Synthesis and Assessment Product 4.6

Chapter 4: Effects of Global Change on Human Welfare

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4.1 Introduction

Human welfare is an elusive concept, and there is no single, commonly accepted definition or approach to thinking about welfare. Yet there is a shared understanding that human welfare, well-being, and quality of life (terms that are often used interchangeably) refer to aspects of individual and group life that improve living conditions and reduce chances of injury, stress, and loss. The physical environment is one factor, among many, that may improve or reduce human well-being. Climate is one aspect of the physical environment, and can affect human well-being via economic, physical, psychological, and social pathways that influence individual perceptions of quality of life.

Climate change may result in lifestyle changes and adaptive behavior with both positive and negative implications for well-being. For example, warmer temperatures may change the amount of time that individuals are comfortable spending outdoors in work, recreation, or other activities, and temperature combined with other climatic changes may alter (or induce) changes in intra- and inter-country human migration patterns. More generally, studies of climate change and the United States identify an assortment of impacts on human health, the productivity of human and natural systems, and human settlements. Many of these impacts—ranging from changes in livelihoods to changes in water quality and supply—are linked to some aspect of human well-being.

Communities are an integral determinant of human well-being. Climate change that affects public goods—such as damaged infrastructure or interruptions in public services—or disrupts the production of goods and services, will affect economic performance including overall health, poverty, employment, and other measures. These changes may have consequences, such as a lost job or a more difficult commute, that affect individual well-being directly. In other cases, individual well-being may be indirectly affected due to concern for the well-being of other individuals, or for a lack of cohesion within the community. The sustainability or resilience of a community (*i.e.,* its ability to cope with climate change and other stressors over the long term) may be reduced by climate change weakening the physical and social environment. In the extreme, such changes may undermine the individual's sense of security or faith in government's capacity to accommodate change.

Completely cataloging the effects of global change on human well-being or welfare would be an immense undertaking. Despite its importance, no well-accepted structure for doing so has been developed and applied. Moreover, little (if any) research focuses explicitly on the impact of global change on human well-being, *per se*. The chapter seeks to make a review of this topic manageable by focusing on several discrete issues:

- Alternative approaches to defining and studying human well-being
- Identifying human well-being and quality of life measures and indicators (qualitative and quantitative)
- Describing economic welfare and monetary methods of assigning value to climate change's potential impacts
- Providing examples of climate change impacts on selected categories of well-being and reporting indicators of economic welfare for these categories

Section 4.2, focuses on valuation and non-monetary metrics and draws on the literature to provide insights into a possible foundation for future research into the effects of climate change on human well-being. This section first discusses the literature defining human well-being. Next, it presents an illustrative place-based-indicators approach (the typical approach of planners and policy makers to evaluating quality of life in communities, cities, and countries). Approaches of this type represent a commonly accepted way of thinking about well-being that is linked to objective (and sometimes subjective) measures. While a place-based indicators approach has not been applied to climate change, it has the potential to provide a framework for identifying categories of human well-being that might be affected by climate change, and for making the identification of measures or metrics of well-being a more concrete enterprise in the future. To illustrate that potential, the section draws links between community welfare and some of the negative impacts of climate change.

Economics has been at the forefront of efforts to quantify the welfare impacts of climate change. Economists employ, however, a very specific definition of well-being—*economic* welfare—for valuing goods and services or, in this case, climate impacts. This approach is commonly used to support environmental policy decision making in many areas. Section 4.3 very briefly describes the basis of this approach, and the techniques that economists use (focusing on those that have been applied to estimate impacts of climate change). This section next summarizes the existing economic estimates of the *non-market* impacts of climate change.[1] An accompanying appendix provides more information on the economic approach to valuing changes in welfare, and highlights some of the challenges in applying valuation techniques to climate impacts.

The fourth section of the chapter summarizes some of the key points of the chapter and the chapter concludes with a brief discussion of research gaps.

4.2 Human Welfare, Well-being, and Quality of Life

No single, widely accepted definition exists for the term human welfare, or for related terms such as well-being and quality of life, and they are all often used interchangeably (Veenhoven, 1988, 1996, 2000; Ng, 2003; Rahman, 2007). Academic economists, epidemiologists, health scientists, psychologists, sociologists, geographers, political scientists, and urban planners have all rendered their own definitions and statistical indicators of life quality at both individual and community levels.[2] For purposes of clarity in this chapter, from this point forward we adopt the convention of the Millenium Assessment (MA, 2005) and the Intergovernmental Panel on Climate Change (IPCC, 2007b), which use "well-being" as an umbrella term—referring broadly to the extent to which human conditions satisfy the range of constituents of well-being, including health, social relations, material needs, security, and freedom of choice. "Quality of life" is here used

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[1] Because more concrete aspects of welfare, such as impacts on prices or income, may be covered by other synthesis and assessment products (see, for example, discussions of dollar values in SAP 4.3, *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity,* which is in draft form at the time this is being written), this report focuses exclusively on the types of intangible amenities that directly impact quality of life, but are not traded in markets, including health, recreation, ecosystems, and climate amenities.

[2] For example, In sociological literature, the terms well-being and welfare are used interchangeably to refer to objectively measurable life chances and experiences, and the term quality of life is used to describe subjective assessments and experiences of individuals.

synonymously with well-being, to reflect usage in a wide range of disciplines, including medical, sociological, psychological, and urban planning literatures. The term "welfare" is generally used herein to refer narrowly to economic measures of individual well-being, although it is also used in the context of communities in a broader sense.

Despite differences in definitions, human well-being—in its broadest sense—is typically a multi-dimensional concept, addressing the availability, distribution, and possession of economic assets, and non-economic goods such as life expectancy, morbidity and mortality, literacy and educational attainment, natural resources and ecosystem services, and participatory democracy. These conceptualizations often also include social and community resources (sometimes referred to as social capital in social scientific literature), such as the presence of voluntary associations, arts, entertainment, and shared recreational amenities (see Putnam, 1993, 2000). The quantity of community resources shared by a population is often called social capital.[3] These components of life quality are interrelated and correlate with subjective valuations of life satisfaction, happiness, pleasure, and the operation of successful democratic political systems (Putnam, 2000).

The concepts of well-being, economic welfare, and quality of life play important roles not only in academic research, but also in practical analysis and policy making. Quality of life measures may be used, for example, to gauge progress in meeting policy or normative goals in particular cities by planners; municipalities in New Zealand, England, Canada, and United States have constructed their own metrics of quality of life to estimate the overall well-being and life chances available to citizens. Similarly, health-related quality of life measures can indicate progress in meeting goals. For example, the U.S. Medicare program uses metrics to track quality of life for beneficiaries and to monitor and improve health care quality (HCFR, 2004). Moreover, international agencies from the United Nations Human Development Programme (UNDP) to the Milllenium Ecosystem Assessment on Ecosystems and Human Well-Being and highly regarded periodicals like *The Economist*, have built composite measures of human and societal well-being to compare and rank nations of the world.[4]

Life quality and human well-being are increasingly important objects of theoretical and empirical research in diverse disciplines. Two analytic approaches characterize the research literature: (1) studies that emphasize well-being as an individual attribute or possession; and (2) studies that treat well-being as a social or economic phenomenon associated with a geographic place.

4.2.1 Individual Measures of Well-being

Approaches focusing on individuals are generally found in medical, health, cognitive, and economic sciences, and it is to these we turn first, and then next to place-focused indicators.

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[3] The concept of social capital has been defined, in different ways, by Putnam (1993, 1995, 2000) and by Coleman (1988, 1990, 1993). For Coleman, social capital is a store of community value that is embodied in social structures and the relations between social actors, from which individuals can draw in the pursuit of private interest. Putnam's definition is similar, but places a stronger emphasis on altruism and community resources.

[4] See, for example, the discussion of the sources of Table 1 subsequently in this chapter, which include a number of country-level quality of life assessments. The UNDP Human Development Index, a country by country ranking of quality of life indicators, can be accessed at http://hdr.undp.org/en/statistics/.

4.2.1.1 Health Focused Approaches

In medical science, quality of life is used as an outcome variable to evaluate the effectiveness of medical, therapeutic, and/or policy interventions to promote population health. Quality of life is an individual's physiological state constituted by body structure, function, and capability that enable pursuit of stated and revealed preferences. In medical science, the concept of life quality is synonymous with good health – a life free of disease, illness, physical, and/or cognitive impairment (Raphael *et al.*, 1996, 1999, 2001).

In addition to objective measures of physical and occupational function, disease absence, or somatic sensation, life quality scientists measure an individual's perception of life satisfaction. The scientific basis of such research is that pain and/or discomfort associated with a physiological impairment are registered and experienced variably. Based on patient reports or subjective valuations, psychologists and occupational therapists have developed valid and reliable instruments to assess how mental, developmental, and physical disabilities interfere with the performance and enjoyment of life activities (Bowling, 1997; Guyatt *et al.*, 1993).

4.2.1.2 Economic and Psychological Approaches

Individual valuations of life quality also anchor economic and psychological investigations of happiness and utility. In the new science of happiness, scholars use the tools of neuroscience, experimental research, and modern statistics to discover and quantify the underlying psychological and physiological sources of happiness (for reviews see Kahneman *et al.*, 1999; Frey and Stutzer, 2002; Kahneman and Krueger, 2006). Empirical studies show, for example, that life satisfaction and happiness correlate predictably with marital status (married persons are generally happier than single people), religiosity (persons that practice religion report lower levels of stress and higher levels of life satisfaction), and individual willingness to donate time, money and effort to charitable causes. Similarly, the scholarly literature notes interesting statistical associations between features of climate (such as variations in sunlight, temperature, and extreme weather events) and self-reported levels of happiness, utility, or life satisfaction.

Individual valuations of health, psychological, and emotional well-being are sometimes summed across representative samples of a population or country to estimate correspondences between life satisfaction and "hard" indicators of living standards such as income, life expectancy, educational attainment, and environmental quality. Cross-national analyses generally find that population happiness or life satisfaction increases with income levels and material standards of living (Ng, 2003) and greater personal autonomy (Diener *et al.*, 1995; Diener and Diener, 1995).[5] In such studies, subjective valuations of life satisfaction are embedded in broader conceptions of quality of life associated with the conditions of a geographic place, community, region or country—the social indicators approach.

4.2.2 The Social Indicators Approach

In this second strand of research, what some refer to as the social indicators approach, scholars assemble location-specific measures of social, economic, and environmental conditions, such as

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[5] Some studies suggest that individual utility or happiness is not positively determined by some absolute quantity of income, wealth, or items consumed, but rather how an individual perceives his or her lot in relation to others or to conditions in their past. See, for example, Frank 1985.

employment rates, consumption flows, the availability of affordable housing, rates of crime victimization and public safety, public monies invested in education and transportation infrastructure, and local access to environmental, cultural, and recreational amenities. These place-specific variables are seen as exogenous sources of individual life quality. Scholars reason that life quality is a bundle of conditions, amenities, and lifestyle options that shape stated and revealed preferences. In technical terms, the social indicators approach treats quality of life as a latent variable, jointly determined by several causal variables that can be measured with reasonable accuracy.

The indicators approach has several advantages in the context of understanding the impacts of climate change on human well-being. First, social indicators have considerable intuitive appeal, and their widespread use has not only made it familiar to both researchers and the general public, but has subjected them to considerable debate and discussion. Second, they offer considerable breadth and flexibility in terms of categories of human well-being that can be included. Third, for many of the indicators or dimensions of well-being, objective metrics exist for measurement.

In addition, while its strength is in providing indicators of progress on individual dimensions of quality of life, the indicators approach has also been used to support aggregate or composite measures, at least for purposes of ranking or measuring progress. Various techniques are also available, or being developed, that aggregate or combine measures of well-being. These range from pure data reduction procedures to stakeholder input models where variables are evaluated on their level of social and economic importance. For example, Richard Florida (2002a) has constructed a statistical index of technology, talent, and social tolerance variables to estimate the human capital of cities in the United States. Given the analytical strengths of the social indicators approach, it may be a good starting point for understanding the relationships between human well-being and climate change.

4.2.2.1 A Taxonomy of Categories of Wellbeing

Taxonomies of place-specific well-being or quality of life typically converge on six categories or dimensions: (1) economic conditions; (2) natural resources, environment, and amenities; (3) human health; (4) public and private infrastructure; (5) government and public safety; and (6) social and cultural resources. These categories represent broad aspects of personal and family circumstances, social structures, government, environment, and the economy that influence well-being. Table 4.1 illustrates these categories, which are listed in Column 1. The third column, "components/indicators of welfare" provides examples of the way in which these categories are often interpreted. These components represent what, in an ideal world, researchers would wish to measure in order to determine how a specific society fares from the perspective of well-being. The fourth column provides illustrative metrics, *i.e.*, objective or quantifiable measures that are often used by researchers as indicators of well-being for each category.[6] Finally, the last column provides some examples of climate impacts that may be linked to that category. This column should not be viewed as an attempt to create a comprehensive list of impacts, or even to list

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[6] Sources that contributed to the development of Table 1 include: MA (2005); Sufian, 1993; Rahman, *2007, and* Lambiri, *et al.*, 2007. Insights were also derived from quality of life studies of individual cities and countries, including: http://www.bigcities.govt.nz/indicators.htm *Quality of Life in New Zealand's Large Urban Areas*; http://www.asu.edu/copp/morrison/public/qofl99.htm *What Matters in Greater Phoenix 1999 Edition: Indicators of Our Quality of Life*; and http://www.jcci.org/statistics/qualityoflife.aspx *Tracking the Quality of Life in Jacksonville.*

impacts with equal weights, in terms of importance or likelihood of occurrence. Further, while Table 4.1 focuses on negative impacts (as potentially more troubling for quality of life), there are also opportunities or potential positive impacts that will result in some categories.

These categories of well-being or life quality are interrelated. For example, as economic or social conditions in a society improve (*e.g.*, as measured by GDP per capita and rates of adult literacy), improvements occur in human health outcomes such as infant mortality, rates of morbidity, and female life expectancy at birth. Thus, while the categories and corresponding metrics of well-being presented in Table 4.1 are analytically separable, in reality they are highly interconnected.[7]

Economics as a source of quality of life refers to a mix of production, consumption, and exchange activities that constitute the material well-being of a geographic place, community, region or country. Standard components of economic well-being include income, wealth, poverty, employment opportunities, and costs of living. Localities characterized by efficient and equitable allocation of economic rewards and opportunities enable material security and subjective happiness of residents (Florida, 2002a).

Natural resources, environment, and amenities as a source of well-being refers to natural features, such as ecosystem services, species diversity, air and water quality, natural hazards and risks, parks and recreational amenities, and resource supplies and reserves. Natural resources and amenities directly and indirectly affect economic productivity, aesthetic and spiritual values, and human health (Blomquist *et al.*, 1988; Glaeser *et al.*, 2001; Cheshire and Magrini, 2006).

Human health as a source of well-being includes features of a community, locality, region or country that influence risks of mortality, morbidity, and the availability of health care services. Good health is desirable in itself as a driver of life expectancy (and the quality of life during those years), and is also critical to economic well-being by enabling labor force participation (Raphael *et al.*, 1996, 1999, 2001).

Public and private infrastructure sources of well-being include transportation, energy and communication technologies that enable commerce, mobility, and social connectivity. These technologies provide basic conditions for individual pursuits of well-being (Lambiri *et al.*, 2007).

Government and public safety as a source of well-being are activities by elected representatives and bureaucratic officials that secure and maximize the public services, rights, liberties, and safety of citizens. Individuals derive happiness and utility from the employment, educational, civil rights, public service, and security efforts of their governments (Suffian, 1993).

Finally, *social and cultural resources* as a source of well-being are conditions of life that promote social harmony, family and friendship, and the availability of arts, entertainment, and leisure activities that facilitate human happiness. The terms social and creative capital have

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[7] More recently, scholars (Costanza *et al.* 2007) and government agencies (like NOAA's Coastal Service Center) have moved toward the global concept of *capital* to integrate indicators and assess community quality of life. The term capital is divided into four types: economic; physical; ecological or natural; and socio-cultural. Various metrics constitute these types of capital, and are understood to foster community resilience and human needs of subsistence, reproduction, security, affection, understanding, participation, leisure, spirituality, creativity, identity, and freedom. See also Rothman, Amelung, and Poleme (2003).

become associated with these factors. Communities with greater levels of social and creative capital are expected to have greater individual and community quality of life (Putnam, 2000; Florida, 2002b).

In thinking about these indicators, it is important to keep two important contextual realities about climate change and well-being at the forefront. First, while discussions of climate change usually have a global resonance to them, the fact is that the effects of any specific changes in temperature, rainfall, storm frequency/intensity and sea level rise will be felt at the local and regional level by citizens and communities living and working in those vulnerable areas. Therefore, not all populations will be placed under equal amounts of climate change-generated stress. Some will experience greater impacts, will suffer greater damage, and will need more remediation and better plans and resource allocations for adaptation and recovery efforts to protect and restore quality of life (see, for example, Zahran *et al.*, 2008; Liu, Vedlitz and Alston, 2008; Vedlitz *et al.*, 2007).

Second, not all citizens in areas more vulnerable to climate change effects are equally at risk. Some population groupings, within the same community, will be more vulnerable and at risk than others. Those who are poorer, minorities, aged or infirmed, and children are at greater risk than others to the stresses of climate change events (Lindell and Perry, 2004; Peacock, 2003). Recognizing that not all citizens of a particular vulnerable area share the same level of risk is something that planners and decision makers must take into account in projecting the likely impacts of climate change events on their populations, and in dealing with recovery of those populations (Murphy and Gardoni, 2008).

Finally, the situation is further complicated as climate stressors negatively affect disease conditions in other nations with particularly vulnerable and mobile populations. Increased communicable disease incidence in developing nations have the potential, through legal and illegal tourism and immigration, to affect community welfare and individual well-being in the United States.

4.2.2.2 Climate Change and Quality of Life Indicators

Social indicators are generally used to evaluate progress towards a goal: How is society doing? Who is being affected? Tracking performance for these indicators——using the types of metrics or measures indicated in Table 4.1—could provide information to the public on how communities and other entities are reacting to, and successfully adapting to (or failing to adapt to), climate change. The indicators and metrics included in Table 4.1 are intended to be illustrative of the types of indicators that might be used, rather than a comprehensive or recommended set. In any category, multiple indicators could be used; and any one of the indicators could have several measures. For example, exposure to natural hazards and risks could be measured by the percentage of a locality's tax base located in a high hazard zone, the number of people exposed to a natural hazard, the funding devoted to hazard mitigation, or the costs of hazard insurance, among others. Similarly, some indicators are more amenable to objective measurement; others are more difficult to measure, such as measures of social cohesion. The point to be taken from Table 4.1 is that social indicators provide a diverse and potentially rich perspective on human well-being.

The taxonomy presented in Table 4.1—or a similar taxonomy—might also provide a basis for analyses of the impacts of climate change on human well-being, providing a list of important categories for research (the components or indicators of life quality), as well as appropriate metrics (*e.g.*, employment, mortality or morbidity, etc.). The social indicators approach, and the specific taxonomy presented here, are only one of many that could be developed.[8] At the least, different conditions and stakeholder mixes may demand different emphases. All taxonomies, however, face a common problem: how to interpret and use the diverse indicators, in order to compare and contrast alternative adaptive or mitigating responses to climate change. For some purposes, metrics have been developed that that aggregate across individuals or individual categories of well-being and present a composite measure of well-being; or otherwise operationalize related concepts, such as vulnerability (see, for example the discussion of Figure 4.1).

Figure 4.1 Geography of Climate Change Vulnerability at the County Scale

4.2.3 A Closer Look at Communities

Looking beyond well-being of individuals to the welfare (broadly speaking) of *communities*—networks of households, businesses, physical structures, and institutions—provides a broader perspective on the impacts of climate change. The categories and metrics in Table 4.1 are appealing from an analytical perspective in part because they represent dimensions of well-being that are clearly important to individuals, but that also have counterparts and can generally be measured objectively at the community level. Thus, for example, the counterparts of individual income or health status are, at the social level, per capita income or mortality/illness rates. The concept of community welfare is linked to human communities, but is not confined to communities in urban areas, or even in industrialized cultures. Human communities in remote areas, or subsistence economies, face the same range of quality of life issues—from health to spiritual values—although they may place different weights on different values; thus, the weights placed on different components of welfare are not determined *a priori*, but depend on community values and decision making.

Viewing social indicators and metrics through the lens of the community can be instructive in several ways. First, communities are dynamic entities, with multiple pathways of interactions among people, places, institutions, policies, structures, and enterprises. Thus, while the social indicators described in Table 4.1 have metrics that can be measured independently of each other, they are not determined independently within the complex reality of interdependent human systems. Second, in part because of this interdependence, the aggregate welfare of a community is more than a composite of its quality of life metrics; sustainability provides one means of approaching a concept of aggregate welfare. Third, vulnerability and adaptation are typically analyzed at the sectoral level: “what should agriculture, or the public health system, do to plan for or adapt to climate change.” The issue can also, however, be addressed at the level of the community. Each of these issues is touched on below.

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[8] In addition to variants on the social indicators approach, other types of taxonomies are possible—for example a taxonomy based on broad systems (atmospheric, aquatic, geologic, biological, and built environment), or on forms of capital that make up the productive base of society (natural, manufactured, human, and social). Well-being can also be viewed in terms of its endpoints: necessary material for a good life, health and bodily well-being, good social relations, security, freedom and choice, and peace of mind and spiritual existence (Rothman, Amelung, and Poleme., 2003).

4.2.3.1 Community Welfare and Individual Well-being

Rapid onset extreme weather events, such as hurricanes or tornadoes, can do serious damage to community infrastructure, public facilities and services, tax base, and overall community reputation and quality of life, from which recovery may take years and never be complete (see additional discussion in Chapter 3). More gradual changes in temperature and precipitation will have both negative and positive effects. For example, as discussed elsewhere in this chapter, warmer average temperatures increase risks from heat-related mortality in the summer, but decrease risks from cold-related mortality in the winter, for susceptible populations. Effects such as these will not, however, be confined to a few individual sectors, nor are the effects across all sectors independent.

To illustrate the interdependence of impacts and, by extension, the analogous social indicators and metrics, consider a natural resource that faces additional stresses from climate change: fish populations in estuaries, such as the Chesapeake Bay, that are already stressed by air and water pollution from industry, agriculture, and cities. In this case, while the direct effects of climate will occur to the resource itself, indirect effects can alter welfare as measured by economic, social, and human health indicators. Table 4.2 presents some of the possible pathways by which resource changes could affect diverse categories of quality of life; the purpose of Table 4.2 is not to assert that all these effects will occur or that they will be significant if they do occur as a result of climate change, but rather to illustrate the linkages. These linkages underscore the importance of understanding interdependencies within the community or, from another perspective, across welfare indicators. Table 4.2 illustrates the general principle of complex linkages in which a general equilibrium approach can be used to model climate change impacts.

4.2.3.2 Sustainability of Communities

Understanding how climate change and extreme events affect community welfare requires a different conceptual framework than that for understanding individual level impacts, such as quality of life.[9] Communities are more than the sum of their parts; they have unique aggregate identities shaped by dynamic social, economic, and environmental components. They also have life cycles, waxing and waning in response to societal and environmental changes (Diamond, 2005; Fagan, 2001; Ponting, 1991; Tainter, 1988). Sustainability is a paramount community goal, typically expressed in terms of sustainable development in order to express the ongoing process of adaptation into the long-term future. “Climate change involves complex interactions between climatic, environment, economic, political, institutional, social, and technological processes. It cannot be addressed or comprehended in isolation from broader societal goals (such as sustainable development)…” (Banuri and Weyant, 2001). Even for a country as developed as the US, continuing growth and development creates both pressures on the natural and built environments and opportunities for moving in sustainable directions.

While the term sustainability does not have a single, widely-accepted definition, a central guideline is to *balance* economic, environmental, and social needs and values (Campbell, 1996;

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[9] Measures of quality of life provide a database of relevant individual characteristics at various points in time, including economic conditions, natural resources and amenities, human health, public and private infrastructure, government and public safety, and social and cultural resources. Sustainable development measures are similar, but reflect more emphasis on long-term and reciprocal effects, as well as a concern for community-wide and equitable outcomes.

Berke *et al.*, 2006), sometimes portrayed as a three-legged stool. It is distinguished from quality of life by its *dynamic linking* of economic, environmental, and social components, and by its *future orientation* (Campbell, 1996; Porter, 2000). Sustainability is seen as living on nature's "interest," while protecting natural capital. Sustainability is a comprehensive social goal that transcends individual sector or impact measurements, although it can include narrower community welfare concepts such as the *healthy city*. Thinking about the impacts of climate change on communities through the lens of sustainable development allows us to envision cross-sector economic, environmental, and social dynamics.

4.2.4 Vulnerable Populations, Communities, and Adaptation

Responding to climate change at the community level requires understanding both vulnerability and adaptive responses that the community can take. Vulnerability of a community depends on its exposure to climate risk, how sensitive systems within that community are to climate variability and change, and the adaptive capacity of the community (*i.e.*, how it is able to respond and protect its citizens from climate change). Different groups within the community will be differentially vulnerable to climate changes, such as extreme events, and infrastructure and community coping capacity will be more or less effective in invoking a resilient response to climate change.

4.2.4.1 Vulnerable Populations

Categories of persons susceptible to environmental risks and hazards include racial and ethnic groups (Bolin, 1986; Fothergill *et al.*, 1999; Lindell and Perry, 2004; Cutter, 2006), and groups defined by economic variables of wealth, income, and poverty (Peacock, 2003; Dash *et al.*, 1997; Fothergill and Peek, 2004). Overall, research indicates that minorities and the poor are differentially harmed by disaster events. Economic disadvantage, lower human capital, limited access to social and political resources, and residential choices are social and economic reasons that contribute to observed differences in disaster vulnerability by race/ethnicity and economic status. While the literature on climate change and vulnerable populations is relatively underdeveloped, Chapter 2 on Human Health and Chapter 3 on Human Settlements each address population vulnerabilities.

Economic, social and health effects are not neatly bounded by geographic or political regions, and so the damage and stresses that occur in a specific locality are not limited in their effects to only that community. As Hurricane Katrina made clear, impacts felt in one community ripple throughout the region and nation. Persons made homeless in New Orleans resettled in Baton Rouge, Lafayette and Houston, creating stresses on those communities. Vulnerable groups migrate from stricken areas to more hospitable ones, taking their health, economic and educational needs and problems with them across both national and state lines

4.2.4.2 Vulnerable Communities

While most analyses of vulnerability tend to be conducted at the regional scale, Zahran *et al.* (2008) have brought the analysis closer to the community level by mapping the geography of climate change vulnerability at the county scale. The study uses measures of both *physical vulnerability* (expected temperature change, extreme weather events, and coastal proximity) and *adaptive capacity* (as represented by economic, demographic, and civic participation variables that constitute a locality's socioeconomic capacity to commit to costly climate change policy initiatives). Their map identifies the concentrations of highly vulnerable counties as lying along the east and west coasts and Great Lakes, with medium vulnerability counties mostly inland in the southeast, southwest, and northeast. (See Figure 4.1, in which darker areas represent higher vulnerability).

Many possible dimensions can be used to identify and measure vulnerabilities to climate change impacts and stressors. The one presented in Figure 4.1 illustrates that the concept of vulnerability is a viable one and can be measured and applied to communities in a GIS context. It is not the purpose of this chapter to focus in great detail on vulnerability measurement issues (for those interested in other formulations of the vulnerability concept, see Dietz *et al.*, In Press).

4.2.4.3 Adaptation

From the perspective of the community, the goal of successful adaptation to climate impacts—particularly potentially adverse impacts—is to maintain the long-term sustainability and survival of the community. Thus, a resilient community is capable of absorbing climate changes and the shocks of extreme events without breakdowns in its economy, natural resource base, or social systems (Godschalk, 2003). Given their control over shared resources, communities have the capacity to adapt to climate change in larger and more coordinated ways than individuals, by creating plans and strategies to increase resilience in the face of future shocks, while at the same time ensuring that the negative impacts of climate change do not fall disproportionately on their most vulnerable populations and demographic groups (Smit and Pilifosova, 2001).

Public policies and programs are in place in the United States to enhance the capacity of communities to mitigate[10] damage and loss from natural hazards and extreme events (Burby, 1998; Mileti, 1999; Godschalk, 2007). A considerable body of research looks at responses to natural hazards, and recent research has shown that the benefits of natural hazard mitigation at the national level outweigh its costs by a factor of four to one on average (Multihazard Mitigation Council, 2005; Rose *et al.*, 2007). Research also has been done on the social vulnerability of communities to natural hazards (Cutter *et al.*, 2003) and the economic resilience of businesses to natural hazards (Tierney, 1997; Rose, 2004). However, there is scant research on U.S. policies dealing with community adaptation to the broader impacts of climate change.

4.3 An Economic Approach to Human Welfare

Welfare, well-being, and quality of life are often viewed as multi-faceted concepts. In subjective assessments of happiness or quality of life (see the discussion in Section 4.2), the individual makes a net evaluation of his or her current state, taking into account (at least implicitly) and balancing all the relevant facets or dimensions of that state of being. Constructing an overall statement regarding welfare from a set of objective measures, however, requires a means of weighting or ranking, or otherwise aggregating, these measures. The economic approach supplies one—although not the only possible—approach to aggregation.[11]

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[10] In the natural hazards and disasters field, a single term—mitigation—refers both to adaptation to hazards and mitigation of their stresses. (See the Disaster Mitigation Act of 2000, Public Law 106-390.)

[11] In part because of the difficulty in compiling the information needed for aggregation of economic measures, Jacoby (2004) proposes a portfolio approach to benefits estimation, focusing on a limited set of indicators of global climate change, of regional impact, and one global monetary measure. The set of measures would not be the only

Quantitative measures of welfare that use a common metric have two potential advantages. First, the ability to compare welfare impacts across different welfare categories makes it possible to identify and rank categories with regard to the magnitude or importance of effects. Welfare impacts can then provide a signal about the relative importance of different impacts, and so help to set priorities with regard to adaptation or research. Second, if the concept of welfare is (ideally) a net measure, then it should be possible to aggregate the effects of climate across disparate indicators. Quantitative measures that use the same metric can, potentially, be summed to generate net measures of welfare, and gauge progress over time, or under different policy or adaptation scenarios.

Given the value of welfare both as a multi-dimensional concept, and as one that facilitates comparisons, the economic approach to welfare analysis—which monetizes or puts dollar values on impacts—is one means of comparing disparate impacts. Further—and this is the second advantage of the economic approach—dollar values of impacts can be aggregated, and so provide net measures of changes in impacts that can be useful to policy makers. This section of the chapter discusses the foundation of economic valuation, the distinction between market and non-market effects (only the latter are covered in this paper), and describes some of the valuation tools that economists use for non-market effects. An appendix covers these issues in additional detail, and also describes the challenges that economic valuation faces when used as a tool for policy analysis in the long term context of climate change.

Fundamental to the economic approach is a notion that a key element of support for decision-making is an understanding of the magnitude of costs and benefits, so that the tradeoffs implicit in any decision can be balanced and compared. However, the economic approach, when interpreted as requiring a strict cost-benefit test, is not appropriate in all circumstances, and is viewed by some as controversial in the context of climate change.[12] Benefit cost analysis is one tool available to decision makers; in the context of climate change; other decision rules and tools, or other definitions of welfare, may be equally, or more relevant. For example, the recent Synthesis Report of the IPCC Fourth Assessment (IPCC, 2007a) presents an average social cost (*i.e.*, damages) of carbon in 2005 of $12 per ton of CO_2, but also notes that the range of the roughly 100 peer-reviewed estimates of this value is -$3 to $95/t$CO_2$.[13] IPCC attributes this very broad range to differences in assumptions on climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses, and discount rates. IPCC therefore suggests consideration of an "iterative risk management process" to support decision-making.[14] Estimated benefits and costs therefore can provide information relevant to decision makers, but some of the methodologies and data

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information generated and made available, but it would represent a set of variables continuously maintained and used to describe policy choices.

[12] See Arrow *et al.*, 1996 - at page 7, "There may be factors other than economic benefits and costs that agencies will want to weigh in decisions, such as equity within and across generations. In addition, a decision maker may want to place greater weight on particular characteristics of a decision, such as potential irreversible consequences."

[13] See IPCC 2007a, page 23.

[14] IPCC further notes that existing analyses suggest costs and benefits of mitigation are roughly comparable in magnitude, "but do not as yet permit an unambiguous determination of an emissions pathway or stabilization level where benefits exceed costs." (IPCC 2007a page 23).

necessary to provide a relatively complete assessment may be unavailable, as discussed subsequently in this section.[15]

4.3.1 Economic Valuation

The framework that economists employ reflects a specific view of human welfare and how to measure it. Economists define the value of something—be it a good, service, or state of the world—by focusing on the well-being, utility, or level of satisfaction that the individual derives. The basic economic paradigm assumes that individuals allocate their available income and time to achieve the greatest level of satisfaction. The value of a good—in terms of the utility or satisfaction it provides—is revealed by the tradeoffs that individuals make between that good and other goods, or between that good and income.[16] The term "willingness to pay" (WTP) is used by economists to represent the value of something, *i.e.*, the individual's willingness to trade money for that particular good, service, or state of the world.

Economists distinguish between market and non-market goods. Market goods are those that can be bought and sold in the market, and for which a price generally exists. Market behavior and, in particular, the prices that are paid for these goods, is a source of information on the economic value or benefit of these goods. The economic benefit—the amount that members of society would in aggregate be willing to pay for these goods—is related to, but frequently greater than, market prices.

Non-market goods are those that are not bought and sold in markets. Consequently, climate change impacts that involve non-market effects—such as health effects, loss of endangered species, and other effects—are difficult to value in monetary terms. Economists have developed techniques for measuring non-market values, by inferring economic value from behavior (including other market behavior), or by asking individuals directly.

A number of studies have attempted to value the range of effects of climate change. For the US, some of the most comprehensive studies are the Report to Congress completed by U.S. EPA in 1989 (U.S. EPA, 1989), Cline (1992), Nordhaus (1994), Fankhauser (1995), Mendelsohn and Neumann (1999), Nordhaus and Boyer (2000), and a body of work by Richard Tol (*e.g.*, Tol, 2002 and Tol, 2005). In all of these studies, the focus is largely on market impacts, particularly the effects of climate change on agriculture, forestry, water resource availability, energy demand (mostly for air conditioning), coastal property, and in some cases, health.

Non-market effects, however, are less well characterized in these studies (Smith *et al.*, 2003); where comprehensive attempts are made, they usually involve either expert judgment or very rudimentary calculations, such as multiplying the numbers of coastal wetland acres at risk of inundation from sea-level rise by an estimate of the average non-market value of a wetland. One such comprehensive attempt generated a value for 17 ecosystem services from 16 ecosystem types (Costanza *et al.*, 1997), but also generated controversy and criticism from many

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[15] Other factors that might be considered, in addition to economic estimates, include emotions, perceptions, cultural values, and other subjective factors, all of which can play a role in creating preferences and reaching decisions. Those factors are beyond what we can evaluate in this chapter.

[16] Although economists are careful to distinguish between the metrics of utility and money as distinct, valuation metric in dollar units (rather than units of utility) may be generally viewed as the outcomes of individual preference expressions among goods, income, and time.

economists (Bockstael *et al.*, 2000; Toman, 1998; see National Research Council 2004 for a summary). Other analysts have attempted to define measures to reflect non-market ecosystem services in terms similar to those used for Gross Domestic Product (Boyd, 2006), or indicators of ecosystem health that reflect ecological contributions to human welfare (Boyd and Banzhaf, 2006).[17] While there are several well-done valuation analyses for non-market effects of climate change (as described later in this chapter), it is fair to characterize this literature as opportunistic in its focus; where data and methods exist, there are high quality studies, but the overall coverage of non-market effects remains inadequate.

4.3.2 Impacts Assessment and Monetary Valuation

The process of estimating the welfare effects of climate change involves four steps: (1) estimate climate changes; (2) estimate physical effects of climate change, (3) estimate the impacts on human and natural systems that are amenable to valuation and (4) value or monetize effects. The first step requires estimating the change in relevant measures of climate, including temperature, precipitation, sea-level rise, and the frequency and severity of extreme events. The second step involves estimating the physical effects of those changes in climate. Such effects might include changes in ecosystem structure and function, human exposures to heat stress, changes in the geographic range of disease vectors, or flooding of coastal areas. In the third step, the physical effects of climate change are translated into measures that economists can value, for example the number and location of properties that are vulnerable to floods, or the number of individuals exposed to and sensitive to heat stress. Many analyses that reach this step in the process, but not all, also proceed on to the fourth step, valuing the changes in dollar terms. .

The simplest approach to valuation would be to apply a unit valuation approach - for example, the cost of treating a nonfatal case of heat stress or malaria attributable to climate change is a first approximation of the value of avoiding that case altogether. In many contexts, however, unit values can misrepresent the true marginal economic impact of these changes. For example, if climate change reduces the length of the ski season, individuals could engage in another recreational activity, such as golf. Whether they might prefer skiing to golf at that time and location is something economists might try to measure.

This step-by-step linear approach to effects estimation is sometimes called the "damage function" approach. A damage function approach might imply that we look at effects of climate on human health as separate and independent from effects on ecology and recreation, an assumption that ignores the complex economic interrelationships among goods and services and individual decisions regarding these. Recent research suggests that the damage function approach, under some conditions, may be both overly simplistic (Freeman, 2003) and sometimes subject to serious errors (Strzepek and Smith, 1995; Strezpek *et al.*, 1999).

Economists have a number of techniques available for moving from quantified effects to dollar values. In some cases, the values estimated in one situation—*e.g.*, one ecosystem or species—can be transferred and used to value another. For example, value or benefits transfer is commonly used by federal agencies such as the US EPA and US Forest Service to value recreation when there is insufficient time or budget to conduct original valuation studies

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[17] Some political economists also emphasize the role of explicit recognition of non-market environmental values as an important step in improving the well-being of poor populations (Boyce and Shelley, 2003).

(Rosenberger and Loomis, 2003). Techniques commonly used by economists to value non-market goods and services include:

- *Revealed preference*. Revealed preference, sometimes referred to as the indirect valuation approach, involves inferring the value of a non-market good using data from market transactions (U.S. EPA, 2000; Freeman, 2003). For example, the value of a lake for its ability to provide a good fishing experience can be estimated by the time and money expended by the angler to fish at that particular site, relative to all other possible fishing sites. Or, the amenity value of a coastal property that is protected from storm damage (by a dune, perhaps) can be estimated by comparing the price of that property to other properties similar in every way but the enhanced storm protection.
- *Stated preference*. Stated preference methods, sometimes referred to as the direct valuation, are survey methods that estimate the value individuals place on particular non-market goods based on choices they make in hypothetical markets. The earliest stated preference studies involved simply asking individuals what they would be willing to pay for a particular non-market good. The best studies involve great care in constructing a credible, though still hypothetical, trade-off between money and the non-market good of interest (or bundle of goods) to discern individual preferences for that good and hence, WTP.
- *Replacement or avoided costs*. Replacement cost studies approach non-market values by estimating the cost to replace the services provided to individuals by the non-market good. For example, healthy coastal wetlands may provide a wide range of services to individuals who live near them (such as filtering pollutants present in water). A replacement cost approach would estimate the value of these services by estimating market costs for replacing the services provided by the wetlands. Analogously, the cost of health effects can be estimated using the cost of treating illness and of the lost workdays, etc. associated with illness.
- *Value of inputs*. This approach calculated value based on the contribution of an input into some productive process. This approach can be used to determine the value of both market and non-market inputs, for example, fertilizer, water, or soil, in farm output and profits

In the remainder of this section, we briefly discuss the relationship between climate change and four non-market effects (human health, ecosystems, recreation and tourism, and amenities), and discuss economic estimates of these effects using these techniques.

4.3.3 Human Health

In the US, climate change is likely to measurably affect health outcomes known to be associated with weather and climate, including heat-related illnesses and deaths , health effects due to storms, floods, and other extreme weather events, health effects related to poor air quality, water- and food-borne diseases, and insect-,tick-,and rodent-borne diseases. In addition to changes in mortality and morbidity, climate change may affect health in more subtle ways. Good health is more than the absence of illness; it includes mental health, the ability to function physically (to climb stairs or walk a mile), socially (to move freely in the world), and in a work environment. Please see Chapter 2 of this report, which provides an overview of health effects that have been associated with climate change.

Despite our understanding of the pathways linking climate and health effects, there is uncertainty as to the magnitude and geographic and temporal variation of possible impacts on morbidity and mortality in the US, primarily due to a poor understanding of many key risk factors and confounding issues, such as behavioral adaptation and variability in population vulnerability (Patz *et al.*, 2001). Even where our understanding of underlying climate and health relationships is better, few studies have attempted to explicitly link these findings to climate change scenarios to quantitatively estimate health impacts. Economists have relatively well established (although sometimes controversial) techniques for valuing mortality and some forms of morbidity, which could, in theory be applied to quantified impacts assessments.

4.3.3.1 Overview of Health Effects of Climate Change

The US is a developed country with a temperate climate. It has a well-developed health infrastructure and government and non-governmental agencies involved in disaster planning and response, both of which can help to mitigate potential health effects from climate change. Nevertheless, certain regions of the US will face difficult challenges arising from some of the following health effects.

- *Illnesses and deaths due to heatwaves*. A likely impact in the US is an increase in the severity, duration, and frequency of heatwaves (Kalkstein and Greene, 1997; IPCC, 2007c). This, coupled with an aging (and therefore more vulnerable) population, will increase the likelihood of higher mortality from exposure to excessive heat (see, for example, Semenza *et al.*, 1996, and Knowlton *et al.*, 2007).
- *Injuries and death from extreme weather events*. Climate change is projected to alter the frequency, timing, intensity, and duration of extreme weather events, such as hurricanes and floods (Fowler and Hennessey, 1995). The health effects of these extreme weather events range from the direct effects, such as loss of life and acute trauma, to indirect effects, such as loss of shelter, large-scale population displacement, damage to sanitation infrastructure (drinking water and sewage systems), interruption of food production, damage to the health care infrastructure, and psychological problems such as post traumatic stress disorder (Curriero *et al.*, 2001).
- *Illnesses and deaths due to poor air quality*. Climate change can affect air quality by modifying local weather patterns and pollutant concentrations (such as ground level ozone), by affecting natural sources of air pollution, and by changing the distribution of airborne allergens (Morris *et al.*, 1989; Sillman and Samson, 1995). Many of these effects are localized and, for ozone, compounded by assumptions of trends in precursor emissions. Despite these uncertainties, all else being equal, climate change is projected to contribute to or exacerbate ozone-related illnesses.
- *Water- and Foodborne Diseases*. Altered weather patterns, including changes in precipitation, temperature, humidity, and water salinity, are likely to affect the distribution and prevalence of food- and waterborne diseases resulting from bacteria, overloaded drinking water systems, and increases in the frequency and range of harmful algal blooms (Weniger *et al.*, 1983; MacKenzie *et al.*, 1994; Lipp and Rose, 1997; Curriero *et al.*, 2001).
- *Insect-, Tick-, and Rodent-borne Diseases*. Vector-borne diseases, such as plague, Lyme's disease, malaria, hanta virus, and dengue fever have distinct seasonal pattern,

suggesting that they may be sensitive to climate-driven changes in rainfall and temperature (Githeko and Woodward, 2003). Moderating factors, such as housing quality, land-use patterns, vector control programs, and a robust public health infrastructure, are likely to prevent the large-scale spread of these diseases in the United States.

4.3.3.2 Quantifying the Health Impacts of Climate Change

A large epidemiological literature exists on the health effects associated with climate change, particularly the mortality effects associated with increases in average monthly or seasonal temperature, and with changes in the intensity, frequency, and duration of heatwaves. As described in Chapter 2, there is considerable speculation concerning the balance of climate change-related decreases in winter mortality compared with increases in summer mortality, although researchers suspect that declines in winter mortality associated with climate change are unlikely to outweigh increases in summer mortality (McMichael *et al.*, 2001; Kalkstein and Greene, 1997; Davis, 2004).

Net changes in mortality are difficult to estimate because, in part, much depends on complexities in the relationship between mortality and the changes associated with global change. Using average temperatures to estimate cold-related mortality, for example, is complicated by the fact that many factors contribute to winter mortality (such as spread of the influenza virus). Similarly, increased summer mortality may be affected not only by average temperature, but also by other temperature factors, such as variability in temperature, or the duration of heat waves. Moreover, quantifying projected temperature-related mortality requires going beyond epidemiology and (for example) projecting adaptive behaviors, such as the use of air conditioning, expanded public programs (such as heat warning systems), or migratory patterns.

Few studies have attempted to link the epidemiological findings to climate scenarios for the United States, and studies that have done so have focused on the effects of changes in average temperature, with results dependent on climate scenarios and assumptions of future adaptation.[18] Moreover, many factors contribute to winter mortality, making highly uncertain how climate change could affect mortality. No projections have been published for the U.S. that incorporate critical factors, such as the influence of influenza outbreaks. Below, we report the results of these studies in order to give a sense of the magnitude of mortality that might be associated with temperature changes associated with climate change and, by intimation, the magnitude of potential changes in economic welfare. The conclusions should be considered preliminary, however, in part because of the complexities in estimating mortality under future climate scenarios. Moreover, none of the studies reported below traces through the quantitative implications of various climate scenarios for mortality in all regions of the United States using region-specific data, suggesting a clear need for future research.

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[18] McMichael et al. (2004) estimate the impact of climate change on DALYs (Disability-Adjusted Life Years) associated with waterborne and vector-borne illness for WHO regions. (DALYs represent the sum of life-years lost due to premature death and productive life years lost due to chronic illness or injury.) For the US, it is not anticipated that climate change will lead to loss of life or years of life due to chronic illness or injury from waterborne or foodborne illnesses. However, there will likely be an increase in the spread of several food- and water-borne pathogens among susceptible populations depending on the pathogens' survival, persistence, habitat range and transmission under changing climate and environmental conditions.

Quantifying the relationship between climate change and cases of injury, illness, or death requires an exposure-response function that quantifies the relationship between a health endpoint (*e.g.,* premature mortality due to cardiovascular disease (CVD), cases of diarrheal disease) and climate variables (*e.g.,* temperature and humidity). The exposure-response function can be used to compute the relative risk of illness or death due to a specified change in climate, *e.g.,* a temperature increase of 2.5°C. Applying this relative risk to the baseline incidence of the illness or death in a population yields an estimated number of cases associated with the climate scenario.

Two studies have attempted to link exposure-response functions to future climate scenarios and thereby develop temperature-related mortality estimates.[19] McMichael *et al.* (2004) estimate the effects of average temperature changes associated with projected climates resulting from alternative emissions scenarios, by WHO region. For the AMR-A region, which includes the United States, Canada, and Cuba, they estimate the impact on cardio-vascular mortality relative to baseline conditions in 1990. Effects are estimated for average temperature projections associated with three alternative emissions scenarios: (1) no control of GHG emissions,[20] (2) stabilization at 750 parts-per-million (ppm) of CO_2 equivalent by 2210, and (3) stabilization at 550 ppm CO_2 equivalent by 2170.[21]

McMichael *et al.* (2004) bases the estimates of the effects of average temperature changes on mortality from cardio-vascular disease (CVD) for AMR-A on Kunst *et al.* (1993). Kunst *et al.* (1993) find CVD mortality rates to be lowest at 16°C, and to increase by 0.5% for every degree C below 16°C and increase by 1.1% for each degree above 16°C. In applying these results to future climate scenarios, McMichael *et al.* (2004) assume that people will adjust to higher average temperatures; thus, the temperature at which mortality rates reach a minimum is adjusted by scenario. No adjustment is made for attempts to mitigate the effects of higher temperatures through (for example) increased use of air-conditioning. The effect of the climate scenarios for the North American region (AMR-A), reported for 2020 and 2030, is, on net, zero—reductions in CVD mortality due to warmer winter temperatures cancel out increases in CVD mortality due to warmer summer temperatures.

Hayhoe *et al.* (2004) examine the impacts on climate and health in California of projected climate change associated with two emissions scenarios. The emissions scenarios are similar to those used in McMichael *et al.* (2004): (1) stabilization at 970 ppm of CO_2 and (2) stabilization at 550 ppm of CO_2.[22] In Los Angeles, by the end of the century, the number of heatwave days (3 or more days with temperatures above 32 °C) increases fourfold under scenario B1 and six to eight times under scenario A1fi. From a baseline of 165 excess deaths in the 1990s, heat-related deaths in Los Angeles are projected to increase two to three times under scenario B1 and five to seven times under scenario A1fi by 2090.

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[19] These studies use climate scenarios that are associated with different emissions scenarios from IPCC (2000), the so-called SRES scenarios.

[20] McMichael *et al.* (2004) represent unmitigated emissions using the IS92a emissions scenario presented in IPCC (2000).

[21] Climate scenarios are projected for 2025 and 2050 using the HadCM2 model at a resolution of 3.75° longitude by 2.5° latitude and interpolated to other years.

[22] Hayhoe uses two SRES (IPCC 2000) emissions scenarios: A1fi (corresponding to 970 ppm of CO_2) and B1 (corresponding to 550 ppm of CO_2).

These results can be compared with those of an earlier study that employed a composite climate variable to examine the impact of extreme temperatures on daily mortality under future climate scenarios. Kalkstein and Greene (1997) analyzed the effect of temperature extremes (both hot and cold) on mortality for 44 US cities in the summer and winter. They then applied these results to climate projections from two GCMs for 2020 and 2050. In 2020, under a no-control scenario, excess summer deaths in the 44 cities were estimated to increase from 1,840 to 1,981-4,100, depending on the GCM used. The corresponding figures for 2050 were 3,190-4,748 excess deaths.

4.3.3.3 Valuation of Health Effects

In benefit-cost analyses of health and safety programs, mortality risks are commonly valued using the “value of a statistical life” (VSL)—the sum of what people would pay to reduce their risk of dying by small amounts that, together, add up to one statistical life. This approach allows valuation economists to focus on how people respond to and implicitly value mortality risk in their daily decisions, rather than attempting to value the lives lost, *per se* (U.S. EPA, 2000). This approach also responds to the type of data that is typically available; the excess deaths associated with a particular climate scenario are indeed the number of statistical lives that would be lost.

Willingness to pay for a current reduction in risk of death (*e.g.,* over the coming year) is usually estimated from compensating wage differentials in the labor market (a revealed preference method), or from contingent valuation surveys (a stated preference method) in which people are asked directly what they would pay for a reduction in their risk of dying. The basic idea behind compensating wage differentials is that jobs can be characterized by various attributes, including risk of accidental death. If workers are well-informed about risks of fatal and non-fatal injuries, and if labor markets are competitive, riskier jobs should pay more, holding worker and other job attributes constant (Viscusi, 1993). In theory, the impact of a small change in risk of death on the wage should equal the amount a worker would have to be compensated to accept this risk. For small risk changes, this is also what the worker should pay for a risk reduction.

For the compensating wage approach to yield reliable estimates of the VSL, it is necessary that workers be informed about fatal job risks and that there be sufficient competition in labor markets for compensating wage differentials to emerge.[23]. To measure these differentials empirically requires accurate estimates of the risk of death on the job—ideally, broken down by industry and occupation. The researcher must also be able to include enough other determinants of wages that fatal job risk does not pick up the effects of other worker or job characteristics. Empirical estimates of the value of a statistical life based on compensating wage studies conducted in the U. S. lie in the range of $0.6 million to $13.5 million (1990 dollars) (Viscusi, 1993; U.S. EPA, 1997), which is the rough equivalent of $0.7 million to $16.5 million in year 2000 dollars.[24]

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[23] Estimates of compensating wage differentials are often quite sensitive to the exact specification of the wage equation. Black *et al.* (2003), in a reanalysis of data from U.S. compensating wage studies requested by the USEPA, conclude that the results are too unstable to be used for policy.

[24] Adjusted using the GDP implicit price deflator produced by the Bureau of Economic Analysis US Department of Commerce, available at http://www.bea.gov/national/nipaweb/TableView.asp#Mid

This challenge is compounded by the long-term nature of climate risks, which suggests that much of the premature mortality associated with higher temperatures will occur in the future. Indeed, McMichael *et al.* (2004) and Kalkstein and Greene (1997) estimate mortality based on climate effects around the years 2020 and 2050; Hayhoe *et al.* (2004) analyze impacts in 2070-2099.

It is also the case that the majority of the health effects of climate change will be felt by persons 65 and over. Recent attempts to examine how the VSL varies with worker age (Viscusi and Aldy, 2007) suggest that the VSL ranges from $9.0 million (2000 dollars) for workers aged 35-44 to $3.7 million for workers aged 55-62. Contingent valuation studies (Alberini *et al.*, 2004) also suggest that the VSL may decline with age. Further, economic theory suggests that, under some assumptions, persons are willing to pay less to reduce a risk they will face in the future (say, at age 65) than they are willing to pay to reduce a risk they face today (Cropper and Sussman, 1990). Both these factors may affect the economic value that would be attached to excess mortality estimates, such as those derived by Kalkstein and Greene (1997).

The potential health effects associated with climate change are much broader than the changes in excess mortality discussed above. The effects of climate on illness have been examined in the literature, as indicated in the previous section; however, there have been few attempts to examine the implications of these studies for future climate scenarios. In addition to quantified estimates of mortality and morbidity, themselves indications of well-being and welfare, a range of economic techniques that have been developed for use in cost-benefit analyses of health and safety regulations could be applied to many of the endpoints that may be affected by climate change, as suggested by Table 4.3. Before these methods could be applied, however, the impacts of climate change must be translated into physical damages.

It is also the case that good health is more than the absence of illness. All of the dimensions of functioning measured in standard questionnaires (including various health outcomes surveys (HCFR, 2004) may be affected by changes in climate. From a valuation perspective, we would expect changes in functional limitations (stiffness of joints, difficulty walking) not to be linked directly to climate or to weather, but rather to be instrumental in people's location decisions and, thus, reflected in wages and property values. The relationship between climate and wages and property values are discussed in the subsequent section on Amenity values.

4.3.4 Ecosystems

Human welfare depends on the Earth's ecosystems and the services that they provide, where ecosystem services may be defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily, 1997). These services contribute to human well-being and welfare by contributing to basic material needs, physical and psychological health, security, and economic activity, and in other ways (see Table 4.4). For example, a variety of ecosystem changes may be linked to changes in human health, from changes that encourage the expansion of the range of vector-borne diseases (discussed in Chapter 2) to the frequency and impact of floods and fires on human populations, due to changes in protection afforded by ecosystems.

The ability of the biosphere to continue providing these vital goods and services is being strained by human activities, such as habitat destruction, releases of pollutants, over-harvesting of plants, fish and wildlife, and the introduction of invasive species into fragile systems. The recent Millennium Ecosystem Assessment reported that of 24 vital ecosystem services, 15 were being degraded by human activity (MA, 2005). Climate change is an additional human stressor that threatens to intensify and extend these adverse impacts to biodiversity, ecosystems, and the services they provide.

Changes in temperature, precipitation, and other effects of climate change will have *direct* effects on ecosystems. Climate change will also *indirectly* affect ecosystems, via, for example, effects of sea level rise on coastal ecosystems, decision-makers' responses to climate change (in terms of coastline protection or land use), or increased demands on water supplies in some locations for drinking water, electricity generation, and agricultural use. Understanding how these changes alter economic welfare requires identifying and potentially valuing changes in ecosystems resulting from climate change. Getting to the point of valuation, however, requires establishing a number of linkages—from projected changes in climate to ecosystem change, to changes in services, to changes in the value of those services—as illustrated in Figure 4.2. The scientific community has not, thus far, focused explicitly on establishing these linkages in the context of climate change. Consequently, the published literature is somewhat fragmented, consisting of discussions of climate effects on ecosystems and of valuation of ecosystems and their services (in only a few cases do the latter focus on climate change).

Figure 4.2 Steps from Climate Change to Economic Valuation of Ecosystem Services

Already observed effects (see reviews in Parmesan and Yohe, 2003; Root *et al.*, 2003; Parmesan and Galbraith, 2004) and modeling results indicate that climate change is very likely to have major adverse impacts on ecosystems (Peters and Lovejoy, 1992; Bachelet *et al.*, 2001; Lenihan *et al.*, 2006; Galbraith *et al.*, 2006). It is also likely that these changes will adversely affect the services that humans and human systems derive from ecosystems (MA, 2005). Climate change may affect ecosystems in the US within this century in the following ways.

Shifting, breakup and loss of ecological communities. As climate changes, species that are components of communities will be forced to shift their ranges to follow cooler temperatures either poleward or upward in elevation. In at least some cases, this is likely to result in the breakup of communities as organisms respond to temperature change and migrate at different rates. In general, study projections include: northern extensions of the ranges of southern broadleaf forest types, with northward contractions of the ranges of northern and boreal conifer forests; elimination of alpine tundra from much of its current range in the United States; and the replacement of forests by grasslands, shrub-dominated communities, and savannas, particularly in the south (*e.g.*, VEMAP, 1995; Melillo *et al.*, 2001; Lenihan *et al.*, 2006). Because of different intrinsic rates of migration, communities may not move intact into new areas (Box 4.1).

Another potential community effect of climate change is the facilitation of community penetration and degradation by invasive weeds that will replace more sensitive native species (Malcolm and Pitelka, 2000)

Extinctions of plants and animals and reduced biodiversity. While some species may be able to adapt to changing climate conditions, others will be adversely affected. It is very likely that one result of this will be to accelerate current extinction rates, resulting in loss in biodiversity. The most vulnerable species within the United States may be those that are currently confined to small, fragmented habitats that may be sensitive to climate change. This is the case with Edith's checkerspot, a western butterfly species that is already undergoing local subpopulation extinctions due to climate change (Parmesan, 1996). Other potentially vulnerable organisms include those that are restricted to alpine tundra habitats (Wang *et al.*, 2002), or to coastal habitats which may be inundated by sea level rise (Galbraith *et al.*, 2002).

Range shifts. Faced with increasing temperatures, populations of plants and animals will attempt to track their preferred climatic conditions by shifting their ranges. Range shifts will be limited by factors such as geology (in the case of plants that are confined to certain soil types), or the presence of cities, agricultural land, or other human activities that block northward migration. Some individual species in North America and the US are already undergoing range shifts (Root *et al.*, 2003; Parmesan and Galbraith, 2004). The red fox in the Canadian arctic shifted its range northward by up to 600 miles during the 20th century, with the greatest expansion occurring where temperature increases have been the largest (Hersteinsson and Macdonald, 1992). More generally, a number of bird species have shifted their ranges northward in the United States over the past few decades. While some of these changes may be attributable to non-climatic factors, it is very likely that some are due to climate change (Root *et al.*, 2003; Parmesan and Galbraith, 2004).

Timing changes. The timing of major ecological events is often triggered or modulated by seasonal temperature change. Changes in timing may already be occurring in the breeding seasons of birds, hibernation seasons of amphibians, and emergences of butterflies in North America and Europe (Bebee, 1995; Crick *et al.*, 1997; Brown *et al.*, 1999; Dunn and Winkler, 1999; Root *et al.*, 2003; Roy and Sparks, 2000). Disconnects in timing of interdependent ecological events may be accompanied by adverse effects on sensitive organisms in the United States. Such effects have already been observed in Europe where forest-breeding birds have been unable to advance their breeding seasons sufficiently to keep up with the earlier emergence of the arboreal caterpillars with which they feed their young. This has resulted in declining productivity and population reductions in at least one species (Both *et al.*, 2006).

Changes in ecosystem processes. Ecosystem processes, such as nutrient cycling, decomposition, carbon flow, etc., are fundamentally influenced by climate. Climate change is likely to disrupt at least some of these processes. While these effects are difficult to quantify, some types of changes can—and have been observed. Increasing temperatures over the past few decades on the North Slope of Alaska have resulted in a summer breakdown of the permanently frozen soil of the Alaskan Tundra and increased activity by soil bacteria that decompose plant material. This has accelerated the rate at which CO_2 (a breakdown product of the decomposition of the vegetation and also a greenhouse gas) is released to the atmosphere—changing the Tundra from a net sink (absorber) to a net emitter of CO_2 (Oechel *et al.*, 1993; Oechel *et al.*, 2000).

Indirect effects of climate change. Climate change may also result in "indirect" ecological effects as it triggers events (the frequency and intensity of fires, for example) that, in turn, adversely affect ecosystems. In U.S. forest habitats, increased temperatures are very likely to result in increased frequency and intensity of wildfires, especially in the arid west, leading to the breakup of contiguous forests into smaller patches, separated by shrub and grass dominated communities that are more resistant to the effects of fire (Lenihan *et al.*, 2006). Other major indirect effects are likely to include the loss of coastal habitat through sea level rise (Warren and Niering, 1993; Ross *et al.*, 1994; Galbraith *et al.*, 2002), and the loss of coldwater fish communities (and the recreational fishing that they support) as water temperatures increase (Meyer *et al.*, 1999).

The linkages between these types of changes and the provision of ecosystem services are difficult to define. While ecologists have developed a number of metrics of ecosystem condition and functioning (*e.g.*, species diversity, presence/absence of indicator species, primary productivity, nutrient cycling rates), these do not generally bear an obvious relation to metrics of services. In some cases, such as species diversity and bird population sizes, direct links might be drawn to services (in this case, opportunities for bird watching). However, in many, if not most cases, the linkages between stressor effects, change in ecosystem metrics, and service flows, are more obscure. For example, it is known that freshwater wetlands can remove contaminants from surface water (Daily, 1997) and this is an important service. However, the specific ways in which wetlands do this—in terms of the ecological processes and linkages within the system—are not well understood, probably vary between different types of wetland (*e.g.*, beaver swamps vs. cattail stands), and may vary spatially and temporally.

4.3.4.1 Economic Valuation of Effects on Ecosystems

Ecosystems are generally considered non-market goods: although land itself can be bought and sold, there is no market for ecosystem services per se, and so land value is only a partial measure of the value of the full range of ecosystem services provided. From the perspective of human welfare and climate change, however, we are concerned less with the ecosystems or the land on which they are located, than with the diverse services they provide, as illustrated in Table 4.4.

Economic valuation of changes in ecosystem services will be easier in cases where there are relationships between market goods and the ecosystem services being valued. For example, ecosystem changes may result in changes in the availability of goods and services that are traded on markets, as in the case of provisioning services, such as food, fisheries, pharmaceuticals etc. In other cases, market counterparts to the services may exist, as in the case of regulating services; for example, insights into the value of water purification services can come from looking at the (avoided) cost of a water purification plant to substitute for the ecosystem service. Services, such as water purification, may also have relationships with market goods and services (*e.g.*, as an input into the production process) that make it possible to estimate economic values at least in part or approximately.

Many ecosystem services are, however, truly non-market, in that there are no market counterparts by which to estimate their value. Recreational uses of ecosystems fall into this category, and so economists have developed means of inferring values from behavior (*e.g.*, travel cost), as discussed in the next section), and in other ways. Most of the support services and cultural values of ecosystems are also in the “true” non-market category. Value can arise even if a good or service is not explicitly consumed, or an ecosystem even experienced.[25] Thus, it can be difficult to define, much less to measure the value of changes in these non-market services. To value these services, economists typically use stated preference (direct valuation) methods, a method that can be used not only for non-market services, but also to value services in other categories, such as the value that individuals place on clean drinking water or swimming facilities.

Below we report on the relevant literature in two categories. First, we report on studies that have looked at the non-market value of specific ecosystems or species. Since only a few of these studies attempt to value the impacts of climate change on ecosystems, we also highlight some non-market studies from the more general literature on ecosystem valuation, which can provide insights into the magnitude of potential values of services that might be vulnerable to climate change. Next we look at a different approach to valuation of ecosystems—a more "top-down" approach—which has been adopted both to look at the effects of climate change and more broadly at the total value of ecosystems. As the discussions indicate, the treatment of climate change, *per se* has been very sparse. Moreover, the lack of studies reflects, in part, a need to develop analytical linkages between the physical effects of climate on ecosystems, the services valued by humans, and appropriate techniques to value changes of the types, and with the breadth, indicated by studies of the effects of global change on ecosystems.

4.3.5.2 Valuation of the Effects of Climate Change on Selected Ecosystem and Species

Although climate change appears in a number of studies, it is often as a context for the scenario presented in the study for valuation, and so the study cannot be interpreted as valuation of climate change or climate effects per se. Only a few studies can be said to value the economic impacts of climate change on a particular ecosystem.

Two studies, Layton and Brown (2000) and Layton and Levine (2003) estimate total values for preventing Colorado (Rocky Mountain) forest loss due to climate change, based on data from the same stated choice or preference survey. The survey was conducted with Denver-area residents, who were expected to be familiar with forested regions in their nearby mountains. Respondents were given detailed information about climate change impacts on these forests, including changes in tree line elevation over both 60-year and 150- year time horizons, and asked to make choices between alternatives, allowing recovery of implied willingness to pay (WTP). Layton and Brown (2000) found WTP in the range of $10 to $100 per month, per respondent, to prevent forest loss, with the range depending, in part, on the amount of forest lost. Layton and Levine (2003) reanalyzed the same data set, using a different approach that focuses on understanding respondents' least preferred, as well as most preferred, choices. They found that respondents' value of forest protection depends also on the time horizon—preventing effects that occur further into the future are valued less than nearer term effects.

Kinnell *et al.* (2002) designed and implemented several versions of stated preference studies that explored the impacts of wild bird (duck) loss due to either adverse agricultural practices, climate

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[25] Economists have devoted much effort to defining the source of non-market values of ecosystems, coining such terms as "use" and "non-use" value, consumption value, existence value, and invoking, as reasons why people care about ecosystesm, the moral philosophies inherent in terms such as stewardship, spiritual values, etc. (see for example, Freeman (2003).

change, or both. The respondents consisted of Pennsylvania duck hunters, although the hypothetical ecosystem impacts occurred in the Prairie Pothole region, which is in the northern Midwestern states and parts of Canada. The authors considered a hypothetical loss in duck populations, with a scenario that presented some respondents with a 30% loss, and other with a 74% loss, some with a 40 year time horizon, and others with a 100 year time horizon. The study cannot be viewed as an estimate of willingness to pay to avoid climate change; however, it is interesting because it suggests that recreational enthusiasts are willing to pay for ecosystem impacts that they do not necessarily expect to use. In addition, the study provides evidence that the context of climate change or other cause of ecosystem harm (in this case agricultural practices)—irrespective of the level of harm—may affect respondents' valuation of the harm.

Although very few studies have valued climate change impacts on ecosystems, economists have conducted numerous studies (primarily using direct valuation methods) of ecosystem values in particular geographic locations, often focusing on charismatic species, or specific types of ecosystems, such as wetlands, in a particular location. In some cases, the estimated values are linked to specific services that the species or ecosystem provide, but in many the services provided are somewhat ambiguous, and it is not always clear what aspect of the species, habitat, or ecosystem is driving the individual respondent's economic valuation.

A number of studies indicate that people value the protection of species or ecosystems. Some of these studies find potentially significant species values, ranging from a few dollars to hundreds of dollars per year, per person. For example, MacMillan *et al.* (2001) estimate the value of restoring woodlands habitat, and separately evaluate the reintroduction of the wolf and the beaver to Scottish highlands. In the United States, species such as salmon and spotted owls, as well as their habitat, have been examined in connection to their respective controversies.

Studies have also looked at the value of ecosystems or changes in ecosystems. In the former case, economists use either the value of productive output (harvest) as an indicator of value, or respondents value protecting the ecosystem. For example, numerous coastal wetland and beach protection studies have used a variety of non-market valuation approaches. A survey of a number of these studies reports values ranging from $198 to approximately $1500 per acre (Woodward and Wui, 2001).

Some studies have looked explicitly at the services provided by ecosystems. For example, Loomis *et al.* (2000) consider restoration of several ecosystem services (dilution of wastewater, purification, erosion control, as fish and wildlife habitat, and recreation) for a 45-mile section of the Platte River, which runs east from the State of Colorado into western Nebraska. Average values are about $21 per month for these additional ecosystem services for the in-person interviewees. While these studies and their values are generally informative, transferring values from studies like the ones above to other ecosystems, and using the results to estimate values associated with climate change impacts, can be problematic.

4.3.4.3 Top-down Approaches to Valuing the Effects of Climate Change and Ecosystem Services

From the perspective of deriving values for ecosystem changes (or changes in ecosystem services) associated with climatic changes, one difficulty with the above studies is that the focus is on discrete changes to particular species or geographic areas. It is therefore difficult to know how these studies relate to, or shed light on, the types of widespread and far-reaching changes to ecosystems (and the services they provide) that will result from climate change. Consequently, some studies have attempted to value ecosystems in a more aggregate or holistic manner. While these studies do not focus specifically on the US, they are indicative of an alternative approach that recognizes the interdependence of ecosystems and their components, and therefore deserve some discussion.

Several models include values for non-market damages, worldwide, resulting from projected climate change. These impact studies have been conducted at a highly aggregated level; most of the models are calibrated using studies of the United States which are then scaled for application to other regions (Warren *et al.*, 2006).

A study of total ecosystem values, but not undertaken in the context of climate change, is the highly publicized study by Costanza *et al.* (1997), which offers a controversial look at valuing the "entire biosphere." Because their reported estimated average value of $33 trillion per year exceeds the global gross national product, economists have a difficult time reconciling this estimate with the concept of economic value (WTP); since WTP cannot equal twice income. Ehrlich and Ehrlich (1996) and Pimental *et al.* (1997) are studies by natural scientists that have attempted to value ecosystems or in the case of the latter, biodiversity. These are important attempts to indicate the value of ecosystems, but the accuracy and reliability of the values are questionable. To paraphrase a study by several prominent environmental economists that is slightly critical of all of these studies, economists do not have any fundamental difference of opinion with these natural scientists about the importance of ecosystems and biodiversity, rather it is with the correct use of economic value concepts in these applications (see Bockstael *et al.*, 2000).

4.3.5 Recreational Activities and Opportunities

Ecosystems provide humans with a range of services, including outdoor recreational opportunities. In turn, outdoor recreation contributes to individual wellbeing by providing physical and psychological health benefits. In addition, tourism is one of the largest economic sectors in the world, and it is also one of the fastest growing (Hamilton and Tol, 2004); the jobs created by recreational tourism provide economic benefits not only to individuals but also to communities.[26] A number of studies have looked at the qualitative effects of climate change on recreational opportunities (*i.e.*, resources available) and activities in the US, but only a few have taken this literature the additional step of estimating the implications of climate change for visitation days or economic welfare. This section describes the results of this research into the impacts on several forms of recreation and reports the economic benefits and losses associated with these changes at the national level.

Slightly more than 90% of the U.S. population participates in some form of outdoor recreation, representing nearly 270 million participants (Cordell *et al.*, 1999), and several billion days spent each year in a wide variety of outdoor recreation activities. According to Cordell *et al.* (1999), the number of *people* participating in outdoor recreation is highest for walking (67%), visiting a beach or lakeshore or river (62%), sightseeing (56%), swimming (54%) and picnicking (49%).

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[26] Effects on jobs, income, and similar metrics are considered market impacts, and are not discussed here.

Most *days* are spent in activities such as walking, biking, sightseeing, bird-watching, and wildlife viewing (Cordell *et al.*, 1999), because of the high number of days per bicycle rider and bird watcher, but the range of outdoor recreation activities in the United States is as diverse as its people and environment. While camping, hunting, backpacking and horseback riding attract a fraction of the people who go biking or bird-watching, these other specialized activities provide a very high value to their devotees. Many of these devotees of specialized outdoor recreation activities are people who "work to live," *i.e.*, specialized weekend recreation is one of their rewards for the 40+ hour workweek.

Climate change resulting from increasing average temperatures as well as changes in precipitation, weather variability (including more extreme weather events), and sea level rise, has the potential to affect recreation and tourism along two pathways. Figure 4.3 illustrates these direct and indirect effects of climate change on recreation. Since much recreation and tourism occurs out of doors, increased temperature and precipitation have a direct effect on the enjoyment of these activities, and on the desired number of visitor days and associated level of visitor spending (as well as tourism employment). Weather conditions are considered one of the four greatest factors influencing tourism visitation (Pileus Project, 2007). In addition, much outdoor recreation and tourism depends on the availability and quality of natural resources (Wall, 1998), Consequently, climate change can also indirectly affect the outdoor recreational experience by affecting the quality and availability of natural resources (and, thus, the availability and quality of recreational experience) used for recreation such as beaches, forests, wetlands, snow, and wildlife.

Figure 4.3. Direct and Indirect Effects of Climate Change on Recreation

Effects of climate change can be both positive and negative. The length of season for and desirability of several of the most popular activities—walking, visiting a beach, lakeshore, or river, sightseeing, swimming, and picnicking (Cordell *et al.*, 1999)—will likely be enhanced by small near- term increases in temperature. However, long-term higher increases in temperature may eventually have adverse effects on activities like walking, and result in sufficient sea level rise to reduce publicly accessible beach areas, just at the time when demand for beach recreation to escape the heat is increasing. In contrast, some activities are likely to be unambiguously harmed by even small increase in global warming, such as snow and ice-dependent activities.

In some ways, one can interpret the direct effects of climate change as influencing the demand for recreation and the indirect effects as influencing the supply of recreation opportunities. For example, warmer temperatures make whitewater boating more desirable. However, the warmer temperatures may reduce river flows since there is less snowpack, higher evapotranspiration, and greater water diversions for irrigated agriculture. Some studies cited below look only at the direct effects, while others represent the combined effect of the direct and indirect pathways.

Direct effects. To date, most studies of the direct effects of climate change on recreation and tourism have been qualitative, although a few have been quantitative. Qualitatively, we would expect both positive and negative effects of climate change on different recreational activities. Many of the qualitative studies rely simply on intuition to suggest that increases in air and water temperatures will have a positive effect on outdoor recreation visitation in two ways: (a) more enjoyment from the activity; (b) a longer season in which to enjoy the activity (DeFreitas, 2005;

Scott and Jones, 2005; Scott, Jones and Konopek (2007). Hall and Highman (2005) note that climate change may provide more days of “ideal” temperatures for water- based recreation activities and some land based recreation activities such as camping, picnicking and golf.

The recreational activities most obviously harmed by warmer climate are sports that require snow or cold temperatures, such as downhill and cross country skiing, snowmobiling, ice fishing, and snowshoeing. Reductions in visitor use (see, for example, the studies reported in Table 4.5) occur primarily from shorter season, particularly early in the year at such traditional times as Thanksgiving and Spring break. But with warmer temperatures, there is also less precipitation as snow and more as rain on snow, which contributes to a much shallower snowpack and harder snow. Further, recreating in freezing rain or slushy temperatures is not a pleasant experience, reducing benefits from skiing, snowshoeing, and snowmobiling, further reducing use.

Some recreation areas that are already hot during the summer recreation season will see decreases in use. For example, the Death Valley National Park, Joshua Tree National Park, and Mesa Verde National Park are all projected to be “intolerably hot” reducing visitation (Saunders and Easley, 2006).

Most quantitative studies of the effects of climate change on recreation evaluate specific projected changes in temperature and/or precipitation, such as a 2.5°C increase in temperature over the next fifty years. Two quantitative studies look at effects of temperature change in Canadian recreation.[27] Scott and Jones (2005) project that the golf season in Banff, Canada could be extended by at least one week and up to eight weeks. The combined effect of warmer temperatures lengthening the golfing season, and the increasing the desirability of golfing during the existing season, together result in an increase in the rounds of golf played by between 50% and 86%. (Similar increases might be expected for golf in northern states of the U.S. such as Minnesota, Wisconsin, New York, etc. with longer golf seasons.) Scott *et al.* (2006) and Scott and Jones (2005) suggest that some of the previously projected large (30% to 50%) reductions in length of ski seasons at northern ski areas (*e.g.,* in Canada, Michigan, and Vermont) can be reduced (to 5% to 25%) through the use of advanced snowmaking. While use of advanced snowmaking to minimize reductions in ski season seems plausible for the studied northern ski areas, it is doubtful that snowmaking would benefit ski areas in California, New Mexico, Oregon and West Virginia where the Thanksgiving and “Spring Break” periods are already too warm for successful snowmaking or retention of snow made in some years.

Some studies have used natural variations in temperature to evaluate the effects of climate on recreation (including measures on monthly, seasonal and inter-annual variation). Two of these have found that while visitation increases with initial increases in temperature, visitation actually decreases as temperature increases even further (Hamilton and Tol, 2004; Loomis and Richardson, 2006). Two of the quantitative studies, which look not only at visitor days but also at monetary measures of economic welfare, are discussed in more detail below, following the discussion of indirect effects.

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[27] Scott and Jones (2005) used +1C to +5C in their scenarios and Scott *et al.* (2006) used +1.5C to +3C in their low impact scenario and +2C to +8C in their high impact scenario.

Indirect effects. While increased temperature may increase the demand for some outdoor recreation activities, in some cases climate change may reduce the supply of natural resources on which those recreational activities depend. As noted above, reduced snowpack for winter activities has been projected in the Great Lakes (Scott *et al.*, 2005), in northern Arizona (Bark-Hodgins and Colby, 2006) and at a representative set of ski areas in the United States (Loomis and Crespi, 1999).[28]

For example, lower in-stream flows and lower reservoir levels have consistently been shown to reduce recreation use and benefits (Shaw, 2005). Thus, changes associated with climate can reduce opportunities for summer boating and other water sports. When less precipitation falls as snow in the winter, and more falls as rain in the spring, early spring season run-off will increase. Summer river flows will be correspondingly lower, at times when demand for whitewater boating is higher. Human responses to the physical changes associated with climate change may exacerbate natural effects reducing recreational opportunities. For example, many current reservoirs are not designed to handle huge spring inflows, and thus this water may be “spilled,” which lowers reservoir levels during the summer season. These lower reservoir levels are then drawn down more rapidly as higher temperatures increase evapotranspiration and increase irrigation releases. In turn, the resulting lower reservoir may leave boat docks, marinas, and boat ramps inaccessible.

Ecosystems that provide recreational benefits may also be at risk from climate change. Wetlands are another recreational environment that is at risk from climate change. Wetland based recreation include wildlife viewing and waterfowl hunting. With sea level rise, many existing coastal wetlands will be lost, and given existing development inland, these lost wetlands may not be naturally replaced (Wall, 1998). The higher temperatures and reduced water availability is also expected to adversely affect freshwater wetlands in the interior of the country. As such waterfowl hunting and wildlife viewing may be adversely affected.

Higher water temperatures and lower stream flows are projected to reduce coldwater trout fisheries (U.S. EPA, 1995; Ahn *et al.,* 2000) as well as native and hatchery stocks of Chinook salmon in the Pacific Northwest (Anderson *et al.,* 1993). Given trout and Chinook salmon sensitivity to warm water temperatures, these affects are not surprising. However, Anderson *et al.*’s estimated magnitude of 50% to 100% reduction in Chinook spawning returns is quite large. Reductions of such magnitude will have a substantial adverse effect on recreational salmon catch rates, and possibly whether recreational fishing would even be allowed to continue in some areas of the Pacific Northwest. However, from a national viewpoint, fishing participation for trout, cool water species and warm water species dominates geographically specialized fishing like Chinook salmon. Warmer water temperatures are projected to eliminate stream trout fishing in 8-10 states and result in a 50% reduction in coldwater stream habitat in another 11-16 states depending on the GCM model used (U.S. EPA, 1995). This could adversely affect up to 25% of U.S. fishing days (Vaughan and Russell, 1982). This 25% loss may be an upper limit as some

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[28] Higher temperatures (while they increase snowmelt reducing the snow skiing season) may have two subtle effects: (a) stimulating demand for snow skiing due to warmer temperatures, for those skiers who prefer “spring skiing” due to the warmer temperatures even if the snow conditions are less than ideal; and (b) reduced snowmelt opens up the high mountains for hiking, backpacking and mountain biking activities somewhat earlier than is the case now, which may lead to increases in those visitor use days.

coldwater stream anglers may substitute to less affected coldwater lakes/reservoirs or switch to cool/warm-water species such as bass (U.S. EPA, 1995). Studies that better account for substitution effects, such as Ahn *et al.* (2000), indicate a 2-20% drop in benefits of trout fishing depending on the projected degrees of temperature increase which ranged from 1°C to 5°C.

Sea level rise reducing beach area and beach erosion are concerns with climate change that may make it difficult to accommodate the increased demand for beach recreation (Yohe *et al.*, 1999). In the near term, recreational forests may also be adversely affected by climate change. Although forests may slowly migrate northward and into higher elevations, in the short run there may be dieback of forests at the current forest edges (as these areas become too hot), resulting in a loss of forests for recreation. In the long term, however, several analyses suggest forest species composition and migration due as well as net increases in forest area due to carbon dioxide fertilization (Joyce *et al.,* 2001; Iverson and Matthews, 2007). Thus, eventually there may be resurgence in forest recreation.

Saunders and Easley (2006) find that natural resources of many western National Parks, National Recreation Areas, and National Monuments resources will be adversely affected by climate change. The most common adverse effects are reductions in some wildlife species, loss of coldwater fishing opportunities and increasing park closures due to wildfire associated with stressed and dying forest stands. The text box discusses in more detail potential effects of climate change on one park: Rocky Mountain National Park, which has been the subject of both ecological and economic analysis.

4.3.5.1 Economic Studies of Effects of Climate on Recreation

Changes in economic welfare due to the effects of climate change on non-market resources, such as recreation, can be evaluated in several ways. First, since decisions regarding recreational activities depend on both direct and indirect effects of climate, changes in human well-being (as a result of these changes) will be reflected in changes in visitor use. Social scientists believe changes in visitor use are motivated by people "voting with their feet" to maintain or improve their well-being. In the face of higher temperatures, people may seek relief, for example, by visiting the beach or water skiing at reservoirs more frequently to cool down. Similarly, reduced opportunities for recreation due to indirect effects of climate change will also be reflected in reduced visitation days. Thus, one metric of effects on human well-being is the change in visitation days.

Second, recreational trips—for example, to reservoirs and beaches—have economic implications to the visitor and the economy. Visitors allocate more of their scarce time and household budgets to the recreational activities that are now more preferred in a warmer climate. This reflects their "willingness to pay" for these recreational activities, which is a monetary measure of the benefits they receive from the activity. Numerous economic studies provide estimates of the value of changes in diverse recreational activities, using various economic techniques (such as travel cost[29] analysis and stated preference methods) (see Section 3 of this chapter and the chapter Appendix for more information). While these studies typically do not focus directly on climate

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[29] The travel cost method traces out a demand curve for recreation using travel cost as proxies for the price of recreation, along with the corresponding number of trips individual visitors take at these travel costs. From the demand curve, the net willingness to pay or consumer surplus is calculated.

change, they can be used to extract values for the types of changes that are projected to be associated with climate change.

Third, some people who do not currently visit unique natural environments may value climate stabilization policies that preserve these natural environments for future visitation. These people have what economists call a value for preserving their option—their ability— to visit the environments in the future (Bishop, 1982). This option value is much like purchasing trip insurance to guarantee that if one wanted to go in the future, that conditions would be as they are today.

As discussed below, economists have available a number of well-studied and techniques to evaluate the impacts of climate change on at least some of the recreational service provided by ecosystems. However, only a few studies have looked explicitly at the effects of climate change on recreation in the US. More research is needed to understand the linkages between weather and recreation, and to extrapolate results to the range of recreational activities throughout the US.

Change in visitation days. Two studies (Loomis and Crespi, 1999; Mendelsohn and Markowski, 1999) have examined the effects of climate on recreational opportunities comprehensively for the entire US. These studies both examined the effects of 2.5°C and 5°C increases in temperature, along with a 7% increase in precipitation. The studies used similar methodologies to estimate visitor days for a range of recreational opportunities. Each study looked at slightly different effects, but between them examined a mix of direct and indirect climate effects, including direct effects of higher temperatures on golf and beach recreation visitor days, and indirect effects of snow cover on skiing. Both studies estimate changes in visitation days due to climate change, and then use the results of a number of economic valuation studies to place monetary values on the visitation days. The studies find that, as expected, near-term climate change will increase participation in activities such as water-based recreation, and reduce participation in snow sports.

Table 4.5 presents the results of the two studies. The results suggest that relatively high participation recreation activities such as beach and stream recreation gain, and low participation activities like snow skiing lose. Although the percentage drop in visitor days of snow sports is much larger than the percentage increase in visitor days in water-based recreation, the larger number of water-based sports participants more than offsets the loss in the low participation snow sports. Thus, on net, there is an overall net gain in visitation associated with the assumed increases of 2.5°C in temperature and 7% in precipitation.[30]

The methods used to forecast visitation were slightly different between the two studies. To estimate visitor days for all recreation activities, Mendelsohn and Markowski regressed state level data on visitation by recreation activity as a function of land area, water area, population, monthly temperature and monthly precipitation. The Loomis and Crespi study used a similar

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[30] Geographic regions within the U.S. will experience different gains and losses. Currently hot areas with less access to water resources (*e.g.,* New Mexico) may suffer net overall reductions in recreation use to due higher heat that makes walking, sightseeing, and picnicking less desirable. States with substantial water resources (lakes, seashores) may gain visitor days and tourism. Currently cold areas such as the Dakotas and New York may see increases in some recreation due to longer summer seasons.

approach to Mendelsohhn and Markowski for some activities, such as golf. Other forecasting techniques were used for other activities; for example, for beach recreation, they used detailed data on to individual beaches in the Northeastern, Southern and Western United States to estimate three regional regression equations to project beach use, and the response of reservoir recreation to climate change was analyzed using visitation at U.S. Army Corps of Engineers reservoirs.

For some of the recreational activities, the Loomis and Crespi study included indirect, as well as direct, effects. For example, the reservoir models incorporated climate-induced reductions in reservoir surface area besides temperature and precipitation. Similarly, the estimate of visitor days for snow skiing used projected changes in the number of days of minimum snow cover to adjust skier days proportionally. In some cases, only indirect (supply) effects were included, as in the case of stream recreation, water fowl hunting, bird viewing and forest recreation. Since these estimates do not include changes in visitation associated with direct effects of climate we have less confidence in the accuracy of these results, than we do for reservoir recreation which takes into account both demand and supply effects on recreation use.

Valuation of gains and losses in visitor days. Since different activities may have different levels of enjoyment provided to the visitor (and, therefore, different economic values), adding up changes in visitation days to produce a “net change” is not an accurate representation of the overall change in well-being. The two studies discussed above used net willingness to pay as a measure of value of each day of recreation (Section 3 of this chapter provides a discussion of the concept of willingness to pay as a common economic measure of changes in welfare).

To date there have been few original or primary valuation studies of climate change per se on recreation; the case study on Rocky Mountain National Park presented below provides one of the few examples. Other studies include Scott and Jones (2005), which focused on Banff National Park, Scott *et al.* (2006), which looked at snow skiing, Scott *et al.* (2007), which focused on Waterton National Parks, and Pendleton and Mendelsohn (1998), which estimated values for fishing in the northeastern US.[31] There have, however, been hundreds of recreation valuation studies; the values from these studies (generally travel cost or stated preference) can be applied to other applications using a “benefit transfer” approach, and applying average values of recreation from previous studies to value their respective visitor days.

Loomis and Crespi (1999) and Mendelsohn and Markowski (1999) estimate the overall net gain in visitor benefits, using the change in visitor days reported in Table 4.5 and estimated values of a visitation day reported in the literature. Loomis and Crespi (1999) adopt a disaggregated activity approach, and Mendelsohn and Markowski (1999) apply a state level approach.[32] Both

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[31] The three papers by Scott are discussed elsewhere in this paper. Pendleton and Mendelsohn use a random utility model of recreational fishing in the northeastern U.S. They find that, while catch rates of rainbow trout would decrease, catch rates of other trout and pan fish would increase. On net, recreational fishing benefits (under a climate scenario associated with a doubling of atmospheric CO_2 concentrations) are reduced in the state of New York, but there are offsetting gains in more northern states like Maine.

[32] As noted above, Mendelsohn and Markowski (1999) used state level regression modeling to estimate effects on all activities. In contrast, Loomis and Crespi (1999), used different regression models and different geographic scales for different recreation activities to take advantage of the more micro-level datasets available for beach and reservoir recreation.

of these studies find that temperature increases of 5°C and up result in increased benefits. However, as noted below, the case study of Rocky Mountain National Park suggests that extreme heat is likely (based on the model results) to cause these visitor benefits to decrease at some point.

Visitors are somewhat adaptable to climate change in the recreation activities they choose and when they choose them. Thus, recreation represents one situation with opportunities to reduce the adverse impacts of climate change, or increase its benefits, via adaptation. As noted by Hamilton and Tol (2004), warmer temperatures may shift visitors northward, and up into the mountains. Thus currently cool areas (*e.g.*, Maine, Minnesota, Washington) may gain, and warm areas (*e.g.*, Florida, Arizona) may lose, tourism.

Some adaptive responses can be expensive, and may be of limited effectiveness; such as snowmaking at night, which is often mentioned as an adaptation for downhill skiing (Irland *et al.*, 2001). Other adaptive behavior may include moving some outdoor recreation activities indoors. For example, bouldering is now taking place in climbing gyms on artificial climbing walls. Running on a treadmill in an air conditioned gym may be a substitute for running out of doors for some people, but casual observation suggests that many people prefer to run out doors when weather permits. Unless preferences adjust to increased temperatures, there may be a loss in human well-being from substituting the treadmill in the air conditioned gym for the out of doors. Box 4.2 summarizes a case study of the impacts of climate change on Rocky Mountain National Park.

4.3.6 Amenity Value of Climate

It is well established that preferences for climate affect where people choose to live and work. The desire to live in a mild, sunny climate may reflect health considerations. For example, people with chronic obstructive lung disease or angina may wish to avoid cold winters. Warmer climates may be more pleasant for persons with arthritis. Climate preferences may also reflect the desire to reduce heating and/or cooling costs. Certain climates may be complementary to leisure activities. For example, skiers may wish to live in colder climates, sunbathers in warmer ones. Or a particular climate may simply make life more enjoyable in the course of everyday life. We would also expect based on the evidence that, in addition to preferring certain temperatures and more sunshine, people would prefer to reduce the risk of experiencing abrupt climate events such as hurricanes and floods.

While climate itself is not bought and sold in markets, the goods that are integral to location decisions—such as housing and jobs—*are* market goods. Consequently, economists look at behavior with regard to location choice (the prices that are paid for houses and the wages that are accepted for jobs) in order to determine how large a role climate plays in these decisions and, therefore, how valuable different climates are to the general public. The remainder of this section discusses methods that have been used to estimate the amenity values people attach to various climate attributes, as well as the value they attach to avoiding extreme weather events. Unfortunately, few studies have rigorously estimated climate amenity values (*e.g.*, the value of a 2°C change in mean January temperature) for the United States and then used these values to estimate the dollar value of various climate scenarios.

4.3.6.1 Valuing Climate Amenities

People’s preferences for climate attributes should be reflected in their location decisions. Other things equal, homeowners should be willing to pay more for housing (and so bid up housing prices) in more desirable climates, and so property values should be higher in those climates. Similarly, workers should be willing to accept lower wages to live in more pleasant climates; if climate also affects firms’ costs, however, actual wages may rise or fall due to the interaction between firms and workers (Roback, 1982).

Early attempts to estimate how much consumers will pay for more desirable climates start from the view that a good—such as housing or a job—is a bundle of attributes that are valued by the homeowner or worker. The price the consumer pays for the good (such as a house) is actually a composite of the prices that are implicitly paid for all the attributes of the good. Using a statistical technique (known as a hedonic value function), economists can estimate the price of a particular attribute, such as climate. The hedonic property value function, thus, describes how housing prices vary across cities as a function of housing characteristics and locational amenities, such as climate, crime, air quality, or proximity to the ocean. Similarly, the hedonic wage function relates the observed wages to job characteristics (such as occupation and industry), worker characteristics (such as education and years of experience), and locational amenities.

The value of locational amenities—*i.e.*, how much individuals are willing to pay for amenities—can be inferred from these estimated hedonic wage and property value functions. Extracting this value, however, assumes that workers and homeowners are mobile, *i.e.*, that they can choose where to live fairly freely within the United States. Similarly, it assumes that, in general, individuals have moved to where they would like to live (at the moment), so that housing and job markets are in what is said to be “equilibrium.” It also assumes that workers and homeowners have good information about the location to which they are moving, and that sufficient options (in terms of jobs and houses and amenities) are available to them. The estimates of the value of a particular amenity—such as climate—will be more accurate the more nearly these assumptions are met.

A number of hedonic wage and property value studies have included climate, among other variables, in their analyses: by Hoch and Drake (1974); Cropper and Arriaga-Salinas (1980); Cropper (1981); Roback (1982); Smith (1983); Blomquist *et al.* (1988); Gyourko and Tracy (1991). The first four studies estimate only hedonic wage functions, while the last three estimate both wage and property value equations. As Moore (1998) and Gyourko and Tracy (1991) note, this literature suggests that climate amenities are reflected to a greater extent in wages than in property values.[33] Roback (1982), Smith (1983), and Blomquist *et al.* (1988) all find sunshine to be capitalized in wages as an amenity, while heating degree days are capitalized as a disamenity (Roback, 1982, 1988; Gyourko and Tracy, 1991).

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[33] The effect of weather variables on property values is mixed, with Blomquist *et al.* (1988) finding property values to be negatively correlated with precipitation, humidity and heating and cooling degree days, but Roback (1982) finding property values positively correlated with heating degree days. Gyourko and Tracy (1991) find heating and cooling degree days negatively correlated with housing expenditures, but humidity positively correlated.

More recent studies using the hedonic approach include Moore (1998) and Mendelsohn (2001), who use their results to estimate the value of mean temperature changes in the United States associated with future climate scenarios. Moore uses aggregate wage data for Metropolitan Statistical Areas (MSAs) to estimate the responsiveness of wages with respect to climate variables for various occupations. Climate is captured by annual temperature, precipitation and by the difference between average July and average January temperature. Moore estimates that a 4.5° C increase in mean annual temperature would be worth between $30 and $100 billion (1987$) assuming that precipitation and seasonal variation in temperature remain unchanged.

Mendelsohn (2001) uses county-level data on wages and rents to estimate hedonic wage and property value models. Separate equations are estimated for wages in retail, wholesale, service and manufacturing jobs. Climate variables, which include average January, April, June and October temperature and precipitation, enter each equation in quadratic form. Warmer temperatures are generally associated with lower wages and lower rents, although the former effect is larger in magnitude. Mendelsohn uses the results of these models to estimate the impact of a uniform increase in temperature of 1°C, 2°C and 3.5°C, paired, alternately with an 8% and a 15% increase in precipitation. The results suggest that warming produces positive benefits in every scenario except the 3.5°C temperature change. Averaging across estimates produced by the 3 models for each of the 6 scenarios suggests annual net benefits (in 1987$) of $25 billion.

Unfortunately, hedonic wage and property value studies have limitations that have caused them to be replaced by alternate approaches to analyzing data on location choices. One drawback of the hedonic approach is that, as mentioned above, it assumes that national labor and housing markets exist and are in equilibrium. As Graves and Mueser (1993) and Greenwood *et al.* (1991) point out, if national markets are not in equilibrium, inferring the value of climate amenities from hedonic wage and property value studies can lead to badly biased results. A second problem is that variables that are correlated with climate (*e.g.*, the availability of recreational facilities) may be difficult to measure; hence, climate variables may pick up their effects. In hedonic property value studies, for example, the use of heating and cooling degree days to measure climate amenities is problematic because their coefficients may capture differences in construction and energy costs as well as climate amenities per se. A related problem in hedonic wage equations is that more able workers may locate in areas with more desirable climates. If ability is not adequately captured in the hedonic wage equation, the coefficients of climate amenities will reflect worker ability as well as the value of climate.

Cragg and Kahn (1997) were the first to relax the national land and labor market equilibrium assumption by estimating a discrete location choice model. Using Census data, they model the location decisions of people in the United States who moved between 1975 and 1980. Movers compare the utility they would receive from living in different states—which depends on the wage they would earn and on the cost of housing, as well as on climate amenities—and are assumed to choose the state that yields the highest utility. This allows Cragg and Kahn to estimate the parameters of individuals' utility functions and thus infer the rate at which they will trade income for climate amenities.

The drawback of this study is that it estimates the preferences of movers, who may differ from the general population. An alternate approach (Bayer *et al.*, 2006; Bayer and Timmins, 2005) is to acknowledge that moving is costly and to explain the location decisions of all households, assuming that all households are in equilibrium, given moving costs. Unfortunately, the discrete choice literature has yet to provide reliable estimates of the value of climate amenities in the United States.

4.3.6.2 Valuing Hurricanes, Floods, and Extreme Weather Events

It is sometimes suggested that the value people place on avoiding extreme weather events can be measured by the damages that such events cause, or by the premiums that people pay for flood or disaster insurance. *Ex post* losses associated with extreme weather events represent a lower bound to the value people place on avoiding these events, as long as people are risk averse. It is also the case that people can purchase insurance only against the monetary losses associated with floods and hurricanes; hence, insurance premiums will not capture the entire value placed on avoiding these events.

The value of avoiding extreme weather events should be reflected in property values, assuming that people are informed about risks: houses in an area with high probability of hurricane damage should sell for less than comparable houses in an area with a lower chance of hurricane damage, holding other amenities constant. To estimate the value of avoiding these events correctly is, however, tricky; it can be difficult, for example, to disentangle hurricane risk (a negative effect) from proximity to the coast (an amenity).

Recent studies use natural experiments to determine the value of avoiding hurricanes and floods. Hallstrom and Smith (2005) use property value data before and after hurricane Andrew in Lee County, Florida, a county that did not suffer damage from the hurricane, to determine the impact of people's *perceptions* of hurricane risk on property values. They find that property values in special flood hazard areas of Lee County declined by 19% after hurricane Andrew. The magnitude of this decline is significant, and agrees with Bin and Polasky (2004). Bin and Polasky find that housing values in a flood plain in North Carolina declined significantly after hurricane Floyd, compared to houses not at risk. For the average house, the decline in price exceeded the present value of premiums for flood insurance, suggesting that the latter are, indeed, a lower bound to the value of avoiding floods.

4.4 Conclusions

The study of the impacts of climate change on human welfare, well-being, and quality of life, is still developing. Many studies of impacts on particular sectors—such as health or agriculture—discuss, and in some cases quantify, effects that have clear implications for welfare. Studies also hint at changes that are perhaps less obvious, but also have welfare implications (such as changes in outdoor activity levels and how much time is spent indoors) and point also to effects with far more dramatic consequences (such as breakdown in public services and infrastructure associated with possible extreme events of the magnitude of Katrina). Adaptation, too, has welfare implications that studies do not always point out, such as the costs (financial and psychological) to the individual of changing behavior.

To our knowledge, no study has made a systematic survey of the myriad welfare implications of climate change, much less attempted to quantify—nor yet to aggregate—them. An almost bewildering choice of typologies is available for categorizing effects on quality of life, well-being, or human welfare. The social science and planning literatures provide not only a range of typologies, but also an array of metrics that could be used to measure life quality.

This chapter explores one commonly used method: the social indicators approach. This approach generally divides life quality effects into broad categories, such as economic conditions or human health, and then identifies subcategories of important effects.

Most of the measures of well-being—including the social indicators approach—focus on individual measures of well-being, although measured at the society level. There is, however, another dimension to well-being—community welfare. Communities represent networks of households, businesses, physical structures, and institutions and so reflect the interdependencies and complex reality of human systems. Understanding how climate impacts communities, and how communities are vulnerable—or can be made more resilient—in the face of climate change, is an important component of understanding well-being and quality of life.

Economics offers one alternative to address the diversity of impacts: valuing welfare impacts in monetary terms, which can then be summed. Estimating value, however, requires completing a series of links—from projected climate change to quantitative measures of effects on commodities, services, or conditions that are linked to well-being, and then valuing those effects using economic techniques.

Regardless of the framework, estimating impacts on human well-being involves numerous and diverse effects. This poses several critical difficulties:

- The large number of effects makes the task of linking impacts to climate change—whether qualitatively or quantitatively—difficult.
- The interdependence of physical and human systems further complicates the process of quantification—both for community effects, and also for ecosystems, raising doubts about a piecemeal approach to estimation.
- The diversity of effects raises questions of how to aggregate effects in order to develop a composite measure of well-being or other metrics that can be used for policy purposes.

4.5 Expanding the Knowledge Base

Despite the potential for impacts on human well-being, little research focuses directly on understanding the relationship between well-being and climate change. Completely cataloging the effects of global change on human well-being or welfare would be an immense undertaking, and no well-accepted structure for doing so has been developed and applied. Moreover, identifying the potentially lengthy list of climate-related changes in lifestyle, as well as in other, more tangible, features of well-being (such as income), is itself a daunting task—and may includes changes that are not easily captured by objective measures of well-being or quality of life.

This chapter has looked at the climate impacts and economics literature in four areas of welfare effects—human health, ecosystems, recreation, and climate amenities. For each of the non-market effects analyzed here, significant data gaps exist at each of the steps necessary to provide monetized values of climate impacts. Although the economics literature for only a few areas of effects is examined, it is probable that similar information gaps exist for the valuation of other impacts of climate change, particularly those that involve non-market effects (see Table 4.1). In addition, economic welfare—as with any other aggregative approach—does not adequately address the question of how to deal with effects which may not be amenable to valuation or with interdependencies among effects and systems.

Developing an understanding of the impacts of climate change on human welfare may require taking the following steps:

- Develop a framework for addressing individual and community welfare and well-being, including defining welfare/well-being for climate analysis and systematically categorizing and identifying impacts on welfare/well-being
- Identify priority categories for data collection and research, in order to establish and quantify the linkage from climate to welfare effects
- Decide which metrics should be used for these categories; more generally, which components of welfare/well-being should be measured in natural or physical units, and which should be monetized
- Investigate methods by which diverse metrics can be aggregated into a synthetic indicator (*e.g.*, vulnerability to climate change impacts, including drought, sea level rise, etc.), or at least weighted and compared in policy decisions where aggregation is impossible
- Develop an approach for addressing those welfare effects that are difficult to look at in a piecemeal way, such as welfare changes on communities or ecosystems.
- Identify appropriate top-down and bottom-up approaches for estimating impacts and value (whether economic or otherwise) of the most critical welfare categories.
- Identify situations in which evaluation following the above steps is likely to be prohibitively difficult, and determining alternative methods for approaching the topic of the impact of global change on well-being.

Together, these steps should enable researchers to make progress towards promoting the consistency and coordination in analyses of welfare/well-being that will facilitate developing the body of research necessary to analyze impacts on human welfare, well-being, and quality of life.

4.6 References

Ahn, S., J. deSteiguer, R. Palmquist, and T. Holmes, 2000: Economic analysis of the potential impact of climate change on recreational trout fishing in the southern Appalachian Mountains. *Climatic Change,* **45**, 493-509.

Alberini, A., M. Cropper, A. Krupnick, and N. Simon, 2004: Does the value of a statistical life vary with age and health status? Evidence from the U.S. & Canada. *Journal of Environmental Economics and Management,* **48(1)**, 769-792.

Anderson, D., S. Shankle, M. Scott, D. Neitzel and J. Chatters. 1993: Valuing effects of climate change and fishery enhancement on Chinook salmon. *Contemporary Policy Issues*, **11(4)**, 82-94.

Arrow, K.J., M.L. Cropper, G.C. Eads, R.W. Hahn, L.B. Lave, R.G. Noll, P.R. Portney, M. Russell, R. Schmalensee, V.K. Smith, and R.N. Stavins, 1996: *Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principles*. American Enterprise Institute, The Annapolis Center, and Resources for the Future, Washington, DC.

Bachelet, D., R.P. Neilson, J.M. Lenihan, and R.J. Drapek, 2001: Climate change effects on vegetation distribution and carbon budget in the U.S. *Ecosystems*, **4**, 164-185.

Banuri, T. and J. Weyant, 2001: Setting the stage: climate change and sustainable development. *Climate Change 2001: Mitigation. Contributions of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. [Metz, B., O. Davidson, R. Swart, and J. Pan (eds.)]. Cambridge University Press, UK, pp. 73-114.

Bark-Hodgins, R. and B. Colby, 2006: *Snow Days? Using Climate Forecasts to Better Manage Climate Variability in the Ski Industry.* Presentation at NOAA Climate Prediction Applications Science Workshop, held March 21-24 in Tucson, Arizona.

Bayer, P. and C. Timmins, 2005: On the equilibrium properties of locational sorting models. *Journal of Urban Economics*, **57(3)**, 462-477.

Bayer, P., N. Keohane and C. Timmins, 2006: *Migration and Hedonic Valuation: The Case of Air Quality*. NBER Working Paper #12106.

Beebee, T.J.C, 1995: Amphibian breeding and climate. *Nature,* **374**, 219-220.

Berke, P., D. Godschalk, and E. Kaiser, 2006: *Urban Land Use Planning*. University of Illinois Press, Urbana, Illinois.

Bin, O. and S. Polasky, 2004: Effects of flood hazards on property values: evidence before and after Hurricane Floyd. *Land Economics,* **80(4)**, 490-500.

Bishop, R., 1982: Option value: an exposition and extension. *Land Economics*, **58(1)**, 1-15.

Black, D.A., J. Galdo, and L. Liu, 2003: *How Robust Are Hedonic Wage Estimates of the Price of Risk?* Final Report to the U.S. Environmental Protection Agency [R 829-43-001].

Blomquist, G.C., M.C. Berger, and J.P. Hoehn, 1988: New estimates of quality of life in urban areas. *American Economic Review*, **78(1)**, 89-107.

Bockstael, N. E., A.M. Freeman, R. Kopp, P. Portney, and V.K. Smith, 2000: On measuring economic values for nature. *Environmental Science and Technology*, **34(8)**, 1384-1390.

Bolin, R., 1986: Disaster impact and recovery: a comparison of black and white victims. *International Journal of Mass Emergencies and Disasters (IJMED)*, **4**, 35-50.

Both, C., S. Bouwhuis, C.M. Lessells, and M.W. Visser, 2006: Climate change and population declines in a long-distance migratory bird. *Nature*, **441**, 81-83.

Bowling, A., 1997: *Measuring Health: A Review of Quality of Life Measurement Scales*. Open University Press, Philadelphia, Pennsylvania, 2nd edition.

Boyce, J. and B. Shelley, 2003: *Natural Assets: Democratizing Environmental Ownership.* Island Press, Washington, DC.

Boyd, J., 2006: *The Nonmarket Benefits of Nature: What Should Be Counted in Green GDP?* Resources for the Future Discussion Paper RFF DP 06-24, Washington, DC.

Boyd, J. and S. Banzhaf, 2006: *What Are Ecosystem Services? The Need for Standardized Environmental Accounting Units*. Resources for the Future Discussion Paper RFF DP 06-02, Washington, DC.

Brown, J.L., S.H. Li, and N. Bhagabati, 1999: *Long-Term Trend Toward Earlier Breeding in an American Bird: A Response to Global Warming?* Proceedings of the National Academy of Sciences, USA, **96**, 5565–5569.

Burby, R. (ed.), 1998: *Cooperating with Nature: Confronting Natural Hazards with Land Use Planning for Sustainable Communities*. Joseph Henry Press, Washington, DC.

Campbell, S., 1996: Green cities, growing cities, just cities? Urban planning contradictions of sustainable development. *Journal of the American Planning Association*, **62**, 296-312.

Cheshire, P. and S. Magrini, 2006: Population growth in European cities: weather matters – but only nationally. *Regional Studies*, **40(1)**, 23-37.

Cline, W.R., 1992: *The Economics of Global Warming.* Institute for International Economics, Washington DC.

Coleman, J.S., 1988: Social capital in the creation of human capital. *American Journal of Sociology Supplement*, **94**, S95-S120.

Coleman, J.S., 1990: *Foundations of Social Theory*. Harvard University Press.

Coleman, J.S., 1993: The rational reconstruction of society, *American Sociological Review*, **58**, 1-15.

Cordell, H.K., B. McDonald, R.J. Teasley, J.C. Bergstrom, J. Martin, J. Bason, and V.R. Leeworthy, 1999: Outdoor recreation participation trends. In: *Outdoor Recreation in American Life: A National Assessment of Demand and Supply Trends.* [Cordell, H.K. (ed.)]. Sagamore Publishing, Champaign, Illinois.

Costanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, M. van den Belt, 1997: The value of the world's ecosystem services and natural capital. *Nature*, **387**, 253-255.

Costanza, R., B. Fisher, S. Ali, C. Beer, L. Bond, R. Boumans, N. Danigelis, J. Dickinson, C. Elliott, J. Farley, D.E. Gayer, L.M. Glenn, T. Hudspeth, D. Mahoney, L. McCahill, B. McIntosh, B. Reed, S. Abu Turab Rizvi, D.M. Rizzo, T. Simpatico, and R. Snapp, 2007: Quality of life: an approach integrating opportunities, human needs, and subjective well-being. *Ecological Economics*, **61**, 267-276.

Cragg, M. and M. Kahn, 1997: New estimates of climate demand: evidence from location choice. *Journal of Urban Economics,* **42(2)**, 261-284.

Crick, H.Q.P., C. Dudley, D.E. Glue, and D.L. Thompson, 1997: UK birds are laying eggs earlier. *Nature,* **388**, 526.

Cropper, M.L. and A.S. Arriaga-Salinas, 1980: Inter-city wage differentials and the value of air quality. *Journal of Urban Economics,* **8(2)**, 236-254.

Cropper, M.L., 1981: The value of urban amenities. *Journal of Regional Science,* **21(3)**, 359-374.

Cropper, M.L. and F. G. Sussman, 1990: Valuing future risks to life. *Journal of Environmental Economics and Management,* **19(2)**, 160-174.

Curriero, F., J. Patz, J. Rose, and S. Lele, 2001: Analysis of the association between extreme precipitation and waterborne disease outbreaks in the United States: 1948-1994. *American Journal of Public Health,* **91(8)**, 1194-1199.

Curriero, F.C., J.M. Samet, and S.L. Zeger, 2003: Re:"on the use of generalized additive models in time-series studies of air pollution and health" and" temperature and mortality in 11 cities of the eastern United States". *American Journal of Epidemiology,* **158(1)**, 93-94.

Curriero, F.C., K.S. Heiner, J.M. Samet, S.L. Zeger, L. Strug, and J. Patz, 2002: Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology*, **155(1)**, 80-87.

Cutter, **S**., 2006: The geography of social vulnerability: race, class, and catastrophe, *Understanding Katrina: Perspectives from the Social Sciences*. Available at: http://understandingkatrina.ssrc.org/Cutter/.

Cutter, S., B. Boruff, and W. Shirley, 2003: Social vulnerability to environmental hazards. *Social Science Quarterly*, **84(1)**, 242-261.

Daily, G.C., 1997: *Nature's Services. Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

Davis, R., P. Knappenberger, P. Michaels, and W. Novicoff, 2004: Seasonality of climate-human mortality relationships in US cities and impacts of climate change. *Climate Research*, **26**, 61-76.

DeFreitas, C.R., 2005: The climate-tourism relationship and its relevance to climate change impact assessment. In: *Tourism, Recreation and Climate Change*. [Hall, C.M. and J. Higham (eds.)]. Channel View Publications, Buffalo, New York, pp. 29-43.

Diamond, J., 2005: *Collapse: How Societies Choose to Fail or Succeed*. Viking, New York.

Diamond, P.A. and J. A. Hausman, 1993: On contingent valuation measurement of nonuse values. In: *Contingent Valuation: A Critical Assessment* [Hausman, J.A. (ed.)]. North-Holland, Amsterdam, Netherlands.

Diener, E. and C. Diener, 1995: The wealth of nations revisited: income and quality of life. *Social Indicators Research*, **36**, 275–286.

Diener, E., M. Diener, and C. Diener, 1995: Factors predicting the subjective well-being of nations. *Journal of Personality and Social Psychology*, **69(5)**, 851–864.

Dietz, T., E. Rosa, and R. York, In Press. Human driving forces of global change: examining current theories. In: *Human Dimensions of Global Change* (In press) [Rosa, E., A. Diekmann, T. Dietz, and C. Jaeger (eds.)]. MIT Press, Cambridge, Massachusetts.

Dunn, P.O. and D.W. Winkler, 1999: *Climate Change has Affected the Breeding Date of Tree Swallows Throughout North America.* Proceedings of the Royal Society of London, Series B, **266**, pp. 2487–2490.

Ehrlich, P. and A. Ehrlich, 1996: *Betrayal of Science and Reason.* Island Press, Washington DC.

Fagan, B., 2001: *The Little Ice Age*. Basic Books, New York.

Frank, R.H., 1985: *Choosing the Right Pond*. Oxford University Press, Oxford.

Florida, R., 2002a: The economic geography of talent. *Annals of the Association of American Geographers,* **92(4)**, 743–755.

Florida, R., 2002b: *The Rise of the Creative Class: And How It's Transforming Work, Leisure and Everyday Life*. Basic Books.

Fowler, A.M., and K.J. Hennessey, 1995: Potential impacts of global warming on the frequency and magnitude of heavy precipitation. *Natural Hazards,* **11**, 283-303.

Fankhauser, S., 1995: *Valuing Climate Change – The Economics of the Greenhouse*. EarthScan, London.

Fothergill, A., E. Maestas, and J.D. Darlington, 1999: Race, ethnicity, and disasters in the United States: a review of the literature. *Disasters,* **23(3)**, 156-173.

Fothergill, A. and L.A. Peek, 2004: Poverty and disasters in the United States: a review of recent sociological findings. *Natural Hazards,* **32**, 89-110.

Freeman, A.M., 2003: *The Measurements of Environmental and Resource Values: Theory and Methods*. Resources for the Future Press, Washington, DC, 2nd edition.

Frey, B.S. and A. Stutzer, 2002: *Happiness and Economics.* Princeton University Press, Princeton, New Jersey.

Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, and G. Page, 2002: Global climate change and sea-level rise: potential losses of intertidal habitat for shorebirds. *Waterbirds,* **25**, 173–183.

Galbraith, H., J.B. Smith, and R. Jones, 2006: Biodiversity changes and adaptation. In: *The Impact of Climate Change on Regional Systems: a Comprehensive Analysis of California* [J.B. Smith and R. Mendelsohn (eds.)]. Edward Elgar, Massachusetts.

Githeko, A.K., and A. Woodward, 2003: International consensus on the science of climate and health: the IPCC Third Assessment Report. In: *Climate Change and Human Health: Risks and Responses* [A.J. McMichael *et al.* (eds.)]. World Health Organization, World Meteorology Organization, and UN Environment Programme, Geneva, Switzerland.

Glaeser, E.L., J. Kolko, and A. Saiz, 2001: Consumer city. *Journal of Economic Geography*, **1(1)**, 27-51.

Glick, P. and J. Clough, 2006: *An Unfavorable Tide: Global Warming, Coastal Habitats and Sportfishing in Florida.* National Wildlife Federation, Washington, DC.

Godschalk, D.R., 2007: Mitigation. In: *Emergency Management: Principles and Practice for Local Government.* Second edition. [Waugh, Jr., W.L., and K. Tierney (eds.)]. International City/County Management Association, Washington, DC, pp 89-112.

Godschalk, D.R., 2003: Natural hazard mitigation: creating resilient cities. *Natural Hazards Review,* **4(3)**, 136-143.

Graves, P.E. and P.R. Mueser, 1993: The role of equilibrium and disequilibrium in modeling regional growth and decline: a critical reassessment. *Journal of Regional Science*, **33(1)**, 69-84.

Greenwood, M., G. Hunt, D. Rickman, and G. Treyz, 1991: Migration, regional equilibrium, and the estimation of compensating differentials. *American Economic Review*, **81(5)**, 1382-1390.

Guyatt, G. H., D.H. Feeny, and D.L. Patrick, 1993: Measuring health-related quality of life. *Annals of Internal Medicine*. **118(8)**, 622-629.

Gyourko, J. and J. Tracy, 1991: The structure of local public finance and the quality of life. *Journal of Political Economy,* **99(4)**, 774-806.

Hall, C.M. and J. Highman, 2005: Introduction: tourism, recreation, climate change. In: *Tourism, Recreation and Climate Change* [Hall, C.M. and J. Higham (eds.)]. Channel View Publications, Buffalo, New York, pp. 3-28.

Hallstrom, D. and V.K. Smith, 2005: Market responses to hurricanes. *Journal of Environmental Economics and Management,* **50(3)**, 541-561.

Hamilton, J. and R. Tol, 2004: *The impact of climate change on tourism and recreation.* FNU-52 working paper, Research Unit Sustainability and Global Change, University of Hamburg, Germany.

Hamilton, J. and R. Tol. 2007: The impact of climate change on tourism in Germany, the UK and Ireland. *Regional Environmental Change,* **7**, 161-172.

Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of Sciences of the United States of America, **101(34)**, 12,422-12,427.

Health Care Financing Review, 2004: *Special Issue on the Health Outcomes Survey.* **25(4)**, 1-119.

Hersteinsson, P. and D.W. Macdonald, 1992: Interspecific competition and the geographical distribution of red and arctic foxes, *Vulpes vulpes* and *Alopex lagopus*. *Oikos*, **64**, 505–515.

Hoch, I. and J. Drake, 1974: Wages, climate, and the quality of life. *Journal of Environmental Economics and Management*, **1**, 268-296.

Holbrook, S.J., R.J. Schmitt, and J.S. Stephens, 1997: Changes in an assemblage of temperate reef fishes associated with a climatic shift. *Ecological Applications*, **7**, 1299-1310.

IPCC, 2007a: *Climate Change 2007: Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report.* Draft Copy, 16 November 2007.

IPCC, 2007b: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

IPCC, 2007c: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B., Averyt, M. Tignor and h.L.Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

IPCC, 2000: *Special Report on Emissions Scenarios*, Coordinating Lead Author: Nebojsa Nakicenovic. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

IPCC, 1996: *Climate Change 1995: Economic and Social Dimensions of Climate Change. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Bruce, J., H. Lee, and E. Haites (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Irland, L., D. Adams, R. Alig, C. Betz, C.Chen, M. Hutchins, B. McCarl, K. Skog, and B. Sohngen, 2001: Assessing socioeconomic impacts of climate change on U.S. forests, wood-product markets, and forest recreation. *BioScience*, **51(9)**, 753-764.

Iverson, L. and S. Matthews, 2007: Potential changes in suitable habitat for 134 tree species in northeastern United States. *Mitigation and Adaptation Strategies for Global Change.* (in press).

Jacoby, H.D., 2004: Informing climate policy given incommensurable benefits estimates. *Global Environmental Change Part A*, **14(3)**, 287-297.

Joyce, **L.**, J. Aber, S. McNulty, V. Dale, A. Hansen, L. Irland, R. Nelson and K. Skog, 2001: Potential consequences of climate variability and change for the forests of the United States. In: *Climate Change Impacts on the United States*. U.S. Global Change Research Program. Washington DC.

Kahneman, D., E. Diener, and N. Schwarz (eds.), 1999: *Well-Being: The Foundations of Hedonic Psychology*. Russel Sage Foundation, New York.

Kahneman, D. and A.B. Krueger, 2006: Developments in the measurement of subjective well-being. *Journal of Economic Perspectives,* **20(1)**, 3-24.

Kalkstein, L.S. and Greene J.S., 1997: An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. *Environmental Health Perspectives,* **105(1)**, 84-93.

Kalkstein, L.S., 1989: The impact of CO_2 and trace gas-induced climate changes upon human mortality. In: *The Potential Effects of Global Climate Change in the United States* [Smith, J. B. and D. A. Tirpak (eds.)]. Document no. 230-05-89-057, Appendix G, U.S. Environmental Protection Agency, Washington, DC.

Kalkstein, L.S. and R. E. Davis, 1989: Weather and human mortality: an evaluation of demographic and interregional responses in the United States. *Annals of the Association of American Geographers,* **79(1)**, 44-64.

Kinnell, J., J.K. Lazo, D.J. Epp, A. Fisher, J.S. Shortle, 2002: Perceptions and values for preventing ecosystem change: Pennsyvlania duck hunters and the prairie pothole region. *Land Economics,* **78(2)**, 228-244.

Knowlton, K., B. Lynn, R. Goldberg, C. Rosenzweig, C. Hogrefe, J. K. Rosenthal and P. L. Kinney, 2007: Projecting heat-related mortality impacts under a changing climate in the New York City region. *American Journal of Public Health,* **97(11)**, 2028-2034.

Kunst, A.E., C.W.N. Looman, and J. P. Mackenbach, 1993: Outdoor air temperature and mortality in the Netherlands: a time series analysis. *American Journal of Epidemiology,* **137(3)**, 331-341.

Lambiri, D., B. Biagi, and V. Royuela, 2007: Quality of life in the economic and urban economic literature. *Social Indicators Research,* **84(1)**, 1-25.

Layton, D. and G. Brown, 2000: Heterogeneous preferences regarding global climate change. *Review of Economics and Statistics,* **82(4)**, 616-624.

Layton, D. F. and R. Levine, 2003: How much does the future matter? A hierarchical Bayesian analysis of the public's willingness to mitigate ecological impacts of climate change. *Journal of the American Statistical Association,* **98(463)**, 533-544.

Lenihan, J.M., R. Drapek, and R. Neilson, 2006: Terrestrial ecosystem changes. In: *The Impact of Climate Change on Regional Systems. A Comprehensive Analysis of California*. [J.B. Smith and R. Mendelsohn (eds.)]. Edward Elgar, Northampton, Massachusetts.

Lindell, M. K., and R. W. Perry, 2004: *Communicating Environmental Risk in Multiethnic Communities*. Sage, Thousand Oaks, California.

Lipp, E.K. and J.B. Rose, 1997: The role of seafood in foodborne diseases in the United States of America. *Revue Scientifique et Technique,* **16**, 620-640.

Liu, X., A. Vedlitz and L. Alston, 2008: Regional news portrayals of global warming and climate change. *Environmental Science and Policy.* Advance online publication: doi:10.1016/j.envsci.2008.01.002 (published online 4 March 2008).

Loomis, J. and R. Richardson, 2006: An external validity test of intended behavior: Comparing revealed preference and intended visitation in response to climate change. *Journal of Environmental Planning and Management,* **49(4)**, 621-630.

Loomis, J., P. Kent, L. Stange, K. Fausch, and A. Covich, 2000: Measuring the total economic value of restoring ecosystem services in an impaired river basin: Results from a contingent valuation survey. *Ecological Economics,* **33**, 103-117.

Loomis, J. and J. Crespi, 1999: Estimated effects of climate change on selected outdoor recreation activities in the United States. In: *The Impact of Climate Change on the United States Economy* [Mendelsohn, R. and J. Neumann (eds.)]. Cambridge University Press, Cambridge, UK, pp. 289-314.

MA, 2005: *Millennium Ecosystem Assessment: Ecosystems and Human Well-being – Synthesis*. Island Press, Washington, DC.

MacKenzie, W.R., W.L. Schell, K.A. Blair, D.G. Addiss, D.E. Peterson, N.J. Hoxie, J.J. Kazmierczak, and J.P. Davis, 1994: A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *New England Journal of Medicine,* **331(3)**, 161-167.

MacMillan, D., E.I. Duff, and D. Elston, 2001: Modelling the non-market environmental costs and benefits of biodiversity projects. *Environmental and Resource Economics,* **18**, 391-401.

Malcolm, J.R., and L.F. Pitelka. 2000. *Ecosystems and Global Climate Change*. Pew Center on Global Climate Change, Washington, DC.

Martens, W.J.M., 1998: Climate change, thermal stress and mortality changes. *Social Science and Medicine*, **46(3)**, 331-344.

McMichael, A.J., D. Campbell-Lendrum, R.S. Kovats, S. Edwards, P. Wilkinson, N. Edmonds, N. Nicholls, S. Hales, F.C. Tanser, D. Le Sueur, M. Schlesinger, and N. Andronova, 2004: Global Climate Change. In: *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factor: Volume 2* [Ezzati

M., A. Rodgers, and C. J. Murray (eds.)]. World Health Organization, Geneva, pp. 1543–1649.

McMichael, A.J. and A. Githeko, 2001: Human health. In: *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA, pp. 453-485.

Melillo, J., A. Janetos, D. Schimel, and T. Kittel, 2001: Vegetation and biogeochemical scenarios. In: *Climate Change Impacts on the United States. The Potential Consequences of Climate Variability and Change*. Report for the US Global Change Research Program, Cambridge University Press, Cambridge, UK.

Mendelsohn, R., 2001: A hedonic study of the non-market impacts of global warming in the US. In: *The Amenity Value of the Global Climate* [Maddison, D. (ed.)]. Earthscan, London, pp. 93-105.

Mendelsohn, R. and J.E. Neumann, 1999: *The Impact of Climate Change on the United States Economy*. Cambridge University Press, Cambridge, UK.

Mendelsohn, R. and M. Markowski, 1999: The impact of climate change on outdoor recreation. In: *The Impact of Climate Change on the United States Economy* [Mendelsohn, R. and J. Neumann (eds.)]. Cambridge University Press, Cambridge, UK, pp. 267-288.

Meyer, J.L., M.J. Sale, P.J. Mulholland, and N.L. Poff, 1999: Impacts of climate change on aquatic ecosystem functioning and health. In: *Potential Consequences of Climate Variability and Change to Water Resources of the United States* [D.B. Adams (ed).]. Conference papers 10-12 May 1999, Atlanta, GA.

Mileti, D.S., 1999: *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Joseph Henry Press, Washington, DC.

Moore, T., 1998: Health and amenity effects of global warming. *Economic Inquiry,* **36(3)**, 471–488.

Morris, M. (ed.), 2006: *Integrating Planning and Public Health: Tools and Strategies to Create Healthy Places*. American Planning Association, Washington, DC.

Morris, R.E., M.S. Gery, M.K. Liu, G.E. Moore, C. Daly, and S.M. Greenfield, 1989: Sensitivity of a regional oxidant model to variations in climate parameters. In: *The Potential Effects of Global Climate Change on the United States* [J.B.Smith and D.A.Tirpak (eds.)]. U.S. EPA, Office of Policy, Planning and Evaluation, Washington, DC.

Multihazard Mitigation Council, 2005: *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities*. National Institute of Building Sciences, Washington, DC.

Murphy, C. and P. Gardoni, 2008: The acceptability and the tolerability of societal risks: a capabilities-based approach. *Science and Engineering Ethics*, **14(1)**, 77-92.

National Research Council, 2004: *Valuing Ecosystem Services: Toward Better Environmental Decision-Making.* Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems, The National Academies Press, Washington, DC.

Ng, Y.K., 2003: From preferences to happiness: toward a more complete welfare economics. *Social Choice and Welfare*, **20**, 307-350.

Nordhaus, W. and J. Boyer, 2000: *Warming the World: Economic Modeling of Global Warming.* MIT Press, Cambridge, Massachusetts.

Nordhaus, W., 1994: *Managing the Global Commons: The Economics of Climate Change.* MIT Press, Cambridge, Massachusetts.

Northbridge, M., E. Sclar, and P. Biswas, 2003: Sorting the connections between built environment and health: a conceptual framework for navigating pathways and planning healthy cities. *Journal of Urban Health,* **80(4)**, 556-568.

Oechel, W.C., S.J. Hastings, G. Vourlitis, and M. Jenkins, 1993: Recent change of arctic tundra ecosystems from net carbon dioxide sink to a source. *Nature,* **361**, 520-523.

Oechel, W.C., G.L. Vourlitis, S.J. Hastings, R.C. Zulueta, L. Hinzman, and D. Kane, 2000: Acclimation of ecosystem CO_2 exchange in the Alaska Arctic in response to decadal warming. *Nature,* **406**, 978-981.

Parmesan, C., and H. Galbraith, 2004: *Observed Impacts of Global Climate Change in the U.S.* Pew Center on Global Climate Change, Arlington, Virginia.

Parmesan, C., and G. Yohe, 2003: A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421**, 37-42.

Parmesan, C., 1996: Climate and species' range. *Nature,* **382**, 765-766.

Patz, J.A., M.A. McGeehin, S.M. Bernard, K.L. Ebi, P.R. Epstein, A. Grambsch, D.J. Gubler, P. Reiter, I. Romieu, J.B. Rose, J.M. Samet, and J. Trtanj, 2001: The potential health impacts of climate variability and change for the United States: executive summary of the report of the health sector of the U.S. National Assessment. *Journal of Environmental Health*, **64**, 20–28.

Peacock, W.G., 2003: Hurricane mitigation status and factors influencing mitigation status among Florida's single-family homeowners. *Natural Hazards Review*, **4(3)**, 1-10.

Pendleton, L.H. and R. Mendelsohn, 1998: Estimating the economic impact of climate change on the freshwater sportsfisheries of the Northeastern U.S. *Land Economics*, **74(4)**, 483-96.

Peters, R.L., and T.E. Lovejoy, 1992: *Global Warming and Biological Diversity*. Yale University Press, New Haven, Connecticut.

Pileus Project, Which factors are typically believed to have the greatest influence on tourists' behaviors? *Pileus Project: Climate Science for Decision Makers*. Retrieved May 28, 2008, from http://www.pileus.msu.edu/tourism/tourism_influencefactor.htm

Pimentel, D., C. Wilson, C. McCullum, R. Huang, P. Dwen, J. Flack, Q. Tran, T. Saltman, and B. Cliff, 1997: Economic and environmental benefits of biodiversity. *Bioscience*, **47(11)**, 747-757.

Ponting, C., 1991: *A Green History of the World: The Environment and the Collapse of Great Civilizations*. Penguin, New York.

Porter, D. (ed.), 2000: *The Practice of Sustainable Development*. Urban Land Institute, Washington, DC.

Putnam, R., 2000: *Bowling Alone: The Collapse and Revival of American Community*. Simon and Schuster, New York.

Putnam, R., 1995: Tuning in, tuning out: the strange disappearance of social capital in America, *Political Science and Politics*, **28(4)**, 664-683.

Putnam, R., 1993: *Making Democracy Work: Civic Traditions in Modern Italy*. Princeton University Press, Princeton, New Jersey.

Rahman, T., 2007: Measuring the well being across countries. *Applied Economic Letters*, **14(11)**, 779-783.

Raphael, D., R. Renwick, I. Brown, and I. Rootman, 1996: Quality of life and health: current status and emerging conceptions. *Social Indicators Research*, **39**, 65-88.

Raphael, D., B. Steinmetz, R. Renwick, I. Rootman, I. Brown, H. Sehdev, S. Phillips, and T. Smith, 1999: The community quality of life project: a health promotion approach to understanding communities. *Health Promotion International*, **14(3)**, 197-210.

Raphael, D., R. Renwick, I. Brown, B. Steinmetz, H. Sehdevc, and S. Phillips, 2001: Making the links between community structure and individual well-being: community quality of life in Riverdale, Toronto, Canada. *Health & Place*, **7**, 179-196.

Roback, Jennifer, 1988: Wages, rents, and amenities: differences among workers and regions. *Economic Inquiry,* **26(1)**, 23-41.

Roback, Jennifer, 1982: Wages, rents, and the quality of life. *Journal of Political Economy*, **90(6)**, 1257-1279.

Root, T.L, J.T. Price, K.R. Hall, S.H. Schneider, C. Rozensweig, and J.A. Pounds, 2003: Fingerprints of global warming on wild animals and plants. *Nature,* **421**, 57-60.

Rose, A., K. Porter, N. Dash, J. Bouabid, C. Huyck, J.C. Whitehead, D. Shaw, R.T. Eguchi, C. Taylor, T.R. McLane, L.T. Tobin, P.T. Ganderton, D. Godschalk, A.S. Kiremidjian, and K. Tierney, and C.T. West, 2007: Benefit-cost analysis of FEMA hazard mitigation grants. *Natural Hazards Review,* **8(4)**, 97-111.

Rose, A., 2004: Defining and measuring economic resilience to disasters. *Disaster Prevention and Management*, **13**, 307-314.

Rosenberger, R. and J. Loomis, 2003: Benefit transfer. In: *A Primer on Non Market Valuation* [Champ, P., K. Boyle, and T. Brown (eds.)]. Kluwer Academic Publishers, Boston, Massachusetts, pp 445-482.

Ross, M.S., J.J. O'Brien, L. Da Silveira, and L. Sternberg, 1994: Sea-level rise and the reduction in pine forests in the Florida Keys. *Ecological Applications,* **4**, 144-156.

Rothman, D.S., B. Amelung, and P. Poleme, 2003: *Estimating non-market impacts of climate change and climate policy.* Prepared for OECD Workshop on the Benefits of Climate Policy, Improving Information for Policy Makers. Available at www.oecd.org/dataoecd/6/30/2483779.pdf.

Roy, D.B., and T.H. Sparks, 2000: Phenology of British butterflies and climate change. *Global Change Biology,* **6**, 407-416.

Sagarin, R.D., J.P. Barry, S.E. Gilman, and C.H. Baxter, 1999: Climate-related change in an intertidal community over short and long time scales. *Ecological Monographs*, **69**, 465-490.

Saunders, S. and T. Easley, 2006: *Losing ground: Western National Parks Endangered by Climate Disruption.* Rocky Mountain Climate Organization and Natural Resources Defense Council, New York.

Scott, D., G. Wall, G. McBoyle, 2005: The evolution of the climate change issue tourism sector. In: *Tourism, Recreation and Climate Change* [Hall, C.M. and J. Higham (eds.)]. Channel View Publications, Buffalo, New York, pp. 44-62.

Scott, D. and B. Jones, 2005: *Climate Change and Banff National Park: Implications for Tourism and Recreation.* Faculty of Environmental Studies, University of Waterloo, Waterloo, Canada.

Scott, D., G. McBoyle and A. Minogue, 2006: Climate Change and the Sustainability of Ski-based Tourism in Eastern North America: A Reassessment. *Journal of Sustainable Tourism*, **14(4)**, 376-398.

Scott, D., B. Jones, and J. Konopek. 2007. Implications of Climate and Environmental Change for Nature-Based Tourism in the Canadian Rocky Mountains. *Tourism Management*, **28(2)**, 570-579.

Semenza, J.C., C.H. Rubin, and K.H. Falter, 1996: Heat-related deaths during the July 1995 heat wave in Chicago. *New England Journal of Medicine*, **335(2)**, 84-90.

Shaw, D., 2005: *Water Resource Economics and Policy*. Edward Elgar Publishing, Northampton, Massachusetts.

Sillman, S. and P.J. Samson, 1995: Impact of temperature on oxidant photochemistry in urban, polluted, rural, and remote environments. *Journal of Geophysical Research*, **100**, 11,497-11,508.

Smit, B, and O. Pilifosova, 2001: Adaptation to climate change in the context of sustainable development and equity. In: *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA.

Smith, J.B., J.K. Lazo, and B. Hurd, 2003: The difficulties of estimating global non-market damages from climate change. In: *Global Climate Change: The Science, Economics, and Politics* [Griffin, J.M. (ed.)]. Edward Elgar, Northampton, Massachusetts.

Smith, V.K., 1983: The role of site and job characteristics in hedonic wage models. *Journal of Urban Economics*, **13(3)**, 296-321.

Strzepek, K.M., and J.B. Smith (eds.), 1995: *As Climate Changes: International Impacts and Implications.* Cambridge University Press, Cambridge, UK.

Strzepek, K., D. Major, C. Rosenzweig, A. Iglesias, D. Yates, A. Holt, and D. Hillel, 1999: New methods of modeling water availability for agriculture under climate change: the U.S. Corn Belt. *Journal of the American Water Resources Association*, **35(6)**, 1639-1656.

Sufian, A.J.M., 1993: A multivariate analysis of the determinants of urban quality of life in the world's largest metropolitan areas. *Urban Studies*, **30(8)**, 1319-1329.

Tainter, J., 1998: *The Collapse of Complex Societies*. Cambridge University Press, Cambridge, UK.

Tierney, K., 1997: Impacts of recent disasters on businesses: the 1991 Midwest floods and the 1994 Northridge earthquake. In: *Economic Consequences of Earthquakes: Preparing for the Unexpected* [B. Jones (ed.)]. National Center for Earthquake Engineering Research, Buffalo, New York.

Tol, R.S.J., 2005: The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. *Energy Policy*, **33(16)**, 2064-2074.

Tol, R.S.J., 2002: Welfare specifications and optimal control of climate change: an application of fund. *Energy Economics,* **24**, 367-376.

Toman, M.A. 1998: Why not calculate the value of the world's ecosystem services and natural capital? *Ecological Economics,* **25**, 57-60.

U.S. EPA, 2000: *Guidelines for Preparing Economic Analyses*. EPA 240-R-00-003, Washington, DC.

U.S. EPA, 1997: *The Benefits and Costs of the Clean Air Act, 1970-1990.* Report to Congress, Washington DC.

U.S. EPA. 1995. *Ecological Impacts from Climate Change: An Economic Analysis of Freshwater Recreational Fishing.* EPA 220-R-95-004. Washington DC.

U.S. EPA, 1989: *The Potential Effects of Global Climate Change on the United States*. J.B. Smith and D.A.Tirpak (eds.). EPA-230-05-89-050, Washington, DC.

Vaughan, **W.J.** and C.S. Russell, 1982: *Freshwater Recreational Fishing: The National Benefits of Water Pollution Control*. Resources for the Future, Washington DC.

Vedlitz, A., L.T. Alston, S.B. Laska, R.B. Gramling, M.A. Harwell and H.D. Worthen, 2007: *Use of Science in Gulf of Mexico Decision Making Involving Climate Change.* Project Final Report, Prepared for the U.S. Environmental Protection Agency under Cooperative Agreement No. R-83023601-0.

Veenhoven, R., 1988: The utility of happiness. *Social Indicators Research*, **20**, 333-354.

Veenhoven, R., 1996: Happy life-expectancy, a comprehensive measure of quality of life in nations. *Social Indicators Research,* **39**, 1-58.

Veenhoven, R., 2000: The four qualities of life. *Journal of Happiness Studies*, **1**, 1-39.

VEMAP Members, 1995: Vegetation/ecosystem modeling and analysis project: comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. *Global Biogeochemical Cycles,* **9**, 407-437.

Viscusi, W.K. and J. Aldy, 2007: Labor market estimates of the senior discount for the calue of statistical life. *Journal of Environmental Economics and Management,* **53**, 377-392.

Viscusi, W.K., 1993: The value of risks to life and death. *Journal of Economic Literature*, **31(4)**, 1912-1946.

Wall, G., 1998: Implications of global climate change for tourism and recreation in wetland areas. *Climate Change,* **40**, 371-389.

Wang, G., N.T. Hobbes, H. Galbraith, D.S. Ojima, K.M. Giesen, 2002: Signatures of large-scale and local climates on the demography of white-tailed ptarmigan in Rocky Mountain National Park, Colorado, USA. *International Journal of Biometeorology,* **46**, 197-201.

Warren, R., C. Hope, M. Mastrandrea, R. Tol, N. Adger, and I. Lorenzoni, 2006: *Spotlighting impacts functions in integrated assessment.* Research report prepared for the Stern review on the economics of climate change by the Tyndall Centre for Climate Change Research, Working paper 91, Norwich, UK.

Warren, R.S., and W.A. Niering, 1993: Vegetation change on a northeast tidal marsh: interaction of sea-level rise and marsh accretion. *Ecology,* **74**, 96–103.

Weniger, B.G., M.J. Blaser, J. Gedrose, E.C. Lippy, and D.D. Juranek, 1983: An outbreak of waterborne giardiasis associated with heavy water runoff due to warm weather and volcanic ashfall. *American Journal of Public Health,* **73(8)**, 868-872.

Woodward, R.T. and Y.S. Wui, 2001: The economic value of wetland services: a meta-analysis. *Ecological Economics,* **37**, 257-270.

World Health Organization, 1997: *City Planning for Health and Sustainable Development.* European Sustainable Development and Health Series: 2.

Yohe, G., J. Neumann, and P. Marshall, 1999: The economic damage induced by sea level rise in the United States. In: *The Impact of Climate Change on the United States Economy*. [Mendelsohn, R. and J. Neumann (eds).]. Cambridge University Press, Cambridge, UK, pp. 178-208.

Zahran, S., S. Brody, A. Vedlitz, H. Grover, and C. Miller, 2008. Vulnerability and capacity: explaining local commitment to climate change policy. *Environment and Planning C: Government and Policy*, **26(3)**, 544-562.

4.7 Appendix 1:

Chapter 4: Human Welfare
Economic Valuation: An Introduction to Techniques and Challenges

Assessments of the benefits and costs, whether explicit or tacit, underlie all discussion and debates over alternative actions regarding climate change. These assessments are frequently used to inform such questions as: What actions are justified to ease adaptation to changing climate? Or how much are we willing to pay to reduce emissions? (Jacoby, 2004). Ideally, such analyses would be undertaken with complete and reliable information on benefits, converted into a common unit, commensurable with costs and with each other (Jacoby, 2004). In reality, however, while many impacts can be valued, some linkages from climate change to welfare effects are difficult to quantify, much less value. This appendix describes the steps in developing a benefits estimate, and the tools that economists have available for monetizing benefits. It also briefly discusses some of the challenges in monetizing benefits, and weaknesses in the approach.

Estimating the Effects of Climate Change

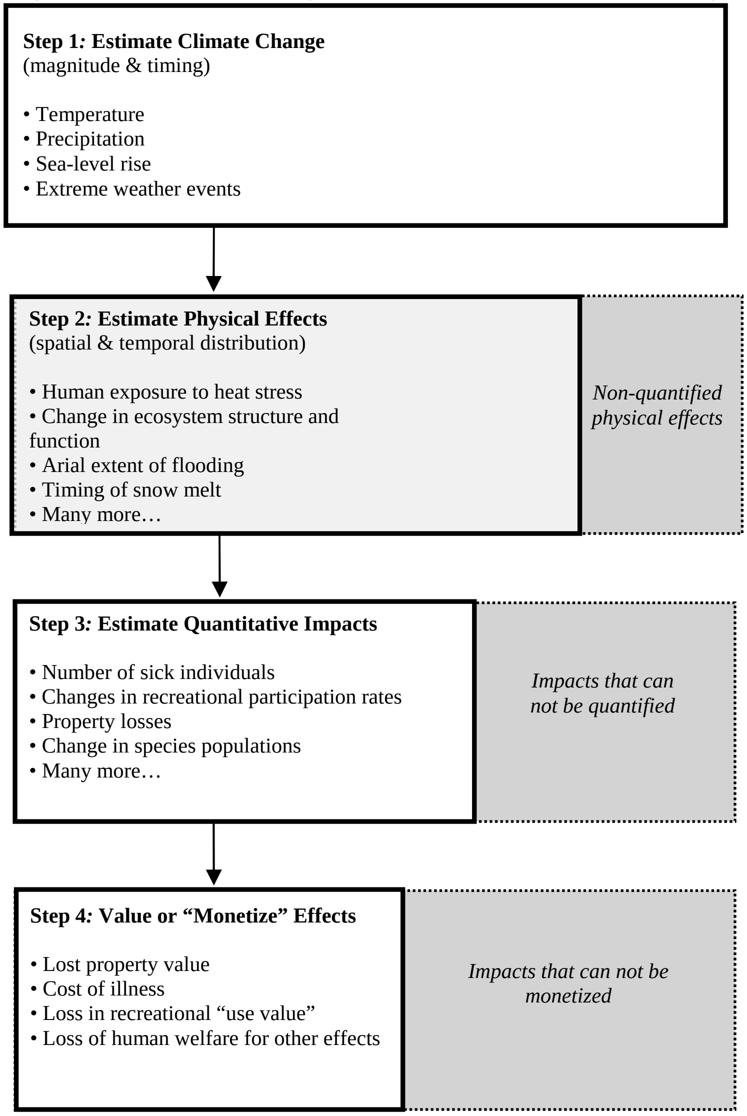
The process of estimating the effects of climate change, including effects on human welfare, involves up to four steps, illustrated in Figure 4A.1. Moving down from the top of Figure 4A.1, the gray area occupies a larger portion of each box, indicating (in rough terms) that at each stage it is more and more difficult to develop quantified, rather than qualitative, results. The first step is to estimate the change in relevant measures of climate, including temperature, precipitation, sea-level rise, and the frequency and severity of extreme events. This step is usually accomplished by atmospheric scientists - some form of global circulation model (GCM) is typically deployed. Some analyses stop after this step.

The second step involves estimating the physical effects of those changes in climate in terms of qualitative changes in human and natural systems. These might include changes in ecosystem structure and function, human exposures to heat stress, changes in the geographic range of disease vectors, melting of snow on ski slopes, or flooding of coastal areas. A wide range of disciplines might be involved in carrying out those analyses, deploying an equally wide range of tools. Many analyses are complete once this step is completed - for example, we may be unable to say anything more than that increases in precipitation will change an ecosystem's function.

The third step involves translating the physical effects of changes in climate into metrics indicating quantitative impacts. If the ultimate goal is monetization, ideally these measures should be amenable to valuation. Examples include quantifying the number and location of properties that are vulnerable to floods, estimating the number of individuals exposed to and sensitive to heat stress, or estimating the effect of diminished migratory bird populations on bird-watching participation rates. Many analyses that reach this step in the process, but not all, also proceed on to the fourth step.

The fourth step involves valuing or monetizing the changes. The simplest approach would be to apply a unit valuation approach; for example, the cost of treating a nonfatal case of heat stress or malaria attributable to climate change is a first approximation of the value of avoiding that case altogether. In many contexts, however, unit values can misrepresent the true marginal economic impact of these changes. For example, if climate change reduces the length of the ski season, individuals could engage in another recreational activity, such as golf. Whether they might prefer skiing to golf at that time and location is something economists might try to measure.

Figure 4A.1 Estimating the Effects of Climate Change



This step-by-step linear approach to effects estimation is sometimes called the "damage function" approach. One practical advantage of the damage function approach is the separation of disciplines—scientists can complete their work in steps 1 and 2, and sometimes in step 3, and then economists do their work in step 4. The linear process can work well in cases where individuals respond and change their behavior in response to changes in their environment, without any "feedback" loop.

The linear approach is not always appropriate, however. A damage function approach might imply that we look at effects of climate on human health as separate and independent from effects on ecology and recreation, but at some level they are inter-related, as health care and recreation both require resources in the form of income. In addition, responding to heat stress by installing air conditioning leads to higher energy demand, which in turn may increase greenhouse gas emissions and therefore contribute to further climate change. Recent research suggests that the damage function approach, under some conditions, may be both overly simplistic (Freeman, 2003) and subject to serious errors (Strzepek *et al.*, 1999; Strzepek and Smith, 1995).

Monetizing and Valuing Non-Market Goods

Economists have developed a suite of methods to estimate willingness to pay for non-market goods (see text for a discussion of the market vs. non-market distinction). These methods can be grouped into two broad categories, based largely on the source of the data: revealed preference and stated preference approaches (Freeman, 2003; U.S. EPA, 2000). Revealed preference, sometimes referred to as the indirect valuation approach, involves inferring the value of a non-market good using data from market transactions. For example, a lake may be valued for its ability to provide a good fishing experience. This value can be estimated by the time and money expended by the angler to fish at that particular site, relative to all other possible fishing sites. Or, the amenity value of a coastal property that is protected from storm damage (by a dune, perhaps) can be estimated by comparing the price of that property to other properties similar in every way but the enhanced storm protection.

Stated And Revealed Preference Approaches

Accurate measurement of the non-market amenity of interest, in a manner that is not inconsistent with the way market participants perceive the amenity, is critical to a robust estimate of value.

Revealed preference approaches include recreational demand models, which estimate the value of recreational amenities through time and money expenditures to enjoy recreation; hedonic wage and hedonic property value models, which attempt to isolate the value of particular amenities of property and jobs not themselves directly traded in the marketplace based on their price or wage outcomes; and averting behavior models, which estimate the value of time or money expended to avert a particular bad outcome as a measure of its negative effect on welfare.

Stated preference approaches, sometimes referred to as ***direct valuation*** approaches, are survey methods that estimate the value individuals place on particular non-market goods based on choices they make in hypothetical markets.[34] The earliest stated preference studies involved simply asking individuals what they would be willing to pay for a particular non-market good. The best studies involve great care in constructing a credible, though still hypothetical, trade-off between money and the non-market good of interest to discern individual preferences for that good and hence, willingness to pay (WTP). For example, economists might construct a hypothetical choice between multiple housing locations, each of which differs along the dimensions of price and health risk. Repeated choice experiments of this type ultimately map out the individual's tradeoff between money and the non-market good. The major challenges in stated preference methods involve study design, particularly the construction of a reasonable and credible market for the good, and estimation of a valuation function from the response data.

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[34] The contingent valuation method (CVM), or a modern variants, a stated choice model (SCM), are forms of the stated preference methods.

In theory, if individuals understand the full implications of their market choices, in real or constructed markets, then both revealed and stated preference approaches are capable of providing robust estimates of the total value of non-market goods. When considering the complex and multidimensional implications of climate change in the application of revealed and stated preference approaches, it can be extraordinarily challenging to ensure that individuals are sufficiently informed that their observed or stated choices truly reflect their preferences for a particular outcome. As a result, these methods are most often applied to a narrowly defined non-market good, rather than to a complex bundle of non-market goods that might involve multiple tradeoffs and synergistic or antagonistic effects that would be difficult to disentangle.

In addition to market or non-market goods that reflect some use of the environment, value can arise even if a good or service is not explicitly consumed, or even experienced. For example, very few individuals would value a polar bear for its ability to provide sustenance - those who do might not express that value through a direct market for polar bear meat, but by hunting for the bear. Whether through a market or in a non-market activity, those individuals have value for a consumptive use—once enjoyed, that good is no longer available to others to enjoy. In addition to the consumptive users, a small but somewhat larger number of individuals might travel to the Arctic to see a polar bear in its natural environment. These individuals might express a value for polar bears, and their "use" of the bear is non-consumptive, but in some sense it does nonetheless affect others' ability to view the bear—if too many individuals attempt to view the bears, the congestion might cause the bears to become frightened or, worse, domesticated, diminishing the experience of viewing them.

A third, perhaps much larger group of individuals will never travel to see a polar bear in the flesh. But many individuals in this group would experience some diminishment in their overall quality of life if they knew that polar bears had become extinct. This concept is called "***non-use value***". Although there are several categories of non-use value - some individuals may wish to preserve the future option to visit the Arctic and see a bear, others to bequeath a world with polar bears to future generations, and others might value the mere existence of the bears out of a sense of environmental stewardship. While not all economists agree that non-use values ought to be relevant to policy decisions (Diamond and Hausman, 1993), there is broad agreement that they are difficult to measure, because the expression of non-use values does not result in measurable economic behavior (that is, there is no "use" expressed). Those that recognize non-use values acknowledge that they are likely to be of greatest consequence where a resource has a uniqueness or "specialness" and loss or injury is irreversible, for example in the global or local extinction of a species, or the distribution of a unique ecological resource (Freeman, 2003).

Other Methods of Monetizing

Analysts can employ other non-market valuation methods: avoided cost or replacement cost, and input value estimates. These methods do not measure willingness to pay as defined in welfare economic terms, but because the methods are relatively straightforward to apply and the results often have a known relationship to willingness to pay, they provide insights into non-market values. This chapter focuses on willingness to pay measures, but recognizes that alternative methods may provide insights and sometimes be more manageable (or appropriate) to estimate a particular non-market value, given data constraints and the limitations imposed by available methods.

Cost of illness studies estimate the change in health expenditures resulting from the change in incidence of a given illness. Direct costs of illness include costs for hospitalization, doctors' fees, and medicine, among others. Indirect costs of illness include effects such as lost work and leisure time. Complete cost of illness estimates reflect both direct and indirect costs. Even the most complete cost of illness estimates, however, typically underestimate willingness to pay to avoid incidence of illness, because they ignore the loss of welfare associated with pain and suffering and may not reflect costs of averting behaviors the individuals have taken to avoid the illness. Some studies suggest that the difference between cost of illness and willingness to pay can be large, but the difference varies greatly across health effects and individuals (U.S. EPA, 2000).

Replacement cost studies approach non-market values by estimating the cost to replace the services provided to individuals by the non-market good. For example, healthy coastal wetlands may provide a wide range of services to individuals who live near them; they may filter pollutants present in water; absorb water in times of flood; act as a buffer to protect properties from storm surges; provide nursery habitat for recreational and commercial fish; and provide amenities in the form of opportunities to view wildlife. A replacement cost approach would estimate the value of these services by estimating market costs for treating contaminants, containing floods, providing fish from hatcheries, or perhaps restoring an impaired wetland to health.

The replacement cost approach is limited in three important ways: 1) the cost of replacing a resource does not necessarily bear any relation to the welfare enhancing effect of the resource; 2) as resources grow scarce, we would expect their value would be underestimated by an average replacement cost; 3) Complete replacement of ecological systems and services may be highly problematic. Replacement cost studies are most informative in those conditions where loss of the resource would certainly and without exception trigger the incidence of replacement costs - in reality, those conditions are not as common as they might seem, because in most cases there are readily available substitutes for those services, even if accessing them involves incurring some transition costs.

Finally, value can also be calculated using the contribution of the resource as an input into a productive process. This approach can be used for both market and non-market inputs. For example, it can be used to estimate the value of fertilizer, as well as water or soil, in farm output and profits. An ecosystem's service input into a productive process could, in theory, be used in this same way.

Issues in Valuation and Aggregation

The topic of issues in valuation is far larger than can be covered here. We focus only on identifying in a superficial way a few of the most important issues, in the context of climate change.

By virtue of the simple process of aggregation, the economic approach creates some difficulties. These difficulties are not specific to the economic approach, however; any method of aggregation would face the same limitations.

- Aggregation, by balancing out effects to produce a “net” effect, masks the positive and negative effects that comprise net effects, hides inequities in the distribution of impacts, or large negative impacts that fall on particular regions or vulnerable populations.
- Any method of aggregation must make an explicit assumption about how to aggregate over time, *i.e.,* whether to weight future benefits the same as current benefits (economic analyses generally discount the future, *i.e.,* weight it less heavily in decision making than the present, for a number of reasons)
- The method of putting diverse impacts on the same yardstick ignores differences in how we may wish to treat these impacts from a policy perspective, and assumes that all impacts are equally certain or uncertain, despite differences in estimation and valuation methods. These differences may be particularly apparent, for example, for non-market and market goods.

Several potential criticisms of the economic approach in the context of climate change relate more directly to how economists approach the task of valuation. One issue is the assumption of stability of preferences over time. Economic studies conducted today, whether revealed or stated preference, reflect the actions and preferences of individuals today, expressed in today’s economic, social, and technological context. For an issue such as climate change, however, impacts may occur decades or centuries hence. The valuation of impacts that occur in the future should depend on preferences in the future. For the most part, however, while there are some rudimentary ways in which economists model changes in technology or income, there is no satisfactory means of modeling changes in preferences over time.

A second issue is the treatment of uncertainty. Economic analysis under conditions of imperfect information and uncertainty is possible, but is one of the most difficult undertakings in economics. While some climate change impacts may be relatively straight-forward, valuation of many climate change impacts requires analysis and use of welfare measures that incorporate uncertainty. When imperfect information prevails, the valuation measure must factor in errors that arise because of it, and when risk or uncertainty prevail, the most commonly used valuation measure is the option price. Two related concepts are option value, and expected consumer’s surplus. All three concepts are more complicated than the discussion here can do justice to, but briefly:

- Expected consumer’s surplus, E[CS] is just consumer’s surplus (CS), or value in welfare terms, weighted by the probabilities of outcomes that yield CS. For example, if a hiker gets $5 of CS per year in a “dry” forest and $10 in a wet forest (one that is greener) and the probability of the forest being dry is 0.40 and of it being wet is 0.60, then the E[CS] = 0.40 X $5 + 0.60 X $10. Expected consumer’s surplus is really an ex-post concept, because we must know CS in each state after it occurs.
- Option price (OP) is the WTP that balances expected utility (utility weighted by the probabilities of outcomes) with and without some change. It is a measure of WTP the individual must express before outcomes can be known with certainty, *i.e.,* a true ex ante welfare measure. For example, the hiker might be willing to pay $8 per year to balance her expected utility with conditions being wet, versus conditions being dry. The $8 might be a payment to support a reduction in dryness otherwise due to climate change.

- Option value (OV) is the difference between OP and E[CS]. A related concept is called quasi-option value and pertains to the value of waiting to get more information.

A third issue concerns behavioral paradoxes. Most economic analyses, particularly if they involve uncertain or risky outcomes, require rationality in the expression of preferences. Such basic axioms as treating gains and losses equally, reacting to a series of small incremental gains with equal strength to a single large gain of the same aggregate magnitude, and viewing gains and losses from an absolute rather than relative or positional scale are particularly important to studies that rely on expected utility theory - that individuals gain and lose welfare in proportion to the product of the likelihood of the gain or loss and its magnitude. Several social and psychological science studies, however, suggest that under many conditions individuals do not behave in a manner consistent with this definition of rationality. For example, prospect theory, often credited as resulting from the work of Daniel Kahneman and Amos Tversky, suggests that behavior under risk or uncertainty is better explained both by reference to a status quo reference point and acknowledgement of unequal treatment of risk aversion when considering losses and gains, even when it can be shown that a different behavior would certainly make the individual better off.

Finally, the issue of perspective—“whose lens are we looking through"—is critical to welfare analysis, particularly economic welfare. In health policy, for example, thinking about whether it is worthwhile to invest in mosquito netting to control malaria depends on whether you are at CDC, are a provider of health insurance, or are an individual in a place where malaria risk is high. In general, the perspective of valuation focuses on the valuation of individuals who are directly affected, and who are living today. The perspectives of public decision makers may be somewhat different from those of individuals, since they will take into account social and community consequences, as well as individual consequences.

4.8 Boxes

Box 4.1 Effects of Climate Change on Selected US Ecosystems

At their most extreme, community changes could result in the loss of entire habitats valued by the general public. For example, sea level rise puts much of the freshwater wetland that comprises Florida Everglades National Park at risk (Glick and Clough, 2006). Even relatively modest sea level rise projections could result in the conversion of much of this low-lying area to brackish or intertidal marine and mangrove habitats. Another such extreme example is alpine tundra habitat in mountain ranges in the contiguous states. Since tundra lies at the highest elevations, there is little or no opportunity for the plants and animals that comprise this ecosystem to respond to increasing temperatures by moving upward. Thus, one of the probable effects of climate change will be the further fragmentation and loss of this unique habitat (VEMAP, 1995; Root *et al.*, 2003; Lenihan *et al.*, 2006).

California already reports an example of how climate change might modify major marine ecological communities. Over the final four decades of the 20th century the average annual ocean surface temperature off the California coast warmed by approximately 1.5°C (Holbrook *et al.*, 1997). Sagarin *et al.* (1999) found that the intertidal invertebrate community at Monterey has changed since first it was characterized in the 1930s. Many of the coolwater species have retracted their ranges northward, to be replaced by southern warm water species. The community that exists there now is markedly different in its make-up from that which existed prior to warming of the coastal California Current.

Box 4.2 Case Study of the Effects of Climate Change on Rocky Mountain National Park

One of the National Parks most closely studied to determine the net effect of direct and indirect effect of climate change on visitation, visitor benefits and tourism employment is Rocky Mountain National Park (RMNP) in Colorado. This alpine national park is located at elevations ranging from 7,000 to 14,000 feet above sea level. It is known for elk viewing, hiking, tundra flowers, snowcapped peaks, and one of Colorado's most visible and recognizable 14,000 foot peaks, Longs Peak.

Loomis and Richardson (2006) compared two approaches to estimating the effect of climate change on visitation and employment in RMNP. The first approach examined variations in monthly visitation in response to historic variations in temperature. The results of this first approach showed a statistically significant positive effect of temperature on visitation (see Loomis and Richardson (2006) for more details). However, increased visitation slowed as temperatures got hotter and hotter, and visitation even declined during one summer of very high temperatures (60 days over 80°F) by 7.5%.

The second approach used a survey that portrayed the direct effects (*e.g.*, temperature) and indirect effects (*e.g.*, changes in elk and ptarmigan (an alpine bird), or percent of the park in tundra). Visitors were then asked to indicate if they would change their visits to RMNP or length of stay in the park. The surveys used three climate change scenarios, one produced by the Canadian Climate Center (CCC) indicating a 4°F increase in temperature by 2020, a Hadley climate scenario that forecasted a 2°F temperature increase by 2020, and an extreme heat scenario designed to capture very hot future conditions (50 days with temperatures above 80°F, as compared to 3 days currently). All climate change scenarios were used with wildlife models to estimate the increase in elk populations and decrease in ptarmigan populations. The extreme heat survey found similar results to that of the monthly visitation model.

Table 4.6 shows the results of the CCC, Hadley, and Extreme Heat temperature scenarios on visitation, visitor benefits and tourism employment as compared to current conditions. As indicated in the table, applying visitor survey estimates of visitation change yields a 13.6% increase with CCC and 9.9% increase with Hadley. Loomis and Richardson also report that applying the historic visitation patterns to the same scenarios yields an 11.6% increase in visitation with CCC and 6.8% with Hadley. Not only is there fairly good agreement between the two methods, but the warmer CCC climate change scenario produces larger increases in visitation. In the extreme heat scenario, however, visitations declines from current conditions.

4.9 Tables

Table 4.1 Categorization of Well-Being

Category of Well-being	Description and Rationale	Components / Indicators of Well-being	Illustrative Metrics / Measures of Well-being	Examples of Negative Climate Linkages*
Economic conditions	The economy supports a mix of activities: opportunities for employment, a strong consumer market, funding for needed public services, and a high standard of living shared by citizens.	▪ Income and production ▪ Economic standard of living, *e.g.*, wealth and income, cost of living, poverty ▪ Economic development, *e.g.*, business and enterprise, employment ▪ Availability of affordable housing ▪ Equity in the distribution of income	▪ Gross Domestic Product (GDP) ▪ Wage rates (*e.g.*, persons at minimum wage) ▪ Employment rates ▪ Business startups and job creation ▪ Housing prices ▪ Dependence on public assistance ▪ Families/children living in poverty ▪ Utility costs, gasoline prices, and other prices	Reduced job opportunities and wage rates in areas dependent on natural resources, such as agricultural production in a given region that faces increased drought. Higher electricity prices resulting from increased demand for Air Conditioning as average temperatures and frequency of heat waves rise.
Natural resources, environment, and amenities	Resources enhance the quality of life of citizens; pollution and other negative environmental effects are kept below levels harmful to ecosystems, human health, and other quality of life considerations; and natural beauty and aesthetics are enhanced.	▪ Air, water, and land pollution ▪ Recreational opportunities ▪ Water supply and quality ▪ Natural hazards and risks ▪ Ecosystem condition and services ▪ Biodiversity ▪ Direct climate amenity effects	▪ Air and water quality indices ▪ Waste recycling rates ▪ Acreage, visitation, funding of recreational and protected/preserved areas ▪ Water consumption and levels ▪ Deaths, injuries, and property loss due to natural hazards ▪ Endangered and threatened species	Sea Level rise could both inundate coastal wetland habitats (with negative effects on marsh and estuarine environments necessary to purify water cycle systems and support marine hatcheries) and erode recreational beaches.
Human health	Health care institutions provide medical and preventive health-care services with excellence, citizens have access to services regardless of financial means, and physical and mental health is generally high.	▪ Mortality risks ▪ Morbidity and risk of illness ▪ Quality and accessibility of health care ▪ Health status of vulnerable populations ▪ Prenatal and childhood health ▪ Psychological and emotional health	▪ Deaths from various causes (suicide, cancer, accidents, heart disease) ▪ Life expectancy at birth ▪ Health insurance coverage ▪ Hospital services and costs ▪ Infant mortality and care of elderly ▪ Subjective measure of health status	Increased frequency of heat waves in a larger geographical area will directly affect health, resulting in higher incidence of heat-related mortality and illness. Climate can also affect human health indirectly via effects on ecosystems and water supplies.
Public and private infrastructure	Transportation and communication infrastructure enable citizens to move around efficiently and communicate reliably.	▪ Affordable, and accessible public transit ▪ Adequate road, air, and rail infrastructure ▪ Reliable communication systems ▪ Waste management and sewerage ▪ Maintained and available public and private facilities ▪ Power generation	▪ Mass transit use and commute times ▪ Rail lines, and airport use and capacity ▪ Telephones, newspapers, and internet ▪ Waste tonnage and sewerage safety ▪ Congestion and commute to work ▪ Transportation accident rates ▪ Noise pollution	Melting permafrost due to warming in the arctic damages road transport, pipeline, and utility infrastructure, which in turn leads to disrupted product and personal movements, increased repair costs, and shorter time periods for capital replacement.
Government and public safety	Governments are led by competent and responsive officials, who provide public services effectively and equitably, such as order and public safety; citizens are well-informed and participate in civic activities.	▪ Electoral participation ▪ Civic engagement ▪ Equity and opportunity ▪ Municipal budgets and finance ▪ Public safety ▪ Emergency services	▪ Voter registration, turnout, approval ▪ Civic organizations membership rates ▪ Availability of public assistance programs ▪ Debt, deficits, taxation, and spending ▪ Crime rates and victimization ▪ Emergency first-responders per capita	Dislocations and pressures created by climate change stressors can place significant new burdens on police, fire and emergency services.
Social and cultural resources	Social institutions provide services to those in need, support philanthropy, volunteerism, patronage of arts and leisure activities, and social interactions characterized by equality of opportunity and social harmony.	▪ Volunteerism ▪ Culture, arts, entertainment, and leisure activities ▪ Education and human capital services ▪ Social harmony ▪ Family and friendship networks	▪ Donations of time, money, and effort ▪ Sports participation, library circulation, and support for the arts ▪ Graduation rates and school quality ▪ Hate, prejudice, and homelessness ▪ Divorce rates, social supports	Disruptions in economic and political life caused by climate change stressors or extreme weather events associated with climate change could create new conflicts and place greater pressure on social differences within communities.

* The focus is on negative impacts as potentially more troubling for quality of life; there are also positive impacts and opportunities in some categories

Table 4.2 An illustration of Possible Effects of Climate Change on Fishery Resources

Linkages/Pathways	**Category of Welfare Effect**	**Possible Metrics**
Fishery resource declines as climate changes	Natural resources, environment, and amenities	Fish populations
Recreational opportunities decline	Natural resources, environment, and amenities	Fish catch, visitation days
Related species and habitats are affected	Natural resources, environment, and amenities	Species number and diversity
Employment and wages in resource-based jobs (including recreation) fall as resources decline	Economic conditions	Number of jobs, unemployment rate, wages
Incomes fall as jobs are lost	Economic conditions	Per capita income
More children live in poverty as jobs are lost and incomes fall	Economic conditions	Families, children below poverty level
Access to health care that is tied to jobs and income falls	Human Health	Households without health insurance increase
Increased mortality and morbidity as a result of reduced health care	Human Health	Disease and death rates increase
Lack of jobs results in out-migration	Economic conditions	Working age population decreases
Fewer new residents attracted, because of reduced jobs and amenities (recreation)	Social and cultural resources	Population growth rate slows
Less incentive/drive to participate in community activities	Social and cultural resources	Drop in volunteerism civic participation, completion of high school

Table 4.3 Techniques to Value Health Effects Associated with Climate Change

Health Effect	Economic Valuation Tools
Premature mortality (associated with temperature changes, extreme weather events and air pollution effects)	Use of revealed preference techniques to value changes in risk of death (*e.g.,* compensating wage studies). Use of stated preference studies to value changes in risk of death. Use of foregone earnings as a lower bound estimate to the value of premature mortality.
Exacerbation of cardiovascular and respiratory morbidity; morbidity associated with water-borne or vector-borne disease	Use of stated preference methods to elicit WTP to avoid illness (*e.g.,* asthma attacks) or risk of illness (heart attack risk) or injury. Estimation of medical costs and productivity losses (known as the cost-of-illness (COI)) as a lower bound estimate of the value of avoiding illness.
Injuries associated with extreme weather events	Use of stated preference methods to elicit WTP. Use of compensating wage studies that value risk of injury. Use of COI as a lower bound estimate.
Impacts of climate change on physical functioning; sub-clinical effects	Use of stated preference methods to estimate WTP to avoid functional limitation.

Table 4.4 Examples of Ecosystem Services Important to Human Welfare*

Service Category	Components of Service	Illustration of Service
Provisioning services	Food Fiber Fresh water Genetic Resources Pharmaceuticals	Harvestable fish, wildlife and plants Timber, hemp, cotton Water for drinking, hydroelectricity generation, and irrigation
Regulating services	Air quality regulation Erosion regulation Water purification Pest control Crop pollination Climate and water supply regulation Protection from natural hazards	Local and global amelioration of extremes Removal of contaminants by wetlands Removal of timber pests by birds Pollination of orchards by flying insects
Support services	Primary production Soil formation Photosynthesis Nutrient and water cycling	Conversion of solar energy to plant material Conversion of geological materials to soil by addition of organic material and bacterial activity
Cultural services	Recreation/tourism Aesthetic values Spiritual/religious values Cultural heritage	Natural sites for “green” tourism/recreation/nature viewing Existence value of rainforests and charismatic species, “holy” or “spiritual” natural sites

*Based on a classification system developed for the Millennium Ecosystem Assessment (MA, 2005)

Table 4.5 Comparison of Changes in US Visitor Days

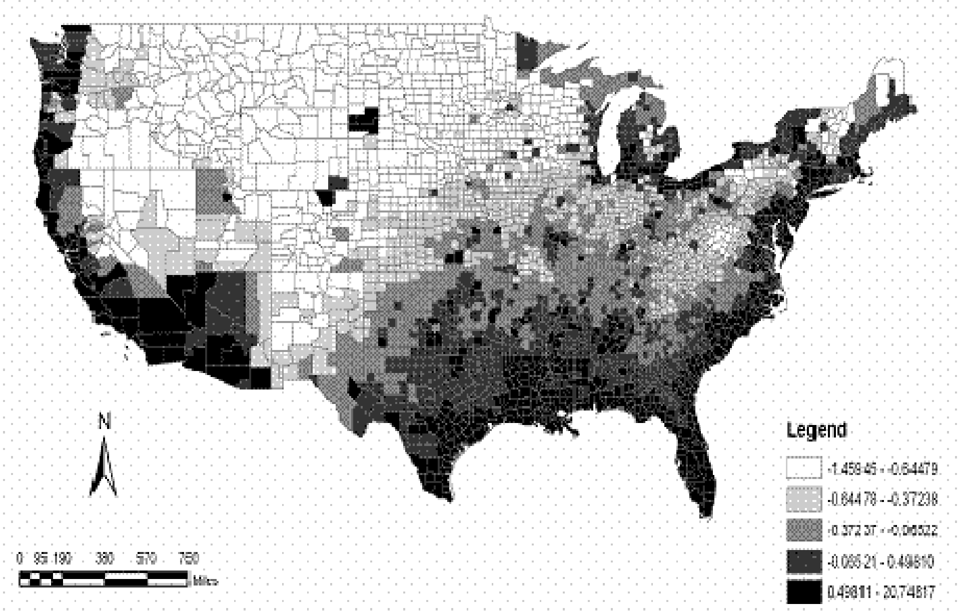
Activity	Loomis and Crespi (1999)	Mendelsohn and Markowski (1999)
Boating	9.2%	36.1%
Camping	-2.0%	-12.7%
Fishing	3.5%	39.0%
Golf	13.6%	4.0%
Hunting	-1.2%	no change
Snow Skiing	-52.0%	-39.0%
Wildlife Viewing	-0.1%	-38.4%
Beach Recreation	14.1%	not estimated
Stream Recreation	3.4%	included in boating
Gain in Visitor Benefits (in Billions)	$2.74	$2.80

Table 4.6 Change in Visits, Jobs and Visitor Benefits with Three Climate Change Scenarios

Climate Scenario	Annual Visits	% change	Tourism Jobs	Visitor Benefits (Millions)
Current	3,186,323		6,370	$1,004
CCC	3,618,856	13.6%	7,351	$1,216
Hadley	3,502,426	9.9%	7,095	$1,157
Extreme Heat	2,907,520	-8.7%	5,770	$959

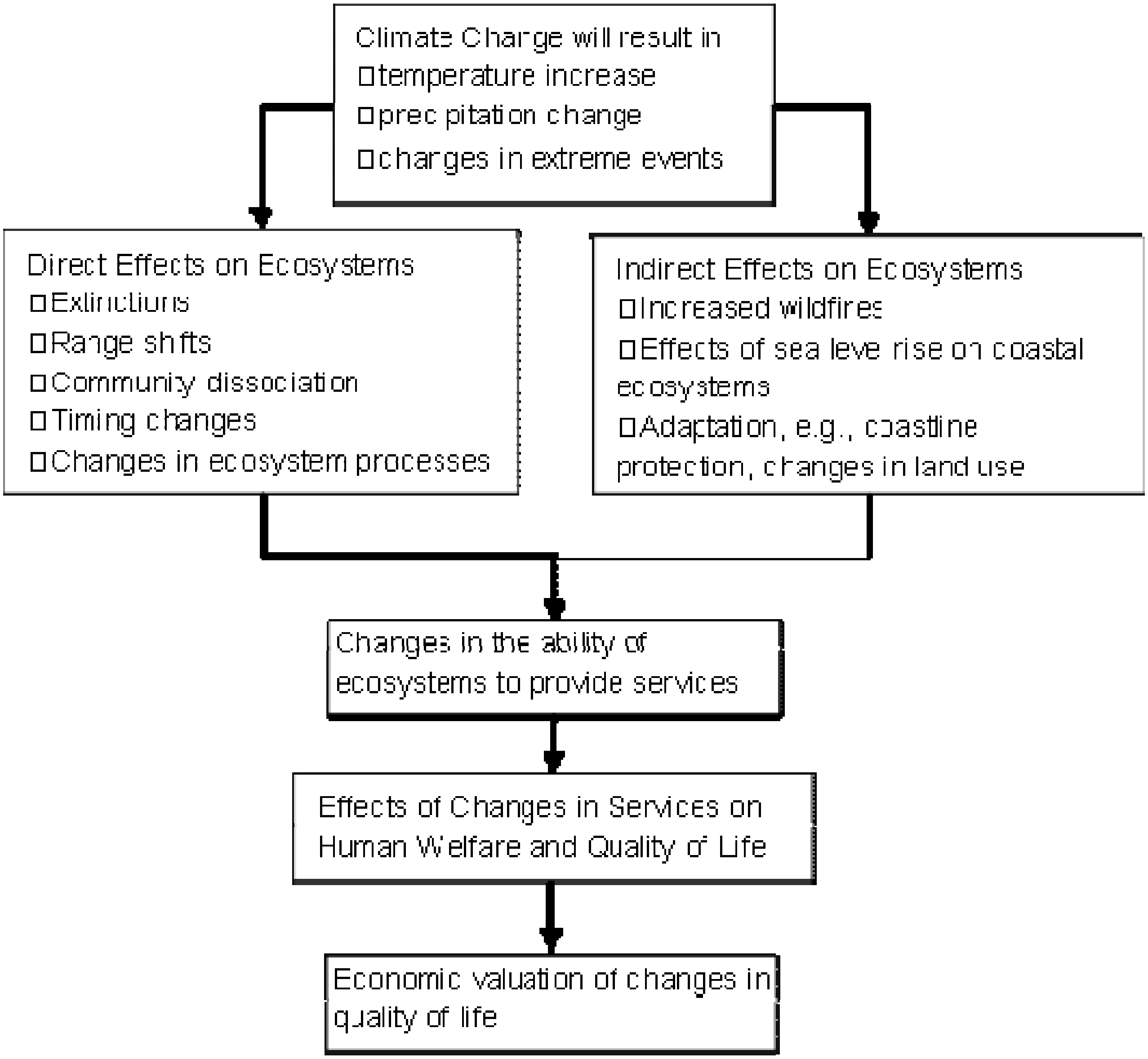
4.10 Figures

Figure 4.1 Geography of Climate Change Vulnerability at the County Scale



Three measures of climate change risk are used to create the vulnerability index: expected temperature change, extreme weather event history, and coastal proximity. Risk measures are geo-referenced at the county scale. The expected *temperature change* variable is measured as the expected unit change in average minimum temperature (in degrees Celsius) for a county from 2004 to 2099. Temperature data are from the Hadley Center. Hadley Center monthly time series data on average minimum temperature for the United States are plotted at the 0.5 x 0.5 degree of spatial resolution. In cases where climate cells intersect county boundaries, temperature data are averaged across intersecting climate cells. To estimate extreme weather event history we summarize the number of reported injuries and fatalities from hydro-meterological hazard events at the county level from Jan 01, 1960 to Jul 31, 2004. Higher values on our natural hazard casualty variable reflect more pronounced histories of injury and death from extreme weather events. Casualty data were collected from the Spatial Hazard Events and Losses Database for the United States (SHELDUS). The *coastal proximity* variable is measured dichotomously. A county receives a score of 1 if it is designated by the National Oceanic and Atmospheric Administration (NOAA) as an "at-risk coastal" county, and a score of 0 if it is not. NOAA defines a county as at-risk coastal if at least 15 percent of its total area is located in a coastal watershed. The vulnerability index was created by standardizing then summing each measure of climate change risk (z-score). The distribution of vulnerability is divided into equal quintiles, with darker colors reflecting higher vulnerability to climate change.

Figure 4.2 Steps from Climate Change to Economic Valuation of Ecosystem Services



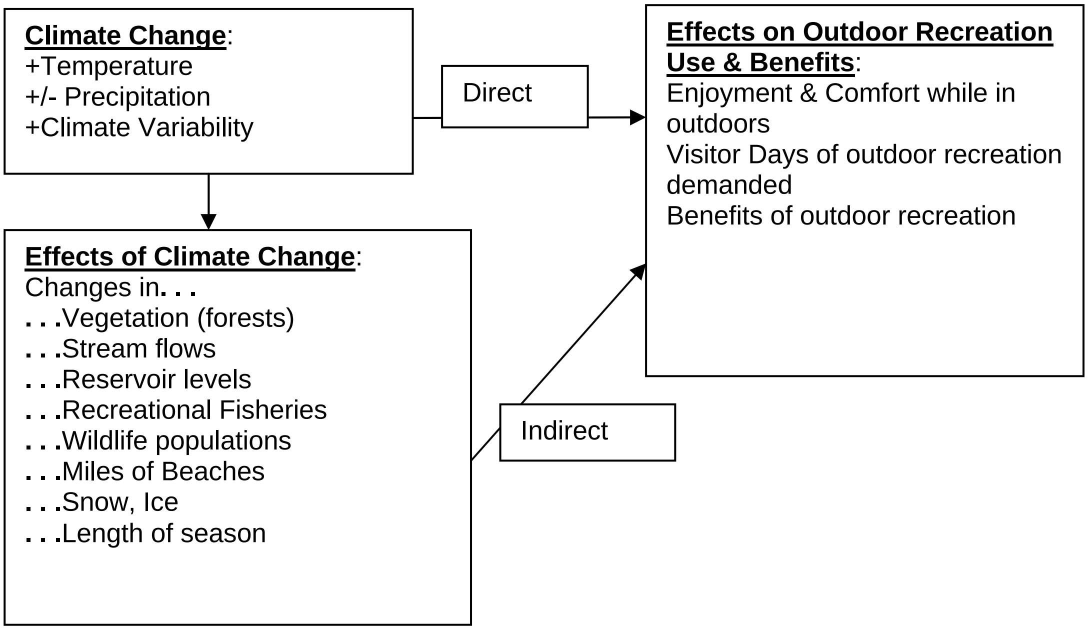


Figure 4.3 Direct and Indirect Effects of Climate Change on Recreation