration [4.4.2.4] and ex-situ conservation [4.4.2.5]	*Specific constraints include*: Access: *[Need specifics/update from SOD]* Structural: 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]; Lack of suitable habitat and dispersal pathways for species, inability to reduce or remove of other stressors, societal resistance Governance: Social and institutional factors including poor ecological understanding are constraints for successful adaptive management [4.4.2]. Economic (Human and financial capital): *[Need specifics/update from SOD]* Information and Science: Inadequate predictive theory for range shifts and extinction risk, combined with climate scenario uncertainty constrain conservation planning.	A clear consensus that climate change will result in shifts in species ranges, that constraints on migration for many species, in the context of highly fragmented habitats and other pressures, will greatly increase extinction risk over the coming century. [4.3.3] Phenotypic or genotypic evolution inadequate to ensure population persistence causing local to global extinction [4.4.1.2]	The most recent synthesis of range shifts indicates that terrestrial species have moved poleward which corresponds to predicted range shifts due to warming (Chen *et al*., 2011) and that range shifts for terrestrial species will accelerate over the coming century. [4.3.2.5] Significant proportion of coral reef species and terrestrial species at risk of extinction, as temperature change increases above 2 to 3 degrees. The cost of adaptation to ensure persistence in the wild increases due to land availability and translocation costs.
Coastal systems and low-lying areas [Chapter 5]	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) the approach should be integrative and implemented through adaptive management [5.6.1]	Minimize risks and impacts from coastal hazards to ensure public safety and welfare; economic development and use of coastal resources; protection of coastal environmental resources, natural assets and ecosystems (5.6.1)	The coastal ecosystems are affected by higher sea level, increasing temperature, changes in precipitation, increased extreme events and reduction in ocean pH from climate change and rapid urbanization in coastal areas and growth of megacities with consequences on	Implementation of the many approaches on integration for better social, ecological, and economic outcomes including Integrated Coastal Management, Community-Based CoAdaptation, Ecosystem-Based Adaptation (EbA), and Disaster Risk Reduction and Management. [5.9.1]	Different constraints typically do not act in isolation but interact [5.9.4] Constraints are many and fall into many categories including the technological feasibility, resources, institutional (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. [Table	Managed retreat from coastal system as adaptation option implemented in response to a soft limit to adaptation FAQ 5.6. Limits to adaptation will be experienced by migrating species and habitat types as sea level rise	The most important effects of climate change on the coastal cities include the effects of sea-level rise, effects of extreme events on built infrastructure (such as wind storms, storm surges, floods, heat extremes and droughts), effects on health, food and water-borne disease, effects on energy use, and

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
			the coastal resources. [5.1]. Global mean sea level (MSL) has been rising since 1900 at a rate of 1.7 mm yr^{-1} and 3.2 mm yr^{-1} since 1993 (AR5, Chap 13).		5-7, 5.9.4] *Specific constraints include*: Access: *[Need specifics/update from SOD]* Structural: Continued development in high risk areas [5.6.1]. Governance/Institutional: The prevalence of mal-adaptation due to interactions across policy domains [5.6.4]. Economic (Human and financial capital): economic constraints at the individual level, institutional and government levels that prevent implementation [5.6.4]. Technological, Information and Science: *[Need specifics/update from SOD]* Social/Psychological/Cultural: *[Need specifics/update from SOD]* Other: *[Need specifics/update from SOD]*	meets human settlements [5.3.1] including coastal marshes [5.6.4]. The decline of seawater pH decreases the rate of calcification of most corals, presenting a limit to coral reef adaptation [5.3.1.6]. Physical limits to unassisted adaptation of coastal marshes as sea levels rise past A1B scenario (5.6.4)	effects on water availability and resources (Hunt and Watkiss, 2010) [5.4.2.1]. The total assets exposed in 2005 across all cities are estimated to be US$3 trillion, which would increase to US$35 trillion by 2070s (Nicholls *et al*., 2008; Hanson et al., 2011) [5.4.2.1]
Ocean systems [Chapter 6]	Ecosystem resilience and marine ecosystem based adaptation [6.4] There is a potential for autonomous adaptation for species and population including through genotypic variation and migration [6.2.2.2]	Resilience of fisheries. *[Update for SOD as majority of adaptation discussion focused on species adaptation to increasing temperatures and changes in acidity]*	Over the last 43 years average warming has occurred by >0.1 °C/decade in the upper 75 m with increase of X% through 2070 [6.1.1.1]. The changes in ocean temperature and acidification will drive changes in nutrients con, salinity, underwater light regime net primary	Opportunities for adaptation of human populations dependent on ocean resources, particularly in developing countries, are limited [6.4.1.1.2]	Constraints are related to ocean temperature, acidification, etc that limit functions of ocean and supply of primary elements to living organism thus preventing autonomous adaptation [6.4]. *Specific constraints include:* Access: *[Need specifics/update from SOD]* Structural: *[Need specifics/update from SOD]* Governance/Institutional: *[Need specifics/update from SOD]* Economic (Human and financial capital): *[Need specifics/update from*	Marine species that already live close to their upper thermal and pH limits will be most sensitive to climate change. There have been reports on climate-induced changes in species abundances but not on climate-induced extinctions in the oceans [6.5.2].	Fisheries and ecosystem management in the future might have to deal not only with the traditional sustainability goals, but to increase the ecosystems resilience to climate variability and change [6.4.2.5] Adaptation and management of risks will build on successful detection and attribution. Ecosystem-based

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
			production and food availability [6.1, 6.2],		*SOD]* Technological, Information and Science: *[Need specifics from SOD]* Knowledge gaps on whether and to what extent species can undergo adaptation to progressive ocean acidification over generations [6.2]. Social/Psychological/Cultural Other: *[Need specifics from SOD]*	Evidence regarding limits to adaptation are scarce for ocean systems however one study finds a limit in which aragonite undersaturation is projected to occur by the year 2030 leading to a decrease rates of calcification and increasing ocean acidification [McNeil and Matear 2008]	management (EBM) with a focus on climate change impacts will need adopted to manage the multitude of anthropogenic pressures on marine ecosystems, [6.4.3]
Food production and food systems [Chapter 7]	Adaptation through reductions in risk and vulnerability by adjusting practices, processes and capital in response to current climate or threat of climate change [7.5.1],	Reduce and vulnerability by adjusting practices, processes and capital [7.5.1.1] to address the eight elements of the food security outcomes including income, employment, wealth, social capital, political capital, human capital, ecosystem stock and flows, ecosystem services and access to natural capital (Figure 7-1).	Crop yields are likely to fall by at least X% by the year 20XX [7.4.4.] with the highest rates of food insecurity are in Sub-Saharan Africa *[Need specifics/update from SOD]*	Opportunities include taking advantage of the increase in the growing season, the range expansion, and yields [7.5].	Constraints include 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] *Specific constraints include:* Access: *[Need specifics/update from SOD]* Structural: Lack of infrastructure. Governance/Institutional: Institutional inertia and lack of adaptive capacity [7.5.1.2.1], lack functioning markets and insurance systems. Economic (Human and financial capital): Lack of financial resources, Inadequacy of required substantial investment to develop new varieties of crops or breeds of livestock [7.5.1.2.1] Technological, Information and	Physiological limits to performance and crop yields requirement to sustain critical backward and forward link infrastructure. [7.5.1]	Adaptation of food systems shows a wide range in effectiveness. With an increase in effective with adaptations aimed at temperature increases which leads to lower reductions in yields than in its absence with more effective adaption at higher latitudes [Executive Summary] However, most reduction in risk are incremental, not transformative, and do not take into account the competing stressors of water availability and increased demand for food

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
					Science: Inadequate information on climate, climate impacts, risks and benefits of option. Lack of technical options. [7.5.1.2.1]. Social/Psychological/Cultural: Other: *[Need specifics/update from SOD]*		[7.5] Many of the elements in the human food system will be adversely affected by projected climate change from about the mid-21st century onwards. Adaptation options have potential to reduce 20 percent yield reduction [ES]. Ongoing increases in potential yield across the globe due to crop improvements may act to mitigate negative impacts (7.4.1)
Urban areas [Chapter 8]	Building resilience of urban infrastructure and social system by integrated planning, investment and addressing structural drivers of social and urban vulnerability [8.3.2.1]	Integrate/mainstream climate change adaptation in urban areas through government led city planning and implementation and disaster risk reduction [8.3.2], coordination of investment from individuals, household and firms, and other levels of government [Executive Summary].	Great diversity exists among the world's urban areas with rates of change as informed by the scale and nature of the climate-related risks. *[Need specifics/update from SOD]*	Opportunities exist in taking advantage of 30 years of experience in municipal disaster risk reduction and in building on the relation between adaptation to climate change and development [8.3.2.2], including implementation of ecosystem-based adaptation to support a range of policy goals including food security, water purification, waste water treatment and flood risk reduction as well as mitigation [8.3.3.7, Box 8.1]]	Constraints include resource limitations, limited adaptive capacity with limited resources, weak institutions, poor/inadequate infrastructure and poor governance in global south [8.5.1] *Specific constraints include:* Structural/capacity: Lack of technical expertise, Lack of capacity of multi-levels of government to implement coordinated plans and responses [Executive Summary] Governance/Institutional: Municipal government priorities driven by short term priorities and nearer term concerns about economic growth and competitiveness [8.4]. Ill-designed institutional mechanisms (compartmentalization and fragmentation) at local level [8.4]. Lack of mandate and clarity at different levels, inadequate policy attention and recognition by national	Coastal system that are inundated as sea level rises and river systems that flood create a soft limit to adaptation [8.4.1.2] unless strategic and managed retreat is developed in advance.	Adaptation in a 4 degree world will have to be a "more substantial, continuous and transformative process" than for a 2 degree world, and will have to contend with the possibility of thresholds, that once crossed, will lead to abrupt, non-linear and unpredictable global environmental change. This will stretch the adaptive capacity not only of existing urban systems, but of the whole global system [8.5].

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
					government [8.4]. Disaster risk reduction is still not integrated into development plans and not drawing in all relevant departments and divisions of local government. Implementation of hard engineering solutions and effectiveness are constrained by technological, financial, institutional and skill [8.3]. Lack of coordinating poverty reduction with climate change responses and making adaptation plans locally relevant [8.5] Economic (Human and financial capital): Lack f financial resources for implementation [8.4] Technological, Information and Science: Uncertainty as to what climate change will bring (and when) in each locality [Executive Summary]. Limited technical expertise. Poorly developed Monitoring, Reporting and Feedback systems [8.5]. Substantial knowledge gaps need to be addressed to determine where the limits or thresholds lay, limits or thresholds to adaptation of various ecosystems. Knowledge about limits within existing systems will be vital in developing appropriate transformative planning responses to future climate challenges [8.3; 8.5] Social/Psychological/Cultural: *[Need specifics/update from SOD]* Other: *[Need specifics/update from SOD]*		
Rural Areas [Chapter 9]	Adaptation, and building capacity to adapt, is a dynamic process and should be linked to other development initiatives aiming for poverty reduction or improvement of rural	Development of resilient agriculture, economic and institutional development, improvements in health, education and infrastructure, growing	Prospects for adaptation depend on the magnitude and rate of climate change, adaptation strategies being inseparable from increasingly strong and complex	Opportunities to benefit rural communities come from expanding the use of seasonal forecast information for coordinating input and credit supply, food crisis	[*To be completed post-SOD]*	There are soft limits to the role of social capital in resilience which context specific and time bound [9.4.1].	Climate change in rural areas in developing countries will take place in the context of many important economic, social and land-use trends. In different regions,

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
	areas [9.4.1]	interconnectedness and technology transfers to help rural societies to develop their human and social capital and link adaptation to other development initiatives aiming for poverty reduction or improvement of rural areas.	global linkages [9.2].	management, trade and agricultural insurance [9.4.4]		Poverty, hunger, malnutrition are already significant challenges being exacerbated by climate variability in rural settings (mainly sub-Saharan Africa), attribution difficult because of the impacts of related and unrelated co-stressors, water supply, food production and agricultural income are seeing increasing residual damages, indicating the approach of limits in many regions [9.4.1].	rural populations have peaked or will peak in the next few decades [9.3.1]. Conservation agriculture and water management for agriculture is critical in rural areas under climate change and adjustment measures relating to there farming practices. Adaptation in marine ecosystems is also of relevance to rural areas. Need to discriminate between developing and developed country rural areas, with the latter at far higher risk of imminent limits, and heavily constrained by a number of factors.
Key economic sectors and services [Chapter 10]	To reduce the cost of adaptation.	*[To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*
Human health [Chapter11]	Climate change acts as a multiplier of risk – in most instances, changes in temperature; rainfall and extreme events compound health problems that are already present. [11.6.1]	Reducing background rates of disease and injury, improvements in public health and health care including access to heath care services for improvement of population resilience and minimizing poor health outcomes	There is a dearth of scientific evidence of the relationship between weather/climate and health in low- and middle-income countries [Box 11-2]	Cross-sectoral adaptation opportunities exists (transportation, building, landuse, forestry and agriculture (Younger et al., 2008). Reduction in disaster mortality through effective	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) *Specific constraints include:*	Climate and/or health conditions that limit the body's ability to respond to stressful events [11.3.1.2].	Health is both a condition for, and a consequence of, development, and there is a similar inter-dependence between a country's social and economic progress and its ability to protect its population against adverse effects of

Sector	*Framing*	*Adaptation Objective*	*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
		resulting from climate change [11.6.1]		collaborations between government, local communities and non-governmental organizations (Khan 2008). Carbon abatement is an opportunity to achieve both climate mitigation and health benefits (UNEP, 2012).	Structural: *[To be completed post-SOD]* Governance/Institutional: *[To be completed post-SOD]* Economic (Human and financial capital): *[To be completed post-SOD]* Technological, Information and Science: Social/Psychological/Cultural: *[To be completed post-SOD]* Other: *[To be completed post-SOD]*		stressors such as climate change [11.1.1]
Human Security (Chapter 12)	Human security in the inverse of social vulnerability in that it implies the protection of people from severe shocks arising from changes in social or environmental conditions [Executive Summary].	Enhance human security through social and environmental policies and programs that ensure social protection and expand people's freedoms and opportunities necessary for survival, sustainable livelihoods, and dignity [12.1.2].	[*To be completed post-SOD]*	Opportunities include migration to enhance human security to climate change impacts [ES].	Lack of flexibility in where and when to relocate, access to resources, changes in the resource base, resource management, encroachment and institutional constraints, *Specific constraints include:* Structural: *[To be completed post-SOD]* Governance/Institutional: [*To be completed post-SOD]* Economic (Human and financial capital): [*To be completed post-SOD]* Technological, Information and Science: Neglecting local and traditional knowledge in policy and research [12.3.2] Social/Psychological/Cultural: Poverty widens disparities and lack of proper entitlements or rights for managing and using resources [12.3.4] Other: [*To be completed post-SOD]*	No hard limits identified but at very high rates of projected warming, all of the aspects of human security likely to be adversely effects creating soft limits that may be difficult to overcome [12.7]	Climate change seems likely to be an increasingly important driver of human insecurity in the future [12.7]
Synthesis	[*To be completed post-SOD]*	*[To be completed post-SOD]*	[*To be completed post-SOD]*	[*[To be completed post-SOD]*	[*To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*

Table 16-4: Regional synthesis.

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
Africa [Chapter 22] [22.3.4: adaptation section is forthcoming]	Mainstreaming adaptation to climate change into national development policies. Sub-regional organizations integrate climate change in their policies and economic management.	Strengthening adaptive capacity of rural and urban contexts by mainstreaming climate change into national development policies as well as sub-regional organizations integrate climate change in their policies and economic management.	*[To be completed post-SOD]*	Opportunities for adaptation include linking adaptation and development, and for low-regrets adaptation strategies that produce developmental co-benefits [22.4], including integrated programmes on desertification, water management and irrigation, promoting sustainable agricultural practices, developing alternative sources of energy [22.4.1] and implementing ecosystem-based adaptation [22.6.5] In addition, reducing health burdens through improving public health surveillance and monitoring, access to safe water and improved sanitation, hygiene education, and waste management strategies; and providing better access to health care and health insurance [22.3.3.2.3]	The constraints to adaptation in Africa interact in multiple and complex ways across scales influencing how local people both decide or are enabled to respond or not to changes in their environment [22.4.4]. *Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Corruption, inadequate extension services and top-down decision making. Institutional weakness, Over-emphasis of mitigation discourse, emphasis of short-term outcomes with a disaster/risk orientation. Economic (Human and financial capital): Lack of resources [22.4.4]. Technological, Information and Science: Lack of capacity, data and integrated analysis related to climate change. Lack of knowledge regarding what influences decision making [22.4.4]. Social/Psychological/Cultural: Cognitive, behavioral and cultural constraints exist regarding the need to adapt and the willingness to accept change [22.4.4]. Other: *[Need specifics/update from SOD]*	Neither autonomous nor planned adaptation to climate change is necessarily materialising neither in the ways expected nor at the pace desired, and that simply providing the right technology and sufficient funding to carry out local level programmes is not a guarantee for change on the ground (Ludi et al. 2012) [22.4].	A wide range of adaptation options, approaches and decision tools are being tested and implemented across Africa but additional efforts at scale are needed to address the complex identified vulnerabilities and needs [Executive Summary], including disaster risk reduction, early warning systems and disaster preparedness; social protection and index-based weather insurance; technological approaches and climate-resilient infrastructure; sustainable land management and ecosystem restoration; and livelihood diversification [Executive Summary], .

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
Europe [Chapter 23]	Integration of climate change into national, local and sectoral development plan and strategies [23.7] aiming at improving competitiveness, the environment, and the quality of life in rural areas [23.7.5].	Focus on cross-sectoral decision making for adaptation with respect to four main categories of impacts: (1) production systems and physical infrastructure; (2) agriculture, fisheries, forestry and bioenergy production; (3) health and social welfare and; (4) protection of environmental quality and biological conservation [23.1.1].	*[To be completed post-SOD]*	Individual and cross sector opportunities are highlighted in each of the four main categories (1) production systems and physical infrastructure; (2) agriculture, fisheries, forestry and bioenergy production; (3) health and social welfare and; 4) protection of environmental quality and biological With a focus on recreation and tourism, insurance and banking, food (fiber, livestock, fish) production, water resources, forestry, disaster risk reduction (drought, flood), infrastructure, water quantity and quality, human health, social and cultural. *[Need specifics/update from SOD]*	*Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Lack of institutional frameworks is a major constraint to adaptation governance [23.10.1] and cross-sector adaptation plans. A lack cross-sector impact and adaptation linkages as an important weakness in the city plans [23.7]. Economic (Human and financial capital): *[Need specifics/update from SOD]* Technological, Information and Science: *[Need specifics/update from SOD]* Social/Psychological/Cultural: *[Need specifics/update from SOD]* Other: Irrigation for agriculture will be constrained by reduced runoff, demands from other sectors, and by economic costs [23.4.1, 23.4.3]. Lack of integrated coastal zone management or climate change adaptation for the Baltic Sea Region.	In agriculture, there are limits to increasing crop yields and production through genetic modification [23.10.1] In natural systems, phenological mismatches will limit both terrestrial and marine ecosystem functioning and ecosystem service production [23.6.4, 23.6.5]. Drought-pest dynamics in forest systems may be a limit to forest persistent and productivity through a state change [23.4.4]. There are soft limits to how far communities can adapt to rapid and large sea-level rise.	Climate change impacts and vulnerability assessments have given rise to an adaptation decision-making framework, at the local, regional, national and pan-European levels leading to the development of a series of national plans and strategies to address adaptation [23.7]. The next step is cross-sectoral decision-making and planning [23.7] in arenas such as Coastal Zone Management [23.7.1]. Integrated Water Resource Management (IWRM) [23,7,2]), land use planning [23.7.4] and rural development [27.7.5].
Asia [Chapter 24]	Adaptive management and mainstreaming climate change into development planning at all scales, levels and sectors [24.2.2].	Adaptive management and mainstreaming climate change into development planning at all scales, levels and sectors including cross-sectorial collaborations for the development of sustainable adaptive measures (24.4.6.5)	*[To be completed post-SOD]*	Opportunities are described in 6 categories (1) Freshwater resources: applying water saving technologies in irrigation, changing to drought tolerant crops, increasing water supply, and improving management [24.4.1.5]. (2) Terrestrial and inland waters: conserving the geophysical stage;	Constraints are identified broadly as being ecological, social and economic, technical and political. *Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Lack of co-ordination in the formulation of responses [24.2.2]. High degree of	Limits are identified as biophysical limits in ecosystems, including limits to dispersal and climate tolerance will lead to species extinctions [24.4.2.3].	Mainstreaming adaptation into government's sustainable development policy portrays a potential opportunity for good practice to build resilience and reduce vulnerability depending on effective, equitable and legitimate actions

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
				protecting climatic refugia, and increasing landscape connectivity [24.4.2.5]. (3) Coastal system and low lying areas: Hard coastal defenses and acquisition of landward buffer zones [24.4.3.5] (4) Food production systems: crop breeding [24.4.4]conservation farming, change to drought-tolerant crops, water conservation efficiency, crop shifting and diversification and strateguc food reserves [Table 24.8] (5) Human settlements, industry and infrastructure: migration, land use change, green infrastructure, flood proofing [Table 24.9] (6) Human Health, Security, Livelihoods, and Poverty: Win-win solutions for public health from the interaction of adaptation and mitigation measures that involve urban environments and air pollution [24.7]. Climate resilient livelihoods can be fostered through the creation of a bundle of capitals (natural, physical, human, financial and social capital) and poverty eradication [Table 24-11]. Community based approaches to address poverty and livelihoods [24.4.6.5]. Technologies and policy options that provide both mitigation potential as well as sustained income generation potential	centralization of the management regime and the lack of vertical integration result low adaptive capacity (24.4.1.5). Lack if information sharing of best practices across countries. Insufficient mainstreaming of adaptation into the broader policy frameworks. Insufficient integration of transboundary policy recommendations into national climate change plans and policies [24.9.1]. Absence of involvement of upstream and downstream stakeholders. Lack of prioritization of employment generation and education as issues at the national level [24.5.4]. Weak governance mechanisms and breakdown of policy and regulatory structures [24.5.4]. Lack of disaster risk reduction [24.5.4]. Economic (Human and financial capital): Lack of financial resources for adaptation implementation [25.5.4]. Lack of higher education in adaptation [24.5.4]. Technological, Information and Science: Spatial and temporal uncertainties associated with forecasts of regional climate, limited national capacities in climate monitoring and forecasting [24.2.2]. Lack of awareness on the impacts of climate change to sustainable development [24.5.4]. Lack of research [24.4.4] Social/Psychological/Cultural: *[Need specifics/update from SOD]*		to overcome barriers and limits to adaptation (24.5.3) Success will depend on promoting good governance including responsible policy and decision making; empowering communities and other local stakeholders so that they participate actively in implementation of adaptation; and mainstreaming climate change into development planning at all scales, levels and sectors [24.2.2], [24.4.6.5].

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
					Other: Existence of biophysical constraints to climate change [35.5.4]		
Australasia [Chapter 25]	The opportunities for and effectiveness of adaptation depend heavily on institutional and governance arrangements that enable decision-makers to consider climate change information [25.5.1]	Maintenance, enhancing resilience and rational use of natural resources (e.g. water, ecosystem) through policy reforms for mainstreaming climate change that comprises an interdependent mix of strategies. Ameliorating some impacts and delivering multiple benefits by reducing other environmental stresses.	*[To be completed post-SOD]*	Adaptation opportunities are highlighted in each of the nine main categories (1) Freshwater Resources: securing water augmentation, sewage recycling and stormwater use, reduction of demand, and integrated planning with consideration of flood risk and stormwater and wastewater infrastructures (2) Terrestrial and Inland Freshwater Ecosystems; increasing resilience, targeted relocation of at-risk species into new habitats (3) Coastal and Ocean Ecosystems: managed retreat from eroding coasts (Box 25-2), removal of human barriers to migration, beach nourishment, translocation of species, management of environmental flows, habitat provision, and modification [25.6.3.3] (4) Production Forestry, species or provenance selection, silvicultural options [25.6.4.2.] (5) Agriculture: crop switching [25.6.5.2] (6) Mining: *[Need specifics/update from SOD]* (7) Energy Supply, Transmission, and Demand: limit increasing urban energy demand [Box 25.9] (8) Tourism: strengthening ecosystem resilience, preparation for extreme	*Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Unclear legislative frameworks, institutional fragmentation, and limited vertical and horizontal integration of different actors with unclear responsibilities, contradictory policies and development goals [25.5.2]. Absence of a consistent information base and binding guidelines that clarify governing principles [25.5.2]. Economic (Human and financial capital): Lack of financial resources particularly at the community level. Limited of social and institutional capital. Technological, Information and Science: Uncertainty about the scale and timing of projected impacts, limited financial and human resources [25.5.2]. Lack of robust frameworks to deal with the uncertainties and dynamic change characteristic of climate change; magnitude and rate of climate change, together with fragmentation of habitat limit migration options for species [25.6.2.3]. Social/Psychological/Cultural: Perception of climate change as a risk, social and cultural values that place attachment	Collapse of coral reef systems in north-eastern and western Australia, driven by increasing sea-surface temperatures and ocean acidification; the natural ability of reefs to adapt to the projected rates of change is very limited [Box 5-3, 25.6.3] Loss of montane ecosystems and some endemic species in Australia [25.6.2], Individual species and ecosystems that occupy climatically constrained ecological niches and/or occur in fragmented habitats or locations where adaptive movement is not possible; e.g. coral reef systems in northeastern and west Australia and ecosystems in the Australian alpine zone currently covered by seasonal snow (25.6.2, 25.6.3).	Adaptation is already occurring and adaptation planning is becoming embedded in planning processes. Capacity to adapt is generally high in many human systems but implementation of effective adaptation measures faces major constraints especially at local and community levels. Some impacts have potential to be severe but can be moderated or delayed significantly by combined global mitigation and a portfolio of available adaptation measures while some cannot be. Two key challenges for adaptation are apparent in the region: identifying when and where a departure from incremental to transformative adaptation measures is needed; and, where specific policies to facilitate proactive adaptation are needed to overcome barriers to mainstreamed and

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
				events [25.6.8.2] (9) Human Health: reshaping government policy, improving healthcare services, developing early warning systems, preparing health system/emergency system, improving maintenance programs for key services, seeking behavioral changes and community awareness to reduce exposure, developing emergency response plan {25.6.9.3] (10) Indigenous: *[Need specifics/update from SOD]*	and differing values on near- versus long-term and private versus public costs and benefits [Box 25-1]. Individual and collective social and cultural values. Other: *[Need specifics/update from SOD]*		autonomous adaptation [25.8.3]
North America [Chapter 26]	*None. [Need specifics/update from SOD]*	Adjusting water infrastructure and institutional mechanism, improving climate resilience and adaptation for ecosystem and biodiversity though changes approach to protected area planning, institutional shift for addressing wildfire	The region is very likely to face increasing warming and extreme high temperatures, higher sea levels, more intense precipitation and droughts, more intense storms, and reduced snowpack and higher sea levels. [26.1.1, 26.2.2, 26.4.1, 26.5]	Opportunities are highlighted in the following 12 sectors: (1) Water Resources and Management: drought management plans, reduced water consumption, system interconnections, improved coordination with other organizations, holistic management of storm water, flood waters, water supply, and wastewater management, incorporating climate change impacts into municipal bond ratings, diversification of supplies and source protection, land use management, better alignment of revenues with fixed and variable costs [23.6.1.2], increased efficiency in farm systems, cooperative crisis management among user, and adjustment water infrastructure [26.3.3], For flooding, updating elevation and land use datasets every 10 years, improved	*Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Decentralized response frameworks focusing reactive measures to cope with rather than preventing problems. Lack of decision-making on priority between extreme events vs. changes in long-term average conditions [Box 26.4]. Lack of coordination and institutional fragmentation of the different tiers of government. Lack of mainstreaming climate change issues into decision-making. Lack of willingness to address adaptation issues [Box 26.4]. Existing deficits in infrastructure. Lack of services (health, education) and institutional capacity [Box 26.4]. Cities with existing deficits in infrastructure (e.g., insufficient coverage, need of major upgrades and climate proofing), services (health, education), and institutional	None identified.	*[Need specifics/update from SOD]*

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
				hydrologic and hydraulic modeling, predicting extent of future floodplains as the climate changes and uncertainties decrease, eventually charging pre NFIP buildings full rates to decrease repetitive loss (2) Ecosystems and Biodiversity: changes in the approach to protected area planning, establishment and management, breeding programs for resistance to diseases and insect pests, alignment of adaptation and mitigation [26.4.3] (3) Wildfires: changes in institutional management, communications of risk [26.5.3] (4) Food Security: Change varieties, crop diversification, capital for on farm improvement in irrigation efficiency, climate tolerant crops, adapt to shifting fish distribution [26.6] (5) Rural Communities: investments into rural adaptive capacity (6) Indigenous Communities: traditional culture with contemporary forms of knowledge, education and economic development [26.7.1.2] (7) Tourism-based Communities: restoration [26.7.2.3] (8) Forest-based Communities: assisted migration, economic diversification, (9) Human Health: none. (10) Infrastructure: none. (11) Urban: create synergies and overcome conflicts with	capacity. Economic (Human and financial capital): High cost, energy and time required to construct, develop and maintain infrastructures and services. Insufficient financial and human resources to address the underlying processes of environmental deterioration [Box 26.4] Technological, Information and Science: Lack of a warning systems and emergency preparedness; lack of regional-to-local spatial scales climate scenarios [Box 26.4] Social/Psychological/Cultural: low social capital and limited economic resources [Box 26.4] Other: *[Need specifics/update from SOD]*		

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
				mitigation and other development goals, Infrastructural upgrades, early warning systems, developing shared-risk schemes for agriculture and livestock activities, and creating insurance schemes against disasters. They also include campaigns for raising public awareness, green infrastructure (12) Key Economic Sectors: introducing and expanding the role of insurance in developing markets [26.11.4.1]			
Central and South America [Chapter 27]	Reducing exposure and vulnerability and increasing resilience to the potential adverse impacts of climate extremes, even though risks cannot be fully eliminated [27.1.1.2]	*[Need specifics/update from SOD]*	The projected mean warming for CA and SA by the end of the century ranges from 2°C to 4°C for the SRES emissions scenario B2, and from 4°C to 8°C for scenario A2. Changes in rainfall and in extremes are more uncertain, especially in CA and tropical SA	Opportunities are highlighted in the following 8 sectors: (1) Freshwater Resources: increase in water supply through groundwater pumping and fog interception, increase infrastructure, reservoirs and irrigation infrastructure capacity, increase irrigation efficiency practices and change crop patterns [27.3.1.2] (2) Terrestrial and Inland Water Systems: Adoption of ecosystem-based adaptation practices [27.3.2.2], restoration (3) Coastal Systems and Low-Lying Areas: marine protected areas, coastal planning, retreat and resettlement [27.3.2.2] (4) Food Production Systems and Food Security: diversification and shifting of crop types, changes in fertilizer use, changes in growing season, genetic	Adaptation is heavily constrained by limited funding available from central governments and lack of institutional capacity to mainstream climate change into policy [27.3.1.2]. Other constraints include: *Specific constraints include:* Structural: Settlements highly vulnerable. Governance/Institutional: Lack of capacity-building and appropriate political, institutional and technological frameworks. Planning efforts focused at the national and regional level while most of the final adaptation implementation actions are local. Lack of structural reforms to provide good governance. Lack of decision-maker capacity-building, absence of a synergetic development-adaptation planning and funding. Economic (Human and	None identified.	Adaptive capacity of developing and emergent countries is low and coping with new situations may require new approaches such as a multilevel risk governance (Corfee-Morlot *et al*., 2011; Young and Lipton, 2006) associated with decentralization in decision making and responsibility [27.4].

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
				techniques, specific scientific knowledge and land-use planning, irrigation and use of rain water, shading, genetic modification of crops, (5) Human Settlements, Industry, and Infrastructure: mainstreaming flood management and warning systems, urban tree planting (7) Renewable Energy: bioenergy production, management of land use change, development of policies for financing and management of science and technology renewable energy [27.3.6.2] (8) Human Health: none.	financial capital): limited financial resources. Income rates are low. Conflict between resources needed for long-term planning to ameliorate present social deficit in the welfare of the population and adaptation planning Technological, Information and Science: Lack of basic information, observation and monitoring systems. Inefficiency in transmission of information to decision makers. Vulnerability and disaster risk reduction does not always lead to long-term adaptive capacity Social/Psychological/Cultural: Perception of risk. Lack of awareness of environmental changes and the implications for livelihoods Other: *[Need specifics/update from SOD]*		
Polar Region [Chapter 28]	Mainstreaming adaptation into existing policy processes and priorities.	*[Need specifics/update from SOD]*	*[To be completed post-FOD]*	Opportunities include changing resource bases, shifting land use and/or settlement areas, combining technologies with Indigenous knowledge, changing timing and location of hunting, gathering, herding, and fishing areas, and improving communication and education; providing hunter support programs; distribution of traditional foods between communities and the use of community freezers; for the permafrost, use of pile foundations, insulation of the surface, clearance of snow, adjustable foundations for	*Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Lack of national policies [28.4] Economic (Human and financial capital): *[Need specifics/update from SOD]* Technological, Information and Science: uncertainties of climate projections, lack of local downscaling combined with uncertainties in future economic, social and technological developments [28.4]. Lack of technical information and capacity. Lack of a systematic assessment of	Fauna unable or poorly able to cope with temperature increases of as little as 1-3°C [28.1]. Polar bears are likely not able to adapt in face of sea ice loss [28.2.2.1.2].	The most effective adaptation options will be those that recognize the nexus between adaptation and sustainable development. Adaptation to climate change occurs in the context of, and is inextricably linked to societal change; and climate is not the most important driver of vulnerability in polar communities nor is it rarely the sole or primary stimulus for taking adaptive action [28.4]

Region	*Framing*		*Rate of change*	*Opportunities*	*Constraint*	*Limits*	*Synthesis*
				smaller structures, and increased use of artificial cooling, selective forest regeneration, sustainable management of ecosystems	risks [28.4] Social/Psychological/Cultural: Other: *[Need specifics/update from SOD]*		
Small Islands [Chapter 29]	Mainstreaming and integrating climate change into development plans is seen as a goal.	Coastal adaptation and protecting coastal ecosystems and communities is of critical importance (29.7.2.1)	*[To be completed post-SOD]*	Building shoreline resilience, island building [29/6/2]	*Specific constraints include:* Structural: *[Need specifics/update from SOD]* Governance/Institutional: Lack of financial resources. Uncertain political and legal framework Economic (Human and financial capital): Lack human resource capacity. Technological, Information and Science: Lack of technology. Lack of climate change and socio-economic scenarios and data at the required scale. Social/Psychological/Cultural: Lack of cultural and social acceptability and Other: *[Need specifics/update from SOD]*	None identified.	Lessons learned from adaptation experiences in one island may offer some helpful guidance to other states, wholesale transfer may not always be advisable, as the 'lenses' through which adaptation options are viewed differ from one community to the next, based on ecological, socio-economic, cultural and political values [29.8].
Synthesis	*[To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*	*[To be completed post-SOD]*	[*To be completed post-SOD]*	[*To be completed post-SOD]*	[*To be completed post-SOD]*

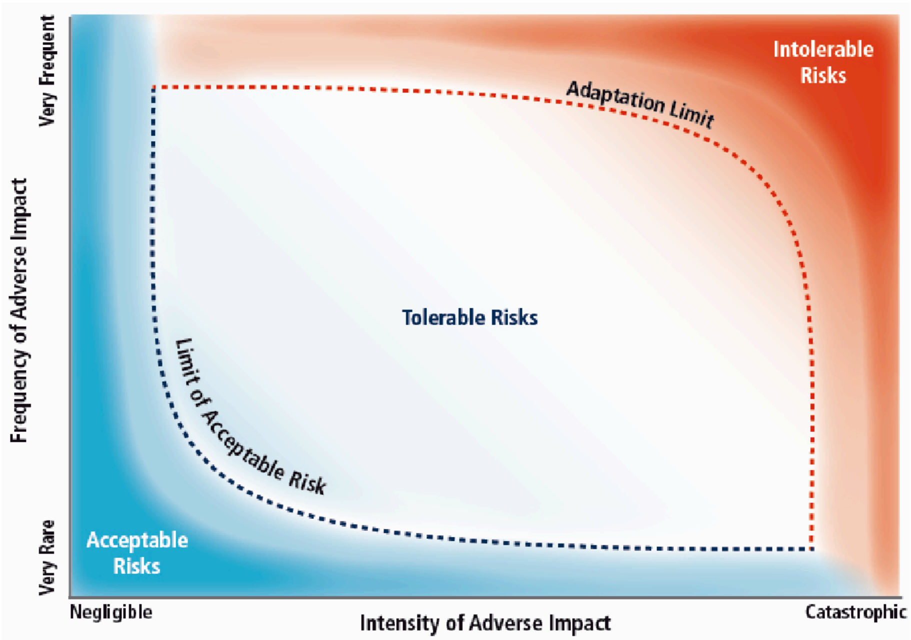

Figure 16-1: Conceptual model of the determinants of acceptable, tolerable and intolerable risks and their implications for limits to adaptation (Dow et al., 2013; after Klinke and Renn, 2002).

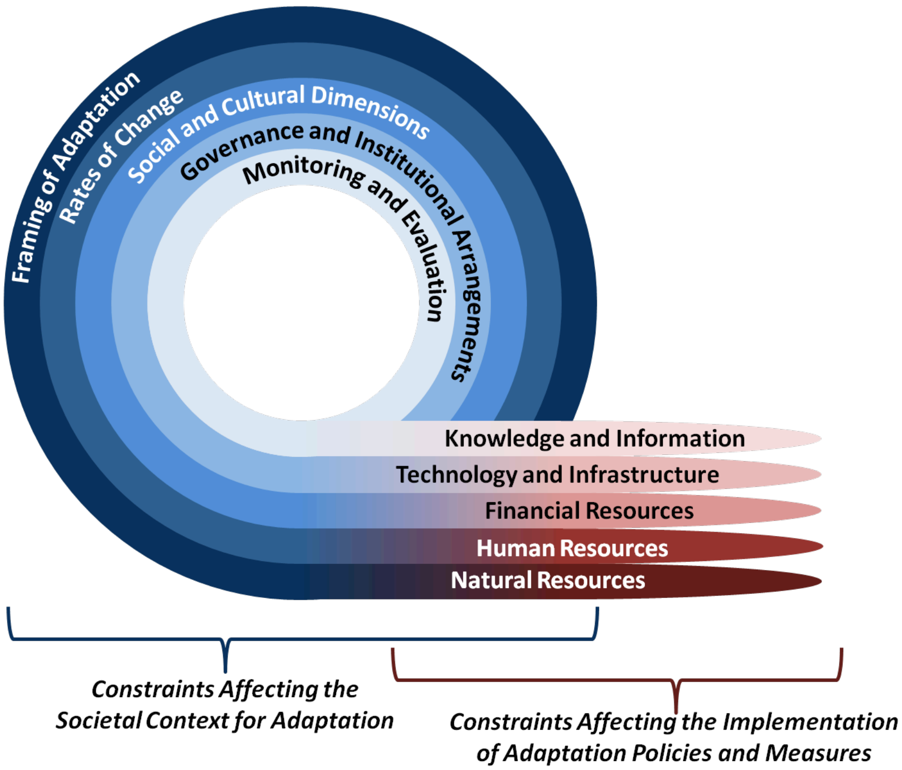

Figure 16-2: Identification of key adaptation constraints considered in this chapter, which are categorized into two groups. One reflects constantly evolving biophysical and socio-economic processes that influence the societal context for adaptation. These processes subsequently influence the implementation of specific adaptation policies and measures that could be deployed to achieve a particular objective.

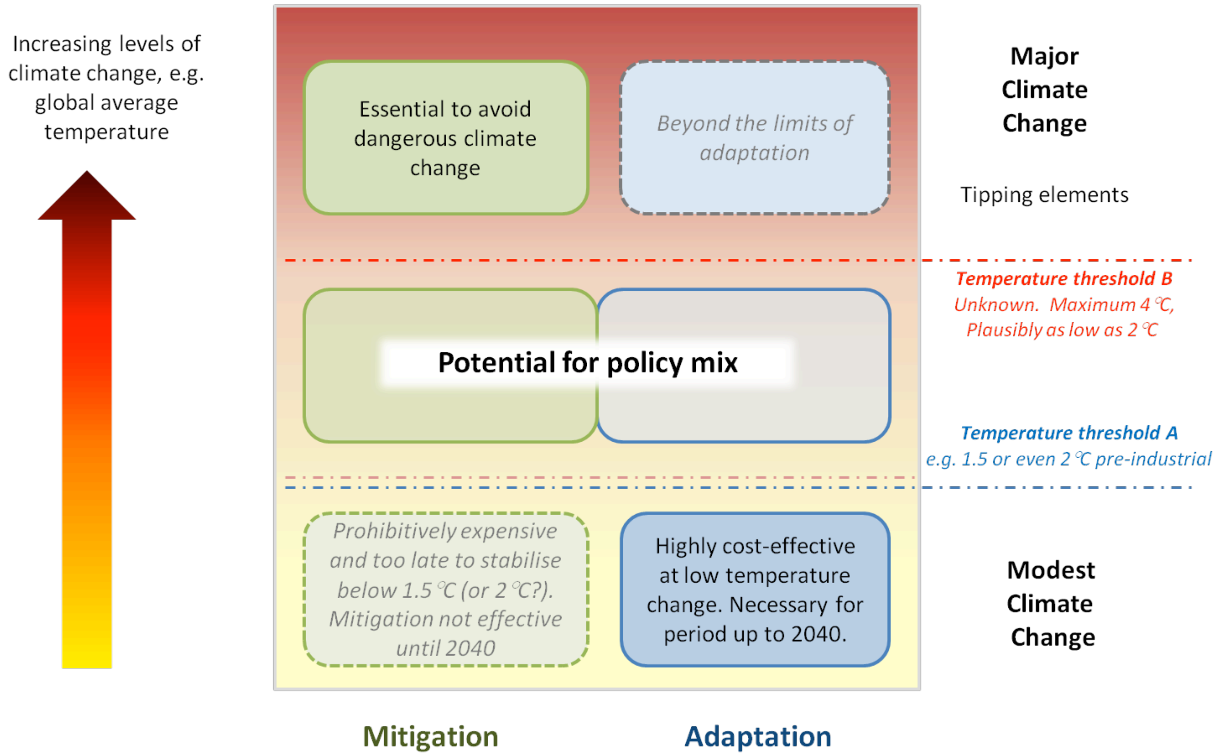

Figure 16-3: Adaptation policy space as a function of mitigation pathways (Watkiss et al., 2013).

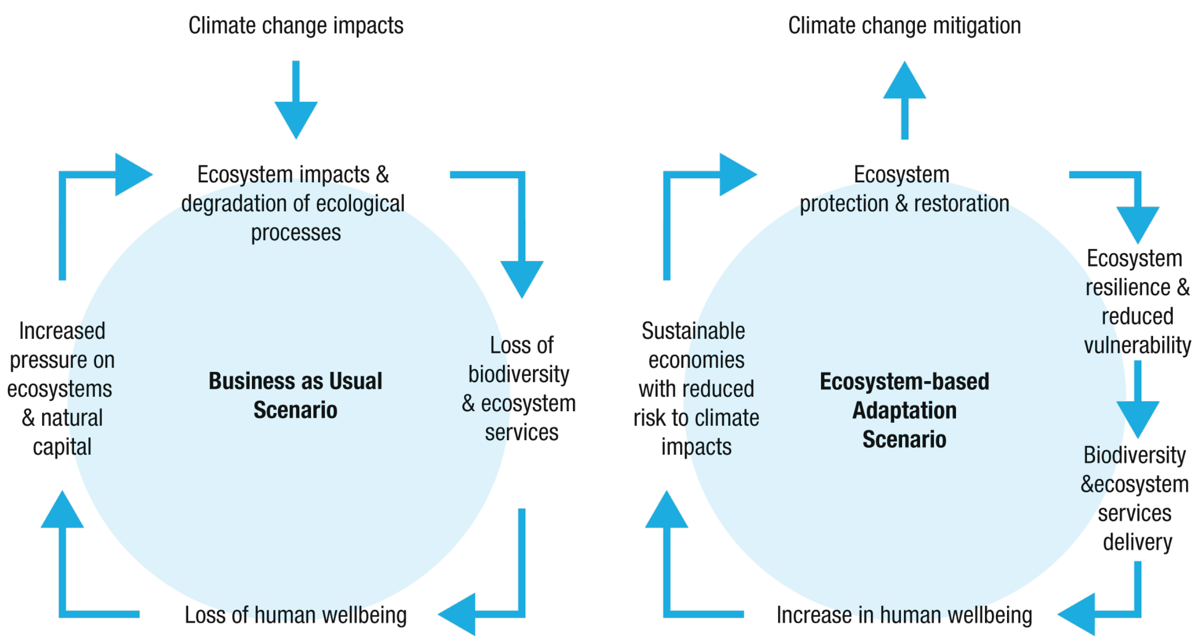

Figure EA-1: Adapted from Munang *et al*. (2013). Ecosystem based adaptation approaches to adaptation can utilize the capacity of nature to buffer human systems from the adverse impacts of climate change through sustainable delivery of ecosystems services. A) Business as Usual Scenario in which climate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