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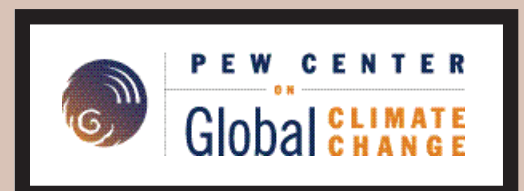
**Observed Impacts** of global  
**climate change** in the U.S.

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**Prepared for the Pew Center on Global Climate Change**

*by*

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*November 2004*

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## Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

For over a century, scientists have documented the important role that the climate plays in the geographic distribution of the world's ecosystems and the wildlife they support. Yet, it is now quite evident that the climate these species depend upon is changing. Global temperatures increased by over 1°F during the past century and are projected to increase 2.5-10.4°F by 2100 as a result of human emissions of greenhouse gases. Given the reliance of plants and animals on their natural environment, they are often early barometers of the effects of climate change.

"Observed Impacts of Global Climate Change in the U.S." is the twelfth in a series of Pew Center reports examining the impacts of climate change on the U.S. environment. While past Pew Center reports have reviewed the potential impacts of future climate change, this report provides compelling evidence that ecosystems are already responding to climate change and provides insights into what we can expect from future changes in the Earth's climate. Looking specifically at the United States, report authors, Drs. Camille Parmesan and Hector Galbraith find:

***A number of ecological changes have already occurred in the United States over the past century in concert with increases in average U.S. temperature and changes in precipitation.*** Warmer temperatures have resulted in longer growing seasons at the national level, altered carbon cycling and storage in the Alaskan tundra, and increased the frequency of fires and other disturbances in U.S. forests. Individual species such as Edith's checkerspot butterfly and the red fox have shifted north or to higher altitudes. Other species including Mexican jays and tree swallows have experienced changes in the timing of reproduction, as have plants such as forest phlox and butterfly weed. While these changes illustrate efforts by species to adapt to a warming climate, these responses may alter competition and predator-prey relationships and have other unforeseen consequences.

***These observed changes have been linked to human-induced warming of the global climate.*** There is increasingly strong evidence that the observed global climate change, particularly that of the past 50 years, is primarily the result of human emissions of greenhouse gases. Changes in U.S. climate have also been linked with human activities.

***Changes in natural systems will continue and become even more apparent in the future, resulting in the degradation and loss of U.S. biodiversity.*** With continued and more severe changes in the climate, the ability of U.S. wildlife to adapt through migration and physiological change will be increasingly limited. Furthermore, because of adaptive migration, species such as the red fox are now competing for habitat previously dominated by the arctic fox, threatening the arctic fox's long-term survival. The challenge is even greater when considered along with the broad range of other environmental threats currently affecting wildlife, such as habitat loss, environmental contamination, and invasive species.

***Efforts to reduce greenhouse gas emissions, protect U.S. ecosystems and wildlife, and provide refuge for sensitive species are all necessary to limit the future ecological consequences of climate change.*** Curbing greenhouse gas emissions can reduce the rate and magnitude of future climate change, consequently reducing the severity of, but not preventing, climatic stresses to wildlife. Meanwhile, the expansion of nature reserves and habitat conservation efforts can alleviate some non-climate stresses and enable species to adapt better to the effects of climate change.

The authors and the Pew Center gratefully acknowledge the input of Drs. Lou Pitelka and Walter Oechel on this report. The Pew Center would also like to thank Joel Smith of Stratus Consulting for his assistance in the management of this Environmental Impacts Series.

## Executive Summary

One of the major, most well-documented, and robust findings in ecology over the past century has been the crucial role of climate in determining the geographical distribution of species and ecological communities. Climate variability and change can affect plants and animals in a number of ways, including their distributions, population sizes, and even physical structure, metabolism, and behavior. These ecological responses to changes in climate have important implications, given the historical and continuing increases in atmospheric concentrations of greenhouse gases associated with human activities. Future human-induced changes in the global climate will directly affect regional conditions, such as geographic patterns of temperature and precipitation. Previous reports by the Pew Center on Global Climate Change have identified a range of future adverse effects that could occur in U.S. marine and freshwater systems, forests, and ecosystem processes due to greenhouse gas-induced global climate change.

The effect of climate change, however, is not relegated to future decades. Scientists have already documented changes in temperature and precipitation patterns in the United States and around the world. Average U.S. temperatures increased by approximately 0.6°C (1°F) over the past century, while precipitation increased by 5-10 percent. The magnitude of warming, however, has varied among different regions within the United States. Alaska, for example, has experienced an average temperature increase of 2-4°C (4-7°F) in just the past 50 years. These climatic changes have altered the environmental contexts within which many species live in the United States, causing physical, behavioral and location changes as the species respond to their changing environments. In addition to being biological indicators of global warming, these changes may have direct adverse effects on U.S. biodiversity and ecosystem stability, resilience, and goods and services.

This report assesses the scientific evidence compiled to date on the observed ecological effects of climate change in the United States and their consequences. It evaluates the strength of that evidence and the relationships between observed biological changes and human activities. Although many species and ecological systems of interest have yet to be studied (often due to inherent limitations of available data) and the attribution of ecological changes to a particular cause remains challenging, a number of robust findings emerge from this report.

**1) Sufficient studies now exist to conclude that the consequences of climate change are already detectable within U.S. ecosystems.** This report reviews more than 40 studies that associate climate change with observed ecological impacts in the United States, and, using objective evaluation criteria, finds that more than half provide strong evidence of a direct link. These studies span a broad range of plant and animal species from various regions of the United States. Yet, despite the diversity among studies, the observed ecological responses are consistent with one another, as well as with the changes that one would expect based on the nature of U.S. climate change observed to date.

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**2) The timing of important ecological events, including the flowering of plants and the breeding times of animals, has shifted, and these changes have occurred in conjunction with changes in U.S. climate.** If these timing shifts are synchronous across species that normally interact with each other (for example, if adult butterflies and the flowers they depend on for nectar both emerge two weeks earlier), then these species' interactions are preserved, and the system may remain healthy. On the other hand, if responses to temperature increases vary across species (for example, if butterflies emerge before the flowers they depend on for survival), then species' interactions may become out of synchrony and could lead to population declines. Both types of situations have been documented.

**3) Geographic ranges of some plants and animals have shifted northward and upward in elevation, and in some cases, contracted.** One of the most detailed and best-studied examples is the Edith's checkerspot butterfly in the western United States. As temperatures have increased over the last century, many southern and lower-elevation populations of this species have disappeared entirely. The effect of this shift has been a contraction of the species' range to the north (i.e., it is disappearing from Mexico but thriving in Canada). The red fox, another example, has shifted northward and is now encroaching on the arctic fox's range, threatening its survival. Similar range shifts within the United States have also been observed in organisms as diverse as birds, mammals, intertidal invertebrates, and plants. Such major shifts in species' locations alter species' interactions and potentially threaten U.S. biodiversity.

**4) Species composition within communities has changed in concert with local temperature rise.** As species within a community change abundances or, ultimately, are added or lost, the relationships among species also change. In particular, such shifts in composition are likely to alter important competitive and predatory/prey relationships, which can reduce local or regional biodiversity. A particularly compelling example of this is the change observed over more than 60 years in the intertidal communities of Monterey, California, where a community previously dominated by northern colder-water species has been "infiltrated" by southern warmer-water species in response to oceanic warming. Similar changes have also been observed in nearby offshore marine fish communities. Thus, many protected lands, such as the marine reserve in Monterey Bay, are experiencing a shift in the communities that they protect.

**5) Ecosystem processes such as carbon cycling and storage have been altered by climate change.** The lengthening of the growing season has altered the annual cycle of carbon-dioxide (CO<sub>2</sub>) levels in the atmosphere, because plants are a major intermediary for carbon flow through ecosystems. The Alaskan tundra has switched from being a net sink of CO<sub>2</sub> (absorbing and storing more carbon from the atmosphere than is released) to being a net source of CO<sub>2</sub> (releasing more carbon than is stored), because warmer winters have allowed dead plant matter previously stored in the soil to decompose and release CO<sub>2</sub>. Like the tundra, boreal forests have become carbon sources because of reduced growth due to climate-mediated increases in water stress, pest outbreaks, and wildfires. Conversely, many of the forests of the lower 48 states have switched in the opposite direction—becoming carbon sinks in recent decades. This transition is attributed to regrowth of forests following logging and abandonment of agricultural fields. However, it is expected to stop as soon as the forests mature.

**6) The findings that climate change is affecting U.S. biological systems are consistent across different geographic scales and a variety of species, and these U.S. impacts reflect global trends.** Even against a background of apparently dominating forces such as direct human-driven habitat destruction and alteration, a climate “fingerprint” is discernible in natural systems. The most rigorous studies within the United States provide strong evidence that climate change has affected the timing of biological events in at least three taxa (i.e., groups of related species). They also provide strong evidence that at least three taxa have shifted their ranges in response to climate change and that climate change has altered ecological communities and processes. Further, very few instances of biotic change run completely counter to climate-change predictions, and the findings of many of the U.S. studies are mirrored by studies elsewhere around the world. Climate change has the potential to degrade ecosystem functions vital to global health. If the observed biological changes are merely one phase in a cyclical pattern of warming and cooling periods, then they may not represent a threat to long-term species and ecosystem health. If, however, they are linked to anthropogenic climate change, they will continue along the same path. Thus, it is essential to address the extent to which the U.S. climate change responsible for observed ecological responses can be attributed to global emissions of anthropogenic greenhouse gases.

**7) There is an emerging link between observed changes in wild plants and animals across the United States and human-driven global increases in greenhouse gases.** In 2001, the Intergovernmental Panel on Climate Change concluded that the global rise in average yearly temperature over the past 50 years was primarily due to increased concentrations of anthropogenic greenhouse gases. U.S. climate trends are consistent with global climate trends. Global biological trends are predicted by (and match) observed climate trends, indicating that anthropogenic global climate change has affected natural systems. Recent research focusing on North America has also shown a significant greenhouse gas signal in North American climate trends over the past 50 years. The combination of strong consistency across climate and biological studies and across scales (from regional to global), coupled with new climate analyses specific to the United States, links U.S. biological changes to anthropogenic climate change. The implications of this link are that current biological trends will continue over future decades as greenhouse gas emissions continue to rise.

**8) The addition of climate change to the mix of stressors already affecting valued habitats and endangered species will present a major challenge to future conservation of U.S. ecological resources.** Many if not most of the ecosystems and organisms in the United States are already suffering from other anthropogenic stressors such as habitat destruction or fragmentation, introduction of invasive species, and contamination. As yet, scientists do not have a clear idea how climate change might affect this already fragile situation. It is likely, however, that in many cases climate change may exacerbate current conditions, further stressing wild species and their associated ecosystems. There is a growing consensus within the scientific community that climate change will compound existing threats and lead to an acceleration of the rate at which biodiversity is lost.



**9) In the future, range contractions are more likely than simple northward or upslope shifts.** During historic glacial cycles, range shifts of hundreds to thousands of miles were common, and species extinction was rare. However, achieving such massive relocation is much more problematic across the human-dominated, artificially fragmented landscapes of today. The large reduction in the areas of natural habitats and the growth of barriers to species' dispersal (urban and agricultural zones) make simple range shifts unlikely. Species that are not adapted to urban and agricultural environments are likely to be confined to smaller total geographic areas as climate causes them to contract from their southern and lower boundaries. Already rare or endangered species, or those living only on high mountaintops, are likely to have the highest risk of extinction.

**10) Reducing the adverse effects of climate change on U.S. ecosystems can be facilitated through a broad range of strategies, including adaptive management, promotion of transitional habitat in nonpreserved areas, and the alleviation of nonclimate stressors.** The protection of transitional habitat that links natural areas might assist in enabling species migration in response to climate change. Meanwhile, promoting dynamic design and management plans for nature reserves may enable managers to facilitate the adjustment of wild species to changing climate conditions (e.g., through active relocation programs). Also, because climate change may be particularly dangerous to natural systems when superimposed on already existing stressors, alleviation of the stress due to these other anthropogenic factors may help reduce their combined effects with climate change.

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