Mitig Adapt Strat Glob Change (2008) 13:643–659
DOI 10.1007/s11027-007-9132-3

ORIGINAL ARTICLE

Adaptation to climate change in the Northeast United States: opportunities, processes, constraints

Susanne C. Moser · Roger E. Kasperson · Gary Yohe · Julian Agyeman

Received: 12 December 2006 / Accepted: 1 May 2007 / Published online: 14 September 2007

Abstract Scientific evidence accumulating over the past decade documents that climate change impacts are already being experienced in the US Northeast. Policy-makers and resource managers must now prepare for the impacts from climate change and support implementing such plans on the ground. In this paper we argue that climate change challenges the region to maintain its economic viability, but also holds some opportunities that may enhance economic development, human well-being, and social justice. To face these challenges and seize these opportunities effectively we must better understand adaptation capacities, opportunities and constraints, the social processes of adaptation, approaches for engaging critical players and the broader public in informed debate, decision-making, and conscious interventions in the adaptation process. This paper offers a preliminary qualitative assessment, in which we emphasize the need for (1) assessing the feasibility and side effects of technological adaptation options, (2) increasing available resources and improving equitable access to them, (3) increasing institutional flexibility, fit, cooperation and decision-making authority, (4) using and enhancing human and social capital, (5) improving access to insurance and other risk-spreading mechanisms, and (6) linking scientific information more effectively to decision-makers while engaging the public. Throughout, we explore these issues through illustrative sectoral examples. We

S. C. Moser (✉)
National Center for Atmospheric Research, Institute for the Study of Society and Environment,
P.O. Box 3000, Boulder, CO 80307, USA
e-mail: smoser@ucar.edu

R. E. Kasperson
Graduate School of Geography and George Perkins Marsh Institute, Clark University,
Worcester, MA, USA
e-mail: rkasperson@clarku.edu

G. Yohe
Department of Economics, Wesleyan University, Middletown, CT, USA
e-mail: gyohe@wesleyan.edu

J. Agyeman
Department of Urban and Environmental Policy and Planning, Tufts University, Medford, MA, USA
e-mail: julian.agyeman@tufts.edu

conclude with a number of principles that may guide the preparation of future adaptation plans for the Northeast.

Keywords Climate change impacts · US Northeast · Adaptation · Adaptive capacity · Social learning · Opportunities · Constraints

1 Introduction

Scientific evidence accumulating over the past decade documents that climate change impacts are already being experienced in the US Northeast (Hayhoe et al. 2007a; see also the papers by Iverson et al.; Ollinger et al.; Rodenhouse et al.; Paradis et al.; and Wolfe et al. in this issue) and elsewhere (e.g., Karl and Knight 1998; Easterling et al. 2000a, b; McCarthy et al. 2001; Parmesan and Yohe 2003). These observations confirm what policy-makers and the public are increasingly recognizing: human-induced climate change is no longer a matter of the future, but a reality emerging with ever more clarity in the present day. By extension, the question of adaptation to these impacts is not just a policy task for the future and for other regions of the world, but a necessary complement to efforts designed to reduce greenhouse gas emissions now in this region and globally. The question then arises how Northeast policy-makers and resource managers can prepare for more impacts from climate change and support implementing such plans on the ground over time.

While place-specific research on adaptation capacity, processes, and constraints is still limited for developed countries such as the USA, or the Northeast in particular, the broader scholarship on adaptation (as synthesized in Smit et al. 2001; Smith et al. 2001; Mirza 2003; Easterling et al. 2004; Adger 2006; Folke 2006; Gallopín 2006; Smit and Wandel 2006) has identified several areas for future research. We focus on two of these areas in this paper: First, the need to go beyond itemizing generic options and constraints of adaptation and moving toward *a better understanding of the social determinants and processes of adaptation* (e.g., Burton 1992); and, second, the need to *better link existing scientific insights about adaptation to policy and practice*, i.e., to those who ultimately will make adaptation decisions "on the ground" (e.g., Vogel et al. 2007).

For public policy-makers the need to pay greater attention to adaptation emerges, first, out of the moral imperative of reducing people's and ecosystems' vulnerability to harm and increasing their resilience in the face of change, and, second, out of the economic imperative of reducing the vulnerability of infrastructure and economic sectors to climate variability and change. Climate change challenges the Northeast to maintain its economic viability, but also holds some opportunities that may enhance economic development, human well-being, and social justice. To face these challenges and seize these opportunities effectively requires a better understanding of adaptation capacities, opportunities and constraints, the social processes of adaptation, approaches for engaging critical players and the broader public in informed debate, decision-making, and conscious interventions in the adaptation process. Only then can governments and communities prepare and plan ahead, take advantage of possible benefits unfolding from climate change, and use limited resources wisely.

In this paper we describe commonly identified factors that contribute to a community's or region's adaptive capacity and examine the opportunities and challenges that arise for the region as it must cope with the impacts from climate variability and change. We briefly review some pertinent literature on adaptation and the social process of adaptation (Section 2) and then discuss adaptation strategies available to various sectors and communities in the Northeast (Section 3) in light of the underlying social processes. Rather than providing a sector-by-sector comprehensive assessment of adaptation options, we highlight the opportunities, historical experiences, and constraints of employing these strategies through illustrative examples. These examples are based on a preliminary qualitative assessment that draws heavily on the findings by the Northeast Climate Impacts Assessment (NECIA) impact assessment teams (see the papers collected in this special issue) and on interviews with members of these teams and other key informants. Where possible, we highlight the differences in the challenges associated with adaptation depending on the emissions trajectory chosen. In Section 4, we suggest several principles for prioritizing future adaptation actions, point to research needs, and identify opportunities for linking science more effectively with management and policy-making in order to increase the adaptive capacity of the Northeast.

2 Adaptation and vulnerability–a brief overview

Adaptation, according to common definitions (reviewed in Smit and Wandel 2006), can help reduce the vulnerability of natural and social systems to the growing risks from climate variability and change, prepare for and cope with the negative impacts, and take advantage of the possible benefits of a warmer climate in the Northeast; Table 1 offers a few brief definitions of the key concepts.

Adaptation to change is necessary only when a system is subject to and affected by a stressor or change driver, and it is possible only when there is at least some basic capacity to respond to it. As simple and obvious as these two statements may appear, their implications for those who try to weigh the likely net vulnerability of a system to a collection of external forces are profound. Smit et al. (2001) showed why by arguing that any system's vulnerability to any external stress is determined by its *exposure* to the manifestations of that stress (felt in the context of other stresses that can compound exposure), its baseline *sensitivity* to those manifestations, and its *ability to cope*. The ability

Table 1 Key concepts and their common definitions

Concept	Definition
Mitigation	The reduction of heat-trapping greenhouse gas emissions into the atmosphere
Adaptation	The range of adjustments of the environment or those taken by individuals, organizations, communities, or other entities to deal with the potential or experienced impacts of climate change
Vulnerability	The extent to which a natural or social system is susceptible to sustained damage from weather extremes, climate variability, and change (and other interactive stressors)
Adaptive capacity	The ability of a system to anticipate and adapt to the potential or experienced impacts of climate change. Sometimes equated with and other times distinguished from *coping capacity*
Coping capacity	The ability of a system to deal with the impacts of present-day weather extremes or climate variability
Resilience	The ability of a system to absorb and rebound from the impacts from weather extremes, climate variability, or change and to continue functioning

Source: Luers and Moser (2006)

to cope depends, in turn, on the degree to which a system can exploit or realize its potential adaptive capacity – a potential that is also supported by a complex list of underlying site-specific determinants that include the availability of economic resources, technology, information and skills, infrastructure, institutions, and equity that also vary widely across space and time (Smit et al. 2001, pp. 895–897; see further discussion below).

Adger and Vincent (2004) reviewed the complex interaction among these factors and concluded that "adaptive capacity" essentially describes the adaptation space within which decision-makers in any system (regardless of location or state of development) might find feasible options but it does not guarantee which adaptations are actually attempted or which, in the end, will be successful (however measured). Clearly, it is not the potential adaptive capacity but what actions are really taken that influence a system's vulnerability and ultimately experienced impacts. As a result, the current state of the art in adaptation and adaptive capacity research focuses on exploring how the determinants of adaptive capacity can be linked to available response (i.e., policy and management) levers and on explaining why certain responses to specific stressors work some times in some places, but not in all places or, perhaps, all the time.

The Northeast is blessed with large measures of potential adaptive capacity. Yet, as in other regions, this capacity has not always been fully exercised to protect its population from the adverse effects of climate variability and extreme weather events. Hurricane Katrina serves as an illustrative example of how and why that disaster was more a failure in *exercising* adaptive capacity than a case of completely missing adaptive capacity, much less a pure natural disaster (Kates et al. 2006). The severe flooding in the Northeast in 2006, various record-setting Nor'easters in the 1990s, and the infamous ice storm of 1998 illustrate the region's vulnerability to such extremes.

Against this backdrop of vulnerability and insufficient realization of available adaptive capacity in the past, adding climate change to the picture only worsens the prognosis. For example, even modest sea-level rise would put surface roads, rail lines, bridges, tunnels, marine and airport facilities and transit stations at risk across the major metropolitan areas of northeastern states (Kirshen et al., this volume), while the infrastructure itself is aging and thus less able to withstand storm and sea level related impacts. Summer-time heat waves such as those in 1995 in Chicago, 2003 in Europe, or 2006 in the USA are likely to become more frequent, more severe, and more persistent as the planet warms (Hayhoe et al. 2006) and may become more challenging to cope with because an aging population is more sensitive to heat extremes (Cox et al. 2007).

Any delay in preparing for such projected changes and/or continued investment in infrastructure and emergency response plans based on historical experience rather than potential future conditions can increase vulnerability by increasing exposure and sensitivity—giving the false impression that the response to projected weather and climate has been strengthen when, in actuality, it falls increasingly short of being able to protect human populations from the growing risks. As the comparison of impacts under a higher and lower emissions trajectory in this special issue shows, mitigation can reduce the likelihood of crossing critical impact thresholds, delay the onset of impacts, and generally reduce the potential severity, but it cannot be expected to entirely prevent such impacts, especially considering that climate change is one of many, and sometimes a source of multiple stresses.

How then can resource managers begin to build potential adaptive capacity and more fully exercise existing capacity? Yohe and Tol (2002) suggest to systematically organize management and planning efforts around an instructive list of underlying determinants of adaptive capacity (based on Smit et al. 2001). These proposed tasks help evaluate the locally specific adaptive capacity that must be enhanced and realized:

1. Examine the range of available *technological options* for adaptation that would be considered in response to a perceived climate-related stress;
2. Evaluate the availability of *resources* with particular attention paid to equitable distribution across the population;
3. Explore the structure and functionality of critical *institutions* to understand the allocation of decision-making authority, institutional flexibility, and the decision criteria that would be employed;
4. Assess the *human and social capital*, including the distribution of educational achievement, differential access to personal security and robust property rights;
5. Document the system's (and individuals') access to *risk-spreading processes* (both formal and informal);
6. Assess decision-makers' *ability to manage information*, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves; and
7. Calibrate the *public's perceived understanding of the stresses* and the population's readiness to engage in implementing necessary adaptation measures.

The current frontier in adaptation and adaptive capacity research explores how these determinants of adaptive capacity can be linked to available management and policy levers and tries to explain, through a focus on the underlying social processes, how and why certain societal responses to climatic stressors work. We cannot do this here exhaustively, but recognize the role of social learning and the spread of adaptation innovations through sectors and communities (based on the influential work on diffusion by Rogers 2003). Adaptation in this framework can be thought of as a sequential process by which changes occur through a network of actors, stimulated by the actions of innovation pioneers or early adopters, who pass on their experiences to others. Social learning thus becomes key to understanding adaptation as a social process (see, e.g., Kok et al. 2002; Pahl-Wostl 2002; Berkhout et al. 2004; Keen et al. 2005).

In what follows, we also highlight issues related to social equity, broadly defined to include not only the distribution of income, but also access to decision-making processes and mechanisms to buffer against risk events (e.g., insurance), in supporting the ability of communities and/or societies to create and sustain processes by which they can cope with existing and anticipated climate-related stresses. Moreover, we are interested in networks of resource managers and experts and in the intersection of such networks (e.g., interaction at the science-practice interface) as arenas wherein knowledge, expertise, and experience of adaptation can be shared and spread. Selected examples of adaptation possibilities in various sectors and areas of the Northeast allow us to use the seven determinants of adaptive capacity listed above to examine (1) the region's ability to deal with climate change and (2) how that ability may differ under the two emissions scenarios underlying the NECIA assessment.

3 Adaptation opportunities and challenges in the Northeast: basic strategies and sectoral examples

The combination of adaptation strategies most relevant and feasible in any one sector or community must be assessed on a case-by-case basis, but more widely applicable technological, financial, institutional, social and other considerations routinely play a role. Here we illustrate the importance of these considerations through specific sectoral examples, documenting both historic successes and constraints to adaptation in the Northeast. These examples also point to the challenges and research questions that need attention in the future to help the region to become better prepared for climate change. The examples are chosen for their iconic (not merely economic) value for the Northeast and because they illustrate important aspects of the adaptation challenges the region will face.

3.1 Assessing the feasibility of technological options for adaptation

Using technological means to reduce one's exposure or sensitivity to climate-related stresses or improve one's ability to adapt to change is a commonly proposed and potentially powerful option. Such options may range from building seawalls or other structural protection against a rising sea, developing new crop varieties that are better adapted to warmer, drier, and carbon dioxide-richer conditions, or installing a warning system for heat extremes.

The availability of such technological adjustments is closely tied to the financial resources needed to develop, deploy, and maintain them. For example, commercial timber harvesting in northern New England typically occurs during the cold winter months when soils are frozen, so that the heavy timber harvesting equipment used for cutting trees is less damaging to forest soils. While climate change may have some benefits for northern forests (see the papers by Iverson et al. and Ollinger et al., this volume), especially under the higher emissions scenario (A1fi), winter warming will result in forest soils being frozen for shorter periods of time, less deeply, or eventually not at all. One technological adaptation to overcome this problem in New England would involve adopting timber harvesting equipment currently employed in more southern regions where soils do not freeze during the winter months. However, switching to that equipment can be expensive and requires that timber managers carefully weigh when the climate signal is clear enough to make that investment relative to the timing of normal equipment turn-over to minimize the economic impact.

In other sectors, technological adaptations may encounter additional costs or other limitations. Snow-dependent winter recreation is a good example (Scott and Jones, this volume). Based on the climate projections underlying the NECIA (Hayhoe et al. 2007b), the Northeast is expected to face higher winter temperatures, more precipitation falling as rain than as snow, and fewer days (i.e., a shorter season) where the ground is covered by snow. Historical evidence of climate changes during winter already documents that southern parts of the region will be affected sooner and harder than more northern, higher elevation areas. As Scott and Jones (this volume) show, ski resorts have already heavily invested in snow-making equipment, especially the larger operations that are less constrained by finances for the acquisition of the equipment and the ongoing operational costs (e.g., rising energy costs). Clearly, this investment in snow-making was not only, and for some perhaps not even primarily, a response to less secure snow seasons, but rather an effort to stabilize and enhance income from winter tourism. The parallel move of companies to diversify into three- or four-season vacation resorts is also indicative of these larger economic drivers of change. In any event, snow-making on clearly defined slopes has enabled these companies to lengthen and secure the skiing season, even when winters were unusually warm. Scott (pers. comm., July 2006) expects the industry to rely ever more heavily on this technology for adaptation in the future, even in northern and high-elevation locations, until temperatures increase so much that snow-making is no longer possible.

The recreational snowmobiling industry faces a different future. While looking at the same winter climate projections, it is not feasible for this industry to invest in adaptive snow-making technology over geographically dispersed and extensive trails in back-country areas. In that industry, the technological feasibility limits may force much more fundamental changes, e.g., a switch to non-snow-dependent outdoor recreation.

Similarly, as the ecological impacts analysis on bird species by Rodenmeier et al. (this volume) suggests, neither technological innovation nor management interventions are practically feasible – especially in remote, higher-elevation habitats – to reduce the vulnerability or increase the resilience of these species to further climate change. Thus, even under the lower emissions scenario (B1), ecologically critical thresholds may be crossed in the near future, beyond which some bird species lose their suitable habitat and/or ideal reproductive conditions.

These few examples illustrate that all technological adaptation options involve costs and risks; in some instances, though, technological fixes may not feasible at all. In any case, it is critical to look beyond the ability of the technology itself to reduce vulnerability and increase resilience in the face of change so that we can understand the environmental and socio-cultural consequences of adopting the new technology. For example, does it strengthen or undermine the social fabric of communities or the social networks of actors in a particular industry? Who first learns about new technologies and can or cannot afford to invest in them and at what pace? What advantages, disadvantages and/or risks accrue to those who adopt the technology first in comparison to those who adopt it later on? Will the new technology create new ecological burdens or will it produce "win–win" improvements? In the next section we further illustrate some of these economic and social aspects.

3.2 Increasing available resources and improving equitable access

The adoption of new technology is often constrained by access to information about them and, as suggested above, by the financial resources required to underwrite their implementation. There is, though, more to the story. Adger et al. (2006, p. 1) make the point that "to date, relatively little attention has been paid to the social justice aspects of adaptation to climate change. This is somewhat surprising considering the intense research on equity issues in mitigation of climate change [...]." Dow et al. (2006) provide a typology of ethical considerations in selecting different adaptation strategies (Table 2).

Table 2 provides a useful framework for beginning to look at the characteristics of adaptation strategies and whether or not they contribute to social justice. Luers and Moser (2006, p. v) note in their report on adaptation options in California that "the ability to cope and adapt is differentiated across population, economic sectors, and regions within the state. [State agencies have] an opportunity to ensure and enhance 'environmental justice' while fostering [that state's] adaptive capacity to climate change and other interactive stressors." Two critical points arise from this. First, adaptation and coping abilities with regard to climate change are demographically, sectorally and spatially differentiated. Secondly, while state or regional interventions in adaptive capacity could lead to greater environmental justice, they could, as well, increase environmental injustice if those considerations are not explicitly included in the evaluation.

3.2.1 Demographic differences in resource access and vulnerability

Demographic differentiation in adaptation and coping abilities occurs frequently with regard to health effects of climate change, especially as a result of differences in wealth,

Table 2 Ethical considerations in selecting adaptation strategies

Considerations	Applications in adaptation strategy
Avoiding harm and reducing risk	*Timing of implementation* – Preference should be given to strategies that aim to avoid harm rather than to compensate after the fact
	Scope of risk addressed – Preference should be given to strategies that both reduce potential impacts and address the causes of climate change
	Burden transfer – Preference should be given to strategies that reduce risk rather than transfer it to other places, populations, or the future
	Liability – Preference should be given to policies that create liability for risks that cannot be eliminated or reduced
Reducing vulnerability	*Scope of social injustice addressed* – Preference should be given to strategies that avert harm *and* address social processes contributing to vulnerability
	Capacity building – Preference should be given to strategies that increase the capacity of the most vulnerable to manage risks on their own
Supporting human rights and well-being	*Human rights* – Preferred strategies contribute to securing fundamental human rights and promoting social progress and better standards of life
	Self determination – Preference should be given to strategies that respect the right to self determination through participatory processes that facilitate input into assessment of the relevance of vulnerability reduction adaptations as well as the range of options developed, offered, and supported

Source: Dow et al. 2006, Table 4.2, p. 95)

age, and race (Epstein 1994; Kalkstein 1998; Ebi et al. 2006; CBCF 2004; Sagar and Banuri 1999; Williams 1999; Kalkstein and Greene 1997; McGeehin and Mirabelli 2001). It also occurs due to differentiated access to health care resources (Collins et al. 2003; Collins et al. 2002; Doty and Ives 2002) and health insurance (Bulatao and Anderson 2004) across socioeconomic and racial groups. As the Congressional Black Caucus Foundation (CBCF 2004, p. 23) note, “the increasing reliance on [expensive forms of] adaptation (e.g., health care and air conditioning) is likely to create a larger disparity between mortality of the rich and poor.” A good illustration of these challenges is in adaptation to increasing heat stress in the Northeast.

Heat-related impacts on human health are likely to increase, especially under the higher emissions scenario. According to the climate projections developed for the NECIA (Hayhoe et al. 2006) many Northeast cities such as Boston, Hartford, and New York City are expected to see large increases in extreme heat days under the lower emissions scenario and in some cases double that increase under the higher emissions scenario. Increases in night-time temperature and longer-lasting heat waves will only add to this challenge (Kalkstein and Greene 1997). Geographically, there is also a differentiation: urban areas typically experience higher levels of heat-related deaths than non-urban areas due to the ‘heat island’ effect (McGeehin and Mirabelli 2001). The CBCF (2004, p. 22) notes, “African Americans are twice as likely as whites to live in the inner city. As of January 2004, over 43% of African Americans lived in the central sections of cities. In stark contrast, less that 20% of whites lived in the same areas [...].” These findings are illustrated in Cox et al.’s 2007 analysis of vulnerability to heat extremes in the Northeast urban corridor. They show that even within individual metropolitan areas, factors such as age, level of income, education, race, and other factors create different levels of exposure, sensitivity, and ability to cope with heat extremes.

To warn urban populations of heat-related dangers, Kalkstein and colleagues have developed heat-health warning systems for different metropolitan areas worldwide

(Sheridan and Kalkstein 2004). The City of Philadelphia, once known by some as the "heat death capital of the world" (EPA 2006, p. 27) was the first to adopt this new system in 1995. The system, along with a broad set of accompanying public health interventions, has proven to save lives in a cost-effective manner (Ebi et al. 2006). In its interventions, the City focuses specifically on the elderly, homeless, poor, and other socially isolated populations. For example, the heat-health warning system initiates a "buddy system" for outreach to these populations, electric utilities are disallowed from shutting off services for nonpayment, Health Department staff do home visits to the elderly and reach out to the homeless, cool-off spaces have longer opening hours, and so on. These efforts are now making Philadelphia the "heat-health warning capital of the world." Other Northeast cities have yet to design their intervention efforts after a city that pays great attention to the underlying differential vulnerability of its population.

3.2.2 Sectoral differences in resource access and vulnerability

Similar equity issues and resource constraints can be found across various economic sectors. For example, the agricultural sector illustrates differential adaptive capacity because access to financial resources can make all the difference between a farm going out of business and actually profiting from climate change.

With \$1.5 billion in annual sales in New York State alone, the dairy industry dominates the agricultural sector of the Northeast. As Wolfe et al. (this volume) describe in their assessment of the potential impacts of heat stress on milk production, increasing temperatures could greatly impact this industry, especially under the higher emissions scenario. Already, observers consider the industry "fragile" (D. Wolfe, pers. comm., July 2006) with little cash buffer for unforeseen challenges, in part because overall milk and dairy consumption in the U.S. has declined considerably in the second half of the twentieth century (Putnam and Allshouse 2003). A complex pricing and taxation structure and considerable government control of milk prices do not allow the industry to respond flexibly to market fluctuations.

Climate change adds uncertainty to this challenging situation: depending on the impacts of climate change on supplemental feed grains, silage, and the competition for feed corn from other consumers (e.g., for biofuels), production costs and farm income may increase or decrease. Yet, cows' sensitivity to heat stress is well known: above 72°F, milk production and reproductive success declines (Chase 2006). To maintain ideal conditions dairy farmers will have to adapt feeding and stabling practices and spend more money on energy to run cooling fans, on labor to hose off animals, or on air conditioning systems in their barns (see Wolfe et al., this volume for additional discussion of agricultural adaptation options).

Especially small family farms – common in New England – that are already on the margins of economic viability may not be able to afford these higher production costs. On the other hand, larger farmers who can afford the higher costs (e.g., move to air-conditioned operations) may well benefit from climate change. The reason is that dairy production in the even-warmer regions south of New England may face even greater challenges, resulting in a general northward shift of the dairy market with large, corporate dairy enterprises in the Northeast gaining market share.

3.3 Increasing institutional flexibility, fit, cooperation, and decision-making authority

The ability to respond to any signal from the environment – climate-related or otherwise – depends considerably on the regulatory context, organizational capacity, and decision-making authority that actors have. Institutions – commonly defined to include not just the physical organizations, but all regulations, rules, and norms that guide behavior (March and Olsen 1989) – can both facilitate and constrain an actor's flexibility and choices. Institutions also influence a decision-maker's access to information, the ways in which she can use information in decision-making, and even the criteria upon which decisions are to be made. Environmental protection legislation, non-discrimination policies, market regulations, and common expectations about socially acceptable behavior are all examples of such institutions. Well-functioning institutions are essential and beneficial, and by their very nature a mechanism to provide stability in an otherwise volatile environment. When that environment changes fundamentally or rapidly, as is projected under the NECIA climate change scenarios, institutions can also hinder flexible adaptation or simply no longer serve their intended function because the environment for which they were designed no longer exists. This is precisely why social learning is of critical interest, as learning can help adjust institutions to new conditions. Thus, they are critically important determinants of adaptive capacity (Jordan and O'Riordan 1995; O'Riordan et al. 1998). The marine and coastal sectors provide illustrative examples of how institutional arrangements can affect adaptive capacity in the Northeast.

In the latter part of the twentieth century, cod and several other commercially exploited benthic fish species in the western North Atlantic declined or were over-fished (Frank et al. 2005; Fogarty et al., this volume). In response, stringent government regulations (quotas on allowable fish harvest) were put in place to limit fishing of these species. Some species responded well and are no longer considered over-fished (NOAA-NMFS 2005), but others have not. Many fishermen experience these stringent regulations as "suffering without success" (L. Incze, pers. comm., July 2006).

Historically, New England fishermen have proven themselves quite adaptable to naturally waxing and waning fish stocks and price fluctuations: they have maintained a number of fishing licenses in order to be able to switch from fishing one species to another, if circumstances required it. This form of diversification has allowed them to maintain an income in the face of environmental and market uncertainty. Now, with governmental regulations restricting their ability to switch fisheries, the diversification adaptation option is no longer available.

For Maine fishermen, the lobster fishery has been one viable alternative. With lobster recruitment rates and market prices high at present, many fishermen that were displaced from ground fisheries have switched to lobster fishing – a switch that required investment in different fishing boats and gear. They are doing well there, at least for now. However, fishermen expect that lobster recruitment would not always be as favorable as at present, and experts do not fully understand the dynamics of recruitment success yet. The question of alternatives then looms large. Traditional values and independent-mindedness among fishermen, the limited extent of higher education and professional training, together with few economic alternatives in coastal (especially island) communities offer few realistic alternatives for Maine fishermen. Deeper institutional and structural adaptation options must then be considered, including moving to community-based co-management structures (e.g., Wroblewski 2006), adaptive management approaches, improved fishermen education, regional collaboratives and cooperatives, and maybe even governmental welfare programs for the hardest hit.

In the coastal sector, yet other institutional issues arise that affect that sector's ability to adapt to rising sea level and changing coastal storm regimes. The Northeast is vulnerable to the impacts from coastal storms almost year-round – especially from Nor'easters, but also from tropical storms and hurricanes. Extreme rainfall, coastal and inland flooding, high winds, coastal erosion, and in the cold season, heavy snowfall are all sources of risk. In the densely populated Northeast, such events can paralyze traffic and economic activity for days, and leave severe damage behind (Moser 1994; Clark et al. 1998). Infamous storms, such as the Hurricane of 1938, the Blizzard of 1978, and the string of 100-year storms in the 1990s, loom in people's memory, circumscribing the risks and the region's vulnerability to these extreme events.

Kirshen et al. (this volume) and Ashton et al. (2007) suggest that threats to coastal areas will increase with climate change, especially under the higher A1fi scenario, increasing the risks from coastal flooding and shoreline erosion. These processes will be locally modified by relative land movement, geology, bathymetry, and human influences on sediment movement and shoreline stabilization. The high concentration of people and development along the shorefront from Cape May to north of Cape Elizabeth, however, place considerable investment and populations at growing risk from coastal hazards.

Future options for managing these growing risks are heavily influenced by past development and land use patterns, significantly constrained by existing coastal laws and regulations, and potentially affected by the expectations these have set among developers, residents, resource users, and businesses regarding their ability to live and do business along the coast. As climate change impacts unfold further, coastal managers are faced with the difficult challenge of adapting these coastal regulations and management goals in a way that accounts for the dynamic environment and growing risks.

Maine leads the region – and the country – with its shorefront development regulations that take climate change-driven sea-level rise into account (Moser 2005a), but Massachusetts (J. Knisel, pers. comm., July 2006) and New York (Rosenzweig and Solecki 2001) are also currently assessing their risks and management options. The necessary institutional changes may involve changes in flood proofing or flood insurance requirements, rebuilding standards after storm damage, setbacks and retreat from the shoreline, changes in commitment to shoreline protection through beach nourishment or hard protection structures, changes in land use planning or dune and wetland protection, and so on. While awareness of the need for such management and regulatory changes is growing, institutional legacies and ingrained socioeconomic interests in the status quo are formidable obstacles. Moreover, responses that may benefit one specific segment of society (e.g., the insurance sector withdrawing coverage from the coastline) can create significant losses in welfare more broadly defined.

3.4 Using and enhancing human and social capital

There is a growing recognition in the adaptation and risk management literature that people's knowledge, experience, and expertise as well as their relationships, their exchange of resources and knowledge, levels of mutual trust, and inevitable conflicts of personal interests are critical to understanding adaptive capacity (Kasperson et al. 1999; Adger 2003; Daniel et al. 2003; Lehtonen 2004; Pelling and High 2005). Both empirically and theoretically, questions remain, however, as to how social capital actually functions to increase adaptive capacity, how important it is relative to other determinants of that capacity, and how social capital interacts with equity concerns. The "web of cooperation" described below in the example of fighting the hemlock woolly adelgid pest, however, is indicative of the importance of social capital for the adaptation process.

As Paradis et al. (this volume) describe, hemlock woolly adelgid is an invasive insect pest that can rapidly kill eastern and Carolina hemlock. They project that warming winter temperatures will help spread the pest northward and seriously affect New England forests. The impacts will be felt by both the timber and recreational fishing industries, and more quickly and extensively so under the higher than the lower emissions scenario. Pesticides that are injected into the trees – an expensive, labor-intensive adaptive measure that needs to be repeated annually and can produce negative side effects for the trees and the environment – can reduce this risk. Absent a biological control (e.g., a beetle specialized to feed on woolly adelgid), though, timber managers have chosen to prematurely harvest trees before they are affected by the pest and lose value. Clearly, this is a risky gamble as any cold winter could protect a tree stand for another year, whereas a warm one may allow the pest to spread and trees be lost (S. Ollinger, pers. comm., July 2006).

The health of hemlocks is also of great concern to recreational fishermen. As the pest kills the trees along coldwater streams and shade is no longer provided, the stream temperature warms beyond what is ideal for trout (Ross et al. 2003; Holmes et al. 2005). Not surprisingly, trout fishermen are willing to help pay for solutions.

The federal USDA Forest Service in collaboration with state forest agencies, university researchers, and these industry interests has created a "web of cooperation" (J. Elkinton, pers. comm., July 2006) for funding of monitoring, detection, physiological research, the identification, testing, and mass rearing of biological controls, and the search for resistant genotypes of hemlock species. Experts consider it a race against time that may only be won with stepped-up funding, lasting commitment, and good cooperation among all concerned.

3.5 Improving access to insurance and other risk-spreading mechanisms

In situations where the probability for any individual's experiencing a loss is very small but the potential losses are catastrophic, the idea of buffering against catastrophic risk by sharing it among a large pool of individuals (so-called "risk-spreading" mechanisms) is highly attractive. If a pool of individuals is exposed to roughly the same level of risk (low probability, but high consequence), risk sharing mechanisms help diffuse any one's cost of protecting against catastrophic loss. Insurance (and reinsurance) is the premier example of such a risk-spreading mechanism, but only if the premiums can be correctly calibrated to the risk.

Direct losses from climate and weather-related events will undoubtedly affect many lines of insurance in the Northeast and other regions, including property and casualty, business interruptions, health and life insurance, insurance for marine operations, or against crop losses. Insurance may be called upon to protect against potential losses and liabilities associated with a variety of new activities resulting from climate change, including technological risks, insurability of carbon credits, trespass and liability from CO_2 sequestration, and liability associated with other advanced technologies (Kunreuther and Michel-Kerjan 2006). Climate change, as well, imposes not only new risks, but also new business opportunities through both the expansion of existing insurance lines and the development of new lines of risk transfer mechanisms. In other words, the relationship between the insurance industry and climate change is a complex one. First, insurance is one important strategy in the portfolio of adaptation option to changing risks. Second, as risks increase, the insurance industry itself becomes increasingly exposed to claims, and thus may be vulnerable to the impacts from climate change, or decide to withdraw from high-hazard zones. Such movement is already being observed in a number of coastal areas in the Northeast (e.g., Mulvaney 2005). And finally, the industry may benefit from societal responses to climate change that require insurance protection. These issues are being explored increasingly by insurance experts and academics around the world (e.g., Kunreuther 2006a; Kunreuther and Michel-Kerjan 2006; Kunreuther 2006b), including experts in the insurance industry center of the Northeast – Hartford, CT – and in regional universities.

How will the Northeast confront the role of insurance as part of society's adaptive response to future climate change? As a center of the US insurance industry, the Northeast faces an opportunity, if not an imperative, to play a leading role in shaping the industry's role in climate change response, and doing so successfully will be critical to the regional economy given the industry's economic importance. Public education about the changing exposure to risk will have to be linked to strict enforcement of building codes and land-use regulations, possibly mandatory insurance coverage, and other hazard mitigation activities. Continued and enhanced access to insurance will play a critical role in achieving social justice goals as will long-term mitigation loans and subsidies to highly vulnerable people in high-hazard areas.

3.6 Linking scientific information to decision-making and engaging the public

In the Northeast, political leaders have shown considerable leadership in developing mitigation options (Moomaw, this volume). The New England Governors'/Eastern Canadian Premiers' conference has also recognized the need for adaptation in an adaptation-focused conference in 2004 to address questions about natural resource management under climate change (NEG/ECP Climate Change Steering Committee 2005). Generally speaking, however, not all climate-sensitive sectors in the Northeast have begun to think seriously about adaptation plans, and stakeholders and the general population have yet to be engaged fully on this complementary climate policy.

In the cases where resource management-relevant climate science has been brought before stakeholders, the initiative has often come from scientists committed to working with decision-makers. Such efforts are challenging, time-intensive, and frequently not rewarded by the normal academic incentive-structure (Vogel et al. 2007). Many of the scientists involved in the NECIA assessment belong to this group and have been active for several years on bringing climate change science to relevant stakeholders. In some instances, existing outreach venues and networks that link scientists with resource managers are being used – such as agricultural, marine, or forest extension services, annual conferences of resource managers or industry associations, industry newsletters, and so on. Some of these efforts have resulted in ongoing discussions, outreach efforts, or web-based information (see, e.g., http://www.climateandfarming.org/). Such efforts are not yet common in all sectors, however, creating inadequate or uneven adaptive capacity across the Northeast. Importantly, the region's significant "scientific capital" on global climate change and adaptation questions is all too often not yet applied to regional challenges – an immense storehouse of knowledge and research capacity that would be extremely useful to harness for increasing the Northeast's adaptive capacity more fully.

The wider public has been engaged even less on adaptation questions, e.g., on changes individuals can make in their homes, properties or behaviors, or on larger community adaptation policies that require public input and support. In 2005 and 2006, public awareness and concern about global climate change has increased among Americans, even if understanding does not run very deep (ABC News et al. 2006; Brewer 2006). Given the profound ways in which climate change impacts could affect the economic activities, landscape, recreational opportunities, lifestyles and human well-being of Northeast residents, engaging the public more deeply on the challenges and opportunities that lie ahead is part of increasing the region's adaptive capacity (Moser 2006).

4 Conclusion: principles for prioritizing adaptation needs in the US Northeast

Based on the review of basic adaptation strategies and the cursory treatment of a few selected sectoral examples, we suggest several principles for prioritizing future adaptation actions and point to research needs that can help increase the adaptive capacity of the Northeast. The principles to consider include:

1. Strong regional support for and participation in global mitigation will help reduce stresses on natural and social systems and thus give society and ecosystems a better chance at successfully adapting to rapid climate change. Mitigation must therefore remain a high priority even as plans are made to prepare for change and to develop necessary coping measures.
2. Improved monitoring of the climate, environment systems, the societal processes that determine adaptive capacity, and of the adaptation process itself, gives decision-makers an early warning of potential crises, clearer signals, more lead time, and invaluable information about possible interventions. Monitoring should thus be a high priority, but it should not be confined to physical indicators.
3. The robustness of all decisions with long-term implications should be tested against the full range of possible climate sensitivity.
4. The most vulnerable sectors and populations should receive high priority to realize and/or maintain social justice in the face of rapid change.
5. Social networks of trusted individuals and organizations are an asset for sector- and community-based adaptation, and thus should be strengthened and employed in the adaptation process whenever possible.
6. The Northeast's considerable "scientific capital" should be harnessed to improve understanding of adaptation opportunities and challenges and linked more effectively to the ongoing work of resource managers and planners.
7. Regular and effective communication with and engagement of the public on climate change can help build the region's adaptive capacity if it is properly supported by sound and timely information, on the one hand, and careful descriptions of persistent uncertainty, on the other.

The impacts analyses conducted for the NECIA (many of which are collected in this special issue) as well as this preliminary and incomplete assessment of the region's adaptive capacity suggest that the Northeast is potentially quite vulnerable to experiencing negative impacts from climate variability and change. At the same time, it is important to recognize that vulnerability and adaptive capacity are not uniform. Both vary across the region's economic sectors, ecological environments, and subsections of the population. In particular, the adaptation challenges that the region would face if the world followed a high-emissions scenario would be far greater and more expensive than on a lower emissions scenario. As the impacts analyses in this special issue illustrate, critical thresholds will be crossed in some instances – thresholds beyond which ecological and social changes may occur that would significantly alter the natural landscape and resource base for the regional economy and way of life of people in the Northeast.

The historical experience with adaptation to change – climatic or not – also highlight that industries, communities, and individuals in the Northeast have found ways in the past to deal with the vagaries of a changing environment and the notoriously variable, and often inclement, weather and climate of the Northeast. This proven adaptability gives considerable hope that the region has at least some relevant experience, know-how, and significant resources to draw on for the adaptations needed to future climate change. The rapid and systematic nature of expected changes, however, poses substantial, and to date insufficiently understood and addressed challenges that leave little room for complacency.

Acknowledgements The authors would like to thank members of the NECIA sector impacts assessment teams and other informants for their time and thoughtful input in identifying adaptation opportunities and obstacles in the US Northeast. Professor Howard Kunreuther provided substantial input to Section 3.5 of this report. We are also grateful for the review comments of two anonymous reviewers as well as the editors of this special issue, which have greatly improved our paper. The mistakes that may remain and the interpretations of the information we obtained, however, are ours alone.

References

ABC News et al (2006) ABC News/TIME Magazine/Stanford Poll: global warming. ABC News, Washington, DC

Adger WN (2003) Social capital, collective action and adaptation to climate change. Econ Geogr 79(4): 387–404

Adger WN (2006) Vulnerability. Glob Environ Change 16:268–281

Adger WN, Vincent K (2004) Uncertainty in adaptive capacity. In: Manning M et al (eds) IPCC workshop on describing uncertainties in climate change to support analysis of risk and options. Intergovernmental Panel on Climate Change, Geneva, pp 49–51

Adger WN et al (2006) Fairness in adaptation to climate change. The MIT Press, Cambridge, MA

Ashton A et al (2007) A discussion of the potential impacts of climate change on the shorelines of the Northeastern USA. Technical Paper prepared for the Northeast Climate Impacts Assessment. Union of Concerned Scientists, Cambridge, MA

Berkhout F, Hertin J, Gann DM (2004) Learning to adapt: organisational adaptation to climate change impacts. Tyndall Centre Working Paper 47

Brewer TL (2006) U.S. public opinion on climate change issues: update for 2005. Available at: http://faculty.msb.edu/brewert/documents/USPublicOpinionupdatefor2005.doc; accessed January 12, 2006

Bulatao R, Anderson N (eds) (2004) Understanding racial and ethnic differences in health in late life: a research agenda. National Academies Press, Washington, DC

Burton I (1992) Adapt and thrive. Canadian Climate Centre, Downsview, Ontario, unpublished manuscript

CBCF (Congressional Black Caucus Foundation) (2004) African Americans and climate change: an unequal burden. Redefining Progress, San Francisco, CA

Chase L (2006). Climate change impacts in dairy cattle. Available at http://www.climateandfarming.org/pdfs/FactSheets/III.3Cattle.pdf, accessed on 20 July 2006

Clark GE et al (1998) Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA, USA. Mitig Adapt Strategies Glob Chang 3:59–82

Collins K et al (2002) Quality of health care for African Americans: findings from the Commonwealth Fund 2001 Health Care Quality Survey. The Commonwealth Fund, New York, NY

Collins K et al (2003) On the edge: low wage workers and their health insurance coverage. The Commonwealth Fund, New York, NY

Cox JR et al (2007) Social vulnerability to climate change: a neighborhood analysis of the Northeast U.S. megaregion. Technical paper prepared for the Northeast Climate Impacts Assessment. Union of Concerned Scientists, Cambridge, MA

Daniel B et al (2003) Social capital in virtual learning and distributed communities of practice. Canadian Journal of Learning and Technology 29(3), available at: http://www.cjlt.ca/content/vol29.3/cjlt29-3_art7.html

Doty M, Ives B (2002) Quality of health care for Hispanic populations: findings from the Commonwealth Fund 2001 Health Care Quality Survey. The Commonwealth Fund, New York, NY

Dow K et al (2006) Exploring the social justice implications of adaptation and vulnerability. In: Adger WN et al (eds) Fairness in adaptation to climate change. The MIT Press, Cambridge, MA, pp 79–96

Easterling DR et al (2000a) Observed variability and trends in extreme climate events: a brief review. Bull Amer Meteor Soc 81(3):417–425

Easterling DR et al (2000b) Climate extremes: observations, modeling, and impacts. Science 289:2068–2074

Easterling W et al (2004) Coping with global climate change: the role of adaptation in the United States. Pew Center on Global Climate Change, Washington, DC

Ebi KL et al (2006) Some lessons learned from public health on the process of adaptation. Mitig Adapt Strategies Glob Chang 11(3):607–620

EPA (2006). Excessive heat events guidebook. EPA 430-B-06-005. Environmental Protection Agency. Office of Atmospheric Programs, Washington, DC

Epstein P (1994) Framework for an integrated assessment of health, climate change, and ecosystem vulnerability. Ann NY Acad Sci 740:423–435

Folke C (2006). Resilience: the emergence of a perspective for social–ecological systems analyses. Glob Environ Change 16:253–267

Frank KT et al (2005) Trophic cascade in a formerly cod-dominated ecosystem. Science 308:1621–1623

Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Change 16:293–303

Hayhoe K et al (2006) Climate change in the U.S. Northeast: a report of the Northeast Climate Impacts Assessment. Union of Concerned Scientists, Cambridge, MA

Hayhoe K et al (2007a) Past and future changes in climate and hydrological indicators in the U.S. Northeast. Clim Dyn 28(4):381–407

Hayhoe K et al (2007b). Quantifying the regional impacts of global climate change: evaluating AOGCM simulations of past and future trends in temperature, precipitation, and atmospheric circulation in the Northeast U.S. Bull Am Meteor Soc (in press).

Holmes TP et al (2005) The economic impacts of hemlock woolly adelgid on residential landscape values: Sparta, New Jersey case study. Proceedings of the Third Symposium on Hemlock Woolly Adelgid in the Eastern United States, Asheville, NC, February 1–3, 2005. In: Onken B, Reardon R (eds), FHTET 2005-01, pp 15–23

Jordan A, O'Riordan T (1995) Institutional adaptation to global environmental change (I): social institutions, policy change and social learning. CSERGE Working Paper GEC 95-20, Centre for Social and Economic Research on the Global Environment (CSERGE). University of East Anglia, Norwich, UK

Kalkstein L (1998) Climate and human mortality: relationships and mitigating measures. In: Auliciems A (ed) Advances in bioclimatology: human bioclimatology. Springer, New York, pp 161–177

Kalkstein L, Greene J (1997) An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. Environ Health Perspect 105:75–102

Karl TR, Knight RW (1998) Secular trends of precipitation amount and frequency in the United States. Bull Amer Meteor Soc 79:231–242

Kasperson RE et al (1999) Trust, risk, and democratic theory. In: Cvetkovich G, Lofsted R (eds) Social trust and the management of risk. Earthscan, London, pp 22–44

Kates RW et al (2006) Reconstruction of New Orleans following Hurricane Katrina. Proc Natl Acad Sci 103:14653–14660

Keen M et al (2005) Social learning in environmental management: towards a sustainable future. Earthscan, London, Sterling, VA

Kok M et al (2002) Global warming and social innovation: the challenge of a climate-neutral society. Earthscan, London, Sterling, VA

Kunreuther HC (2006a) Disaster mitigation and insurance: learning from Katrina. Ann Am Acad Polit Soc Sci 604:208–227, March

Kunreuther HC (2006b) Reflections on U.S. disaster insurance policy for the 21st century. In: Quigley JM, Rosenthal LA (eds) Risking house and home: disasters, cities, public policy. Berkeley Public Policy Press, Berkeley, CA; also available at: http://opim.wharton.upenn.edu/risk/library/06-19.pdf

Kunreuther HC, Michel-Kerjan EO (2006) Climate change, insurability of large-scale disasters and the emerging liability challenge. Paper presented at the University of Pennsylvania, Law Review conference on climate change, Philadelphia, 16–17 November 2006

Lehtonen M (2004) The environmental–social interface of sustainable development: capabilities, social capital, institutions. Ecol Econ 49(2):199–214

Luers, AL, Moser, SC (2006) Preparing for the impacts of climate change in California: opportunities and constraints for adaptation. Report prepared for the California Energy Commission (CEC) and California Environmental Protection Agency, CEC-5000-198-SF, CEC, Sacramento, CA

McCarthy JJ et al (eds) (2001) Climate change 2001: impacts, adaptation, and vulnerability. Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK

March JG, Olsen JP (1989) Rediscovering institutions: the organizational basis of politics. Free Press, New York, NY

McGeehin M, Mirabelli M (2001) The potential impacts of climate variability and change on temperature related morbidity and mortality in the United States. Environ Health Perspect 109(Supplement):85–189

Mirza MMQ (2003) Climate change and extreme weather events: can developing countries adapt? Climate Policy 3:233–248

Moser SC (1994) Wheels of misfortune: a 34-year record of winter storms and their impacts on Massachusetts, USA. Diplom thesis. University of Trier, Germany

Moser SC (2005) Impacts assessments and policy responses to sea-level rise in three U.S. states: an exploration of human dimension uncertainties. Glob Environ Change 15:353–369

Moser SC (2006) Communicating climate change-motivating civic action: opportunity for democratic renewal? In: VanDeveer S, Selin H (eds) Climate Change Politics in North America. Wilson Center Occasional Papers No.2, Wilson Center, Washington, DC, pp 109–118

Mulvaney K (2005) Waterfront properties losing insurance. The Providence Journal, February 6, 2005; available at: http://www.projo.com/news/content/projo_20050206_ins6.222b755.html

NEG/ECP Climate Change Steering Committee (2005) Climate change in New England and Eastern Canada: natural resource impacts and adaptation response. Symposium Proceedings, Boston, March 15–16, 2004; available at: http://www.neg-ecp-environment.org/newsletters/News_Adaptation_Symposium_Report.pdf

NOAA-NMFS (National Marine Fisheries Service) (2005) Report on the status of the U.S. fisheries for 2005. NMFS, Department of Commerce, Washington, DC; available at: http://www.nmfs.noaa.gov/docs/Report_text_FINAL3.pdf

O'Riordan T et al (1998) Institutional frameworks for political action. In: Rayner S, Malone EL (eds), Human choice and climate change, vol 1. Batelle Press, Columbus, OH, pp 345–440

Pahl-Wostl C (2002) Towards sustainability in the water sector: the importance of human actors and processes of social learning. Aquat Sci 64:394–411

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42

Pelling M, High C (2005) Understanding adaptation: what can social capital offer assessments of adaptive capacity? Glob Environ Change 15(4):308–319

Putnam J, Allshouse J (2003) Trends in U.S. per capita consumption of dairy products, 1909–2001. Amber Waves 1(3), available at: http://www.ers.usda.gov/Amberwaves/June03/DataFeature/; accessed 1 August 2006

Rogers EM (2003) Diffusion of innovations, 5th edn. (1962). Free Press, New York

Rosenzweig C, Solecki WD (2001) Climate change and a global city: the potential consequences of climate variability and change. Metro East Coast. Report for the U.S. Global Change Research Program's U.S. National Assessment. Columbia Earth Institute, New York, NY

Ross RM et al (2003) Influence of eastern hemlock (Tsuga canadensis L.) on fish community structure and function in headwater streams of the Delaware River basin. Ecology of Freshwater Fish 12:60–65

Sagar A, Banuri T (1999) In fairness to current generations: lost voices in the climate debate. Energy Policy 27:509–514

Sheridan SC, Kalkstein LS (2004) Progress in heat watch-warning system technology. Bull Am Meteor Soc 85(12):1931–1941

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Change 16:282–292

Smit B et al (2001) Adaptation to climate change in the context of sustainable development and equity. In: McCarthy, JJ et al (eds). Climate change 2001: impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK, pp 877–912

Smith JB et al (2001) Vulnerability to climate change and reasons for concern: a synthesis. In: McCarthy, JJ et al (eds). Climate change 2001: impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, Cambridge, UK, pp 913–967

Vogel C et al (2007) Linking vulnerability, adaptation, and resilience science to practice: pathways, players, and partnerships. Global Environmental Change (in press)

Williams R (1999) Environmental injustice in America and its politics of scale. Polit Geogr 18:49–73

Wroblewski J (2006) Local management of local stocks. The Navigator: the voice of the marine industry 9 (1):74–76

Yohe G, Tol R (2002) Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. Global Environmental Change 12:25–40