Chapter 1—Introduction and Background

1.1 The Problem of Sudden Change in Ecological Systems

The carbon dioxide (CO_2) concentration in the Earth's atmosphere has reached 385 parts per million (ppm), a level that is unprecedented over the past one-half million years (based on ice core data) to 24 million years (based on soil data) (Hoegh-Guldberget al.et al. 2007). CO_2 levels have been increasing during the past 150 years, with most of the change occurring in just the past few decades. Global mean temperature has risen in response to increased CO_2 concentration and is now higher than at any time in the past 1,000 years (based on tree rings) to 160,000 years [based on oxygen 18 (^{18}O) and deuterium (D) isotopes in ice]. The relatively sudden increase in the energy balance of the planet has led to abrupt global climate changes that alter physical processes and biological systems on many scales and will certainly affect ecosystems that support human society. One of the ways that a rapidly changing climate will affect ecosystems is by causing sudden, irreversible effects that fundamentally change the function and structure of the ecosystem with potentially huge impacts to human society.

Even small, gradual change can induce threshold changes. For instance, in 1976-77, major shifts occurred in sea surface temperatures, fisheries landings, zooplankton abundance, and community composition in the North Pacific (Hare and Mantua, 2000). Later analysis suggested that nonlinear regime shifts operate in this ecosystem, such that even small changes in physical conditions (for example, an increase in temperature from global warming) can provoke a regime shift that may not be easily or symmetrically reversed (Hsiehet al.et al. 2006). This tendency can be compounded by additional environmental stressors that predispose ecosystems to experience threshold changes in response to climate change. For example, in North America in the late 1990s, forests, woodlands, grasslands, and shrublands exhibited extensive dieback across the arid southwestern United States as overgrazing, fire suppression, and climate variability led to massive insect outbreaks and an unprecedented breadth of area consumed by fire (Allen, 2007).

Abrupt changes in ecosystems may result in dramatic reductions in ecosystem services, such as water supplies for human use. In the Klamath River basin in the Pacific Northwest, for example, the delicate socioecological balance of water allocation between needs for irrigated agriculture and habitat for endangered species of fish, which had been established in 1902, collapsed in 2002 during a multiyear drought because the system’s resilience to maintain water quality in the face of climatic variability was degraded by long-term nutrient loading.

Thresholds pose perhaps the greatest challenge currently facing climate change scientists. There is clear evidence that climate change has the potential to increase threshold changes in a wide range of ecosystems, but the basic and practical science necessary to predict and manage these changes is not well developed (Groffman et al. 2006). In addition, climate change interacts with other natural processes to produce threshold changes. Disturbance mechanisms, such as fire and insect outbreaks (Krutzen and Goldammer 1993, Lovett et al. 2002, respectively), shape landscapes and may predispose many of them to threshold change when the additional stress of climate change is added (Swetnam and Betancourt 1998). To complicate matters further, climate change can alter the disturbance mechanisms themselves and, on a global scale, altered disturbance regimes may influence rates of climate change. Another challenge is the multidisciplinary nature of threshold changes. These changes almost always involve coupled socioecological dynamics where human actions interact with natural drivers of change to produce complex changes in ecosystems that have important implications for the services provided by the ecosystems (Wamelink et al. 2003).

A sense of urgency regarding thresholds exists because of the increasing pace of change, the changing features of the drivers that lead to thresholds, the increasing vulnerabilities of ecosystem services, and the challenges the existence of thresholds poses for natural resource management. These challenges include the potential for major disruption of ecosystem services and the possibility of social upheaval that might occur as new ways to manage and adapt for climate change and to cope with the unanticipated change are required.

Research on ecological thresholds is being assessed critically. The Heinz Center conducted several workshops that presented case studies of likely threshold change and began looking at possible social and policy responses. Another study included numerous case studies focused on nonlinearities in ecological systems (Burkettet al.et al. 2005) and considered how thresholds are nonlinear responses to climate change. Recently, specific requests for proposals have been issued for research on thresholds (for example, see *es.epa.gov/ncer/rfa/2004/2004_aqua_sys.html*), and there are active efforts to bridge the gap between research and application in this area (see, for example, www.ecothresholds.org). Assessment of the “state of the science” as it relates to ecosystems in the United States and for articulation of critical research needs is needed.

1.2 The Response of the Climate Change Community

Climate change is a very complex issue, and policymakers need an objective source of information about the causes of climate change, its potential environmental and socioeconomic consequences, and the adaptation and mitigation strategies to respond to the effects of climate change. In 1979, the first World Climate Conference was organized by the World Meteorological Organization (WMO). This conference expressed concern about man's activities on Earth and the potential to "cause significant extended regional and even global changes of climate" and called for "global cooperation to explore the possible future course of global climate and to take this new understanding into account in planning for the future development of human society." A subsequent conference in 1985 focused on the assessment of the role of CO_2 and other greenhouse gases in climate variations and associated impacts, concluding that an increase of global mean temperature could occur that would be greater than at any time in humanity's history. As a follow up to this conference, the Advisory Group on Greenhouse Gases (AGGG), a precursor to the Intergovernmental Panel on Climate Change (IPCC), was set up to ensure periodic assessments of the state of scientific knowledge on climate change and the implications of climate change for society. Recognizing the need for objective, balanced, and internationally coordinated scientific assessment of the understanding of the effects of increasing concentrations of greenhouse gases on the Earth's climate and on ways in which these changes may potentially affect socioeconomic patterns, the WMO and the United Nations Environment Programme (UNEP) coordinated to establish an ad hoc intergovernmental mechanism to provide scientific assessments of climate change. Thus, in 1988, the IPCC was established to provide decisionmakers and others interested in climate change with an objective source of information about climate change.

The role of the IPCC is to assess on a comprehensive, objective, open, and transparent basis the scientific, technical, and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation and to provide reports on a periodic basis that reflect existing viewpoints within the scientific community. Because of the intergovernmental nature of the IPCC, the reports provide decisionmakers with policy-relevant information in a policy neutral way. The first IPCC report was published in 1990, with subsequent reports published in 1995, 2003, and 2007.

In 1989, the U.S. Global Change Research Program (USGCRP) began as a Presidential initiative and was codified by Congress in the Global Change Research Act of 1990 (Pub.L. 101–606), which mandates development of a coordinated interagency research program. The Climate Change Science Program (CCSP) (www.climatescience.gov), a consortium of Federal agencies that perform climate science, integrates the research activities of the USGCRP with the U.S. Climate Change Research Initiative (CCRI).

The CCSP integrates federally supported research on global change and climate change as conducted by the 13 U.S. Government departments and agencies involved in climate science. To provide an open and transparent process for assessing the state of scientific information relevant to understanding climate change, the CCSP established a synthesis and assessment program as part of its strategic plan. A primary objective of the CCSP is to provide the best science-based knowledge possible to support public discussion and government and private sector decisionmaking on the risks and opportunities associated with changes in the climate and related environmental systems.

The CCSP has identified an initial set of 21 synthesis and assessment products (SAPs) that address the highest priority research, observation, and decision-support needs to advance decisionmaking on climate change-related issues. This assessment, SAP 4.2, focuses on abrupt ecological responses to climate change, or thresholds of ecological change. It examines the impacts to ecosystems when thresholds are crossed. It does not address those ecological changes that are caused by major disturbances, such as hurricanes. These externally driven changes, or exogenous triggers, are distinguished from changes caused by shifts in the ecosystem's response to a driver, such as a gradual rise in temperature. These internal changes in system response, or endogenous triggers, are the focus of this SAP. This SAP is one of seven reports that address the Ecosystems research element and Goal 4 of the CCSP strategic plan to understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

1.3 The Goal of SAP 4.2

This SAP summarizes the present state of scientific understanding regarding potential abrupt state changes or regime shifts in ecosystems in response to climate change. The goal is to identify specific difficulties or shortcomings in our current ability to identify the likelihood of abrupt state changes in ecosystems as a consequence of climate change.

Questions addressed by this SAP include:

1. What specifically is meant by abrupt state changes or regime shifts in the structure and function of ecosystems in response to climate change?

2. What evidence is available from current ecological theory, ecological modeling studies, or the paleoecological record that abrupt changes in ecosystems are likely to occur in response to climate change?
3. Are some ecosystems more likely to exhibit abrupt state changes or threshold responses to climate change?
4. If abrupt changes are likely to occur in ecosystems in response to climate change, what does this imply about the ability of ecosystems to provide a continuing supply of ecosystem goods and services to meet the needs of humans?
5. If there is a high potential for abrupt or threshold-type changes in ecosystems in response to climate change, what changes must be made in existing management models, premises, and practices in order to manage these systems in a sustainable, resilient manner?
6. How can monitoring systems be designed and implemented, at various spatial scales, in order to detect and anticipate abrupt or threshold changes in ecosystems in response to future climate change?
7. What are the major research needs and priorities that will enhance the ability in the future to forecast and detect abrupt changes in ecosystems caused by climate change?

1.4 Standard Terms

The 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (*IPCC, 2007*) is the most comprehensive and up-to-date report on the scientific assessment of climate change. This assessment (SAP 4.2) uses the standard terms defined in the IPCC's AR4 with respect to the treatment of uncertainty and the likelihood of an outcome or result based on expert judgment about the state of that knowledge. The definitions are shown in figure 1.1. This set of definitions is for descriptive purposes only and is not a quantitative approach from which probabilities relating to uncertainty can be derived.

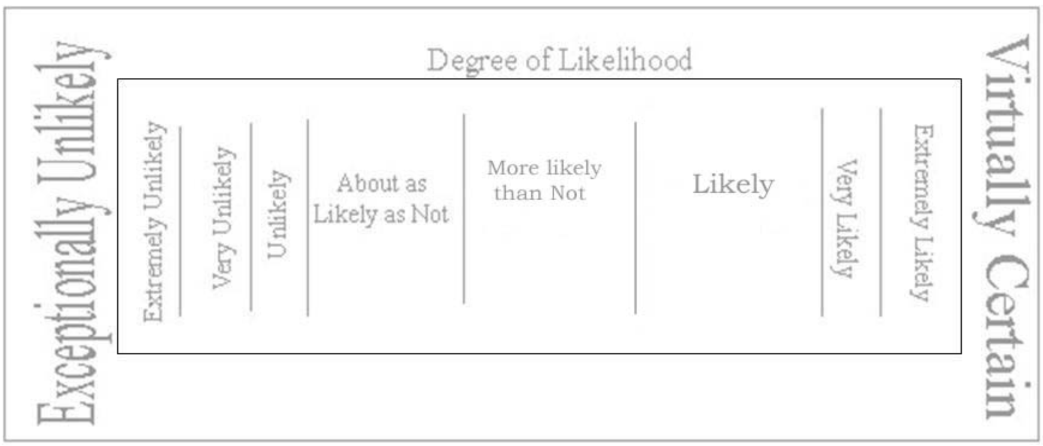

Figure 1.1. **Degrees of outcome likelihood as defined in the IPCC's Fourth Assessment Report (AR4) (IPCC, 2007).**