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Report to Congressional Requesters

August 2007

CLIMATE CHANGE

Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources

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GAO-07-863

August 2007

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Highlights

Highlights of GAO-07-863, a report to congressional requesters

CLIMATE CHANGE

Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources

Why GAO Did This Study

Climate change has implications for the vast land and water resources managed by the Bureau of Land Management (BLM), Forest Service (FS), U.S. Fish and Wildlife Service (FWS), National Oceanic and Atmospheric Administration (NOAA), and National Park Service (NPS). These resources generally occur within four ecosystem types: coasts and oceans, forests, fresh waters, and grasslands and shrublands.

GAO obtained experts' views on (1) the effects of climate change on federal resources and (2) the challenges managers face in addressing climate change effects on these resources. GAO held a workshop with the National Academies in which 54 scientists, economists, and federal resource managers participated, and conducted 4 case studies.

What GAO Recommends

GAO recommends that the Secretaries of Agriculture, Commerce, and the Interior develop guidance incorporating agencies' best practices, which advises managers on how to address climate change effects on the resources they manage and gather the information needed to do so. In commenting on a draft of this report, the three departments generally agreed with the recommendation and provided technical comments, which GAO has incorporated into the report as appropriate.

www.gao.gov/cgi-bin/getrpt?GAO-07-863.

To view the full product, including the scope and methodology, click on the link above. For more information, contact John B. Stephenson at (202) 512-3841 or stephensonj@gao.gov.

What GAO Found

According to experts at the GAO workshop, federal land and water resources are vulnerable to a wide range of effects from climate change, some of which are already occurring. These effects include, among others, (1) physical effects, such as droughts, floods, glacial melting, and sea level rise; (2) biological effects, such as increases in insect and disease infestations, shifts in species distribution, and changes in the timing of natural events; and (3) economic and social effects, such as adverse impacts on tourism, infrastructure, fishing, and other resource uses.

Experts at the GAO workshop also identified several challenges that resource managers face in addressing the observed and potential effects of climate change in their management and planning efforts. In particular, BLM, FS, FWS, NOAA, and NPS have not made climate change a priority, and the agencies' strategic plans do not specifically address climate change. Resource managers focus first on near-term, required activities, leaving less time for addressing longer-term issues such as climate change.

In addition, resource managers have limited guidance about whether or how to address climate change and, therefore, are uncertain about what actions, if any, they should take. In general, resource managers lack specific guidance for incorporating climate change into their management actions and planning efforts. Without such guidance, their ability to address climate change and effectively manage resources is constrained. While a broad order developed in January 2001 directed BLM, FWS, and NPS to consider and analyze potential climate change effects in their management plans and activities, the agencies have not yet provided specific direction to managers on how they are to implement the order. A BLM official stated at an April 2007 hearing that BLM is establishing policy and technical committees to address necessary actions and develop guidance to address climate change in agency management practices. FWS and NPS officials said that their agencies have not developed specific guidance but believe that they are operating in a manner consistent with the 2001 order. While NOAA and FS have not provided specific guidance to their resource managers, NOAA officials said that the agency is establishing a working group to determine what actions to take to address climate change effects. FS officials said that FS planning processes are designed to identify and respond to emerging issues such as climate change.

Finally, resource managers do not have sufficient site-specific information to plan for and manage the effects of climate change on the federal resources they manage. In particular, the managers lack computational models for local projections of expected changes and detailed inventories and monitoring systems for an adequate baseline understanding of existing local species. Without such information, managers are limited to reacting to already-observed climate change effects on their units, which makes it difficult to plan for future changes.

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Abbreviations

BLM	Bureau of Land Management
CCP	Comprehensive Conservation Plan
CESU	Cooperative Ecosystem Study Unit
EEZ	Exclusive Economic Zone
EMS	Environmental Management System
ESA	Endangered Species Act of 1973
FS	Forest Service
FWS	U.S. Fish and Wildlife Service
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
NEON	National Ecological Observatory Network
NEPA	National Environmental Policy Act
NGO	nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
USGS	U.S. Geological Survey

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United States Government Accountability Office
Washington, D.C. 20548

August 7, 2007

The Honorable John Kerry
United States Senate

The Honorable John McCain
United States Senate

A growing body of evidence shows that increasing concentrations of greenhouse gases—primarily carbon dioxide, methane, and nitrous oxide—in the Earth's atmosphere have resulted in a warmer global climate system, among other changes. The Intergovernmental Panel on Climate Change (IPCC), a leading source for international climate expertise, noted in April 2007 that "observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases." The IPCC further noted that climate change has, in some areas, led to rising sea levels, declining snow cover, melting glacial and Arctic ice, coral bleaching, and changes in the timing and amount of precipitation, among other things. The stresses caused by climate change could be exacerbated by existing stresses on ecosystems from such sources as pollution, human settlement, land-use change, and invasion by nonnative species. Together, climate change and ecosystem stresses may cause substantial damage to, or the complete loss of, some ecosystems and the extinction of species. Furthermore, scientists project that changes in temperature and precipitation may result in more extreme weather events, such as more frequent and severe droughts, storms, and floods as well as changes in local climate conditions.

Federal agencies manage over 600 million acres of land—almost 30 percent of the land area of the United States—and more than 150,000 square miles of protected waters, including 13 national marine sanctuaries and 1 marine national monument. These federal resources are managed primarily by the U.S. Department of Agriculture's (Agriculture) Forest Service (FS); the Department of Commerce's (Commerce) National Oceanic and Atmospheric Administration (NOAA); and the Department of the Interior (Interior), specifically the Bureau of Land Management (BLM), the National Park Service (NPS), and the U.S. Fish and Wildlife Service (FWS).

The resources managed by federal agencies generally occur within four principal ecosystem types—coasts and oceans, forests, fresh waters, and grasslands and shrublands—and support a rich diversity of plant and

animal communities, including endangered and threatened species, such as the Florida panther, the desert tortoise, the whooping crane, and the Santa Cruz cypress, among others. Federal resources also support a range of economically and socially valuable activities, such as mineral extraction and recreation. In fiscal year 2005, the public visited federal lands over 600 million times, according to estimates by Agriculture and Interior.

These agencies manage their resources for a variety of purposes related to preservation; recreation; and, in some cases, resource use, yet each agency has distinct responsibilities for the resources it administers. The statutes governing these agencies' resource management activities generally do not require the agencies to manage for specific outcomes, such as a certain number of visitors, or to provide a specific response to changes in ecological conditions, such as insect outbreaks. Instead, these laws give the agencies discretion to decide how best to carry out their responsibilities in light of their respective statutory missions as well as the need to comply with or implement specific substantive and procedural laws, such as the Endangered Species Act of 1973 (ESA),[1] the National Environmental Policy Act (NEPA),[2] or the Clean Air Act. The agencies are generally authorized to plan and manage for changes in resource conditions, regardless of the cause that brings about the change.[3] As a result, federal resource management agencies are generally authorized, but are not specifically required, to address changes in resource conditions resulting from climate change in their management activities.

[1]The ESA (16 U.S.C. § 1531 et seq.) is designed to conserve the ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend. The act is administered by FWS and NOAA Fisheries.

[2]NEPA (42 U.S.C. § 4321 et. seq.) requires federal agencies to assess and report on the likely environmental impacts of major actions they propose that affect the environment. If a proposed activity is expected to have significant environmental effects, the agency is required to prepare an environmental impact statement.

[3]In its technical comments on a draft of this report, Interior told us that the NPS's Management Policies (2006) discusses treatment of the cause of change. It stated that natural resources will be managed to preserve fundamental physical and biological processes and maintain all of the components and processes of naturally evolving park ecosystems. Natural change will also be recognized as an integral part of the functioning of natural systems. NPS will not intervene in natural biological or physical processes except when directed by the Congress; in emergencies in which human life and property are at stake; to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities; or when a park plan has identified the intervention as necessary to protect other park resources, human health and safety, or facilities.

In this context, we obtained (1) experts' views on the observed and potential effects of climate change on federal resources within the four principal ecosystem types and (2) the views of federal resource managers on the challenges they face in addressing the observed and potential future effects of climate change in their management actions and planning efforts. In addition, four case studies illustrate some of the effects of climate change on federal resources as well as the challenges to addressing them.

To solicit experts' views on the effects of climate change and federal resource managers' views on the challenges to addressing climate change on federal resources within the four ecosystem types, we convened a 2-day workshop in collaboration with the National Academies' Board on Atmospheric Sciences and Climate. Descriptions in this report of the effects of climate change come from experts at the workshop; we did not independently review articles from the scientific literature or verify participants' statements. To identify experts for the first day of the workshop, which addressed science issues, the National Academies and GAO agreed on selection criteria, which included recommendations from other experts, a demonstrated record of publication in the field, and experience contributing to climate change impact assessments or other peer-reviewed scientific reports and articles relating to climate change.[4] Individuals' availability on the date of the workshop was also a key factor. The National Academies and GAO gave particular preference to individuals recommended by more than one expert. In addition to ecosystem expertise, we gave priority to those candidates whose expertise also included an understanding of climate change (e.g., an understanding of how climate change might affect coral reefs or forests). GAO identified most of the federal resource managers for the second day of the workshop because the National Academies does not interact extensively with the federal resource management community. To select these managers, we asked for recommendations from both agency headquarters officials and managers in the field. We gave priority to senior federal resource managers with management experience in the field. We also invited managers from Washington, D.C., headquarters offices to ensure a balanced perspective. We selected managers who had a general familiarity with relevant statutes,

[4]Major impact assessments include, among others, the IPCC's Working Group II report, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*; the U.S. Global Change Research Program's report, *Climate Change Impacts in the United States*; the United Nations Environment Program's report, *Millennium Ecosystem Assessment*; and the Arctic Council and the International Arctic Science Committee's report, *Arctic Climate Impact Assessment*.

regulations, agreements, executive orders, and other management directives aimed at protecting the resources under their agencies' jurisdictions. We also selected managers who had a general familiarity with the issue of climate change and how it could affect one of the four relevant ecosystem types—although this knowledge was not essential. We sought to have representation from each major agency that manages resources corresponding to each of the four ecosystem types. Fifty-four scientists, economists, and federal resource managers from academia, government, and nongovernmental organizations attended the workshop. Appendix I contains a list of the workshop participants and moderators.

To illustrate the vulnerability of federal resources to the potential effects of climate change as well as the various management challenges discussed at the workshop, we conducted case studies of four federal resource units, one case study for each ecosystem type, using a nonprobability approach.[5] The four units are the Florida Keys National Marine Sanctuary in southern Florida (coasts and oceans ecosystem); the Chugach National Forest in south-central Alaska (forests ecosystem); Glacier National Park in northwestern Montana (fresh waters ecosystem); and the BLM Kingman Field Office in northwestern Arizona (grasslands and shrublands ecosystem). We selected our specific case study units after soliciting selected experts' views on which federal resources may be most vulnerable to climate change. We then visited each of the four units, interviewed a number of experts and resource managers at the units, and viewed some of the resources discussed at the meetings. More detailed information on our objectives, scope, and methodology is presented in appendix II. A summary of the workshop can be found in appendix III, and summaries of the individual case studies can be found in appendix IV.

In this report, we use the term "federal resources" to refer to federal lands managed by BLM, FS, FWS, and NPS and to national marine sanctuaries and one marine national monument managed by NOAA; the term "ecosystem" to refer to a system of interacting living organisms together with their physical environment; the term "resource managers" to refer to individuals who manage federal resources; the term "physical effects" to refer to observable changes in the physical condition of some part of a natural system, including, among others, extreme weather events—that is,

[5]Nonprobability samples cannot be used to generalize or make inferences about a population. In this instance, we cannot generalize the results of our case studies to all federal resources or resources of the same ecosystem type.

weather events that are rare at a particular place (this may vary from place to place); the term "biological effects" to refer to changes in the interaction among organisms living in a given ecosystem; and the phrase "economic and social goods and services" to refer to economic resources, such as revenue-producing industries, including forestry and fishing, among others, and social or cultural resources, such as recreational activities, scenic views, and historical artifacts, among others. We recognize that all of these effects are interrelated, and that certain effects may belong to more than one category. Although the workshop experts discussed a wide range of possible climate-related effects, we describe only some of these effects in our report because we could not cover the full range of effects on all federal resources across the country. We also did not attempt to rank effects according to severity, owing to a lack of criteria to make such rankings. We conducted our work between May 2006 and July 2007 in accordance with generally accepted government auditing standards.

Results in Brief

U.S. federal resources within the four principal ecosystem types are vulnerable to a wide range of effects from climate change, including physical, biological, and economic and social effects. Some of these climate-related effects have already been observed, according to scientific experts participating in our November 2006 workshop. Officials at our four case study sites also pointed to examples of climate-related effects that are already occurring on federal resources. Among the types of effects identified are the following:

- Physical effects of climate change include drought, floods, glacial melting, sea level rise, and ocean acidification, among others. For example, warmer springs have resulted in earlier snowmelt, longer summer drought, and increased wildland fire activity in western U.S. forest ecosystems, where fires are linked more to climatic conditions than to land management techniques. Both the frequency of large fires and the area burned increased significantly in the western United States during the period of 1987 through 2003 compared with 1970 through 1986. In addition, as illustrated at Glacier National Park, climate change is causing glaciers to melt. Since 1850, the estimated number of glaciers in the park has dropped from 150 to 26. Both summer and winter temperatures are increasing in the park, and some projections suggest that if current trends in the rate of melting continue, the remaining glaciers will be gone in the next 25 to 30 years. Furthermore, rising sea levels that are attributable to climate change already have affected low-lying areas, as illustrated at Big Pine Key in the Florida Keys. According

to an FWS official in the Keys, saltwater intrusion on land, amplified by increased hurricane activity, has overwhelmed sources of fresh waters and habitat that support resident plants and animals, such as the Key deer and the Lower Key marsh rabbit. This official further stated that these effects will pose a threat in the future, not only to wildlife, but also to humans who live on the islands.

- Biological effects of climate change include increases in insect and disease infestations, shifts in species distribution, coral bleaching, and changes in the timing of natural events, among others. For example, warmer temperatures and reduced precipitation associated with climate change have contributed to insect outbreaks in some areas, as illustrated at the Chugach National Forest in Alaska. According to an FS official at the forest, a spruce bark beetle outbreak has led to high mortality rates for certain types of spruce trees on over 400,000 acres of the Chugach. In the Kenai Peninsula, Alaska, on which part of the forest is located, about 1 million acres have been affected by the beetles. Officials at the Chugach indicated that continued increases in temperature and decreases in precipitation could further change vegetation composition and structure, and increase the incidence and severity of future insect outbreaks. Similarly, in the Mojave Desert near the BLM Kingman Field Office, invasive grasses, combined with drought caused, at least in part, by climate change, have increased the frequency and severity of wildland fires, destroying native plants and transforming some desert communities into annual grasslands. Prolonged drought weakens the natural plant communities and then, in periods of wetness, invasive species—particularly grasses—fill the gaps between native vegetation. These invasive grasses can spread and grow faster than native species; the thicker and less evenly spaced vegetation leads to increased fire danger. If a fire starts, it burns much hotter due to the invasive grasses. Native plant communities, such as saguaro cacti and Joshua trees, are damaged, which provides further environment for invasive species and increased fire danger. According to experts, this shift in ecosystems from desert to grassland is likely to continue as the climate changes, which will in turn result in a loss of species diversity in these areas.

- Economic and social effects of climate change include adverse impacts on recreation and tourism; infrastructure; water supplies; and fishing, ranching, and other resource-use activities. For example, according to NOAA officials at the Florida Keys National Marine Sanctuary, the continued bleaching of coral reefs caused by climate change in the

Florida Keys may adversely affect the fishing and tourism industries, which are important sources of revenue for communities in the area. Coral reefs play a key role in these industries because they are an important habitat for fish and other marine species and are popular with snorkelers and scuba divers. Bleaching occurs when corals eject the microscopic algae that live within their tissues in response to stressful conditions, such as warmer water. (Corals can recover from bleaching events if the stress is not too severe or long-lasting, but the stress caused by bleaching can lead to secondary problems, such as coral diseases.) If water temperatures in the Florida Keys continue to increase as a result of climate change, more coral bleaching may occur, adversely affecting the area's fishing and tourism industries. Alaska may also be affected by the economic effects of climate change in the future. Many aquatic species are adapted to cold-water conditions, and temperature increases and seasonal shifts may adversely affect fishery resources, upon which commercial, sport, and subsistence fishers all depend.

Scientific experts at the workshop noted that the nature and extent of climate change effects will depend on the rate and magnitude of climate change. They also stated that some changes will occur quickly and will be readily apparent, while others will occur gradually and be less apparent in the near term.

In our workshop, resource managers identified several challenges to addressing the observed and potential effects of climate change in their management actions and planning efforts. These challenges include the following:

- Undertaking activities that address the effects of climate change is currently not a priority within the five resource management agencies in our review. Resource managers have a wide range of responsibilities, and they focus first on near-term activities that they are specifically required to undertake, leaving less time and resources for longer-term issues such as climate change. For example, officials at the BLM Kingman Field Office said that, due to resource constraints, they can only address the most immediate, highest-priority issues, and that backlogs of required actions, such as permits, are continually growing, leaving many issues, including climate change, unaddressed. Furthermore, in general, climate change effects are not specifically addressed in agency planning activities. For example, at the Chugach National Forest, managers stated that climate change is not a priority because it is not included in the most recent list of priority threats

developed by the FS Chief and is not considered a strategic issue by the agency. To plan and manage for climate change, these resource managers stated that agencies would have to change how they approach their missions because addressing climate change would require managers to anticipate potential future change in their planning processes, as opposed to using historical data to react to observed changes.

- Resource managers have limited guidance from their agencies about whether or how to address climate change in management actions and planning efforts. Under these circumstances, these resource managers are uncertain about what actions, if any, they should take. A 2001 Interior order directed BLM, FWS, and NPS to consider and analyze, among other things, potential climate change effects in management plans and activities developed for public lands. However, headquarters officials from these agencies told us that they have yet to provide direction to resource managers about how to implement this order. Officials at BLM headquarters stated that the lack of specific authority, guidance, and direction may have limited the agency's efforts to address the effects of climate change. Furthermore, in testimony before the House Appropriations Committee's Subcommittee on Interior, Environment, and Related Agencies on April 26, 2007, BLM's National Science Coordinator acknowledged that there is little current guidance at BLM dealing with climate change. However, the coordinator said that BLM is establishing policy and technical committees to address necessary actions and develop guidance to address climate change in agency management practices. Headquarters officials at FWS and NPS said that, although they have not developed specific guidance, they operate in a manner consistent with Interior's 2001 order in their general planning activities. However, resource managers from BLM, FWS, and NPS told us that they have received no direction for how to incorporate climate change into their planning activities. Headquarters officials from NOAA, under Commerce, said that the agency is establishing a working group to determine what actions it should and can afford to take to address the effects of climate change. FS headquarters officials said that, although they have not provided specific guidance on addressing the effects of climate change, the agency's planning process is designed to identify emerging issues, such as climate change, and respond in ways to promote the sustainability of the nation's land and water resources. Resource managers from FS and NOAA said that they have received no specific direction from their agencies about how to address climate change in their planning activities. In general, resource

managers from all of the agencies said that they need specific guidance to incorporate climate change in their management actions and planning efforts.

- These resource managers do not have sufficient site-specific information to plan for and manage the effects of climate change on the federal resources they oversee. In particular, they lack computational models capable of providing local projections of expected changes. For example, at the Florida Keys National Marine Sanctuary, officials said that they currently lack adequate modeling and scientific information that would enable managers to predict change on a small scale, such as that occurring within the sanctuary. Without such models, most of the managers' options for dealing with climate change are limited to reacting to already-observed effects on their units, making it difficult to plan for future changes. Furthermore, these resource managers generally lack detailed inventories and monitoring systems to provide them with an adequate baseline understanding of the plant and animal species that currently exist on the resources they manage. For example, at the Chugach National Forest, managers told us that, without accurate baseline inventory data of the plants and animals in the forest, it is difficult to determine whether changes to species populations are within the normal range of variability.

Furthermore, these resource managers said that climate change is inherently a complex, global issue. Greenhouse gas emissions generally originate outside the boundaries of federal resources, yet these resources are affected by the cumulative effects of the emissions. These managers further noted that climate change-related effects can interact with and amplify the effects of other, preexisting environmental problems, such as nonnative species or fire on a given resource unit, making resource managers' jobs more difficult.[6]

Resource managers are uncertain about what actions, if any, they should take to address the current effects of climate change and to plan for future effects on their resources. Agencies have not assigned climate change a priority among the other factors they must address and have not provided

[6]In technical comments on a draft of this report, Interior stated that changes in greenhouse gas concentrations and associated changes in climatic variables (e.g., temperature and precipitation) could also modify (up and down) these other nonclimate change-related stresses on the resources managed by federal agencies. Such changes could also have some positive effects on resources, further complicating matters.

resource managers with direction on how or whether to address the effects of climate change. Without such guidance—and additional site-specific data—resource managers are constrained in their ability to address climate change in their planning and management activities. Therefore, to better enable federal resource management agencies to take into account the existing and potential future effects of climate change on federal resources, we are recommending that the Secretaries of Agriculture, Commerce, and the Interior—in consultation with the Directors of FS; the Administrator of NOAA; and the Directors of BLM, FWS, and NPS, respectively—develop clear, written communication to resource managers that explains how managers are expected to address the effects of climate change, identifies how managers are to obtain any site-specific information that may be necessary, and reflects best practices shared among the relevant agencies, while also recognizing the unique missions, objectives, and responsibilities of each agency. In commenting on a draft of this report, Agriculture (for FS), Commerce (for NOAA), and Interior (for BLM, FWS, and NPS) all generally agreed with our recommendation and offered technical comments, which we have incorporated into the report as appropriate.

Background

Greenhouse gases—including carbon dioxide, methane, and nitrous oxide, among other gases—trap some of the sun's heat in the Earth's atmosphere and prevent the heat from returning to space. This insulating effect, known as the greenhouse effect, moderates atmospheric temperatures, keeping the Earth warm enough to support life. However, according to the IPCC, global atmospheric concentrations of these greenhouse gases have increased markedly as a result of human activities over the past 200 years and now far exceed preindustrial levels. The IPCC further reports that these increases have contributed to a warming of the Earth's climate. Table 1 shows the shares of greenhouse gas emissions and their global warming potentials from U.S. sources.[7]

[7]Since greenhouse gases differ in their potential to contribute to global warming, each gas is assigned a unique weight, called a global warming potential, which is based on its heat-absorbing ability relative to carbon dioxide over a fixed period. This provides a way to convert emissions of various greenhouse gases into a common measure, such as carbon equivalent. Thus, each molecule of methane, for example, has 21 times as much effect on warming as a molecule of carbon dioxide.

Table 1: Shares and Global Warming Potentials of Greenhouse Gas Emissions from U.S. Sources, 2004

Greenhouse gas	Major sources	Percentage of total U.S. greenhouse gas emissions	Global warming potential
Carbon dioxide	Fossil fuel combustion, nonenergy use of fuels, and iron and steel production	85%	1
Methane	Landfills, natural gas and petroleum systems, agriculture, and coal mining	8	21
Nitrous oxide	Agricultural soil management, transportation, and manure management	6	310
Synthetic gases (HFCs, PFCs, and SF_6)[a]	Substitution of ozone-depleting substances, electric power transmission and distribution, and aluminum production	2	140 to 23,900

Source: Environmental Protection Agency.

Note: Percentages do not sum to 100 percent due to rounding.

[a]HFCs (hydrofluorocarbons), PFCs (perfluorocarbons), SF_6 (sulfur hexafluoride).

The IPCC attributes increases in average global air and ocean temperatures, widespread melting of snow and ice, and rising mean global sea levels to a warming of the Earth's climate system. The IPCC reports that 11 of the 12 years between 1995 and 2006 rank among the 12 warmest years since 1850 (the first year that global temperatures were recorded) and are indicative of a strong upward warming trend over the last 50 years. Furthermore, according to the IPCC, since 1961, average global ocean temperatures have increased, because the oceans have absorbed more than 80 percent of the heat added to the Earth's climate system. Such warming causes seawater to expand, contributing to sea level rise. The IPCC also reports that mountain glaciers and snow cover have declined, on average, in both hemispheres, and that widespread decreases in the sizes of glaciers and polar ice caps, combined with losses in the ice sheets of Greenland and Antarctica, have very likely contributed to a sea level rise of 0.17 meters during the 20th century.

The federal government manages nearly 30 percent of the land in the United States. Three federal agencies within Interior—BLM, FWS, and NPS—and Agriculture's FS administer over 90 percent of these lands. NOAA, within Commerce, administers 14 Marine Protected Areas.[8] These agencies manage their resources for a variety of purposes related to

[8]Marine Protected Areas are areas where natural or cultural resources, or both, are given greater protection than the surrounding waters.

preservation; recreation; and in some cases, resource use, yet each agency has distinct responsibilities for the resources it administers. The statutes governing these agencies' resource management activities generally do not require the agencies to manage for specific outcomes, such as a certain number of visitors, or to provide a specific response to changes in ecological conditions, such as insect outbreaks. Instead, these laws give the agencies discretion to decide how best to carry out their responsibilities in light of their respective statutory missions as well as the need to comply with or implement specific substantive and procedural laws, such as the Clean Air Act, the ESA, or NEPA. The agencies are generally authorized to plan and manage for changes in resource conditions, regardless of the cause that brings about the change. As such, federal resource management agencies are generally authorized, but are not specifically required to address in their actions and planning efforts changes in resource conditions resulting from climate change.

BLM, FS, FWS, NOAA, and NPS have unique management missions, as follows:

- BLM's mission is to sustain the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations under the principles of multiple use and sustained yield as provided in the Federal Land Policy Management Act. BLM manages more than 260 million acres located primarily in 12 western states. The agency manages and issues permits for activities such as recreation, livestock grazing, timber harvesting, and mining.

- FS's mission is to sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations under the Multiple Use and Sustained Yield Act and the National Forest Policy Management Act. FS manages more than 190 million acres throughout the country. The agency manages and issues permits for activities such as skiing, livestock grazing, recreation, timber harvesting, and mining and for rights-of-way for road construction.

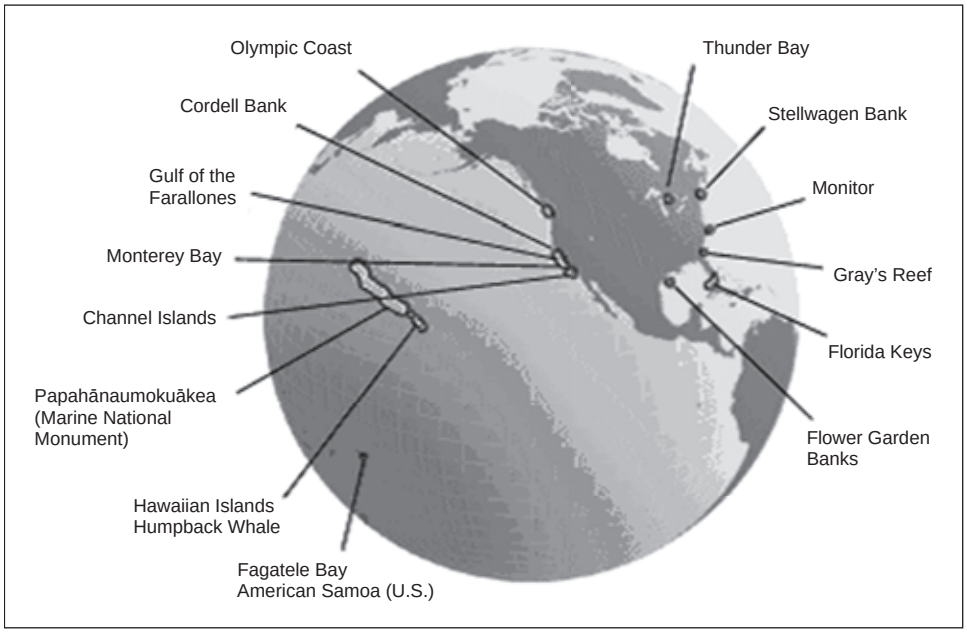
- FWS's mission is to work with others to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people. FWS also has a regulatory function, in that it enforces laws, including the ESA and others. FWS manages 547 national wildlife refuges and 37 large, multiple-unit Wetland Management Districts on more than 96 million acres of land throughout the nation; 69 national fish hatcheries; and 46 administrative sites. The National

Wildlife Refuge System, which performs FWS's land management functions, administers a national network of lands and waters for the conservation; management; and, where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States.

- In addition to these 4 agencies, NOAA seeks to preserve the biological and ecological integrity of U.S. marine systems, which include its National Marine Sanctuary System, consisting of 14 Marine Protected Areas that encompass more than 150,000 square miles of marine and Great Lakes waters. (See fig. 1.) NOAA also manages the waters of the Exclusive Economic Zone, the outer boundary of which is 200 nautical miles from the U.S. coastline.

- NPS's mission is to conserve the scenery, the natural and historic objects, and the wildlife of the national park system so that they will remain unimpaired for the enjoyment of current and future generations. NPS manages 391 national park units covering more than 84 million acres throughout the United States and its territories. The agency manages many of the nation's most precious natural and cultural resources.

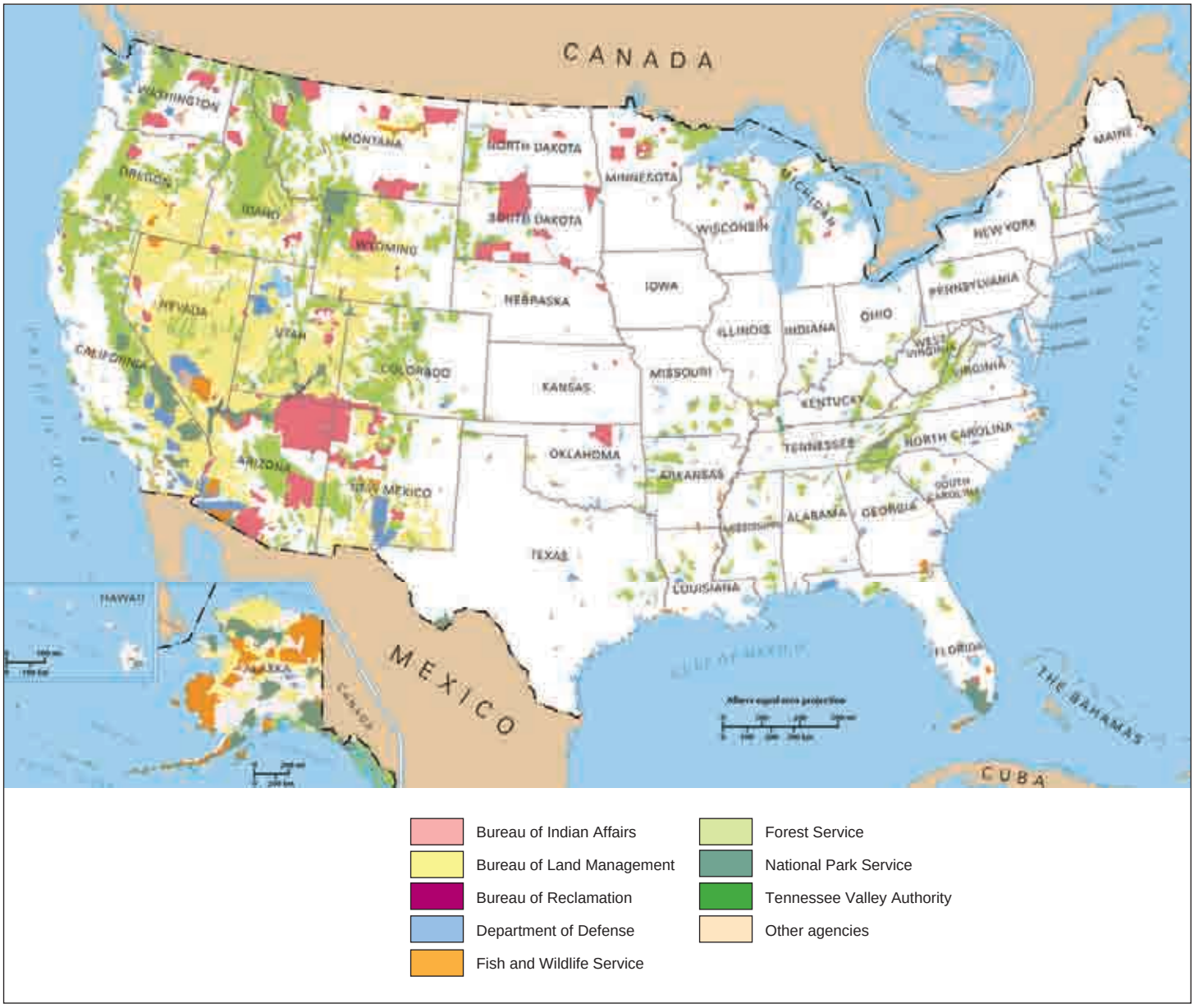
Figure 1: Map of NOAA National Marine Sanctuaries



Source: National Oceanic and Atmospheric Administration.

Other federal entities that manage various federal land and water resources include the Bureau of Indian Affairs, the Bureau of Reclamation, the Department of Defense, and the Tennessee Valley Authority, among others. Figure 2 shows federal resources according to the entity responsible for their management.

Figure 2: Map of Federal Resources and the Entities Responsible for Their Management



Source: U.S. Geological Survey.

The resource units managed by the federal government encompass four principal ecosystem types, as shown in table 2.

Table 2: Key U.S. Ecosystem Types

Ecosystem type	Description
Coasts and oceans	Estuaries, coastal habitats, and ocean waters as far as 200 miles from the U.S. shoreline.
Forests	Land areas of 1 acre or more that are at least 10 percent covered by trees, including areas in which trees are intermingled with other cover and both naturally regenerating forests and areas planted for future harvest.
Fresh waters	Streams, rivers, lakes, ponds, reservoirs, fresh water wetlands, groundwater, and riparian (riverbank) areas.
Grasslands and shrublands	Lands in which the dominant vegetation is grasses and other nonwoody vegetation, or where shrubs are the norm, including bare-rock deserts, alpine meadows, and Arctic tundra.[a]

Source: H. John Heinz III Center for Science, Economics, and the Environment, *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States* (2002).

Note: The Heinz Center classification system also includes two additional ecosystems: farmlands and urban and suburban areas. However, we did not consider these two ecosystem types in this report, because the majority of these lands are in private hands.

[a]Alpine refers to the zone made up of slopes above the timberline and characterized by, among other things, the presence of low, shrubby, slow-growing woody plants. Tundra is a treeless, level, or gently undulating plain characteristic of the Arctic and subarctic regions.

Experts Stated That Federal Resources Are Vulnerable to a Wide Range of Observed and Potential Climate Change Effects, and That the Nature and Extent of These Effects Will Vary

Experts at our workshop told us that climate change is likely to affect federal resources in a number of ways. For example, the experts said that climate change has already caused—and will likely continue to cause—physical changes, including drought, floods, glacial melting, sea level rise, and ocean acidification. Climate change will also cause biological changes, such as increases in insect and disease infestations, shifts in species distribution and abundance, and changes in the timing of natural events (referred to as phenological changes), among others. The experts further said that climate change is likely to adversely affect economic and social goods and services supported by federal resources, including recreation, tourism, infrastructure, water supplies, fishing, ranching, and other resource uses. Officials at our four case study sites provided us with additional examples of some of these climate-related effects already occurring on federal resources. As we have previously mentioned, these four sites are the Florida Keys National Marine Sanctuary in southern Florida (coasts and oceans ecosystem); the Chugach National Forest in south-central Alaska (forests ecosystem); Glacier National Park in northwestern Montana (fresh waters ecosystem); and the BLM Kingman Field Office in northwestern Arizona (grasslands and shrublands ecosystem).

Physical Effects of Climate Change on Federal Resources Are Already Apparent and Will Likely Increase

Experts at our workshop and officials at our four case study sites stated that climate change can result in physical changes, and that many such changes have already occurred and are likely to continue in the future. Physical effects of climate change include warmer temperatures, drought, glacial melting, floods, sea level rise, and ocean acidification, among others.

Experts from the workshop identified increased temperatures as one of the key physical effects of climate change. According to these experts, effects of increasing temperatures that have already been observed include the declining duration of lake and river ice cover throughout the northern hemisphere and increased temperatures of 7 to 10 degrees Fahrenheit in eastern water bodies after storm events.

A scientist at Glacier National Park told us that, while the estimated global average temperature has risen 0.6 degree Celsius (about 1 degree Fahrenheit) since about 1897, the estimated average temperatures of the highest elevations in the park have risen 1.6 degrees Celsius (about 3 degrees Fahrenheit) over the same period. This scientist expects this trend to continue. Winter and summer temperatures within the park also are increasing. The data suggest that the number of frost days below 0 degree Celsius (32 degrees Fahrenheit) in Montana from 1900 to 2005 declined by 3 weeks. Furthermore, in 1900, the estimated number of extreme heat days—defined as days with temperatures above 90 degrees Fahrenheit—was about 5 days per year in Glacier National Park (and western Montana); in 2005, this estimated number was about 20 days per year. A record was set in 2003, with 31 days above 90 degrees Fahrenheit. Experts consider 90 degrees to be a major threshold beyond which there are negative impacts on human health and plants in the region. Increased moisture stress due to increased temperatures makes plants more vulnerable to fire, and fire activity in the region has increased in recent years. In 2003, 74,000 hectares in Glacier National Park—about 13 percent of the park's total area—burned, in what was the largest fire year since 1910, when the park was founded.[9] Other major fires occurred in 1988 and 2001, according to NPS and U.S. Geological Survey (USGS) officials.

According to experts at the workshop, warmer spring seasons—due at least partly to climate change—have already resulted in earlier snowmelt,

[9]A hectare is a unit of area equal to 10,000 square meters, or 2.47 acres.

longer summer dry periods, and increased wildland fire activity in western U.S. forest ecosystems, where the experts stated that fires are linked more to climatic conditions than to land management techniques. Both the frequency of large fires (greater than 400 hectares) and the area burned increased significantly in the western United States during the period of 1987 through 2003 compared with 1970 through 1986, and wildland fire size and severity are likely to further increase with climate change, according to these experts. Furthermore, workshop participants noted that, in general, climate change will likely increase droughts in the future.

Drought conditions that are potentially caused by climate change are already affecting trees, shrubs, and water resources in some areas. For example, according to officials from the BLM Kingman Field Office, about 30 percent of old growth pinyon pine trees in the Cerbat Mountains of Arizona; extensive stands of black brush near Dolan Springs in Arizona; and shrubs, such as cliffrose and juniper on shallow soils on the Colorado Plateau, have died due to severe drought conditions. Similarly, officials from the Chugach National Forest told us that closed-basin lake levels in the Kenai Lowlands in south-central Alaska have declined by as much as 1 meter as a result of drought, and many ponds that appeared on 1950 maps and aerial photographs are now grassy basins with spruce and hardwood trees.

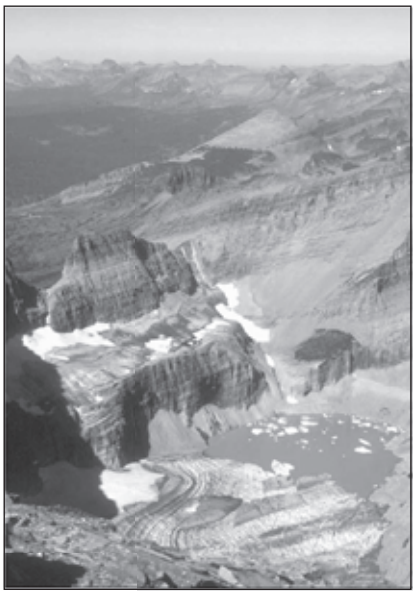
Experts participating in all of our workshop discussions also identified ice and glacial melting as physical effects resulting from climate change. Experts said that there is evidence that sea ice retreat, accelerating glacier melt, and measurable coastal erosion in the Arctic—due, at least in part, to climate change—are now greater than they were just 5 years ago. These experts noted that there also has been a major loss of glaciers in the western United States, such as in Montana and Alaska. According to a scientist at Glacier National Park, the estimated number of glaciers in the park has dropped from 150 to 26 since 1850, and some projections suggest that if current trends in the rate of melting continue, the remaining glaciers will be gone in the next 25 to 30 years. Figure 3 shows the melting of Grinnell Glacier between 1938 and 2005. Furthermore, according to officials at the Chugach, many Kenai Peninsula glaciers in south-central Alaska began retreating in the 1850s. For example, the Harding Icefield lost 70 vertical feet and 5 percent in surface area in the last 50 years, according to these officials. In addition, an official at the Chugach said that glaciers in the forest have generally been declining very quickly in surface area and volume, with a few exceptions due to local topography. Furthermore, according to our workshop participants, increasing air, ocean, and coastal

water temperatures will likely lead to a continuing loss of sea ice, a reduction in permafrost, decreased snowpack, and increased glacial melting.[10]

[10]Permafrost is perennially frozen ground that occurs wherever the temperature remains below 32 degrees Fahrenheit for several years. Melting permafrost leads to the release of methane, a greenhouse gas, which is trapped below the permafrost. This melting further raises greenhouse gas concentrations in the atmosphere.

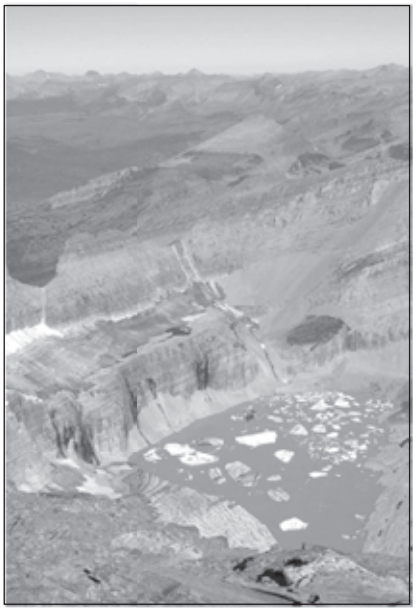
Figure 3: Grinnell Glacier as Viewed from Mt. Gould in Glacier National Park, between 1938 and 2005

1938



1981

1998



2005

Source: U.S. Geological Survey.

According to experts discussing the fresh waters ecosystem at our workshop, flooding is another physical effect potentially caused by climate change. For example, they noted that rain-on-snow events (i.e., rain following snow) increase the potential for flooding, because rainwater and melted snow cause very high runoff rates in winter and early spring. Officials at Glacier National Park who have observed such changes told us that regional precipitation patterns are changing, such that more precipitation falls as rain and less as snow. (They said that snowpack has declined by up to 30 percent since the mid-20th century.) With less snow and warmer winters, the timing of spring runoff can be up to 20 days earlier than normal. This is causing winter streamflow to increase and summer streamflow to decrease. Scientists expect to continue to receive less snow in winter with more rain, rain-on-snow conditions, and midwinter melting of snowpack. These warmer winters may lead to more winter flooding in the park—as well as more avalanches. The experts further noted that high runoff in winter and early spring is likely to increase soil erosion, enlarge stream channels, increase sediment loads in streams, and increase stream turbidity.[11] Because of the higher volume of runoff in the spring, combined with less snowpack, streams could shrink or dry up completely every summer. Not only would this affect riparian vegetation growth and aquatic animals, the associated drying of adjacent soils and vegetation would also increase the risk of forest fires.[12]

Experts discussing the coasts and oceans ecosystem at our workshop also identified sea level rise as one of the key physical effects of climate change. Global ocean and coastal trend analyses that are based on satellite measurements of sea level change suggest that sea levels are rising faster to higher levels at different rates in different places. According to these experts, sea level rise may lead to flooding and the permanent loss of coastal wetlands and barrier shorelines; degradation of fresh waters, brackish coastal waters, and low-lying ecosystems, which could impact the drinking water supply; the loss of storm buffers for low-lying areas; increased vulnerability to storm surge and flooding; and increased erosion and retreat of shorelines around barrier islands and estuaries. For example, these experts said that the Alligator River National Wildlife Refuge in North

[11]Turbidity, or water cloudiness, is one of the indicators used to assess the environmental health of water bodies. It is caused by the presence of suspended and dissolved matter, such as clay, silt, finely divided organic matter, and other substances.

[12]Riparian areas are those on the bank of a natural watercourse, such as a river, or sometimes a lake or tidewater.

Carolina, the Blackwater National Wildlife Refuge in Maryland, as well as various southeast and southwest Louisiana national wildlife refuges, are among the federal resources particularly vulnerable to sea level rise. Also, according to experts discussing the grasslands and shrublands ecosystem, as sea levels rise, saltwater will encroach on coastal prairies, turning them into coastal wetlands.

Rising sea levels that are attributable to climate change already have affected low-lying areas, such as Big Pine Key in the Florida Keys. According to an FWS official in this area, saltwater intrusion on land, amplified by increased hurricane activity, has overwhelmed sources of fresh waters and habitat that support resident plants and animals, such as the Key deer and the Lower Key marsh rabbit that live on the Keys refuges.[13] This official further stated that these effects will pose a threat in the future, not only to wildlife, but also to humans who live on the islands.

Finally, experts discussing the coasts and oceans ecosystem at our workshop also identified ocean acidification as one of the physical effects of climate change. Acidification occurs when increased carbon dioxide levels decrease the concentration of carbonate ion in seawater. Because carbonate ion is a substance that coral reefs need to build their skeletons, ocean acidification may reduce the calcification rate in corals (and other calcium carbonate-based species) and cause other changes in the oceanic food chain, plankton communities, and the distribution of certain species. This could affect the coral reefs comprising the Florida Keys National Marine Sanctuary and corals in any other marine protected area, state, or territory. A University of Miami scientist who has been studying coral reefs and climate change for a number of years, and with whom we spoke while conducting our Florida Keys case study, told us that by 2050, carbonate ion could be 34 percent less abundant than today.[14]

[13]Since the Florida Keys National Marine Sanctuary is linked ecologically to four National Wildlife Refuges on the Florida Keys and to the Everglades and Dry Tortugas National Parks ecosystems, we also interviewed officials from these sites.

[14]However, this University of Miami scientist noted that, because emissions are already exceeding the pace assumed for this estimate, the 34 percent reduction point will likely be reached sooner than 2050.

Biological Effects of Climate Change on Federal Resources Are Already Apparent and Are Likely to Increase

Experts participating in our workshop and officials at our four case study sites stated that climate change can result in biological changes, and that many such changes have already occurred and are likely to continue in the future. The biological effects of climate change include increases in insect and disease infestations, shifts in species distribution, and changes in the timing of natural events (referred to as phenological changes), among others.

Experts discussing the forests and the grasslands and shrublands ecosystems noted that the infestation of pests—especially those that emerge under warmer or drier conditions—is a key biological effect attributable, at least in part, to climate change. Examples of such pests include bark beetles, grasshoppers, and various fungi as well as diseases caused by bacteria, parasites, and viruses. According to experts at the workshop plenary session, the spruce bark beetle, the mountain pine beetle, and the southern pine beetle have already infested some U.S. forests, thriving in areas where the cold winters would have previously prevented them from colonizing. These experts noted, for example, that the southern pine beetle has migrated into red spruce areas in the southeastern United States, and that pests have also damaged New England sugar maples. The experts further noted that increased temperatures will increase the range and effects of insects and disease infestation. In particular, experts stated that there have been shifts in the intensity and extent of the spruce bark beetle in the Pacific Northwest and Alaska caused by an acceleration of the beetle's life cycle due to warmer and drier climatic conditions.

A spruce bark beetle infestation has already occurred at the Chugach National Forest, according to an FS official at the forest. Warmer temperatures and reduced precipitation associated with climate change have contributed to a spruce bark beetle outbreak that has led to high mortality rates for certain types of spruce trees on over 400,000 acres of the forest (see fig. 4). About 20 percent of the forest's land and the adjacent Kenai National Wildlife Refuge are located on the Kenai Peninsula. According to FS experts, about 1 million acres of the peninsula have been affected by the beetles, including 400,000 acres within the forest itself. Officials at the Chugach indicated that continued increases in temperature and decreases in precipitation could further change vegetation composition and structure and increase the incidence and severity of future insect outbreaks. The officials stated that spruce bark beetle populations increase greatly when warm weather climate events combine

with forest stresses.[15] (Officials at the Kenai National Wildlife Refuge noted, however, that not all spruce bark beetle damage is attributable to climate change. Another scientist explained that the key link to climate change is that outbreaks are now persistent and not episodic.)

[15]FS officials noted that spruce bark beetle outbreaks are normal events in forested ecosystems. A study conducted by experts at the Kenai National Wildlife Refuge indicated that the recent outbreaks on the Kenai Peninsula between 1971 and 1996 were positively associated with the 5-year backward running average of summer temperatures. Their research found that warm temperatures influence spruce bark beetle population size through a combination of increased winter survival, a doubling of the maturation rate from 2 years to 1 year, and the regional drought-induced stress of mature host trees. (Edward E. Berg, J. David Henry, Christopher L. Fastie, Andrew D. De Volder, and Steven M. Matsuoka, "Spruce Beetle Outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to Summer Temperatures and Regional Differences in Disturbance Regimes," *Forest Ecology and Management*, vol. 227, issue 3, June 1, 2006, 219-232.)

Figure 4: Spruce Trees Killed by the Spruce Bark Beetle in the Kenai Peninsula, Alaska

Source: Forest Service, Forest Health Protection.

Note: The brown-colored trees shown in this figure are white spruce killed by spruce bark beetles.

Experts discussing the fresh waters ecosystem said that increased water body temperatures may increase the risk of toxic algal blooms as well as the severity of fish diseases. They said that there have been recent

observations of severe pathogen problems in the Yukon River in Alaska.[16] (The Yukon River flows through the Yukon Delta National Wildlife Refuge.) Experts in the coasts and oceans ecosystem likewise noted that increasing air and water temperatures could increase the incidence of toxic algal blooms in ocean environments. They observed that increased microbial activity could affect fish, shellfish, corals, sea turtles, and some sea grasses.

Another biological effect of climate change that was identified by the workshop experts is anticipated shifts in the distribution, abundance, and ranges of both plant and animal species. As an example of one observed change that is due at least in part to climate change, fresh waters ecosystem experts noted that the nonnative zebra mussel has extended its range in the Great Lakes as lake temperatures have warmed. Experts discussing other ecosystem types similarly agreed that changes in species distribution are likely to occur in the future, and that nonnative species might eventually dominate or replace native species in some areas. For example, experts discussing the coasts and oceans ecosystem noted that marine and nonnative species may invade estuaries where they have typically not lived. Oyster predators from the ocean may move into the Chesapeake Bay, for example. Likewise, experts on the forests ecosystem said that forest species composition—both the trees and the species that depend on the trees and forest vegetation—may change. They indicated that sugar maple, white bark pine at high elevations, and subalpine spruce fir forests in the Rocky Mountains have already experienced such changes. Experts discussing the grasslands and shrublands ecosystem, moreover, stated that tree die-offs triggered by drought and exacerbated by higher temperatures may lead to a shift from woodland to shrubland or grassland. They said that midwestern savannas and the southwestern pinyon and juniper woodlands are particularly vulnerable to such changes.[17] They further noted that some rare ecosystems, such as alpine tundra, California chaparral, and blue oak woodlands in California may become extinct altogether.[18] These experts said that native biodiversity will decrease in

[16]A pathogen is a disease-causing agent, such as a bacterium or a virus.

[17]A savanna is a rolling grassland with scattered individual trees. The climate is generally warm or hot.

[18]Chaparral is a type of plant community where shrubs are dominant. It usually occurs in regions having from 10 to 20 inches of rainfall annually; it is found in the western part of the United States.

many areas, and that new assemblages of species will be living together, with unknown consequences.

Evidence of changes in species distribution is already apparent on some federal resources. For example, according to officials at the BLM Kingman Field Office, drought conditions are causing native Mojave Desert scrub plant communities in the region to convert into nonnative annual grassland communities, which are more vulnerable to fire.[19] This phenomenon has contributed to problems related to fire management. Prolonged drought acts as a source of stress to native plant communities. Then, in periods of wetness, invasive species (typically, invasive annual grasses) fill in the gaps between native vegetation. Invasive species can spread and grow faster than native species.[20] As a result, the thicker and less evenly spaced vegetation leads to fire danger. If a fire starts, it burns much longer and hotter due to the invasive grasses. Native plant communities, such as saguaro cacti and Joshua trees, are not fire resistant, so fire damages these communities and provides further environment for invasive species and increased fire danger. In some instances, repeated fires of this nature have destroyed native plant communities, such that only invasive grasslands remain. A severe drought occurred in 2002 that resulted in the loss of perennial grasses, shrubs, and trees. Drought, coupled with increased annual growth in wet years, accelerates the conversion of hot desert plant communities into annual grasslands. Should continued severe drought become the norm, this conversion can be expected to continue.

Furthermore, according to BLM Kingman officials, pinyon-juniper woodlands (which include pinyon pine trees and various types of junipers) near the BLM site have died off, as have some ponderosa pines and chaparral. These officials said these changes are likely due to the severe drought the region has experienced since about 1996. According to these officials, even pinyon pines hundreds of years old that have survived drought events in the past are dying, which the officials said was unusual and unique. Ponderosa bark beetles and mistletoe infestations have also stressed the trees, contributing to the die-off of the ponderosa pines. BLM officials said that changes to forested plant communities would be significant, since these communities already are small and disjunct. The

[19]An annual grassland is one in which the grasses complete their life cycle within 1 year of germination.

[20]Experts noted that invasive species have a relative advantage in a changing climate because they tend to be more adaptive.

resource managers said that these communities probably would either be greatly reduced in size or eliminated from many areas.

Experts discussing fresh waters told us that temperature increases are most likely to threaten cold-water species, such as trout, salmon, and amphibians. An FWS fish biologist who studies and provides expertise on certain resources in Glacier National Park told us about a park species, the bull trout, that is at particular risk from climate change. The bull trout, listed as a threatened species under the ESA, is native to the western United States. It migrates in the spring from lakes and streams, such as Flathead Lake up the Flathead River system near the park, where it spawns in the fall in tributaries as far as 150 miles upstream. This fish is very sensitive to water temperature and clarity. Its spawning temperature range is 6 to 10 degrees Celsius (43 to 50 degrees Fahrenheit), and its young-rearing temperature range is below 16 degrees Celsius (61 degrees Fahrenheit). It is found in only the coldest streams. If temperatures increase, streams may become intolerable for the bull trout. In addition, if isolated glaciers disappear due to temperature increase, the mountain streams the glaciers feed may dry up late in the season, further reducing habitat. Therefore, the bull trout can only survive in a very limited area, and many of its migration corridors have been cut off as a result of ecosystem fragmentation.

Scientists at Glacier National Park further noted that warming trends are expected to cause an upward migration of vegetation, changing the ground cover in many areas of the park and affecting wildlife species that depend on those habitats. As alpine habitats warm, the tree line is expected to move upslope, with forests beginning to invade alpine and subalpine meadows.[21] Some of these changes are already occurring. Animals that may be harmed by the loss of alpine and subalpine habitat include bighorn sheep, pikas (relatives of the rabbit), mountain goats, wolverines, and grizzly bears. Many rare plants and animals in Glacier are near extinction, and the experts said that climate change may increase the likelihood that these species will cease to exist in the park.

Experts on several ecosystem types also stated that climate change will affect phenology, that is, plant and animal life-cycle events that are influenced by environmental changes, especially seasonal variations in

[21]Subalpine vegetation is that just below the tree line, often dominated by pine or spruce trees.

temperature and precipitation. Experts discussing the forests ecosystem, for example, said that changes will affect critical species interactions, such as pollination and seed dispersal. Experts discussing the grasslands and shrublands ecosystem observed that the distribution of plants that undergo photosynthesis during the cool season and plants that undergo photosynthesis during the warm season may change, with implications for the animals—both vertebrates and invertebrates—that are associated with them. They further noted that pollination could become out-of-sync with flowering. Likewise, one expert on the fresh waters ecosystem also stated that the phenology of fish migration and reproduction may be disrupted by changing patterns of water flow or availability.

Officials at the Chugach National Forest indicated that the recent spruce bark beetle outbreaks on the Kenai Peninsula may be attributed, to some extent, to phenological changes. For example, the spruce bark beetle's life cycle has accelerated from 2 years to 1 year. These officials explained that populations of many insects are regulated by low winter temperatures and many outbreaks end by episodes of cold temperature. However, as the climate warms, infestations by insects whose populations are controlled by cold will likely increase. Furthermore, an FWS biologist in the Florida Keys pointed out that, on the basis of some limited data sets, it appears that green turtles in the Keys region may be nesting earlier, possibly as a result of climate change. The biologist also noted that a larger study of loggerhead turtles conducted in another part of Florida between 1989 and 2003 found that the median date of loggerhead turtle nesting occurred approximately 10 days sooner.[22] During this same 15-year period, according to the study, average sea surface temperatures increased by 0.8 degree Celsius during May, when loggerheads typically begin to nest on these beaches. This study suggests that the turtles may be responding to recent climate trends.[23]

[22]The area covered by the study of loggerhead turtles includes the Archie Carr National Wildlife Refuge on the east coast of Florida.

[23]John F. Weishampel, Dean A. Bagley, and Llewellyn M. Ehrhart, "Earlier Nesting by Loggerhead Sea Turtles Following Sea Surface Warming," *Global Change Biology*, vol. 10, issue 8 (August 2004), 1424-1427.

Climate Change Is Likely to Affect the Economic and Social Goods and Services Supported by Federal Resources

Experts participating in our workshop noted that climate change is likely to have adverse effects on a range of economic and social goods and services supported by federal resources, including recreation and tourism, infrastructure, water supplies, fishing, ranching, and other resource-use activities.

According to experts on the grasslands and shrublands ecosystem, if FWS-managed wetlands—called prairie potholes—in the upper midwest dry up, waterfowl populations would decline, since these wetlands serve as resting, feeding, and nesting habitat for migratory waterfowl.[24] The loss of the prairie potholes would hurt midcontinent waterfowl populations and the many resources that interact with them. This loss would further result in wide-ranging economic impacts on a variety of industries, such as hunting, and on communities in that part of the country.

The experts also pointed out that the increasing frequency of extreme events, such as fire or drought, could limit recreational activities on federal lands. For example, experts on the coasts and oceans ecosystem observed that accelerated sea level rise could result in a loss of beaches and associated recreational activities. They further stated that increasing air and water temperatures could affect such recreational activities as fishing and bird-watching, and that ocean acidification could negatively affect tourism and sport fishing in coastal areas. Similarly, managers at the BLM Kingman Field Office told us that climate change could cause declines in the recreational use of the land by hunters (owing to less game to hunt) and by the visiting public.

NOAA officials at the Florida Keys National Marine Sanctuary told us that the continued bleaching of coral reefs in the Florida Keys—caused, at least in part, by climate change—may adversely affect the tourism and fishing industries, which are important sources of revenue for communities in the area. Coral reefs play a key role in these industries because they are important habitats for fish and other marine species and are popular with snorkelers and scuba divers. Bleaching occurs when corals eject the microscopic algae that live within their tissues in response to stressful

[24]A prairie pothole is a wetland that fills with snowmelt and rain in the spring. Some are permanent, and some are temporary. Virtually all of the Wetland Management Districts within the National Wildlife Refuge System are located in the upper midwest. These Wetland Management Districts are made up of about 30,000 individual Waterfowl Production Areas.

conditions, such as warmer water. (Corals can recover from bleaching events if the stress is not too severe or long-lasting, but the stress caused by bleaching can lead to secondary problems, such as coral diseases.) If water temperatures in the Florida Keys continue to increase as a result of climate change, more coral bleaching may occur, adversely affecting the area's tourism and fishing industries. Figure 5 shows two brain coral colonies in the Upper Keys area of the Florida Keys National Marine Sanctuary in July 2005. The smaller colony (bottom of the figure) shows healthy coloration, while the larger colony (top of the figure) is nearly completely bleached.

Figure 5: Bleached Brain Coral, July 2005

Source: National Oceanic and Atmospheric Administration, Florida Keys National Marine Sanctuary.

Experts from three workshop groups noted that climate change could affect infrastructure and operational costs on federal lands. For example, experts in the grasslands and shrublands ecosystem noted that, as wildland fires become more frequent and severe as the climate changes, the costs of fire-fighting and rehabilitating land increases. Experts stated that rising sea

levels will affect resource use on federal lands, and that changes in precipitation will affect dams, canals, flood protection, and reservoirs. Experts discussing the fresh waters ecosystem said that some park visitation levels, particularly in colder climates, have been restricted by weather conditions. Climate change, they noted, is expected to result in a change of visitor patterns and may result in a wider use of the land's resources and infrastructure. Managers at Glacier National Park agreed with this perspective, saying that climate change may lengthen the primary visitation period for the park as spring comes earlier and winter comes later. According to these officials, June through August used to be the peak visitation time frame, but already companies affiliated with the park (e.g., concession owners) are getting more requests to conduct activities in May and September. Roads and facilities may need to stay open longer, which will require more staff and resources, and the potential for weather-related infrastructure damage will require more maintenance and improvements. These officials further noted that if the park is open longer, there will be more crime, more bear-human interactions, and a greater need for search-and-rescue operations, all of which will require more resources to manage.

Climate change has already affected the infrastructure on some federal lands. For example, officials from the Chugach National Forest indicated that, to the extent that large storm events are related to climate change, there have been significant impacts on bridges and infrastructure in Alaska, and that the frequency of severe storm events appears to be increasing. (Forest officials noted that in the last 10 years, the Chugach National Forest region has experienced two 100-year storm events.) Similar effects and other impacts on infrastructure are illustrated at Glacier National Park. Officials at the park told us that, in 2003, the most popular and scenic road in the park, the Going-to-the-Sun Road, was shut down for 23 days due to fire. To the extent that climate change is linked to more frequent and severe forest fires, western Montana could face more fires. Glacier National Park staff noted that fires distract FS and NPS staff from their regular duties, and that if more fires occur, the visitor experience could be diminished by poor air quality and limited access to fire-ravaged areas of the park. As a result, the park and local communities could face lost revenues associated with declines in visitation.

Experts in the fresh waters ecosystem indicated that climate change may also adversely affect water supplies and quality. Snow and ice serve as natural reservoirs in mountainous areas and northern regions of the United States, gradually supplying water into the summer months. Much of the

west relies on spring snowmelt to provide a steady stream of water into summer months, when demand is highest. However, warmer temperatures and changes in winter precipitation patterns from snow to rain are expected to continue causing reduced snowpack and early snowmelt. Water supply shortages will likely increase the cost of water. In addition, the experts said that water quality is likely to decline if harmful algal blooms, bacteria, or botulism occur as a result of increased temperature; such occurrences would likely result in increased water treatment costs. Moreover, coastal areas that rely on groundwater supplies will have to be careful not to overdraw from the aquifer to avoid saltwater intrusion and contamination, particularly in water-stressed areas of the southwest. Experts on the coasts and oceans ecosystem stated that accelerated sea level rise could increase saltwater intrusion, affecting drinking water supplies in some regions.

Water issues are particularly significant in the southwestern United States. For example, BLM Kingman Field Office managers told us that climate change-related economic costs resulting from declines in the availability of water in the region could be extremely high. According to experts discussing the fresh waters ecosystem, less surface water availability means lower groundwater recharge rates and further demand on the existing groundwater resources. The BLM managers further said that reductions in groundwater could affect communities within the field office boundary by causing wells to dry up, thereby forcing people to abandon homes or greatly increasing the cost of living in the area.

Experts on various ecosystem types noted that the use of certain resources on public lands could be affected by climate change. For example, experts discussing the fresh waters ecosystem noted that Alaska may be affected economically by climate change. They said that many fish species are adapted to cold-water conditions, and that temperature increases and seasonal shifts may adversely impact fisheries upon which commercial, sport, and subsistence fishers depend. Also, experts discussing the grasslands and shrublands ecosystem stated that changing climate conditions might reduce Native Americans' use of federal lands and reduce revenue from natural resources on their lands. They also noted that changes in the water supply might lead to greater competition for water, which could have a negative economic impact on ranchers and some communities situated near federal lands. Officials at the BLM Kingman Field Office agreed that if the climate becomes hotter and drier, there could be a decline in the ranching industry in the Kingman area. In addition, officials at the Chugach National Forest told us that large storms can be

harmful for the fishing industry; they said that the last major storm destroyed salmon spawning areas in the Chugach for 1 year.

Scientific experts at the workshop noted that the nature and extent of climate change effects will depend on the rate and magnitude of this change. They also stated that some changes will occur quickly and will be readily apparent, while other changes will occur gradually and be less apparent in the near term.

Resource Managers Identified Several Challenges in Addressing the Observed and Potential Effects of Climate Change on Federal Resources

Resource managers from the five key resource management agencies—BLM, FS, FWS, NOAA, and NPS—who participated in our workshop identified several challenges to addressing the observed and potential effects of climate change.[25] These challenges include (1) the lack of priority given to addressing the effects of climate change within their agencies, (2) limited guidance from headquarters about whether or how to address the effects of climate change in management actions and planning efforts, and (3) insufficient site-specific information to plan for and manage the effects of climate change on the federal resources they oversee. Resource managers further stated that climate change is a complex, global issue that is difficult for one resource unit or agency to address on its own. In addition, resource managers interviewed for our case studies described similar challenges and provided illustrative examples.

Addressing the Effects of Climate Change Is Not a Priority Within Resource Managers' Agencies

According to resource managers from our workshop and case studies, addressing the effects of climate change is currently not a priority within the federal resource management agencies. These resource managers said that they can use their existing management practices to respond to changing conditions at their units—some of which could be caused, at least in part, by climate change. However, they said that specifically addressing

[25]All five resource management agencies—as well as Interior's Bureau of Reclamation and USGS—were represented in the workshop as a whole, but were not consistently represented in the four individual ecosystem discussion sessions. Resource managers from FWS, NOAA, NPS, and USGS participated in the sessions discussing coasts and oceans; managers from FS, FWS, and NPS participated in the forests sessions; managers from the Bureau of Reclamation, FWS, and NPS participated in the fresh waters sessions; and managers from BLM, FS, FWS, and NPS participated in the grasslands and shrublands sessions. Except when otherwise noted, all statements identified as coming from a specific workshop session reflect the collective views of the individual participants and apply to the resource management agencies represented by the managers at that session.

the current and potential future effects of climate change is not a priority.[26] For example, in discussing the grasslands and shrublands ecosystem at the workshop, resource managers agreed that climate change is not on their agencies' agendas as a policy issue. Furthermore, resource managers from the BLM Kingman Field Office and the Chugach National Forest stated explicitly that climate change is not a priority for them.

Resource managers in all of the workshop groups agreed that they have a wide range of responsibilities and that, because none of the agencies have designated climate change as a priority, the managers focus first on near-term activities that they are specifically required to undertake, leaving less time and resources for longer-term issues such as climate change. For example, resource managers discussing the fresh waters ecosystem told us that they are typically accountable for things on a short-term time frame, and current planning horizons may be too short for incorporating long-term factors such as climate change into management practices. In addition, managers at the BLM Kingman Field Office said that, due to resource constraints, they can only address the most immediate, highest-priority issues, and that backlogs of required actions, such as permits, are continually growing, leaving other issues unaddressed, including the effects of climate change. Furthermore, NOAA resource managers at the Florida Keys National Marine Sanctuary said that, due to limited staffing and fiscal resources, NOAA expects sanctuary managers to place a priority on meeting the many daily challenges they face, such as implementing the management plan for the 2,900 square nautical mile sanctuary and, specifically, managing no-boating or no-fishing zones to protect sensitive areas. Climate change has not been identified as a priority in the National Marine Sanctuaries. Resource managers discussing all four ecosystem types at the workshop stated that, to address the long-term issue of climate change, agencies would have to change how they approach their missions. In this regard, they said that resource managers are currently bound to using historical data to react to observed changes, while addressing the

[26]In contrast to these statements, in written testimony for an April 26, 2007, hearing before the House Appropriations Committee's Subcommittee on Interior, Environment, and Related Agencies, the NPS's Superintendent of Point Reyes National Seashore stated that climate change was identified at a series of workshops in 2006 as the highest priority for park managers and scientists in NPS's Pacific West Region. At the same hearing, BLM's Great Basin Restoration Initiative Coordinator, stated in written testimony, that climate change is ranked as the 9th of 19 threats to sage grouse and the sage-grouse habitat in Idaho in the *2006 Conservation Plan for Greater Sage-grouse in Idaho*.

effects of climate change would require managers to anticipate potential future changes in their planning processes.

In our workshop, resource managers told us that climate change effects are typically not addressed in agency planning activities. Specifically, resource managers discussing the coasts and oceans ecosystem at the workshop said that climate change has not been considered in management plans. BLM, FWS, and NPS resource managers discussing the grasslands and shrublands ecosystem also said that current management plans do not specifically account for climate change. Similarly, resource managers discussing the fresh waters ecosystem agreed that climate change effects are not explicitly addressed in agency strategic plans. Furthermore, resource managers interviewed for the Chugach National Forest case study stated that they do not consider addressing the effects of climate change in the forest to be a priority because it is not included in the most recent list of priority threats developed by the FS Chief and is not considered a strategic issue by the agency. However, some resource managers from the workshop and case studies said that climate change effects are beginning to be addressed in resource unit planning processes, but on an inconsistent, case-by-case basis. For example, resource managers discussing the coasts and oceans ecosystem said that planning for individual units is bottom up, not top down, and is driven by local constituents. They said that climate change vulnerability issues have begun to get consideration in some planning efforts.

Resource managers at our workshop also said that climate change is not a priority, in part, because of limited support from agency leaders. Specifically, resource managers discussing the coasts and oceans ecosystem said that there has been little support from agency leaders to comprehensively address climate change issues. In addition, resource managers discussing the fresh waters ecosystem at our workshop told us that there are political hazards associated with discussing climate change, and that it is not politically profitable to talk about the issue. Resource managers interviewed for our case studies made similar points. For example, NOAA resource managers at the Florida Keys National Marine Sanctuary said that they have difficulty using terms like “global warming” in presentations and in publications due to concerns raised within NOAA. Similarly, an official at Glacier National Park said that top NPS management monitored public statements on climate change more closely than any other issue, and that park managers are reluctant to talk about climate change. However, another official stated that this reluctance may

be changing, although he noted that no funding or resources have been allocated directly to the issue.

Limited Guidance Constrains Resource Managers' Efforts to Plan for and Manage Potential Climate Change Effects

Resource managers have limited guidance from their agencies about whether or how to address the effects of climate change in management actions and planning efforts, according to agency headquarters officials and resource managers from our workshop and case studies. Under these circumstances, resource managers are uncertain about what actions, if any, they should take with regard to addressing or preparing for the effects of climate change.

Agency headquarters officials agreed that they have provided limited climate change guidance to their resource managers. Interior issued an order in 2001 directing its agencies, including BLM, FWS, and NPS, to consider and analyze, among other things, potential climate change effects in management plans and activities developed for public lands.[27] However, headquarters officials from these agencies told us that they have not yet provided specific direction to resource managers about how to implement this order.[28] Officials at BLM headquarters stated that the order was signed during the prior administration, and that the order has not been emphasized because it was not consistent with the current administration's previous position on climate change. These BLM headquarters officials added that the lack of specific authority, guidance, and direction may have limited the agency's efforts to address the effects of climate change, and that an authoritative statute, a regulation, or guidance would provide a greater impetus to address climate change effects. In testimony before the House Committee on Appropriations, Subcommittee on Interior, Environment, and Related Agencies, on April 26, 2007, BLM's National Science Coordinator acknowledged that there is little current guidance at BLM dealing with climate change. He said that BLM is establishing policy and technical committees to address necessary actions and develop

[27]Department of the Interior Secretary's Order 3226, "Evaluating Climate Change Impacts in Management Planning" (Jan. 19, 2001).

[28]In written testimony at an April 26, 2007, hearing on climate change before the House Appropriations Committee's Subcommittee on Interior, Environment, and Related Agencies, the Deputy Secretary of the Department of the Interior stated that the department has convened a Climate Change Task Force to coordinate and focus efforts on climate change. She said that the task force consists of subcommittees on (1) legal and policy issues, such as how to incorporate climate change into planning decisions; (2) land and water management; and (3) climate change science issues specifically relevant to Interior's responsibilities.

guidance to address climate change in agency management practices. Headquarters officials at FWS and NPS said that, although they have not developed specific guidance, they operate in a manner consistent with Interior's 2001 order in their general planning activities.[29]

NOAA, under Commerce, and FS, under Agriculture, are not subject to Interior's order. However, National Marine Sanctuary Program headquarters officials said that the agency is establishing a working group to determine what actions it should and can afford to take to address the effects of climate change.[30] FS headquarters officials said that, although they have not provided specific guidance on addressing the effects of climate change, the agency's planning process is designed to identify emerging issues, such as climate change, and respond in ways to promote the sustainability of the nation's land and water resources.[31] FS headquarters officials further stated that they have been concerned that they would encounter litigation if they initiated activities specifically

[29]In subsequent communications, FWS officials told us that they were not aware of any efforts within Interior to advertise or promote the order. Some FWS officials were unaware of the order's existence until we called it to their attention during the course of this review.

[30]In their technical comments on our draft report, NOAA officials disagreed with our statement that climate change effects are not specifically addressed in agency planning activities. They pointed to the NOAA strategic plan for fiscal years 2006 through 2011, which mentions climate variability and change on pages 2, 6, and 7. However, we reviewed the plan and found that its discussion of climate change is limited to understanding and predicting the consequences of climate variability and change on marine ecosystems and does not discuss site-specific management responses. Likewise, in the agency's technical comments, NOAA noted that "climate change effects are specifically addressed in NOAA's planning activities and the concerns of our customers." As an example, NOAA cited its most recent Annual Guidance Memorandum, detailing the agency's planning, programming, budgeting, and execution cycle for the fiscal years 2010 through 2014 period. We believe that NOAA should be addressing climate change effects currently occurring. The three focus areas cited by NOAA in the memorandum include (1) new regional information products in response to climate extremes and abrupt climate change; (2) understanding the links between climate and regional impacts, including drought, hurricanes, fires, floods, and weather extremes; and (3) understanding climate-ecosystem interactions, particularly ocean acidification, loss of sea ice, and long-term ocean warming and their impacts on biological productivity and distribution. We believe that these scientific research planning goals are laudable and will provide useful information, but they do not appear to address how managers should consistently incorporate the effects of climate change into site-specific planning and management decisions.

[31]The FS land management planning handbook states the following: "Where data are available, consider the influence of climate change on the characteristics of ecosystem diversity."

designed to address the effects of climate change within FS's current broad authority.

Resource managers who participated in our workshop said that they are not aware of any agency guidance to address the effects of climate change, and that they have received no direction on how to incorporate climate change into their planning activities. For example, resource managers discussing the coasts and oceans ecosystem said that they are not aware of any formal climate change guidance from their respective agencies—FWS, NOAA, NPS, and USGS. Resource managers discussing the forests ecosystem said that agency policies are, in some cases, geared toward responding to events as they occur, constraining the ability of managers to incorporate anticipated events in their planning efforts. These individuals added that managers are unclear about the nature of their agencies'—FS, FWS, and NPS—mandates with respect to climate change and, accordingly, differences in interpretation and implementation take place at the management level. In addition, resource managers from the Bureau of Reclamation, FWS, and NPS discussing the fresh waters ecosystem told us that most managers do not know how to build climate change into the management process but believed that there is a need to do so. These managers identified a need for direction or guidance on how to incorporate climate change into management plans. Furthermore, resource managers discussing the grasslands and shrublands ecosystem agreed that their agencies—BLM, FS, FWS, and NPS—have no explicit guidance on climate change. They further noted that there are differing views in their agencies about how to interpret broad resource management authorities with respect to climate change, and that, as a result, efforts to address the effects of climate change are ad hoc and piecemeal. These managers also stated that they need better guidance at all levels on the effects of climate change and the appropriate agency responses to those effects. They also said that their agencies need an overall mandate and a coordinated approach to address the issue, and that it will take very strong direction from high-level officials to get agencies to address the effects of climate change. Moreover, resource managers at the workshop generally agreed that they need direction on how to account for climate change when making land management decisions, and that high-level planning should recognize the potential effects of climate change and promote integrated, cross-agency approaches to addressing these effects.

Resource managers we interviewed for our case studies also said that they are not aware of any guidance or requirement to address the effects of climate change, and that they have not received direction regarding how to

incorporate climate change into their planning activities. Resource managers from the BLM Kingman Field Office, the Chugach National Forest, the Florida Keys National Marine Sanctuary, and Glacier National Park all explicitly stated that they do not have guidance for how or whether they should account for climate change in planning and management decisions. Resource managers from the Kingman Field Office said that they need a national directive from headquarters to implement climate change-related activities, and that such a directive could give some imperative to take action. In addition, Chugach resource managers stated that they need a clear policy about how to address the effects of climate change, including clear and focused goals. They added that they are not sure whom to contact if climate change becomes an issue because there is no agencywide facilitator or contact point regarding climate change. Furthermore, resource managers at the Everglades National Park, which is ecologically linked to the Florida Keys National Marine Sanctuary, told us that limited guidance makes deciding what, if anything, to do about climate change difficult. Moreover, resource managers at Glacier said that a formal written position on climate change would be useful to further clarify the exact official stance on the science, impacts, and communication strategy.

Some resource managers identified potential complications with issuing guidance related to climate change. In our workshop, resource managers discussing the grasslands and shrublands ecosystem said that policy development can take years; therefore, in their view, the agencies may not be able to respond to climate change in an appropriate time frame. In addition, BLM Kingman Field Office resource managers said that social, political, and legal obstacles would likely present challenges to addressing the effects of climate change, even if guidance were issued. Furthermore, they told us that if they received a directive to address the effects of climate change, the field office would adjust its work priorities for the year and would have to shift or delay other activities. Moreover, resource managers at the Chugach National Forest thought that a general requirement for each forest to address the effects of climate change in its land management plans may be counterproductive because each forest would be forced to "reinvent the wheel" on its own. These managers thought that any guidance

should be accompanied by an agencywide structure, which would allow land management plans across the National Forest system to be consistent.[32]

Resource Managers Need Site-Specific Information to Plan for and Manage the Effects of Climate Change

Resource managers told us that they do not have sufficient site-specific information to plan for and manage the effects of climate change on the federal resources they oversee. Specifically, resource managers said that they need local- and regional-scale models to predict change on a small scale as well as improved inventory and monitoring.

Resource managers at our workshop said that they lack computational models capable of providing local projections of expected changes. Without these models, they said that most of their options for dealing with climate change are limited to reacting to already-observed effects on their units, making it difficult to plan for future changes.[33] In discussing the coasts and oceans ecosystem at the workshop, for example, resource managers stated that they need local- and regional-scale modeling of specific ecosystems and predictive modeling tools for fisheries management and coastal erosion management to plan appropriately. Similarly, resource managers discussing the forests ecosystem said that developing high-resolution models should be a research goal because current models are not specific enough. Likewise, resource managers discussing the fresh waters ecosystem stated that they often do not know how to plan for the effects of climate change because they lack information on temperature and precipitation changes expected in their management areas and, therefore, do not know what management actions will help the resource unit adapt to the effects of climate change. They agreed that climate projection methods must be improved, and that regional climate

[32]A House bill introduced on May 16, 2007, would require the Secretary of the Interior to submit a plan to the Congress describing the steps that certain federal agencies will take to develop consistent protocols to incorporate climate change impacts in land and water management decisions across land and water resources under the jurisdiction of those agencies. The affected Interior agencies include BLM, FWS, NPS, USGS, and the Bureau of Reclamation. Affected agencies outside Interior include FS, NOAA, and the Council on Environmental Quality.

[33]In technical comments on a draft of this report, Interior noted that, as one attempts to model at finer spatial scales, uncertainties in climatic variables and changes in these variables increase. Therefore, Interior notes that access to models is not a comprehensive solution, and any models (and their outputs) used should be verified and validated at the local scale.

projections with accurate temperature and precipitation projections, rather than global-scale projections, would be helpful in more accurately identifying and planning for the likely effects of climate change. These managers also said that they need climate predictions on an ecoregion or site-specific scale. Moreover, resource managers discussing the grasslands and shrublands ecosystem told us that they need better regional models to help in the decision-making process. These managers said that information needs to be packaged to help local land managers better understand what climate change means at the local level.

Resource managers interviewed for our case studies also said that they need models capable of providing local projections of expected changes. For example, BLM Kingman Field Office resource managers said that, to make proactive management decisions, they need to know what climate changes to expect. These managers said that if they could accurately and confidently predict what changes would occur in the future, they could adjust their management practices accordingly. Likewise, Chugach National Forest resource managers stated that they need projections and models of a high enough resolution to generate decisions. They said that they currently do not have the necessary information to make projections, and that it is desirable to anticipate changes and identify means for effective mitigation or adaptation. Similarly, resource managers at the Florida Keys National Marine Sanctuary said that they currently lack adequate modeling and scientific information to enable managers to predict change on a small scale, such as change occurring within the sanctuary.

Resource managers at the workshop said that they generally lack detailed inventories and monitoring systems to provide an adequate baseline understanding of the plant and animal species that currently exist on the resources they manage. Resource managers discussing coasts and oceans said that they need to develop baseline information and long-term monitoring systems to detect habitat changes over time. They said that they need to target inventory and monitoring systems on particularly sensitive ecosystems and species, and focus on indicators unambiguously related to climate change. In addition, resource managers discussing the forests ecosystem stated that they need a monitoring strategy that reflects the key vital signs of forests to inform management decisions. Similarly, resource managers discussing the fresh waters ecosystem said that there must be increased investment in monitoring efforts, particularly in sites identified as likely to be adversely affected by climate change. These managers also recommended an evaluation of the current monitoring system for its ability

to detect and predict climate change. They also said that there is often a lack of a clearly defined purpose for monitoring, and that the link between data collection and when to take action is not always clear. They recommended that there be a clearly defined purpose for monitoring efforts, with clear linkages between data collection and habitat protection. Resource managers discussing the grasslands and shrublands ecosystem stated that the lack of baseline information is a key issue because without it, managers do not know what is changing and how fast it is changing. They recommended conducting baseline inventories of species on federal lands and periodically repeating monitoring on a scale that could provide feedback on changes. Finally, resource managers at the workshop plenary session emphasized the need to link environmental information with decision making.

Resource managers interviewed for our case studies also stated that they need better resource inventories and monitoring systems. For example, managers at the Chugach National Forest told us that, without accurate baseline inventory data of the plants and animals in the forest, it is difficult to determine whether changes to species populations are within the normal range of variability. Furthermore, an official at Glacier National Park told us that staff could make various predictions about how different climate change scenarios might affect different species, communities, and processes, but without better status information and some degree of monitoring, they probably would not be able to detect predicted changes until they are catastrophic and obvious to everyone. Resource managers interviewed for the other case studies made similar points.

Climate Change Is a Global Issue, and It Is Difficult to Address Its Effects at a Local Level

Resource managers at our workshop pointed out that climate change is inherently a complex, global issue. These managers added that greenhouse gas emissions generally originate outside the boundaries of federal resource units, yet these units are affected by the cumulative effects of the emissions. They said that local managers cannot control the drivers of climate change, such as the burning of fossil fuels, but local action is needed to manage its effects. Furthermore, resource managers said that federal land units are fixed on the landscape, while climate change has no boundaries, posing challenges for managing an administrative unit that does not move as the climate changes. They said that cooperative arrangements are necessary because climate change will require managers to work beyond administrative borders. For example, panelists discussing the fresh waters and grasslands and shrublands ecosystems stated that interagency coordination and collaboration are necessary to address the

effects of climate change. Furthermore, panelists discussing the forests ecosystem noted the value of developing a shared vision of key climate change issues and solutions to these issues.

Officials with whom we spoke in our case studies further emphasized this point. For example, officials at the Chugach National Forest said that climate change is a larger issue than one federal land management unit can address. They further said that climate change is a global issue that transcends forests and agencies, and that any strategy to address the effects of climate change should be integrated across broad landscapes, not individual forests. Similarly, managers at the BLM Kingman Field Office noted that climate change is a national issue that is difficult to address locally. Resource managers further noted that climate change-related effects can interact with and amplify the effects of other, preexisting environmental problems on a given resource unit, such as nonnative species and fire, making resource managers' jobs more difficult. Despite these challenges, some resource managers said they have taken steps to reduce greenhouse gas emissions at their units. For example, resource managers at Glacier National Park and Everglades National Park told us that they participate in the Environmental Protection Agency's Climate Friendly Parks Program, which focuses on reducing parks' greenhouse gas emissions. Glacier also has an Environmental Management Plan that includes a number of energy efficiency and renewable energy initiatives. In addition, Glacier requires the concessioners that run businesses in the park to abide by certain environmental requirements, some of which affect greenhouse gas emissions.

Conclusions

Climate change has already begun to adversely affect federal resources in a variety of ways. Most experts with whom we spoke believe that these effects will continue—and likely intensify—over the coming decades. Some federal resources, depending on a variety of factors, may be more vulnerable than others. Because this issue is long term, global, and may affect federal resources in a number of ways, it will require foresight on the part of federal agencies to prepare for and minimize the adverse effects of climate change. However, federal resource management agencies have not yet made climate change a high priority. BLM, FS, FWS, NOAA, and NPS are generally authorized, but not specifically required, to address changes in resource conditions resulting from climate change in either their resource management actions or planning efforts. However, none of these agencies have specific guidance in place advising their managers how to address the effects of climate change in either their resource management

actions or planning efforts. The resource managers with whom we spoke stated that in the absence of such guidance, they are unsure whether or how to take the effects of climate change into account when carrying out their responsibilities. Such uncertainty may, as unanticipated circumstances arise, force resource managers to set their own priorities, which may be inconsistent with those of the agencies' management and may result in misdirected efforts and wasted resources. Because there is growing evidence that climate change is likely to have wide-ranging consequences for the nation's land and water resources, elevating the importance of the issue in their respective strategies and plans would enable BLM, FS, FWS, NOAA, and NPS to provide effective long-term stewardship of the resources under their purview.

At least one resource management agency—BLM—has acknowledged if not the need for, at least the value of, guidance on climate change. In April 2007, BLM's National Science Coordinator testified in a congressional hearing that BLM is establishing committees to, among other actions, develop guidance to address the effects of climate change in agency management practices. BLM officials told us that the lack of specific guidance, among other factors, may have limited that agency's efforts to address the effects of climate change, and that having such guidance would help to provide a greater impetus to address climate change effects. In this light, at a minimum, guidance on addressing the effects of climate change would allow resource managers to better take into account one of the key factors that is likely to affect all aspects of the resources they manage.

Recommendation for Executive Action

To better enable federal resource management agencies to take into account the existing and potential future effects of climate change on federal resources, we recommend that the Secretaries of Agriculture, Commerce, and the Interior—in consultation with the Director of FS; the Administrator of NOAA; and the Directors of BLM, FWS, and NPS, respectively—develop clear, written communication to resource managers that explains how managers are expected to address the effects of climate change, identifies how managers are to obtain any site-specific information that may be necessary, and reflects best practices shared among the relevant agencies, while also recognizing the unique missions, objectives, and responsibilities of each agency.

Agency Comments and Our Evaluation

We provided a draft of this report to Agriculture (FS), Commerce (NOAA), and Interior (BLM, FWS, and NPS) for review and comment. We received written comments from all three departments. These comments are included in this report as appendixes V, VI, and VII, respectively. In addition to the comments addressed in the following text, each department also provided technical comments, which we have incorporated into this report as appropriate. While we have acknowledged many of the departments' comments regarding efforts they are undertaking to address climate change, we did not have sufficient time to verify the accuracy of the information presented in either their letters or technical comments prior to issuing this report.

In its written comments, Agriculture's FS agreed with our recommendation, acknowledging the need to develop clear, written communication for resource managers that explains how they should address the effects of climate change, and the need to coordinate with other departments and agencies on resource management practices in preparing this guidance. FS said that the agency will work to address clarity in communicating climate change mitigation and adaptation strategies to field units.

With regard to the draft report's contents, FS stated that the report did not adequately capture the scope and urgency of the agency's commitment to climate change adaptation, mitigation, and research. FS listed a number of initiatives that were omitted, including research measuring forest-based carbon, participation in the California Climate Action Registry, efforts to reduce the agency's own carbon emissions, and other efforts. Although we commend FS for undertaking these useful activities, an examination of mitigation and research activities was beyond the scope of this report, which focused primarily on management actions.

FS also stated that our examination of one national forest (the Chugach National Forest) is inadequate as a proxy for the 193 million acres of diverse ecosystems managed by FS, and that 12 national forest plans do, in fact, consider the effects of climate change on existing programs and local resource values. The agency further noted that forest plans are revised every 10 to 15 years to incorporate new scientific information and management strategies. Although we used only one forest as an illustrative example in our report, FS resource managers participating in several workshop sessions and the case study said that they had limited guidance from their agencies about whether or how to address the effects of climate change in management actions and planning efforts. Furthermore, these

officials said that efforts to address climate change were lacking, due to a general absence of guidance and differences in interpretation and implementation of broad resource management authority. FS headquarters officials also confirmed that they have not provided specific guidance on addressing the effects of climate change. We also believe that, out of 155 national forests and 20 national grasslands, 12 forests with plans that consider the effects of climate change is not a high percentage; we encourage all 175 units managed by FS to incorporate climate change into their plans when they next update them. FS also pointed out that we neglected to mention efforts under way at the Chugach to treat thousands of acres in the forests to mitigate the threat posed by spruce bark beetles. In the second objective of our report, we sought to identify challenges that resource managers face in addressing the observed and potential effects of climate change. These challenges include the priority of the climate change issue, the lack of agency guidance, and the lack of site-specific data. Although we believe it is important to react to individual changes observed at the site level, such as treating forests to mitigate spruce bark beetle outbreaks, the larger issue—that is, the absence of a coordinated response to climate change in agency guidance—remains.

Finally, FS stated that we did not give adequate recognition to FS's Four Threats to the Health of the Nation's Forests and Grasslands, a messaging tool that disseminates the strategic view of the agency. (The Four Threats identified by FS are fuels and fires, invasive species, unmanaged recreation, and habitat fragmentation.) FS commented that the Four Threats include two aspects of climate change discussed in this report: forest fire and invasive species. Although we agree that at least some of the Four Threats may be related to climate change, we believe that climate change is a larger, overarching issue that should be addressed in a more comprehensive manner.

In commenting on a draft of this report, Commerce's NOAA agreed with our recommendation. In this regard, NOAA stated that the agency will work toward clarifying written communication to resource managers to explain how they are to address the effects of climate change on federal resources and identify how they are to obtain site-specific information that may be needed to implement these efforts. Furthermore, NOAA stated that the agency will continue to work with relevant federal resource management agencies on a range of climate change and land management issues and, as applicable, strive to share best practices.

With regard to the information presented in the draft report, NOAA noted that we did not present information on several cross-government initiatives and NOAA management actions to address climate change. For example, NOAA stated that we did not examine the current state of modeling and observation systems, such as the Global Earth Observation System of Systems and the National Integrated Drought Information System, or the agency's contribution to the collaborative efforts with federal, state, and local partners, including the U.S. Climate Change Science Program. Although we recognize that NOAA has a well-developed research and monitoring program, a detailed review of NOAA's many research programs was beyond the scope of our work: the focus of the second objective of our report was to obtain the views of federal resource managers on the challenges they face in addressing the observed and potential future effects of climate change in their management actions and planning efforts. In this regard, a number of NOAA managers at our November workshop, at our site visit, and at NOAA headquarters told us that resource managers need more localized, site-specific information, and that there is often a disconnect between physical science research and implementation activities at the site level. Thus, while NOAA may be undertaking a number of initiatives, these initiatives do not appear to address the site-specific information needs of the on-site resource managers.

NOAA also said that the *Reef Manager's Guide*, prepared by NOAA with Australia's Great Barrier Reef Marine Park Authority, details strategies to help local and regional reef managers reduce threats to coral reefs, and that NOAA staff implement some of these ideas. Although we agree that the *Reef Manager's Guide* contains many useful suggestions for managers in their efforts to respond to coral bleaching, we do not believe that it is a substitute for official agency headquarters guidance. Similarly, we applaud NOAA's involvement with the Nature Conservancy's Florida Reef Resiliency Program, aimed at measuring the extent of coral bleaching and improving the ability of reefs to survive bleaching events. However, we continue to believe that NOAA needs a more comprehensive approach to managing for the effects of climate change throughout the entire sanctuary system.

In its comments, Interior agreed with our recommendation, and said that the department will be using the information in the report to ensure that the department is addressing concerns it shares with GAO regarding climate change. Interior also pointed out that it had already taken steps to assess the effects of climate change on public lands by convening a task force involving nearly 100 people, including the department's assistant secretaries and other top leaders as well as career scientists,

superintendents, refuge managers, and others. According to Interior, the task force is examining how possible climate changes would affect disaster management, water resource management, and habitat management and is evaluating, among other things, new responses to manage changing landscapes. Furthermore, according to Interior, the task force is currently reviewing the development of accurate modeling and the weight to put on modeling relative to the use of historic data and agrees with our recommendation that the department will need to provide direction on how to implement these new tools as they are developed and validated. The task force is also evaluating how Interior might set priorities for generating essential information to create baseline assessments of plants and animals to appropriately manage the species the department oversees.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to interested congressional committees; the Secretaries of Agriculture, Commerce, and the Interior; and other interested parties. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staffs have any questions about this report, please contact me at (202) 512-3841 or stephensonj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report are listed in appendix VIII.

John B. Stephenson
Director, Natural Resources
and Environment

List of National Academies Workshop Participants

November 2, 2006 – Science Issues

Coasts and Oceans Ecosystem
Virginia Burkett, U.S. Geological Survey, Moderator
Don Boesch, University of Maryland
Mark Eakin, National Oceanic and Atmospheric Administration, Maryland
Mark Harwell, Florida A&M University
Michael Kearney, University of Maryland
Craig Landry, East Carolina University, North Carolina
Steve Murawski, National Oceanic and Atmospheric Administration, Maryland

Forests Ecosystem
Tony Janetos, University of Maryland, Moderator
Jill Baron, U.S. Geological Survey, Colorado
Steve McNulty, Forest Service, North Carolina
Ron Neilson, Forest Service, Oregon
Peter Reich, University of Minnesota
Steve Running, University of Montana
Brent Sohngen, Ohio State University
Monica Turner, University of Wisconsin
Tony Westerling, Scripps/University of California

Fresh Waters Ecosystem
Don Scavia, University of Michigan, Co-Moderator
John Healey, Government Accountability Office, Co-Moderator
Doug Curtis, National Park Service, Washington, D.C.
Dan Fagre, U.S. Geological Survey, Montana
Gordon Grant, Forest Service, Oregon
Margaret Palmer, University of Maryland

Grasslands and Shrublands Ecosystem
Hal Mooney, Stanford University, Moderator
Barbara Allen-Diaz, University of California, Berkeley
David Breshears, University of Arizona
Dennis Ojima, Colorado State University
David Pyke, U.S. Geological Survey, Oregon
Norm Rosenberg, University of Maryland

November 3, 2006 – Management Issues

Coasts and Oceans Ecosystem
Virginia Burkett, U.S. Geological Survey, Moderator
Mike Bryant, U.S. Fish and Wildlife Service, North Carolina
Billy Causey, National Oceanic and Atmospheric Administration, Florida
Brian Czech, U.S. Fish and Wildlife Service, Washington, D.C.
Andrew Gude, U.S. Fish and Wildlife Service, Washington, D.C.
Margaret Davidson, National Oceanic and Atmospheric Administration, South Carolina
Randall Kosaki, National Oceanic and Atmospheric Administration, Hawaii
Cliff McCreedy, National Park Service, Washington, D.C.
Anne Morkill, U.S. Fish and Wildlife Service, Florida

Forests Ecosystem
Tony Janetos, University of Maryland, Moderator
Al Abee, Forest Service, Washington, D.C.
John Dennis, National Park Service, Washington, D.C.
Kathy Jope, National Park Service, Washington, D.C.
Linda Joyce, Forest Service, Colorado
John Morton, U.S. Fish and Wildlife Service, Alaska
Al Sample, Pinchot Institute for Conservation, Washington, D.C.
Jim Sanders, Forest Service, Minnesota
Bill Sommers, George Mason University, Virginia

Fresh Waters Ecosystem
Don Scavia, University of Michigan, Co-Moderator
John Healey, Government Accountability Office, Co-Moderator
Dan Ashe, U.S. Fish and Wildlife Service, Washington, D.C.
Levy Brekke, Bureau of Reclamation, Colorado
Jeffrey Bromaghin, U.S. Fish and Wildlife Service, Alaska
Mike Estey, U.S. Fish and Wildlife Service, North Dakota
Sharon Kliwinski, National Park Service, Washington, D.C.
Robert Krumenaker, National Park Service, Wisconsin

Grasslands and Shrublands Ecosystem
Anne Johnson, Government Accountability Office, Moderator
Bob Adamcik, U.S. Fish and Wildlife Service, Virginia
Barbara Allen-Diaz, University of California, Berkeley
Bud Cribley, Bureau of Land Management, Washington, D.C.
Pauline Drobney, U.S. Fish and Wildlife Service, Iowa
Misty Hays, Forest Service, Wyoming
Julie Thomas, National Park Service, Washington, D.C.

Objectives, Scope, and Methodology

This report examines (1) experts' views on the observed and potential effects of climate change on federal resources within the four principal ecosystem types and (2) the views of federal resource managers on the challenges they face in addressing the observed and potential future effects of climate change in their management actions and planning efforts. In addition, four case studies illustrate some of the effects of climate change on federal resources as well as the challenges to addressing them.

To select the four ecosystem types, we used a classification system used by the H. John Heinz III Center for Science, Economics, and the Environment (the Heinz Center) in its 2002 report entitled *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States.* This classification system is generally accepted by the scientific community and uses a limited number of distinct divisions to identify ecosystem types (in contrast to certain other classification systems). The Heinz Center's classification is also based on a "land cover" approach. That is, it is based on dominant vegetation or other physical characteristics, as opposed to a geographic approach. We found this classification useful because many natural resource management decisions are differentiated by land type. The Heinz Center classification system identifies six ecosystem types: (1) coasts and oceans, (2) farmlands (primarily croplands), (3) forests, (4) fresh waters, (5) grasslands and shrublands, and (6) urban and suburban areas. Our work excluded farmlands and urban and suburban areas because resources within these ecosystem types are generally not managed by federal agencies.

To solicit experts' views on the potential effects of climate change on the four ecosystem types, we convened an expert workshop on November 2 and 3, 2006, in collaboration with the National Academies' Board on Atmospheric Sciences and Climate. The workshop consisted of concurrent breakout sessions for experts in each ecosystem type, and plenary sessions in which all participants contributed. The National Academies, under contract to GAO, helped identify appropriate workshop moderators and participants, organized logistics, and issued the workshop invitations. The National Academies and GAO worked together to prepare the agenda and to identify scientific experts and economists for the first day of the workshop, using specific selection criteria (described in greater detail in the following text). GAO identified most of the federal resource managers for the second day of the workshop because the National Academies does not interact extensively with the federal resource management community.

We asked National Academies staff to help us identify four individuals with the following attributes to serve as breakout session moderators: (1) experience in leading climate change assessments; (2) a strong professional reputation that might attract other highly regarded experts; (3) knowledge of one of the four ecosystem types; (4) a balanced perspective on climate change (i.e., politically neutral, with no strong ideological views on climate change expressed in past work); and (5) a willingness to assist in planning the workshop's substance.

To identify experts for the first day of the workshop on science issues, the National Academies and GAO agreed on selection criteria, which included recommendations from other experts, a demonstrated record of publication in the field, and experience contributing to climate change impact assessments or other peer-reviewed scientific reports and articles relating to climate change.[1] Other factors were also considered, such as the individuals' availability on the date of the workshop. The National Academies and GAO gave particular preference to individuals recommended by more than one expert. In addition to ecosystem expertise, we gave priority to those candidates whose expertise also included an understanding of climate change (e.g., an understanding of how climate change might affect coral reefs or forests). We also sought to have an economist in each session. The National Academies reviewed names in its database of experts and solicited recommendations from various National Academies officials and scientists with whom National Academies' staff regularly collaborate. In addition, GAO identified scientists on the basis of interviews with climate change experts that we conducted in the early phases of our work; we had asked these individuals to name others with ecosystem expertise who might be good candidates for the workshop. Workshop moderators also suggested participant names. Once a consolidated list of potential invitees was finalized, it was reviewed by the Chairman of the Executive Office of the National Research Council, the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering.

[1]Major impact assessments include, among others, the Intergovernmental Panel on Climate Change's Working Group II report, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*; the U.S. Global Change Research Program's report, *Climate Change Impacts in the United States*; the United Nations Environment Program's report, *Millennium Ecosystem Assessment*; and the Arctic Council and the International Arctic Science Committee's report, *Arctic Climate Impact Assessment*.

GAO and the National Academies focused the search for experts primarily on individuals from government, academia, and nongovernmental organizations (NGO) because most climate impact-related work is either funded by these types of institutions or carried out by experts from these types of bodies. However, since many NGOs have taken strong positions on climate change, we drew upon this community to only a limited extent.

To select experts for the second day of the workshop on management issues, we asked for recommendations from both federal resource management agency headquarters officials and managers in the field as well as our workshop moderators. We gave priority to senior federal resource managers with "on-the-ground" management experience in the field. We also invited managers from Washington, D.C., headquarters offices to ensure a balanced perspective. We selected managers who had a general familiarity with relevant statutes, regulations, agreements, executive orders, and other management directives aimed at protecting the resources under their agencies' jurisdictions. We also selected managers who had a general familiarity with the issue of climate change and how it could affect one of the four relevant ecosystem types—although this knowledge was not essential. We sought to have representation from each major agency that manages resources corresponding to each of the four ecosystem types. For example, the Bureau of Land Management (BLM), Forest Service (FS), U.S. Fish and Wildlife Service (FWS), and National Park Service (NPS) all manage grasslands, and each of these agencies was represented in the grasslands and shrublands breakout session. To keep the scope of the project manageable, we did not include all federal agencies that oversee federal resources, such as the Bureau of Indian Affairs, the Department of Defense, the Tennessee Valley Authority, or others (although we did have one representative from the Bureau of Reclamation, which manages water resources in the west). We also did not include Exclusive Economic Zone waters managed by the National Oceanic and Atmospheric Administration (NOAA).

Fifty-four scientists, economists, and federal resource managers from academia, government, and NGOs, attended the workshop. Appendix I contains a list of the workshop participants and moderators.

Prior to the workshop, we sent all participants an information packet containing, among other things, graphs showing the range and average of model projections for the change in monthly temperature (degrees Celsius) and precipitation (millimeters per day) in the years 2020 and 2090 for 11 U.S. regions under a medium impact Intergovernmental Panel on

Climate Change (IPCC) scenario. The graphs were based on publicly available results from the full suite of models used in the IPCC's Fourth Assessment report. The graphs, prepared for GAO by the National Center for Atmospheric Research, were intended to provide a framework for the workshop discussions by bounding the range of possible future temperature and precipitation outcomes.[2] We provided this material to participants for background information purposes only; participants were given the option of referring to these graphs when responding to the questions posed at the workshop. We also sent participants, as background reading, copies of the IPCC Third Assessment Report Working Group II's first chapter, entitled "Overview of Impacts, Adaptation, and Vulnerability to Climate Change." Each participant was further sent the IPCC Third Assessment chapter that corresponded to the ecosystem type (e.g., forests or coasts and oceans) on which the participant was expected to speak.

On the first day of the workshop, 27 scientific experts and economists, each having particular expertise on 1 of the 4 ecosystem types, discussed scientific questions related to the potential effects of climate change on federal resources. (These questions can be found in app. III.) On the second day of the workshop, also organized according to ecosystem type, 28 resource managers discussed the challenges, constraints, and limitations they faced in managing federal resources, given the potential effects of climate change identified on the previous day. The workshop was designed to give the scientists the leading role on the first day and managers the leading role on the second day. However, in most cases, both sets of individuals participated in discussions both days because some managers had scientific backgrounds, and some scientists had experience in resource management. There were also two plenary sessions addressing questions of science and management that applied to all four ecosystem types. Summaries of the ecosystem breakout sessions and the plenary sessions are presented in appendix III. After the workshop, we sent drafts of the findings from each of the breakout sessions to participants, giving them an opportunity to comment on the accuracy of the information.

It is important to note that the expert views represented at the workshop are the views of scientists and managers, not those of GAO. We did not independently review articles from the scientific literature or verify

[2]The National Center for Atmospheric Research conducts collaborative research in atmospheric and Earth system science and provides a broad array of tools and technologies to the scientific community. Its primary sponsor is the National Science Foundation.

participants' statements. In addition, although the workshop experts discussed a wide range of possible climate-related effects, we describe only some of these effects in our report. We also did not attempt to rank effects according to severity, owing to a lack of criteria to make such rankings.

To illustrate some of the effects of climate change on federal resources and possible options for addressing them at federal resource units, we conducted four case studies, one case study for each ecosystem type, using a nonprobability approach.[3] We selected our specific case study sites after soliciting selected experts' views on which federal resources may be most vulnerable to climate change. The experts we consulted included many of those whom we invited to the first day of the workshop (including some unable to attend), as well as others recommended by other experts or individuals whose names appeared frequently in the peer-reviewed literature for the relevant ecosystem type. We e-mailed these individuals, soliciting their views on which specific federal land units they considered to be most vulnerable to climate change impacts and the nature of any adverse impacts. In making our final land unit selections, we also considered responses obtained at the workshop; one of our workshop questions asked participants which areas of the United States may be most vulnerable to climate change. Furthermore, we took into consideration land unit visitation levels, size, location, geographical diversity, ecological and geological variation, and land unit management agency in making our selections. For example, we gave priority to larger land units and to units with high levels of visitation and a range of geographic features. We also gave priority to units where more than one agency is involved in management decisions. We further considered accessibility, since it was important to visit each site. The four units we selected on the basis of these criteria are the Florida Keys National Marine Sanctuary in southern Florida (coasts and oceans ecosystem); the Chugach National Forest in south-central Alaska (forests ecosystem); Glacier National Park in northwestern Montana (fresh waters ecosystem); and the BLM Kingman Field Office in northwestern Arizona (grasslands and shrublands ecosystem). All of these units encompass multiple ecosystem types. For example, Glacier consists of glaciers, lakes, forests, and alpine meadows, among other features, while the Chugach contains a mix of forests, coasts and oceans, and fresh waters ecosystems.

[3]Nonprobability samples cannot be used to generalize or make inferences about a population. In this instance, we cannot generalize the results of our case studies to all federal lands or federal lands of the same ecosystem type.

Management agencies for these four sites include BLM (Kingman, Arizona); FWS (four national wildlife refuges near the Florida Keys National Marine Sanctuary, the Kenai National Wildlife Refuge adjacent to the Chugach, and certain resources within Glacier); and NPS (Glacier), all under the jurisdiction of the Department of the Interior; FS, which falls under the jurisdiction of the Department of Agriculture (the Chugach and the Flathead National Forest near Glacier); and NOAA, which falls under the jurisdiction of the Department of Commerce (Florida Keys National Marine Sanctuary). In addition to the managers and experts at each case study location, we also spoke with officials from adjacent federal lands. We spoke with these officials because resource units in our specific case study land units coordinate with adjacent land units, and the ecosystems supported by the case studies generally overlap with surrounding federal resource units. For example, for the Chugach case study, we spoke with FWS experts and managers from the adjacent Kenai National Wildlife Refuge as well as staff from FS's Alaska Regional Office in Juneau. For the Florida Keys National Marine Sanctuary case study, we spoke with experts and managers from the Everglades and Dry Tortugas National Parks as well as FWS experts and staff who oversee four Keys national wildlife refuges located near the sanctuary. For the Glacier case study, we spoke with experts and managers from FS's Flathead National Forest as well as an FWS fish biologist based in the park. At a number of sites, we viewed firsthand some of the resources discussed at the meetings.

We also spoke to representatives of some private sector organizations. For example, for the Glacier National Park case study, we also spoke with representatives of firms that do business in the park and with staff from a private foundation. We also spoke with local academic researchers, state government offices, and representatives of NGOs with expertise on the respective sites, as appropriate. It is important to note that the four case studies are illustrative only and not projectable. That is, physical and management conditions that apply to a given federal resource may not apply to all federal land or water units of a similar ecosystem type or managed by the same agency. Detailed summaries of the individual case studies can be found in appendix IV.

To assess the reliability of data related to changes in Glacier National Park, spruce bark beetle infestations in Alaska, and loggerhead turtle nesting patterns in Florida, we spoke with park officials, Kenai National Wildlife Refuge officials, and University of Central Florida researchers, respectively, about data quality control procedures and reviewed relevant

studies. We determined that the data and expert views obtained were sufficiently reliable for the purposes of this report.

Finally, in concluding our work, we contacted legal counsel at each of the five resource management agencies as well as the White House Council on Environmental Quality, to ascertain the scope and nature of federal authority and requirements to address the impacts of climate change in resource management and planning.

In this report, we use the term "federal resources" to refer to federal lands managed by BLM, FS, FWS, and NPS, and to national marine sanctuaries and one marine national monument managed by NOAA; the term "ecosystem" to refer to a system of interacting living organisms together with their physical environment; the term "resource managers" to refer to individuals who manage federal resources; the term "physical effects" to refer to observable changes in the physical condition of some part of a natural system, including, among others, extreme weather events—that is, weather events that are rare at a particular place (this may vary from place to place); the term "biological effects" to refer to changes in the interaction among organisms living in a given ecosystem; and the phrase "economic and social goods and services" to refer to economic resources, such as revenue-producing industries, including forestry and fishing, among others, and social or cultural resources, such as recreational activities, scenic views, and historical artifacts, among others. We recognize that the various effects of climate change are interrelated, and that certain effects may belong to more than one category.

We conducted our work between May 2006 and July 2007 in accordance with generally accepted government auditing standards.

Climate Change and Federal Lands Workshop Proceedings, November 2 and 3, 2006

Background

This appendix summarizes the results of an expert workshop convened by GAO, in collaboration with the National Academies' Board on Atmospheric Sciences and Climate, on November 2 and 3, 2006, to solicit experts' views on (1) the potential vulnerabilities of four ecosystem types—coasts and oceans, forests, fresh waters, and grasslands and shrublands—to climate change and (2) the challenges to and approaches for addressing climate change on federally managed lands and waters associated with these four ecosystem types. The workshop consisted of moderated breakout sessions for experts in each ecosystem type, and plenary sessions, in which all participants contributed. Specifically, this appendix summarizes the responses of experts and selected federal resource managers to questions developed by GAO for each session. These summaries are based on professionally transcribed notes and information documented by GAO observers. After the workshop, we sent draft summaries of each of the four breakout groups to participants, giving them an opportunity to comment on the accuracy of the information. The summaries below reflect the comments we received from participants. The length and format of responses may vary by ecosystem type because each breakout session was moderated independently. A list of workshop participants and moderators can be found in appendix I, and a detailed description of the objectives, scope, and methodology describing the selection of experts and other topics is available in appendix II.

Questions for Workshop Participants

November 2, 2006: Breakout Session Questions

Question 1: Based on your understanding of potential climate change in the United States, how might this ecosystem type be affected over the near term (~25 years) and over the longer term (50-100 years)? What might be some of the key ecological effects, economic effects, and social/cultural effects?

Question 2: Which of these effects are most significant and adverse?

Question 3: Are there certain thresholds beyond which the ecosystem in the identified areas cannot recover? Please describe the nature and scope of these thresholds and provide examples.

Question 4: Which areas of the United States may be most vulnerable to climate change and why?

Question 5: What types of information (e.g., research, monitoring/measurement) are needed to better understand and prepare for potential changes on these ecosystems?

November 2, 2006: Afternoon Plenary Session Questions

Question 1: What key new findings related to the effects of climate change on ecosystems have emerged in the past 5 or 6 years?

Question 2: What are the gaps in scientists' understanding of how climate change might affect these four U.S. ecosystem types?

November 3, 2006: Breakout Session Questions

Question 1: Given some of the potential climate-related effects on this ecosystem described at yesterday's session, what might be the implications for your unit, including how it is currently used and managed?

Question 2: What are the challenges, constraints, and limitations associated with adapting to the effects of climate change on federal lands and waters?

Question 3: What land management practices or approaches to planning may be considered when responding to the effects of climate change?

Question 4: What is the most important type of information (research, monitoring/measurement) needed to better understand, prepare for, and address the effects of climate change on federal lands? What resources will be required to achieve this?

November 3, 2006: Afternoon Plenary Session

Workshop participants provided suggestions for matters of congressional consideration related to challenges land managers face with regard to the effects of climate change on their lands and waters.

Day 1: Breakout Session Questions and Responses

Question 1

Based on your understanding of potential climate change in the United States, how might this ecosystem type be affected over the near term (~25 years) and over the longer term (50-100 years)? What might be some of the key ecological effects, economic effects, and social/cultural effects?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Below is a summary of participants' responses to Question 1, with particular focus on coasts and oceans. Panel members noted that the primary (direct) and corresponding secondary (indirect) effects and impacts of a changing climate were likely to be the following:

- Accelerated sea level rise
  - Inundation and permanent loss of coastal wetlands and barrier shorelines, including loss of island communities (other U.S. possessions, low-lying atolls, etc.)
  - Increased saltwater intrusion, degradation of fresh and brackish coastal waters, and low-lying ecosystems; this could impact the drinking water supply
  - Drowning/Migration of submerged aquatic vegetation and vegetated shorelines
  - Interaction of climate impacts with shoreline development via impact on infrastructure and development on federal land; increased coastal erosion, necessitating retreat or armoring of coastal communities with impacts on ecological systems, historic lands, and cultural sites
  - Loss of storm buffer for low-lying areas
  - Increasing wave power/energy and increased vulnerability to storm surge and flooding

- Increased erosion and retreat of shorelines around bar areas and estuaries
- Increased sediment transport into nearshore habitats
- Invasion of marine and exotic species into estuaries (e.g., oyster predators in the Chesapeake Bay)
- Impact on tourism, recreation, and leisure (e.g., loss of beaches)
- Migration of mobile species could create conflicts on private lands
- Federal and state legal relationships/conflicts—impacts on legal regimes?
- Effects on protected species, such as loss of turtle and shorebird nesting habitats

- Increased storm intensity and frequency
  - Exacerbate all effects identified above
  - Physical disturbance - storm surge, shore erosion, wave run-up, and wind (e.g., shore erosion, vegetation inundation, and damage to coral and other reefs)
  - Damage to infrastructure and cultural resources
  - Altered timing and volume of fresh waters delivery to estuaries resulting in changes in salinity (impacts change in precipitation regime), flushing rates of nutrients, turbidity, flow regime, and many other variables
  - Shifts or loss in the extent of barrier islands (e.g., creating more inlets, reducing dune systems, and declining aerial extent)
  - Interaction with coastal developments (e.g., interference of barrier island migration)
  - Increased runoff and land-based pollution (e.g., nutrients, sediments, turbidity, and debris)

  - Changes in regional storm patterns

- Increasing air, ocean, and coastal water temperatures

  - Loss of sea ice and coastal permafrost[1] in Alaska; loss of ice platforms used by marine mammals and seabirds; and loss of subsistence for Alaskan natives

  - Mass coral bleaching events and disease events

  - Pest systems—increase in incidences of harmful algal blooms; increased outbreak of pests, disease, and pathogens (e.g., increased microbial activity could affect shellfish, fish, corals, sea turtles, and some sea grasses)

  - Migration or loss of species in combination with ocean acidification (e.g., corals or other calcifying organisms)

  - Changes in stratification regime (layers of habitats)—could affect primary productivity of oceans

  - Changes in hydrologic and salinity regimes of coastal systems due to increased glacial melt

  - Changes in timing of snowmelt/accumulation

  - Loss of ecological functions along shoreline

  - Economic impact on marine, coastal, and recreational (tourism—fishing, bird-watching, etc.) industry in all areas

  - Indirect effects on eutrophication[2] via increase in rate of phosphorus release from sediment to water

  - Increase in invasive species and loss of native species due to changes in temperature

[1]Permafrost is perennially frozen ground that occurs wherever the temperature remains below 32 degrees Fahrenheit for several years.

[2]Eutrophication is the process by which a body of water becomes rich in dissolved nutrients with a seasonal deficiency in dissolved oxygen.

- Ocean acidification
  - Possible reduction in calcification rate of corals and other calcium carbonate-based species
  - Environmental ecological niche shifts (impacts of changing ecosystems on the oceanic food chain)—changes in plankton communities
  - Change in distribution of species
  - Erosion (physical and chemical) of carbonate reef structures; this has economic impacts and reduces coastal protection from storms
  - Feedback on global biogeochemical cycles
  - Above will impact tourism and commercial and recreational fishing.
  - Will change resource extraction environments
- Changes in ocean currents and thermohaline circulation[3]
  - Affects upwelling, nutrient dynamics; change in biogeochemical cycling (e.g., increase in dead zones), phytoplankton productivity, and productivity of fish-based ecosystems; loss of marine mammals, fish, and birds
  - Changes in thermohaline circulation—could provide large-scale feedback on global climate systems (there is higher uncertainty about this effect, but the consequences would be extreme)
  - Impact on land temperature regimes, precipitation, and wind
  - Changes in the distribution of species, including changes in larval stages

[3]Thermohaline circulation refers to changes driven by density gradients, which are controlled by temperature and salinity. The global thermohaline circulation or conveyor belt is a system of surface and bottom currents that carry ocean water and heat around the globe.

  - Changes distribution of marine debris and pollution

- Changes in wave climate

  - The group agreed that the effects of "Changes in wave climate" would be the same as those listed under "Accelerated sea level rise" and "Increased storm intensity and frequency."

- Changes in precipitation regime

- Changes in salinity regime in estuaries and coastal waters

  - Changes in quality, quantity, timing, and rate of fresh waters delivery

  - In general, wet areas will get wetter, while dry areas will get drier, affecting groundwater, fresh waters availability, surface water, and drinking water supplies.

- Changes in water-quality-related incidents, such as harmful algal blooms, anoxic (oxygen deficient) zones, pathogens, diseases, and habitat quality

- Changes in hydrologic regimes interact with water quality and water management (e.g., dams, canals, flood protection, and reservoirs)

- Mosquito and disease vectors

- Changes in coastal runoff, sedimentation, and erosion

- Ability of ecosystems to flush pollutants and nutrients

Panel members also identified the following two "high-order" primary and corresponding secondary effects. The group noted that the timing and magnitude of these effects is less certain than other effects previously listed.

- Climate variability

  - Natural variability in storms, currents, and other climate factors have important ecological impacts.

- Natural variability interacts with long-term climate change in all of these impacts.
- Long-term climate change influences climate variability.
- Climate variability can be an indicator of the consequences of climate change (e.g., El Niño simulates warmer climates for much of the globe).[4]
- Creates uncertainty for economic decision making and resource management
- Makes it difficult to understand if goals are achieved if climate variability is considered—management is more difficult
- Interaction of climate variability and change has impacts on long-term economic investment and infrastructure development.

- Changes in biogeochemical cycles
  - The group agreed that the results of "Changes in biogeochemical cycles" were similar to some changes already listed, especially those referring to currents and upwelling, stratification, runoff, and precipitation regimes.

Forests Ecosystem Workshop Breakout Session Responses

See Question 2 (Day 1).

Fresh Waters Ecosystem Workshop Breakout Session Responses

Workshop participants discussed the pervasive nature of climate change events and their belief that no single event is attributable to a climate-related cause, but the composite of several events points toward climate-related causes. Therefore, over time, one would expect to see a higher number of incident-based phenomena, including forest fires, storms, and chronic phenomena, such as species migration. Many believed that it was important for people to understand the nature of the timing problem—that different types of resource management decisions must be made across

[4]El Niño is a climate phenomenon that recurs at 2- to 7-year intervals. It affects precipitation and temperature over a large portion of the globe.

different time horizons. Some decisions will have to be made in terms of variables that land managers do not fully understand.

- Reduced snowpack and early snowmelt

  - Snow and ice serve as natural reservoirs in mountainous areas and northern regions of the United States, gradually supplying water into the summer months. Much of the west relies on spring snowmelt to provide a steady stream of water into summer months, when demand is highest; however, warmer temperatures and a shift of the winter precipitation regime from snow to rain are expected to cause reduced snowpack and early snowmelt. "Rain-on-snow" events increase the potential for flooding, as rainwater and melted snow cause very high runoff rates in winter and early spring. Because of this temperature-driven shift of precipitation (from snow to rain), there is an increased variance in annual streamflow volumes, with greater flow in winter months and decreased streamflows in summer months, and increased reliance on groundwater stores (which are themselves affected by precipitation changes).

  - High runoff in winter and early spring is likely to increase soil erosion, enlarge stream channels and increase channel instability, increase sediment load, and increase turbidity in rivers and streams. If a high runoff event follows dry periods, high nutrient flux is expected, as nitrogen and phosphorus from agricultural fertilizers and decayed organic matter will be washed into streams. The extra nutrient load may stimulate plant growth (eutrophication), resulting in oxygen depletion in the water body, and the increased turbidity will likely reduce ecosystem productivity. Furthermore, disturbance events, such as peak streamflow events, are likely to occur and are expected to adversely affect the biodiversity of aquatic species, particularly insects.

  - The reduction of summer streamflows will limit the amount of habitat available for every species dependent on the stream, since reduced streamflow and reduced stream connectivity inhibits an aquatic species' ability to move through an area. Low summer streamflows will limit hydropower generation capacity, and it will be necessary to balance human and ecological demands for water resources. The phenology[5] of critical biological functions, such as fish migration and reproduction, may be disrupted by changing patterns of water flow or availability, according to one expert

commenting after completion of the workshop. Reduced summer flows can limit habitat directly by decreasing available habitat area, in addition to reducing connectivity, according to another expert commenting after the workshop. Furthermore, according to one expert commenting after the workshop, reduced summer streamflows will result in a contraction of the stream network and a reduction in the density of headwater streams. Since most of the total length of the stream network is in these headwater streams, there is likely to be a fairly dramatic decrease in the amount of flowing surface water late in the summer, meaning that streams will dry up sooner, according to this expert.

- Increased temperature of lakes, reservoirs, and rivers

  - Higher land surface temperatures will increase temperatures of surface water bodies and will cause warmer runoff to enter streams, raising the temperature of receiving waters. For example, increased temperatures of 7 to 10 degrees Fahrenheit have been observed in water bodies in the east after storm events. Increased water body temperatures may include the following adverse effects: increased risk of toxic algal blooms; reduction in summer habitat or increased juvenile mortality of cold water and headwater obligate aquatic species[6] (e.g., trout, salmon); or possible invasion of ecosystems by opportunistic warmer-water exotic species[7] (this may have significant economic consequences). For example, the nonnative zebra mussel has extended its range in the Great Lakes as lake water temperatures have warmed. Furthermore, temperature changes may result in the introduction of disease or extirpation (elimination of a species or subspecies from a particular area, but not from its entire range), particularly if the species cannot migrate to other areas.

  - Warmer temperatures speed up metabolic processes and deplete the water of its dissolved oxygen. The increased productivity in lakes

[5]Phenology is the study of natural phenomena that recur periodically (e.g., blooming, migrating) and their relation to climate and seasonal changes.

[6]Headwater obligate aquatic species are species that must live at the headwaters, or source waters of a stream.

[7]Opportunistic warmer-water exotic species are species that would not typically occupy an area but can do so because of temperature increases that resemble their preferred habitats.

may lead to increased rates of hypoxia (conditions of low oxygen in water), reducing ecosystem health.

- Lake mixing cycles and stratification of lake water are temperature-driven processes, which are necessary for nutrient cycling (turnover) and ecosystem health. If temperatures do not drop low enough in winter months, lake mixing may be reduced or stopped altogether.

- Reduced winter ice cover on large lakes, such as the Great Lakes, may alter "lake effect" snow patterns, resulting in more rain and less snow in areas down wind or down weather. Reduced ice cover also allows for a great deal of evaporation from the lakes through winter months, reducing the springtime water levels in the lake. This is likely to affect the shipping industry by opening routes in the winter, but restricting routes in the summer if lake levels are too shallow. If water levels of the Great Lakes are shallow during summer months and require smaller ships or dredging in lake inlets, substantial costs may ensue.

- Cold temperatures and lack of biological activity also help to preserve submerged cultural resources, such as shipwrecks (e.g., Lake Huron). Similarly, the United Nations has been looking at preservation challenges at archeological sites around the world, due to increased decay and erosion resulting from climate change.

- An FWS representative said that the fisheries in Alaska may be vulnerable to climate change effects. Many species are adapted to cold-water conditions, and temperature increases and seasonal shifts may adversely impact fisheries resources upon which commercial, sport, and subsistence fishers all depend. (Note: Subsistence is also an issue in and near the Great Lakes, regarding treaty-related Native American harvesting rights.) Critical aspects of fish reproduction, such as incubation time for eggs and juvenile growth and survival, are temperature-related. The metabolic rate of aquatic organisms, such as fish, increases with increasing temperature, thus more of a species' energy will be used for maintenance functions, rather than for growth and reproduction. Fish diseases can be more virulent under warm- water conditions, and there have been recent observations of severe pathogen problems in the Yukon River. Furthermore, cold-water adapted species are likely to be susceptible to threshold-type temperature effects. For example, mass die-offs of migrating salmon have recently been observed under warm water

conditions in western North America. Salmon also play an important role in the energy and nutrient cycle in many northern streams, and if salmon abundance declines substantially, the availability of energy and nutrients to numerous aquatic and terrestrial species, such as insects, birds, and bears, will be reduced accordingly. In general, most climate forcing ecosystem impacts are occurring in higher latitudes, where ecosystems are simpler and potentially more vulnerable to both change and disturbance.[8]

- Rising sea levels
  - Coastal areas that rely on groundwater supplies will have to be careful not to overdraw from the aquifer to avoid saltwater intrusion and contamination. This is particularly important in water-stressed areas of the southwest. Also, coastal wetlands may become contaminated with salt, killing off grasses that would normally assist in the water purification process.
- Damage to infrastructure
  - Increased storm surges or flow volumes may damage infrastructure, including roads, offices, and housing built in floodplains. Experts acknowledged the importance of maintaining public access to public lands, but they questioned societal decisions made to construct facilities on sites that may be vulnerable. According to one expert commenting after completion of the workshop, it is important to identify high hazard zones and then determine what to do with infrastructure that is currently sited there and to build this kind of thinking into future planning and development decisions.

Nonclimate-Related Effects:[9]

- Reduced nutritional quality of leaves

[8]The FWS expert primarily responsible for these statements substantially edited the wording but not the content of the section after the completion of the workshop.

[9]One expert commenting after completion of the workshop said that the "nonclimate-related" heading used in this summary seemed incorrectly worded. This expert said that the distinction that should be made is one between those effects that are due to changing climate directly and those due to other consequences of an increasingly greenhouse gas rich atmosphere. We did not change the heading because other experts did not request such a change.

- Increase of atmospheric CO_2 results in recalcitrant[10] leaves, which can be less nutritional or palatable for herbivores.

Less Certain Effects:

- Ecosystem services impacted
  - Wetlands also purify water and provide spawning ground for amphibians (e.g., vernal pools).[11] However, they depend on high-flow events associated with heavy rainstorms or high runoff events to disperse seeds. Changing surface water-flow regimes will result in unanticipated changes in wetland conditions, threatening some.
- Rising snow lines at high elevation are expected to result in a longer growing season with increased forest growth at these elevations. Water will likely be stored in the increased biomass and transpired back into the atmosphere, rather than running off into streams. Ephemeral streams[12] are expected in these areas. According to one expert commenting after completion of the workshop, rising snow lines will result in increased forest growth with an associated increase in evapotranspiration, resulting in less water available in the soil, further reducing streamflows and the density of streams on the land.
- Resiliency of a system may be compromised.
- Regime shift—it is possible to have a fundamental change in the way an ecosystem is put together, such that it is very difficult to return to a prior state.

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

The grasslands and shrublands breakout group collaboratively developed the following summary statement that describes the potential effects of climate change on this ecosystem type:

[10]Recalcitrant is defined as difficult to degrade under natural conditions and usually not responsive to treatment.

[11]Vernal pools are temporary pools that fill with snowmelt and spring runoff, then dry sometime during the summer.

[12]Ephemeral streams are characterized as those flowing for only a portion of the year. Similar to tidal pools, they dry up during summer months.

- Grasslands, shrublands, and tundra are all at risk of having a fundamental shift in dominant vegetation type and/or loss of that system, and these changes are likely to be sufficiently large to have effects that cascade through many ecological, economic, and social systems.[13] These effects are most likely to occur in the long term (50 to 100 years), but there is risk that they can also occur in the near term. In addition, existing ecological problems, such as wildfires, invasive species, and nitrogen deposition, would be exacerbated by climate change.

The group also noted the following:

- Tundra systems are temperature-sensitive (i.e., temperature is the fundamental driver for change).
- Shrublands are relatively more water-sensitive than grasslands and tundra.
- Grasslands are both temperature- and water-sensitive.
- Climate models are weakest in predicting precipitation.

Breakout group participants further agreed that:

- Climate change will have impacts on all of the lands throughout the country, and some of these impacts will have implications for the integrity of grasslands. There will be increasing pressure on public lands for different uses for reasons related to climate change. Such potential uses include water storage and development of renewable energy sources. All of the effects described below are effects that will be observed in the next 25 years but will be intensified in the longer term.

The group noted that the primary (direct) effects of a changing climate were likely to be the following, listed in the general order in which they were discussed:

- Increased CO_2 emissions levels

[13]Tundra is a treeless plain found in the Arctic region. It is characterized by low shrub vegetation.

- Increased temperature
- An increase in extreme events (i.e., weather events that occur infrequently, such as drought, heat waves, heavy rainfall, and tornadoes)
- Altered seasonality of precipitation (i.e., more or less precipitation in the summer or winter)
- Increased wildfire frequency and severity
- The melting of mountain glaciers, which will affect systems downstream

Next, participants identified a number of existing problems that will be exacerbated by climate change (referred to as secondary effects). These problems are also listed in the general order in which they were discussed:

- Influx of invasive species
- Increased nitrogen deposition from atmospheric pollution (especially in Southern California)
- Ecosystem fragmentation: migration corridors for flora and fauna could be cut off
- Loss of coastal prairies due to increase in mean sea level (i.e., as sea levels rise, saltwater will encroach on coastal prairies, turning them into coastal wetlands)
- Greater desertification in certain areas, such as the shortgrass steppe of eastern Colorado and farmed portions of the Nebraska sandhills[14]
- Earlier snowmelt, altering the amount of water available to plants at critical times; earlier snowmelt will also affect the amount and timing of water available to rivers
- Phenological changes, such as plant flowering or bird migration; the growing season will lengthen in the north and shorten in the south; pollination could be out-of-sync with flowering

[14]A steppe is a type of grassland found in areas where the climate is dry. The grass is generally shorter than in prairie grasslands.

- Amplification of drought effects
- Changes in distribution of plants that photosynthesize during the cool season (referred to as C3 plants) and plants that photosynthesize during the warm season (referred to as C4 plants)
- Increases in the number and intensity of wildfires (although in some shortgrass systems, wildfires might actually be less frequent, because there is less fuel)
- Increased competition between people and natural systems for water; stress on property rights as people and agriculture migrate in response to a changing climate; increased pressure to use land for different purposes, such as human settlement, water storage, or energy development
- Increases in pest outbreaks, especially pests that emerge under warmer or drier conditions (e.g., bark beetles in woodland systems, grasshoppers that thrive under drought conditions, various fungi, as well as diseases caused by bacteria, parasites, and viruses)
- Loss of or decline in certain ecological communities, in some cases leading to extinctions (e.g., alpine[15] tundra, prairie pothole[16] communities, vernal pools)
- Decrease in native biodiversity in many areas and new assemblages of species living together (i.e., new communities will emerge with unknown dynamics)
- Changes in the quantity and quality of forage (plants available for livestock or wildlife grazing)
- Changes in soil moisture dynamics
- Changes in soil organic matter dynamics

[15]Alpine refers to the zone made up of slopes above the timberline and characterized by, among other things, the presence of low, shrubby, slow-growing woody plants.

[16]A prairie pothole is a wetland that fills with snowmelt and rain in the spring. Some are permanent and some are temporary. Potholes serve as resting, feeding, and nesting habitats for migratory waterfowl.

- Loss of tundra and of Arctic permafrost
- Shift from nonvascular to vascular[17] plants in parts of the Arctic
- Increase in airborne dust (particulate matter) as a result of drought
- Increase in tropospheric ozone[18] formation, which may harm vegetation
- Change in dominant vegetation types, providing opportunities for subdominant species
- Increase shift to dominance or replacement by invasive species (both plants and animals)
- Changes in issues associated with wildland/urban interface (fire, pests, human/wildlife interactions—e.g., when coyotes or bears migrate from the natural to the urban environment)

Question 2

Which of these effects are most significant and adverse?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Panel members identified the impacts they believed to be most significant and adverse. The group did not categorize such impacts according to their separate ecological, economic, or social effects because it believed that the impacts affect all three categories of effects.

- Inundation and permanent loss of coastal wetlands and barrier shorelines, including loss of island communities (other U.S. possessions, low-lying atolls, etc.)
- Loss of sea ice and coastal cryosphere (coastal permafrost) in Alaska; loss of ice platforms used by marine mammals and seabirds; and loss of subsistence for Alaskan natives

[17]Vascular plants are plants that, among other things, have specialized tissues for conducting water. Nonvascular plants are the simplest of all land-dwelling plants and lack an internal means for water transportation.

[18]Tropospheric ozone is formed when nitrogen oxides react with certain other chemicals in the presence of sunlight. It is both a greenhouse gas and an air pollutant.

- Mass coral bleaching events and disease events
- Changes in biochemical cycling (e.g., increase in dead zones); phytoplankton productivity; productivity of fishery ecosystems; and loss of marine mammals, fish, and birds
- Changes in thermohaline circulation
- Changes in salinity regime in estuaries and coastal waters
- Economic impacts: recreational and commercial fishing, quality of life, cultural/maritime heritage, shorebirds, marine recreational coastal fishing, migratory water fowl, hunting, tourism, and coastal development and infrastructure (docks, housing, etc.)

Forests Ecosystem Workshop Breakout Session Responses

Before addressing the posed questions, forests ecosystem workshop participants suggested a list of items commonly viewed as valuable forest services. Participants suggested this as a first step toward answering Question 2, Question 1, and Question 3 (below). Valuable services forests provide include the following:

- Ecological
  - Carbon storage
  - Biodiversity/Composition
  - Ecosystem processes
- Economic
  - Timber
  - Water (quality, quantity)
- Social/Other
  - Recreation
  - Scenery
  - Living area

Forests ecosystem workshop participants generally agreed that the scientific community has reached consensus that climate change will do the following:

- Cause forest fires to grow in size and severity. Fires already have increased in size in areas such as Alaska, Northern Rocky Mountains, high elevations, and the Sierra Nevada Mountains. Climate variability and other fire management approaches, such as suppression, also have affected the southwest. It is likely that other areas in the west, such as the Pacific Northwest and the Colorado Rockies, could see temperature-driven fire activity in the future. One expert added, after completion of the workshop, that climate and demographic changes are likely to increase fire risk to communities in the east.

- Affect air quality. For example, increased ozone pollution and increased smoke from forest fires will impact air quality.

- Affect species composition—tree species, species that depend on trees, and vegetation. For example, sugar maple, white bark pine at high elevations, and subalpine spruce fir forests in the Rockies have already experienced changes.

- Affect phenology, disconnecting some critical species interactions, such as pollination and seed dispersal, and creating the opportunity for other, unpredictable changes

- Cause a reduction in permafrost, decreased snowpack, and increased glacial melting

- Affect water regimes, which are critically important to the ecosystem. Changes in precipitation, storm intensity, temperature increase, evaporative demand, timing of snowmelt, groundwater level, and/or flashing may occur.

- Impact wind disturbance activity, an important ecosystem trigger. However, exactly how wind patterns will change is uncertain. Impacts of hurricane-caused timber blowdowns and subsequent buildup of down and dead fuel is a concern in the southeast.

- Produce more surprises in terms of unanticipated consequences and interactions with other environmental stressors. For example, increased

nitrogen in conjunction with insects and climate can result in significant forest diebacks.

- Result in increased temperatures, which will increase insect and disease infestation range and extent. Three recent examples are the recent spruce beetle, the mountain pine beetle, and the southern pine beetle infestations.

In addition, one workshop participant added the following:

- There are positive effects of climate change. For example, changes in precipitation (increases), or distribution (to dry areas), or increases in temperature in cold areas where such are limiting, or a combination of such, will enhance forest growth and development. Thus, some deserts and/or marginal forest areas could become highly productive forests. In general, there is an ebb and flow of ecosystem types over time.

Fresh Waters Ecosystem Workshop Breakout Session Responses

Participants identified the following effects as among the most significant and adverse:

- Variability of runoff volumes
  - Droughts will have the greatest impact with the least ability to mitigate. Floods can be problematic for river areas and the people living within those areas (e.g., due to increased channel changes, such as widening streambeds and floodplains, and instability), although some potential mitigation is possible, through construction of dams, etc. An NPS representative believed that an increase in extreme runoff (and drought) events would lead to more human emergencies, greater costs, and disruptions to operations.
- Rate of climate change vs. rate of (invasive) species shift
  - Although the relative rate of climate change versus the rate of species migration is not always known, experts expect invasive species to have a relative advantage in a changing climate because they tend to be more adaptive. Some experts have said that invasive species may compromise the resiliency of a system or may impact economic resources of an area, etc.
- General temperature increase

  - Temperature increases are most likely to threaten cold-water species, such as trout and salmon, and amphibians.

- General reduction of water supply

  - Reduced supply and increased demand due to population growth is likely to result in competition between human and ecological uses.

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

The group identified the effects that they believed to be most significant and adverse. They defined "most significant" as the effects that are relatively certain to happen.[19] They categorized such impacts according to ecological and economic/social effects.

Most Critical in Terms of Ecological Effects:[20]

- Extinction of rare ecosystems, such as alpine tundra, California chaparral, and blue oak woodlands in California[21]

- Regime shifts[22]

- Changes in soil content, organic matter, and moisture

- Disappearance of wetlands

- Shift in biomes from one type to another or from one location to another.[23] For example, there will likely be a change from a shrub grassland system to a tree-dominated system in upper elevations at some locations and a change to an annual grassland system in lower elevations.

[19]One participant disagreed with the definition, noting that he believed "most significant" should be defined as "immediate things that have economic impact."

[20]One participant noted that ecological effects are also economic and social, since human systems depend on nature.

[21]Chaparral is a type of plant community in which shrubs are dominant. It usually occurs in regions having from 10 to 20 inches of rainfall annually; it is found in the western part of the United States.

[22]A regime shift is a change in frequency and intensity of a cyclical process.

[23]A biome is a grouping of similar plant and animal communities into landscape units that occur under similar environmental conditions.

- Large-scale, transregional effects that extend beyond the region where they occur and feed back into climate change. (That is, things that happen in a local context have larger impacts on the Earth's climate system.) Examples of transregional effects with feedbacks include dust storms, wildfire, and methane release from the tundra. (Methane is a greenhouse gas.)

- Simplification of certain ecosystems through loss of species diversity (e.g., replacement of native species by invasive species that become monocultures) or loss of endangered species. Examples include the shift from a shrub grassland to an annual grassland system in the sagebrush biome and the loss of forbs (wildflowers) in the California native grasslands.

Most Critical in Terms of Economic and Social Effects:

- Changes in wildfire frequency and severity, with associated costs of fire-fighting and rehabilitation after fires

- Potential loss of national parks and forests with named features/species: for example, Glacier National Park (with no glaciers), Saguaro National Monument (with no saguaro cacti), Joshua Tree National Park (with no Joshua trees), and Tallgrass Prairie Reserve (with no tallgrasses)

- Loss of refuge function/purpose and the economic impact associated with the refuge. For example, if certain FWS wetlands dry up, the waterfowl hunting industry may be hurt in those areas, with economic implications for local communities. Waterfowl reproduction may be reduced. The refuge may thus no longer be relevant for the original purpose for which it was established.

- Increased frequency of extreme events, such as drought and fire, and the associated cost of the loss in productivity, wildlife, livestock, recreation, or other land-use activities

- Exacerbated urban/wildland interface (i.e., increased costs of fighting fires and rehabilitating land, and property loss)

- Reduced Native American use of lands and revenue from natural resources on their lands (e.g., livestock, and reindeer and caribou herds in Alaska)

- Changes in water supply (more water in some areas than others), possibly leading to greater competition for water, with economic impacts for ranchers and some communities situated near federal lands

Question 3

Are there certain thresholds beyond which the ecosystem in the identified areas cannot recover? Please describe the nature and scope of these thresholds and provide examples.

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Panel members provided the following examples and descriptions of various thresholds within the coasts and oceans ecosystem that, if breached, will be difficult to recover from:

- Corals: Clear temperature threshold above which bleaching and mortality occur. For tropical corals, the bleaching threshold is generally more than 1 degree Celsius over the average temperature of the warmest summer month at that location. Mortality results from accumulated thermal stress influencing various factors, such as bleaching and disease.

- Arctic/Subarctic coastal ecosystems: A 1- to 2-degree-Celsius increase in temperature would result in a change in ice formation dynamics, sea ice, permafrost, and glacial melt. For example, if sea ice retreats to the point where the diving depth of the seals is exceeded, the seals will die. Another example is fragmentation of ice packs for walruses and polar bears, which increases the energy needed for foraging. This impacts juvenile survival in walruses and polar bears.

- Coastal wetlands: Coastal wetlands have both salinity and sea level rise thresholds. In coastal fresh waters wetlands, salinity of 5 parts per thousand would result in a loss or shift of ecosystem type and a die-off of vegetation. The coastal fresh waters marsh would cease to exist in some areas. For brackish coastal wetlands, shifts in salinity will lead to shifts in species composition. If salinity levels rise above approximately 20 parts per thousand, there will be significantly less diversity. For a sea level rise threshold for coastal wetlands, tidal inundation could be high enough to transform the system to open water. When the sea level rise exceeds the ability of plant communities to grow vertically through accretion, then the community can turn to open water.

- Climate regime shifts: Several shifts have already been observed where complete shifts in ecosystem structure and services have changed

relatively rapidly over a few years. This is an ecosystem dependent and a nonlinear response. Examples include the Northern Pacific and some fisheries.

- Ocean acidification: When oceanic carbonate ions drop below 200 micromoles per kilogram (approximately 425 parts per million atmospheric CO_2), corals will no longer be able to build reefs faster than they naturally erode. Elimination of coral reef ecosystems, many types of plankton, and fundamental shifts in food chains could result. Entire ocean food chains could change, influencing important fishing industries.

- Invasive species and pests: Many have their own thresholds. Loss of certain events, such as low salinity or low temperature, would wipe out certain species and introduce invasive species. For example, marine oyster predators invade oyster-growing waters when the oyster bars do not have periodic low salinity events. There is also a threshold for the capacity to control invasive species. If biological thresholds are exceeded, invasive species will persist. For example, some invasive species are freeze-intolerant.

- Islands and flood-prone coastal areas: There are some critical sea level rise and storm thresholds above which the islands and flood-prone coastal areas would be inundated. Some examples include insular areas, including Freely Associated States in the South Pacific, Louisiana, and Florida, and Alaskan communities. Some island territories have a maximum elevation of a few meters or less.

- Loss of fresh groundwater and low-lying islands: A threshold at which water supplies are contaminated by saltwater intrusion. The threshold for this depends on the island.

- Change in fishery productivity: Due to differential temperature preferences of predators and prey, there are different threshold temperatures for different animals. For example, in the mid-Atlantic region, the upper geographic limit is 18 degrees and moving northward for some types of clams, limiting the distribution range in the southern geographic region.

Forests Ecosystem Workshop Breakout Session Responses

Forests ecosystem workshop participants identified the following regarding climate-related ecosystem thresholds:

- Habitat specialists, such as the spotted owl, are more at risk.
- Climate extremes, such as drought and temperature, threaten certain species, such as the pinyon pine.
- High-elevation red spruce forests and whitebark pine are at severe risk of extinction.
- Endemic (native) species

Fresh Waters Ecosystem Workshop Breakout Session Responses

The fresh waters group of experts described thresholds as very context-specific, often complexly nonlinear, and difficult to identify in prospect (i.e., easier to identify in retrospect, after exceeding the threshold). Although thresholds are valuable conceptual frameworks, they may not turn out to be accurate because there are often synergistic effects between two or more variables. The group tried to identify thresholds that are sensitive to physical parameters (e.g., freezing points, etc.), but it did not identify many clear-cut examples of thresholds. One participant noted that ecologists use the word, "threshold" to describe physical parameters that stray from the traditional path of an ecosystem.

Some experts questioned the importance of identifying thresholds, although they acknowledged the value of understanding the issues surrounding thresholds and identifying the types of thresholds that could be crossed, and the factors that could contribute to approaching a threshold. Land managers believed that it may be useful to set aside lands to serve as buffers to mitigate potential damages associated with reaching a threshold.

Whereas land managers are accountable for protecting endangered species and upholding agency mission, they believed that they may be driven more and more to managing toward the protection of "niche" species, or managing against invasive, "opportunistic" species. They expressed concern that the threshold question may be species-specific, rather than a biodiversity issue. They also believed that there may be a false security in "managing to thresholds" (versus "managing at levels beneath thresholds"). The fresh waters scientists and managers agreed that an understanding of thresholds is important so that early-warning signals that a threshold is approaching may be developed.

The fresh waters group of experts identified the following thresholds:

- Temperature threshold (stratified lakes)
  - Lakes will not thermally stratify and "turnover" in the spring if winter temperatures do not drop below 4 degrees Celsius. Lake turnover is an important temperature-driven process that helps to oxygenate waters and cycle organic matter and nutrients through the water column. This threshold is presumably more significant in large lakes and has to do with the depth of the lake and latitude.
- Temperature threshold (cold-water species)
  - According to an expert commenting after completion of the workshop, the mortality rate of some cold-water species, such as salmon, increases dramatically above certain temperatures.
- Stream network connectivity
  - If streams dry up earlier within the annual hydrologic cycle, the threshold itself may shift as a result of changing precipitation patterns and/or warmer temperatures associated with climate change. Year-round streams may become ephemeral streams, small ponds may become vernal pools, etc. We may see a dramatic reduction of nitrogen removal from microbes in streams and wetlands, and a possible loss of species (e.g., salamanders). Areas with greater precipitation will likely result in increased connectivity (which opens migration corridors for invasive and endemic species). An expert commenting after completion of the workshop said that there is not a clear threshold for stream network connectivity. The expert said that the area necessary to sustain certain streams will be larger if more water falls as rain in the winter with less snowpack.
- Snowline in high elevations
  - Topographically driven and elevation-controlled incremental change in the rain-to-snow ratio affects the position of the snowline (the dynamic position where snow typically accumulates on the landscape) for areas with snow-dominated precipitation in the west. If the climate forces the snowline to move up in elevation, there will be a radically nonlinear decline in snow area, likely to cause huge changes in fresh waters systems in those areas. Migration corridors may open (for warm-water species), or species habitat may become fragmented (especially true for cold-water species). Even if

migration corridors exist, they would have to be temperature-appropriate for species migration and interaction. Land use/Land management systems, such as dams, canals, and construction projects, increase this effect of habitat fragmentation. With added terrestrial connectivity (due to less winter snow cover), there is possibility of a bark beetle invasion across the United States (i.e., achieve continental connectivity). One expert commenting after completion of the workshop said that bark beetle invasions would be triggered by warmer temperatures that allow the beetles to reach existing forests to the north that are connected across Canada to eastern forests. The expert said that beetle invasions have nothing specifically to do with less winter snow cover because the connectivity is already there. According to the expert, it has been too cold for the beetles to survive until recently.

- Presence of keystone species[24]
  - Land managers may want to manage to protect the habitat of these species, which have a disproportionate positive impact on ecosystem processes (e.g., beaver, Black-Tailed Prairie Dogs). An NPS representative asked, "Under what conditions will species migrate out of particular national parks?" A species shift could have social ramifications, since park visitors value the experience of seeing species within the park. In some cases, federal land acquisition has been motivated by the presence of particular species, which may migrate to unprotected areas, according to an expert commenting after completion of the workshop.
- Indicator species
  - Temperature- or climate-sensitive species may be indicators of impending thresholds; enormous regional shifts are possible in systems with a high degree of connectivity, but this is not necessarily true for species that cannot easily migrate to other areas (i.e., insects can fly, fish cannot easily migrate).

[24]A keystone species is a species that has a major influence on the structure of an ecosystem. Its presence impacts many other members of the ecosystem, and if its population dwindles or disappears, there can be far-reaching consequences for the ecosystem.

- Wildfire frequency
  - Wildfires are strongly dependent on the degree of spring "wet-up" conditions and the sequence of wet and dry years, since presence of an adequate amount of moisture can protect against burning. Fire is a huge driver of ecological change, so anything that changes the fire regime is likely to have ramifications and ripple effects through feedbacks into hydrological, geomorphic, and temperature response. This threshold is expressed in terms of years (i.e., years between fire events).
- Frequency of storm events
  - Humans have installed a great deal of infrastructure in the west to manage water resources, including dams. Increased storminess will adversely affect aging infrastructure. With thousands of small dams in the United States, climate change may exacerbate existing stresses of aging infrastructure and inadequate water supplies in growing areas. Rain-on-snow events, characteristic of "warm" snowpacks, are a recipe for big floods and may result in damage to docks, roads, or other infrastructure on or adjacent to streams, lakes, and coasts. One expert commenting after completion of the workshop said that rain-on-snow induced floods generally result in increased damage to river-related infrastructure, not coastal infrastructure.
- Social tolerance threshold
  - Panelists expressed concern that society may become less tolerant for taking action to mitigate climate change, such as spending money or reconstructing infrastructure (levees) to address climate change issues.
- Minimum flow rate in rivers
  - As metropolitan areas grow, water demand increases, resulting in a decrease in water levels. If we do not keep minimum flows available for aquatic species, there will be more problems for species survival; natural storage facilities (lakes, reservoirs, and streams) may not be sufficient if water demand increases.
- Water quality degradation

- Water quality is likely to decline if harmful algal blooms, bacteria, botulism, etc., occur as a result of increased temperature. This will likely result in the increased cost of water treatment.

- Temperature

  - Increased temperatures are associated with an increased rate of disease outbreaks. The temperature effect may be compounded by a low-flow effect—thresholds may not be based on a simple change of a single variable, but a complex interaction of several changing variables (e.g., gypsy moths and acid rain—acidification of the system weakened the vegetation in the system, making it vulnerable to invasion by gypsy moths). This point is characteristic of the (aquatic) system's behavior.[25]

- Climate change impact on ecosystem services

  - For example, wetlands absorb nutrient load—we can allow a certain amount of nitrogen runoff, if passing wetlands before reaching lake, but if we lose the wetlands, the system no longer has as much capacity to absorb nitrogen; if the water availability is intermittent, the wetland may not be as efficient at removing nitrogen—terrestrial systems may be more nitrogen-burdened.

- Occurrence of snow avalanches

  - Snow avalanches bring nutrients and debris down to streams with direct effect on stream chemistry. The regular disturbance of snow avalanches is ecologically important at high elevations, allowing herbaceous plants to grow in tree-laden forests. A reduction in herbaceous plants results in reduced grizzly bear habitat (a culturally valued animal). Greater variability of winter runoff volumes, from high snow followed by rain, is likely to result in more snow avalanches and increased frequency of landslides and debris flows. This is a threshold-driven phenomenon sensitive to small changes in

[25]One expert in the fresh waters group commenting after the completion of the workshop said that the logic of this section was not clear. The expert was not sure what the "low flow effect" was referring to, and said that the issue of complex interactions was real, but needed to be restated. We did not restate this section because other experts did not raise the same concerns in their review.

precipitation with the potential to result in extreme events in soil erosion.

- Salinity level of aquatic systems
  - fresh waters inundation to saltwaters—for example, through increased runoff volumes in early spring—rapidly decreases salinity. This may be detrimental to some species, such as sea grass.
- Development threshold at low elevations
  - Older federal lands tend to be high elevation, lower elevation areas (run-out zone where debris flows end up) are often outside of federal jurisdiction. However, lower elevation areas may be vulnerable to adverse effects of climate change, and it may be necessary to consider development thresholds in lower elevation areas, floodplains, etc.
- Human construction/changes to ecosystem
  - Experts believed that stream systems in the west are managed in ways that might "trump" climate change effects that we anticipate. For example, many man-made dams currently create a wider range of flow than anticipated with climate change. Land managers identified examples of a dam's role in isolating populations versus opening migration corridors, and they asked whether dam operators should change practices in light of climate change. If dams are removed from an area, or if they can no longer function, a migration corridor is opened for nonnative species to move beyond the dam area. In the Great Lakes, dam removal has opened corridors for species migration from the lakes into river systems.

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

The grasslands and shrublands group of experts defined a threshold as "the point at which an ecosystem cannot recover without substantial input in time and energy." The group agreed that the causes of the threshold changes will be complex, and that some changes will occur quickly and obviously, but others will occur gradually and insidiously and may be overlooked until it is too late to address them. Among the key thresholds identified by the group were the following:

- A shift from tundra to shrubs in the Arctic, resulting in less snow to reflect sunlight, which will lead to other warming-related effects, such as the release of methane

- Permafrost melting will also affect the biological chemistry and the integrity of the tundra systems.

- Increase in the rate of invasion of annual grasses, changing shrublands to grasslands and changing the fire regime. Example: BLM lands in the western United States, from the Canadian to the Mexican borders.

- Tree die-offs triggered by drought and exacerbated by temperature, leading to a shift from woodland to shrubland or to grassland. Examples: midwestern savannas or the southwestern pinyon juniper woodlands.

- Transition to high-erosion conditions could occur through the drought-induced loss of grasslands. Example: entire United States.

- Disruptions in biological interactions as a result of changes in temperature and growing seasons. (That is, the life cycles of some mutually dependent organisms may change, affecting the ecosystem food web.) Example: entire United States.

- Seawater intrusion on coastal prairies. Examples: southern Louisiana and Texas.

- Loss of glaciers, changing the hydrologic flow in downstream systems

Question 4

Which areas of the United States may be most vulnerable to climate change and why?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Below is a list of specific types and examples of systems or habitats related to coasts and oceans that panel members considered most vulnerable to climate change:

Specific types of systems or habitats	Examples (locations)
Coral reefs	Florida Keys Protected Areas - Florida Keys National Marine Sanctuary, Dry Tortugas National Park, Everglades National Park (for temperature); U.S. Virgin Islands National Park (bleaching); the Caribbean; Northwestern Hawaiian Islands National Marine Monument (inundation—already lost islands—and ocean acidification); Palmyra Atoll National Wildlife Refuge (undisturbed, 2 meter elevation); Flower Garden Banks National Marine Sanctuary; and Biscayne National Park
Arctic systems	Arctic National Wildlife Refuge; BLM National Petroleum Reserve; Kenai Fjords National Park; Gulf of Alaska/Bering Sea/Aleutians (regime shift, ocean circulation, biogeochemical cycling, and acidification); Pribilof Islands (sea ice); and 20 other coastal parks and refuges on the coast in Alaska
Coastal wetlands	Delta National Wildlife Refuge; Jean Lafitte National Park and Historic Preserve; Southeast and Southwest Louisiana National Wildlife Refuge complexes; Blackwater National Wildlife Refuge; Alligator River National Wildlife Refuge (sea level rise, storm vulnerability, and salinity regimes); National Estuarine Research Reserves (Texas, coastal North Carolina, Florida, etc.); Everglades National Park; San Francisco Bay Delta; and the Chesapeake Bay
Barrier islands	Fire Island National Seashore; Gulf Islands National Sea Shore; Cape Hatteras protected lands (shoreline management); and other National Seashores—Assateague Island, Texas Coast, Corpus Christi, etc.
Low-lying islands and coastal lands	Pacific Freely Associated States (Marshall Islands, Palmyra, and Northern Mariana Islands); Florida Keys; Northwest Hawaiian Islands (Midway, etc.); Johnston Atoll; Wake Island; and Kwajelin Island
Maritime forests	Ace Basin South Carolina; Coastal Louisiana Refuges and Jean Lafitte National Park; St. Mark's National Wildlife Refuge; Florida Everglades; Big Cypress National Park and Preserve; Pine Island; National Key Deer Refuge; Savannah coastal refuge complexes; Cape Romaine National Wildlife Refuge; national estuarine research reserves; Loxahatchee National Wildlife Refuge; and Cumberland Island National Seashore
Continental shelf ecosystems	Exclusive Economic Zone; California current; Oregon coast; North Pacific; Gulf of Mexico (climate regime shifts, biogeochemical, and storms); North Atlantic (e.g., Georges Bank and Gulf of Maine); and sanctuaries and national estuarine research reserve sites

Forests Ecosystem Workshop Breakout Session Responses

Forest ecosystem workshop participants identified the following areas as more vulnerable to climate change:

- Higher latitude and mid- to high-elevation areas
- Ecotones (also know as transition zones)—boundary zone between different types of ecosystems, such as upper or lower timberline

- Western United States—at risk of increased fire, pest/pathogen outbreak, and changes in heat and water regimes
- Eastern United States—at risk of drought, hurricane damage, and forest fire
- Alaska

Fresh Waters Ecosystem Workshop Breakout Session Responses

Prior to identifying areas considered to be most vulnerable to climate change, the workshop participants briefly discussed a definition of vulnerability. The group based its responses on vulnerabilities likely to have an impact on important ecological processes and on human quality of life, and areas for which there are viable management response options or proactive responses.

In general, experts identified areas along the west coast; southwestern United States; ephemeral habitats, such as the Prairie Pothole region of the Great Plains; coastal wetlands at risk of saltwater intrusion; and wetlands and areas with warm snowpack and low groundwater storage. They also identified areas with large groundwater and surface water systems, since they have some of the highest vulnerability to change. The following list of vulnerable sites was generated at the workshop and from preworkshop surveys sent to scientists and land managers:

Specific types of systems or habitats	Examples (locations)
Streams/Rivers	Klamath River/Upper Klamath, Oregon; McKenzie River, Oregon; Willamette River; Rio Grande; Tennessee River; Chattooga River; Trinity River Ecosystem; Flathead River; Salmon River; Columbia and Snake Rivers; Colorado River; Sacramento and San Joaquin Rivers; and streams in urban areas (heat island effects)
Lakes	Great Lakes (20 percent of the world's accessible fresh waters); high-elevation lakes, such as Crater Lake, Diamond Lake, Mono Lake, Lake Tahoe, and other lakes in the Cascades or Sierra Nevada mountains
Wetlands/vernal pools/headwater streams	Florida Everglades—risk of saltwater intrusion, Prairie Pothole Region, Kenai National Wildlife Refuge, and Yukon Delta National Wildlife Refuge
Cryosphere and areas with warm snowpack	Glacier National Park and Cascades National Park

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

Below is a list of specific types of grasslands or shrublands that the group considered most vulnerable to climate change, along with some specific sites:

Specific types of systems or habitats	Examples (locations)
Tundra	Alaskan Arctic and alpine (Rocky Mountains and Sierra Nevada)
Sonoran desert system	Saguaro cactus ecosystem (Arizona)
Sagebrush biome (steppe)	All federal lands in intermountain west
Pinyon juniper woodland	Southwestern United States
Remnant prairie biome and sedge meadows (small parcels)	Great Plains (Neal Smith National Wildlife Refuge, Iowa) and various FWS and NPS lands
"California complex" (large regions of the state)	BLM, FS, and NPS lands in California
Gulf coastal prairies	Southern Texas, Southern Louisiana
Midwest oak savanna	Sherburne National Wildlife Refuge, Minnesota; Neceeda National Wildlife Refuge, Wisconsin

Question 5

What types of information (e.g., research, monitoring/measurement) are needed to better understand and prepare for potential changes on these ecosystems?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Panel members provided the following list of various types of information and activities that are needed to understand, prepare for, and address the potential changes to the coasts and oceans ecosystem:

- Develop basic baseline environmental characterizations
- Long-term monitoring
- In situ physical monitoring, monitoring the carbon system
- Integrated risk assessments, including ecological, sociological, and economic factors
- Long-term assessment of responses of ecosystems to variable climate conditions
- Comprehensive suite of ecosystem indicators ("red flags") to develop time series data. Need to be linkable to describe causality. Target observations on particularly sensitive ecosystems and species for which

changes are already occurring. Focus on indicators that are unambiguously related to climate change.

- Long-term record, focus on historical and paleoclimatic records to describe past changes
- Integrate ecological modeling with economic/behavioral modeling
- Habitat characterization to detect changes over time. Interface with land-margin, land-ocean margin habitat data.
- More accurate hydrographic and topographic/bathymetric (water depth) data. Water depth data are often of poor resolution.
- Assessments of how climate change is likely to impact lands and associated resources
- Characterization from genetic/microbial to landscape-scale conditions
- There are four components of research needed on climate change: (1) physical changes (this has been the bulk of the effort so far), (2) ecological impacts, (3) social/economic impacts, and (4) adaptation/mitigation. The focus should now be shifted to ecological, social/economic, and adaptation/mitigation research. We need to focus on vulnerabilities and mitigation/adaptation. How have systems changed in the past and how can we expect them to change in the future? The U.S. Climate Change Science Program should focus more on the ecological and societal impacts of climate change than it currently does. Need to focus research on regional and local scales.
- Need for risk communication—illustrate how climate change affects individuals, better communication with the public
- Adapting today's management strategy to account for applied science—ecosystem approach
- Research and development programs to develop mitigation techniques and strategies that are cost-effective
- Supply the science needed to allow local management decisions to account for climate change in the background, both short-term and long-term considerations

- National database of the timing of biological phenomena
- Vulnerability and risk assessment of the value of historic sites and other assets and recreational or commercially valuable species on federal lands
- Better analytical management tools for ecosystem management – these need to be dynamic so they can evolve over time. For example, predictive modeling tools for fisheries management or coastal erosion management that show impacts on property values, etc.
- There is currently an emphasis on reducing uncertainty. The desired level of uncertainty appears lower than the level of uncertainty applied in everyday decision making. There are tools in place to allow decision making under ambiguous risks. Develop robust policies that perform well in the worst case and better than alternatives in the best case.
- Tools for management, such as sea level rise estimates and projected land/sea boundary across the United States. For local management – need topography and bathymetric data. Where are shorelines in relation to commercial structures, etc? Storm surge projections, etc. Look at synergistic effects.

Forests Ecosystem Workshop Breakout Session Responses

Panelists ran out of time before they could answer Question 5.

Fresh Waters Ecosystem Workshop Breakout Session Responses

In answering this question, the group considered the types of information needed to monitor or detect current manifestations of climate change and to predict future climate conditions. The following statements represent broad categories of needed information identified during the group discussion and some overarching recommendations for further research and development:

- Develop early-warning signals, or “red flags”
    - Although many monitoring programs exist, and much scientific data are generated, there is often a lack of a clearly defined purpose for monitoring, and the link between data collection and action points is not always clear. There is a lack of contextual sophistication for the collected data, and data are not analyzed to indicate when managers should begin to be concerned about changes or take action to mitigate changes. Therefore, managers recommended that there be a

clearly defined purpose for monitoring efforts, and clear linkages between data collection and habitat protection. A panelist opined that the national parks and federal lands are good environments for detecting the effects of climate change, since they are relatively isolated from other effects.

- Assess and build on the current monitoring system
  - Many monitoring systems in place today, such as systems to monitor stream flow, precipitation, soil, etc., were not designed specifically with climate change in mind. The panelists recommended that a "gap analysis" be performed to evaluate the current monitoring system for its ability to detect and predict climate change. They believed that current monitoring networks do not collaborate, and they recommended that a list of parameters (e.g., gas fluxes, soil moisture, and basic water chemistry) be established, and that these parameters be monitored at various sites throughout the country.
- Manage for resilience
  - Panelists believed that it was important to manage aquatic systems so that they can "withstand the unexpected" with respect to climate change. They suggested that managers consider ways of providing buffers for systems to restore characteristics of unimpacted systems, despite the stresses of climate change. For example, if an area is likely to experience increased flooding, management options might include building a dam or moving houses or businesses from the flood zone. When deciding between management responses, it is important to consider how the particular adaptation action may affect other ecosystem processes.

Managers identified the need to know when to try to prevent changing conditions versus when to adapt to them. To make such management decisions, it is important to develop technical modeling and detective capacity to know which management decisions will maximize benefits. Participants identified the need to build institutional capacity, improve record-keeping, deploy scientists and researchers on-site, and improve modeling capacity to summarize broad-scale changes.

- Regional scale climate predictions are needed

- Managers need climate predictions on an ecoregion or site-specific scale. Managers said that they often do not know how to plan for the effects of climate change because they lack information on the types of physical changes (i.e., temperature and precipitation changes) that are expected in their management areas. Therefore, they do not know what management actions will help the system adapt to the effects of climate change. The scientists suggested using the current monitoring networks or developing well-distributed monitoring networks to create a series of nested monitoring stations to monitor snow-water equivalent extent and groundwater stocks. Panelists believed that interagency coordination and collaboration are necessary, and that there must be an increased investment in monitoring efforts, particularly in sites identified as likely to be adversely affected by climate change.

If changes in temperature and precipitation were detected and understood at a regional scale, managers could compare projections of climate models with observed changes. Managers need to consider what the response of waterfowl and wetland extent is likely to be with respect to a range of climate projections, and they will need to make decisions based on how much land must be set aside to support wildlife through added stresses of weather extremes.

- Collaboration between scientists and land managers

  - Workshop participants believed that it was important that scientists and land managers work together at early stages of the planning process, and that federal lands would benefit from having scientific expertise on-site, (i.e., to serve as park interpreters, naturalists, and data analysts). FWS land managers said that it is difficult to detect changes in wetlands, because the technology to determine and monitor wetland extent is expensive and requires specialized skills, including flyover photography and geographic information system analysis.

- Crosswalk between land-use change and water quality

  - If hydrologic aspects, such as streamflow variability, are better understood and linked to ecological responses, models can be used to project ecological responses to physical changes in runoff volumes, whether as a result of climate change or land-use changes.

Panelists agreed that land management and planning are not just related to the question of future climate conditions, but also about land-use changes, and they believed that there is a general lack of understanding in the relationship between land-use change, land management, and erosion and deposition processes. Some suggested that managers should view anticipated change in the context of anthropogenic stressors that are already present and likely to be exacerbated by future anthropogenic and climate stressors. One scientist from FS suggested that the Congress should look at the projected changes in temperature and precipitation overlaid with projected population growth. By developing "vulnerability maps" that incorporate societal impacts, managers might be able to view areas under stress and consider the added stress of climate change when making management decisions.

- Study synergistic effects of extreme weather events and multidecadal events
    - Panelists identified the need to study the synergistic effects of two dynamic systems—extreme weather events (such as intense storms) and multidecadal events.

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

The group agreed that the most important types of information or research needed include the following:

- Improved precipitation modeling to better understand and prepare for temperature and precipitation changes on these ecosystems. Precipitation modeling is currently one of the greatest weaknesses in projecting future climate change effects.
- Research and consensus on the criteria and indicators of ecosystem change or thresholds, with specific research on identifying monitoring methods to help scientists detect change thresholds
- Information on the economic value of grassland and shrubland ecosystem services
- Better information on the location and rate of desertification
- Information on positive feedback (i.e., the interaction of climate change on natural systems that can lead back to an intensification of climate change itself)

- Experiments on interactions between climate change and other ecological drivers, such as those previously identified (e.g., nitrogen deposition, etc.)

- Synthesis of information collected by the Long-Term Ecological Research and the proposed National Ecological Observatory Network (NEON).[26] Are these programs in a position to provide answers to climate-related questions?

- Data on land use and the number of livestock grazing on federal lands (to be able to distinguish between ecosystem effects related to livestock grazing versus effects related to climate change)

- Research to improve understanding of the mechanisms that trigger complete regime changes. Is there just a single trigger, such as nitrogen deposition, management style, and El Niño, or are there multiple triggers?

- Conversion of shrubland to grassland (i.e., the ratio of annual alien grasses to native perennial plants that triggers a conversion to an annual grassland system in some areas) as well as research to improve understanding of the mechanisms that lead to a complete regime change

- Conversion of grasslands to shrublands or woodlands, due to shifts in precipitation timing and intensity, altering water availability to favor deep-rooted woody species

- Research on the consequences of alpine community disruption

- Research on the consequences of a transition to high-erosion conditions through the drought-induced loss of grasslands

- Research to determine conditions to predict tree, grass, and forb mortality.

[26]According to the NEON Web site, NEON will be the first national ecological measurement and observation system designed both to answer regional- to continental-scale scientific questions and to have the interdisciplinary participation necessary to achieve credible ecological forecasting and prediction.

- Research to clarify the factors influencing the trends and direction of change in the controls of soil moisture and soil organic matter on groundwater hydrology
- Research on phenological changes, including development of a U.S. phenological network
- Research on saltwater intrusion on coastal prairies

Day 1: Afternoon Plenary Session Questions and Responses

In this session, workshop participants were asked two questions. The first question was to identify key new findings related to the effects of climate change on ecosystems that have emerged in the past 5 or 6 years (i.e., since the publication of the *National Assessment of the Potential Consequences of Climate Variability and Change* in 2000 and the IPCC Third Assessment Report in 2001).[27] For the second question, we asked the participants to identify the gaps in scientists' understanding of how climate change might affect the four U.S. ecosystem types. This session was moderated by Dr. Virginia Burkett of the U.S. Geological Survey (USGS). Dr. Burkett also moderated the coasts and oceans breakout group.

Question 1 and Responses

What key new findings related to the effects of climate change on ecosystems have emerged in the past 5 or 6 years?

Participants identified the following new findings that have emerged in the past 5 or 6 years:

- 2005 Caribbean coral bleaching event
  - Results from Virgin Islands National Park: About 47 percent of previously healthy Caribbean corals are now dead due to bleaching and disease, both associated with thermal stress (increasing temperature). Prior to 2005, the first massive loss of corals was in 1990. Global events also occurred in 1997 and 1998. Documentation

[27] *The National Assessment of the Potential Consequences of Climate Variability and Change* was mandated under the Global Change Research Act of 1990 and prepared by the U.S. Global Change Research Program. The report evaluated what was known about the potential consequences of climate variability and change for the nation, in the context of other pressures on the public, the environment, and the nation's resources.

of 2005 bleaching events elsewhere corroborated that sea surface temperatures are causing coral die-offs. This phenomenon is not only limited to tropical areas, but is also beginning to affect temperate waters such as the northwest Hawaiian Islands. Also, many corals not typically associated with bleaching have been affected, like elkhorn coral, recently listed as threatened under the Endangered Species Act (ESA).

- Climate regime shift in the Pacific
  - Documentation exists about the climate regime shift in the Pacific and its impacts that have cascaded up the food chain, ultimately affecting fish populations and phytoplankton communities and resulting in a loss of marine mammals and seabirds.
- Ocean acidification
  - Increases in atmospheric CO_2 concentrations result in drops in pH (acidification) in near-surface waters. The rate of acidification has been more rapid than anticipated. Near-surface ocean waters have already dropped to levels that cause live plankton to dissolve. Recent findings have shown drops in pH in near-surface waters that are occurring much more rapidly than anticipated in response to increased carbon dioxide concentrations in the atmosphere. This has caused live plankton to dissolve their calcareous skeletons.
- Arctic change
  - There is more evidence of sea ice retreat, accelerating glacial melt, measurable coastal erosion, and declining populations of polar bears, Beluga whales, walruses, ice seals, and other Arctic mammals. See the *Arctic Climate Impact Assessment* for more detailed information on this issue.[28]
- Hypoxia off the Pacific coast
  - The "dead zone" off the Pacific coast, while not proven to be related to climate change, is an example of future events that could

[28]Arctic Climate Impact Assessment, *Arctic Climate Impact Assessment*, (http://www.amap.no/acia) Cambridge University Press (2005).

potentially represent a major, new, unanticipated climate change consequence.

- Intensification of tropical cyclones
  - Recent evidence suggests that sea surface temperature increases are related to the intensification of destructive tropical cyclones.
- The Stern Report
  - This report, published in late October 2006, is a global assessment that discusses the causes and consequences of climate change (externalities in public goods are valued on a global level) with long-term and persistent impacts (intergenerational inequity).[29] Uncertainties and risks are pervasive (ambiguity reigns, given large uncertainties). There is a serious risk of major irreversible, nonmarginal changes ("Act now or it will cost a lot more later").
- Faster and more heterogeneous sea level rise
  - Satellite Altimetry Measurements of sea level change have enabled global ocean and coastal trend analysis.

Published/Documented Changes Since 2000:

- Observational evidence (National Aeronautical and Space Administration data) suggests that the Greenland Ice Sheet is breaking up faster than any models projected, with major implications for sea level rise. This implies that current models are not competent to deal with the rate of loss of both the Greenland Ice Sheet and also the West Antarctic.
- Warmer springs have resulted in earlier snowmelt, longer summer drought, and increased wildfire activity in forest ecosystems where fires are limited by drought, rather than fuel in the western United States. The bottom line is a 300 percent increase in the frequency of large fires and a 600 percent increase in area burned, comparing 1970-1986 with 1987-2003. Dr. Tony Westerling acknowledged that if he had changed the time

[29]This report was released as a book in 2007. Nicholas Stern, *The Economics of Climate Change: The Stern Review*, First Edition (New York: Cambridge University Press, 2007).

periods of comparison, the previously mentioned percentages would have changed significantly. He chose these years because he had 34 years of data, and he cut that time period in half.

- Unprecedented ocean-oscillation changes from 1987-1988 took place that affected many systems. These have been well-documented since 2000.

- An unprecedented pine bark beetle migration across British Columbia heading east has been observed. Migration patterns have been driven by warm winters. Similarly, the southeastern United States has seen southern pine beetle migration into red spruce area caused by drought, nitrogen deposition, and beetle infestation. There have also been shifts in the intensity and extent of the spruce bark beetle in the Pacific Northwest and Alaska caused by an accelerated life cycle from 2 years to 1 year. New England sugar maples have been damaged by pests as well.

- There has been a major loss of glaciers in the western United States and Alaska, coupled with other kinds of ecosystem changes. Loss of glaciers is not simply an iconic signal of climate change.

- Early estimates of the role of terrestrial ecosystems as a carbon sink (through CO_2 fertilization) are less than thought.

- There have been multiple observed shifts in species distribution of both animals and plants. Examples include manatees in the Carolinas and Mid-Atlantic and polar bear decline.

- A paper by Thomas, et al. (2004), which is the most cited paper in environment and ecology in the last 2 years, shows that climate change has caused changes in species and extinctions over the last 30 years.[30]

- Die-off of pinyon pines across the southwestern United States—magnitude of the die-off has been tied to warmer temperatures. Cascading effects include the infestation of beetles.

[30]Chris D. Thomas, Alison Cameron, Rhys E. Green, and Michel Bakkenes, et al, "Extinction Risk From Climate Change," *Nature*, vol. 427 (Jan. 8, 2004).

- Dust storms coming out of the Great Basin impact the rate at which snow melts during the season. Both grazing and drought are contributing causes of dust storms and are becoming more frequent.

- There have been documented increases of net primary production in both temperate and boreal forests related to natural factors.

- There is evidence of increased turnover rates in tropical forests. This is considered, by some, to be an indication of some kind of climate shift, possibly climate change. Turnover rates in undisturbed primary forests have increased all around the world.

- There is well-documented evidence of the impacts/consequences of permafrost thaw in Arctic ecosystems and economies.

- There is documentation of temperature-induced drought die-back in boreal systems in Alaska and Canada.

- There has been a decline in the duration of lake and river ice cover throughout the northern hemisphere associated with increasing temperature.

- There has been an increase in continental runoff in North America.

- There has been an increase in shrub cover in the grasslands of Alaska.

- There has been wetland drying in Alaska.

Question 2 and Responses

What are the gaps in scientists' understanding of how climate change might affect these four U.S. ecosystem types?

Participants identified the following gas in scientific understanding of climate change effects:

- The role of elevated CO_2 in mitigating temperature-induced drought stress and die-back in forest ecosystems

- The interactions of climate, nitrogen, and CO_2

- The ability to model and project amount, timing, and distribution of rainfall, especially for all grasslands, scrublands, deserts, and rangelands

- The ability to downscale and upscale climatic predictions to a level of specificity that is useful for resource managers (modeling at the appropriate scale)

- Currently, much data are collected among different entities. If all of the data that are being collected could be inventoried and put in one place, a lot could be done with these data.

- Will federal forest lands make it easier or harder to meet some kind of international obligations to reduce greenhouse gases (GHG). What if federal forest lands are more susceptible to fire?

- Many questions exist about carbon sequestration.

- We need to know the direction of the net ecosystem exchange for forests in the United States.

- The mechanisms that control the loss of atmospheric carbon (carbon sinks) are not well-understood and carbon turnover is not well-modeled. Models might falsely project an elevated level of carbon storage.

- There is uncertainty about the interactions among snow, groundwater, streamflow, and vegetation in reducing flow regimes of the future. In other words, how do these different elements of the hydrologic cycle interact in a climate-challenged world?

- How flexible (plastic) will individual species be in adapting to climate change? Phenotypic plasticity of species is rarely discussed in the modeling community, but is a significant consideration in the real world. How are these differences associated with climate gradients?

- What is the interaction of climate change and demographic changes in assessing future vulnerability to climate change?

- Sensitivity analysis of water balance—how much precipitation is needed, and at what timing, to balance an increase in temperature? This coupling between terrestrial ecosystems and water resources is in the early stages of modeling and development.

- Use the modeling technique previously mentioned to assess how important precipitation uncertainty is given expectations about temperature.

- Aquatic ecosystems—we are probably experiencing longer durations of late summer, low streamflow that is degrading aquatic ecosystems, but no papers quantifying this have been released.

- Management—how will land managers begin to address climate change issues? It is a science issue of determining the most effective way of addressing and coping with these changes.

- Have scientists and managers come to consensus on the criteria or indicators of ecosystem thresholds? We need research identifying adequate research tools so that we can identify thresholds before they happen.

- What are the changed use patterns of federal lands? How does this affect infrastructure? How will this affect the staffing and services that the land management agency provides to the public? What are the strategies for addressing these issues?

Day 2: Breakout Session Questions and Responses

Question 1

Given some of the potential climate-related effects on this ecosystem described at yesterday's session, what might be the implications for your unit, including how it is used and managed?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Panel members provided examples of implications on various land units based on the climate-related effects of the scientific panel:

- Lose acreage (inundation): On refuges, acreage will be lost due to storm events in combination with sea level rise (increase in storm surge) – Coastal plain of Louisiana (hardwood – swamp – fresh waters marsh – barriers islands). Land is being lost in all of these. This is a possibility for all federally managed lands that are prone to flooding.

Applies across the board (including national seashores and other coastal assets), but may manifest differently, especially with human development impacting the ability of species to migrate. There are 157 coastal refuges - Atlantic and Gulf coast salt marshes are the key ecosystem type that is threatened by sea level rise – impacts ability to support shorebirds and other species. Models of sea level rise identify areas that will be impacted. The United States Geological Survey Coastal Vulnerability index and maps are a good source for this information.

- Complete loss of low-lying islands: Islands of 1- to 3-meter elevation may be lost. This could result in the loss of critical habitats and, therefore, the loss of species that have no capacity for migration.

- Transition of habitat: Inundation and saltwater intrusion will cause different species to take over or existing species to move. For example, the pine rockland habitat community in the lower Florida Keys is shrinking due to declines in the extent of the fresh waters lens. As a habitat is lost, the species that live in that habitat are lost as well. Beach erosion is also a problem for some species, such as turtles that nest on eroding beaches. Coastal development is also putting pressure on some habitats. Federal lands are one of the last remaining undisturbed habitats for some species, but these refuges can only protect fragments of ecosystems. However, development, combined with sea level rise, impact some refuge areas (e.g., Assateague Island). Federal lands are also a unique tool to educate the public about habitats and species. If these lands are lost, a very valuable educational tool will be lost.

- Saltwater intrusion into fresh waters table: Dramatic effects on low-lying islands. For example, the only population of key deer is limited to the lower Florida Keys because this is the only area with fresh waters. The fresh waters lens loss is affecting species. Intrusion into surface water as well for long periods of time changes habitats and species that are supported.

- Loss and alteration of intertidal habitats and sessile species (such as sponges and coral polyps): Some species cannot move, so if certain habitats are lost, the species is lost. Some man-made structures, such as causeways, cause considerable alteration to natural areas. For example, Hurricane Wilma's storm surge of 6 feet led to extensive flooding.

- Due to the broad realm of federal holdings, including holdings such as the Exclusive Economic Zone (EEZ), there is a great potential for adaptive management and experiments (some are already under way).[31]

- Other drivers

  - Warm conditions creating low soil moisture conditions (brown marsh events)

  - What happens to recreational usage, economy, and competition for water resources when we start to respond to climate change? Per capita density is heaviest along the coast—this compounds the effects and the ability to respond with management strategies.

  - Climate change has not been considered in management plans. In the Everglades, studies have found that interannual variable precipitation is most important for the ecosystem. Far more important than the Comprehensive Everglades Restoration Plan influence.[32] If the future is drier, the restoration plan reduces vulnerability, but not enough to offset the impact of climate change.

  - Infrastructure for ports and commerce: Engineering impacts—U.S. Army Corps of Engineers is trying to figure out how to deal with these issues. Dredged materials' influence on habitat.

  - Much more pollution: Sea level rise and storm surges will increase pollution along highly developed coastlines.

  - Coral bleaching: There is an increasing trend in occurrence of bleaching and related diseases. Beginning in 1978, 1980 (fish die-off), 1982 (first basin-scale bleaching event, linked with climate change drivers), and 1997—coral bleaching has expanded geographically and intensified each time. Inshore reefs (1990—lost 65 percent of one

[31]The EEZ consists of those areas adjoining the territorial sea of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, and United States overseas territories and possessions. The outer boundary of the EEZ extends 200 nautical miles from the U.S. coastline.

[32]Approved in the Water Resources Development Act of 2000, the Comprehensive Everglades Restoration Plan provides a framework and guide to restore, protect, and preserve the water resources of central and southern Florida, including the Everglades.

species, the Fire Coral), which are more resistant to bleaching, have started to bleach. In 2005-2006, the Virgin Islands National Park lost one-half of its live coral cover to bleaching and disease. Sea surface temperatures drive coral bleaching. Dissolved oxygen and light are also important. Higher metabolic rates, lower oxygen levels, and greater stratification are all related to temperature. Lack of wind, combined with the previous issues, results in large problems with bleaching. The Florida Keys and U.S. Virgin Islands reefs would provide a good case study for this issue.

Panel members provided the following examples of potential effects of the previous list on the value of federal lands:

- Economic impact—cultural and historical value—impact on Alaska coastal societies and subsistence-based societies

- Fisheries lost—subsistence economies, recreational economy, and major component

- Outdoor recreation activities (approximately $5 billion in National Wildlife Refuges alone) will be impacted. Much due to waterfowl hunting. Some of these species will be impacted.

- Coastal parks—75 million visits per year; $2.5 billion in revenues and 57,500 jobs generated for local economies.

- Florida Keys—4 million visitors per year, resulting in 14.3 million visitor days. Visitors to the Keys spend $1.2 billion dollars directly while visiting. The Keys are dependent on snorkeling, scuba diving, and fishing ($50-$70 million worth of seafood, totally dependent on a healthy coral reef system).

- Not limited to subsistence communities. Apalachicola Bay provides 70 percent of the oysters from Florida. The economy is dominated by oyster production, but now the economy is shifting to retirees and housing developments. Harmful algae blooms and toxins can limit fisheries as well as coastal development.

- According to the Department of Labor's National Ocean Economics Program, the United States' coast accounts for more than 60 percent of the Gross National Product. State-level data about this topic are

expected to be released (California and Florida also have studies). Coasts drive the economy of coastal states.

- The U.S. Army Corps of Engineers spends significant amounts of money on federal activities in coastal areas. If federal activities in these areas are factored in, they have a huge multiplier to economic and resource effects. Between the Corps and the Department of Transportation, much money is spent on roads and bridges, etc., so impacts could be great.

- Not all climate-related changes are bad. For example, the Arctic may open up, presenting some economic opportunities in the area. Also, there may be shrimp in the Chesapeake Bay as the ecosystem changes, but pollution problems must be resolved. Change is a given over the next 50 years, regardless of actions in changing greenhouse gas emissions. However, changes in emissions can change the rate and extent of the change. Adaptation is within the realm of influence for some systems.

- General loss of ecological integrity. Degrading ecological integrity. Need to understand paleoclimatic context.

Forests Ecosystem Workshop Breakout Session Responses

See Question 2 (Day 2).

Fresh Waters Ecosystem Workshop Breakout Session Responses

Participants identified the following potential climate-related effects on this ecosystem:

- Change in public use and visitor patterns

  - An NPS representative said that some park visitation levels, particularly in colder climates, have been restricted by weather conditions, resulting in a “self-selection” of visitors, based on their willingness to participate in water activities in cold water. Climate change is expected to result in a change of visitor patterns and may also result in a wider use of the land’s resources and infrastructure. As water temperatures increase, there have been more people using the parks, sometimes in inappropriate or illegal ways. This requires greater enforcement and rescue efforts, and may require more frequent replacement of equipment or a change in infrastructure. Because funding is not related to the number of visitors to a park, the change in visitor patterns may impose an additional stress on park managers. According to one expert commenting after completion of

the workshop, if climate change leads to substantial reduction in the abundance of actively managed species, more-intensive management plans may need to be developed, particularly on those federal lands where consumptive uses are permitted (e.g., wildlife refuges).

- Cultural resources at risk
  - An NPS representative said that NPS may face challenges in preserving many cultural resources that were previously preserved by dry conditions (e.g., archeological resources in the desert) or cold waters (e.g., shipwrecks in the Great Lakes). With warmer conditions and the possibility for increased erosion, cultural resources and landscapes may be at risk of degradation.
- Reduced supply of water during the summer season
  - A representative from the Bureau of Reclamation said that the expected reduced summer season supply of fresh waters (due to earlier and reduced snowmelt volumes), when demand is highest, is likely to be exacerbated by a lower storage capacity in the winter season (due to reservoir flood control rules being adjusted to reserve more space, compensating for elevated snowlines and more of the upstream watershed participating in runoff generation during threshold storm events, according to this expert commenting after completion of the workshop). This will likely cause an increase in the cost of water. Land managers along the Great Lakes region expressed similar concern, saying that lake levels may fall during dry periods, requiring dredging near docks, extending docks, or limiting shipping routes or recreational access to smaller vessels. Whether dredging or limiting the size of ships in the Great Lakes, this is likely to have an adverse economic impact.
- Changed migration corridors
  - As runoff volumes and patterns change, migration corridors may open in some areas and close in others. This migration pattern change may necessitate additional support for local and regional wildlife, such as the introduction of migration corridors. Managers asked fundamental management questions, including whether particular mitigation and adaptation strategies (such as construction of artificial migration corridors) were necessary, and, if so, under what conditions. An FWS manager said that it was important to also

consider the risks associated with implementing particular strategies.

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

Representatives of four federal land management agencies (BLM, FS, FWS, and NPS) described some of the challenges they face on their land types. The group generally agreed that, because all grassland and shrubland ecosystem types are likely to change, there are going to be cascading effects on public lands. The full group—including participants from the previous day's discussion on impacts—further agreed on some management-related issues that apply across all agencies and developed the following overarching statement:

- Because all of these ecosystems will change, and there will be cascading effects for all major land management agencies, there are several issues of concern: (1) managers of individual management units need to recognize that the entire system is vulnerable to vegetation change, (2) increased coordination and strategic planning across isolated units are needed to increase management effectiveness and minimize ecosystem/species losses due to climate change, (3) agencies need additional resources to address these issues, and (4) agencies need an overall mandate and a coordinated approach to address the climate change issue.

In addition, the group noted the following:

- Agencies cannot easily process new information due to current bureaucratic structures. (They lack the agility to adapt quickly to new scientific information.) Climate change will most affect federal lands and these lands will be the reservoirs containing the species that will populate the earth in the future. However, climate change is currently not a priority in agencies that manage the federal lands.

The following is a summary of some of the specific concerns identified by representatives of BLM, FS, FWS, and NPS with respect to the types of units they manage:

BLM:

- Land cover conversions are occurring as a result of wildfire in the Great Basin. The challenge is to reestablish sagebrush cover, which is very difficult to do, but these cover types are critical from a habitat and species management perspective. (The same thing is also occurring in

the Mojave and Sonoran Deserts, which are losing native cover after high-intensity wildfires, with the invasion of red brome.)[33] (Note: An NPS representative pointed out that this is also true for NPS.)

- Water cycles and managing water resources on the rangelands are issues of concern for BLM. Things are changing, but it is unclear exactly how, and it is unclear how changes in precipitation will affect water resources and the habitats dependent on them. (Note: An NPS representative pointed out that this is also true for NPS.)

- Riparian areas are important on BLM lands, as they represent critical habitats and water sources for both commercial livestock and wildlife.[34] Small shifts in temperature and precipitation may cause these riparian habitats to be lost. (Note: An NPS representative pointed out that this is also true for NPS.)

- A key BLM task, the allocation of forage resources among wildlife, livestock, and watershed needs, may need to change if resources are changing (i.e., if temperature and precipitation patterns change). To date, BLM has not managed with this possibility in mind.

- The National Environmental Policy Act (NEPA) and litigation are major concerns for BLM. Environmental organizations are attacking BLM on how it is dealing with climate change, but climate is not on the radar screen as a policy issue for BLM or other agencies. Paradigm and cultural changes are needed for agencies to be able to manage and think about climate change; agencies need to develop processes to adapt. (Note: An NPS representative pointed out that this is also true for NPS.)

- If climate warms, fires may become more frequent on areas that have not historically burned except for in very exceptional years. This will present challenges for postfire reclamation. (Note: An NPS representative pointed out that this is also true for NPS.)

[33]Red brome is a nonnative annual grass that flourishes in warm climates. It competes with other grasses and displaces native species. The grass sprouts early in the spring, grows quickly, and dies, leaving a dense carpet of dry grass that carries fire.

[34]Riparian areas are those on the bank of a natural watercourse, such as a river, or sometimes a lake or tidewater.

- BLM does not manage landscapes. Rather, it manages smaller planning units and site-specific activities. The agency needs new strategies to manage on a landscape basis, especially in light of climate change. For example, BLM should start looking regionally at habitat types, fragmentation of habitats, and changes in cover types. A large-scale vegetation map is needed. (Note: An NPS representative pointed out that this is also true for NPS.)

FS:

- Managing habitat under severe drought conditions will be a challenge. If droughts become more severe, how should FS manage national grasslands? How should FS manage for changes in species and habitats (e.g., sage grouse, other birds, mammals, etc.)?

- Reduction and loss of wooded habitats—including, to name a few, juniper woodlands, pine woodlands, green ash, and cottonwood flood plains—is a concern.

- The ESA obligates federal land management agencies to prevent loss of species, yet species will inevitably shift due to climate change. The question arises as to how to meet the intent of the ESA while also managing for the shift in species. (If the FS mandate is to recover an endangered species, but the systems that support that species no longer exist, what do we do?)

- Climate change represents a moving target: What are we managing toward, given that the historical policy has been to manage for the status quo (i.e., policy to manage for pre-European habitats, mandates to manage for native species)?

- Invasive species will be a major issue, particularly invasive cheatgrass and invading bromes.

- Better regional models and multiple scenarios are needed to help in the decision-making process.

FWS:

- Some rare prairie and savanna types are being lost at a rapid rate. For example, oak barrens at the northern edge of the United States are a type of dry savanna that is critical for certain threatened and

endangered species that are being lost. Some of these oak barrens support threatened and endangered species—such as the Karner blue butterfly, for example, which is dependent upon lupine, a plant species that grows in the barrens.

- Phenological relationships may be threatened, especially C3 and C4 plant species composition and relationships and all fauna—both vertebrates and invertebrates—that are associated with them.

- Species currently on the edge of the range in which they can survive may become important as future "last survivors" of their species. This is an issue in the dry areas of the tallgrass region, for example. New areas may become the main part of the range. As temperature or water availability changes, favorable habitat may shift from one geographic area to another. For a nonmobile species, such as plants or certain invertebrates, rare outholdings may serve as sources for repopulation if new areas become favorable to its growth. For example, a species in a warm, moist area of midwestern grassland that is becoming hot and dry may cease to exist where it was previously most common. A small population existing in a cooler area with a shorter growing season in suboptimal conditions for the species may become the main part of the range if that area becomes warmer, with an extended growing season.

- Riparian areas may be threatened as a result of both drought and temperature increases. This could have implications for certain species, such as sandhill and whooping cranes, for which water habitats are important for migration. "Funneling points" where birds congregate prior to migration may disappear.

- Lowland oak savannas (rare ecosystem) that occur in oxbows (a bend in a river) and wet areas will be threatened if water disappears or if the timing of water changes (e.g., if snowmelts come earlier). Timing, frequency, and intensity of wildfires may also threaten these savannas as the environment becomes drier.

- Sedge meadows (wet areas partially covered by water) and fens (rare communities with upwellings of water and certain pH levels) may be vulnerable. (Note: An NPS representative pointed out that this is also true for NPS.)

- Invasive species will become a problem. In particular, there are two kinds of invasives in tallgrass prairie areas: (1) those, such as smooth

brome and sweet clover, that are persistent but can be managed with fire, herbicide, and mechanical means and (2) those, such as *sericia lespedeza* that are specifically difficult to control, due to deep, spreading roots and specific defense systems of the plant. If climate becomes warmer in areas that now have cold winters and extended periods of snow cover, and winters become shorter and warmer, a longer growing season will develop. Invasive species that could not bloom and make seed in shorter growing seasons will be successful in reproducing by seed and will spread rapidly. Intensive control of these species by chemical, mechanical, or biocontrol treatment will be necessary in new areas. (Note: An NPS representative pointed out that this situation is also true for NPS.)

- "Invisible" species (e.g., soil microorganisms, mychorrizal fungi, butterflies, and other invertebrates) that are critical to ecosystem functioning and, in some cases, for crop pollination, may become endangered.[35] (Note: An NPS representative pointed out that this is also true for NPS.)

- Wildland/Urban interface issues may emerge, particularly with respect to fire management. Rising temperatures may be associated with more wildfires, including corn stubble fires that are difficult to put out and that sweep across the landscape. (Incentives in the farm bill encourage increased production of corn, so this may be a greater issue in the future.) There are also more houses in the danger zone. (Note: An NPS representative pointed out that this is also true for NPS.)

- It is very difficult for organizations and bureaucracies to cope with climate change, since these bureaucracies are driven by so many competing interests. It will take very strong direction from very high up to get agencies to address climate change. (Note: An NPS representative pointed out that this is also true for NPS.)

- Managers need to be aware of unknowns and cascading effects as a result of thresholds and things of which they are as yet unaware. They cannot manage for these things. (Note: An NPS representative pointed out that this is also true for NPS.)

[35]Mychorrizal fungi live in and around the roots of most plants, serving as a secondary root system. Mychorrizae extract mineral elements and water for their host plants and live off the plants' sugars. They may confer increased resistance to pathogens to the plants' roots.

- The skills and abilities to reconstruct natural systems need to be developed so that buffers can be developed in critical areas for effective connection of land management areas.

- FWS has guidance for many things, such as maintaining biological diversity and integrity, for habitat management planning, and for other issues. However, there is no guidance on how to deal with changing realities, such as those associated with climate change. Current FWS plans assume a steady-state, rather than a dynamic, "moving target" environment. The biological integrity policy directs management for "historic conditions" (i.e., prior to European settlement). It is unclear what FWS will do with refuges whose purposes are no longer functional or if the conditions FWS is managing for are no longer achievable. How should this be addressed in planning? What kinds of lands should FWS be acquiring (or not acquiring)? (Note: An NPS representative pointed out that this is also true for NPS, and that NPS needs a similar translation in planning for climate change.)

- The current FWS approach to addressing climate change is ad hoc and piecemeal. Each region deals with climate change in a different way. There are even differing views at high levels on what the agency should be saying. There is no agencywide assessment of what the agency is going to do regarding current policies and practices. It may be useful to have a systemwide approach to planning, including a plan for strategic land acquisition. Policy development can take years, which means the agencies may not be able to respond in an appropriate time frame. (Note: An NPS representative pointed out that this is also true for NPS.)

- The FWS mandate is to manage for historical landscapes with shrinking budget and staff, but the historical landscape is not what it is going to be in the future. Is money being put into the right places, given expected changes? Is it even possible to save some species? Is some form of triage necessary? What does it mean if a particular refuge's purpose is no longer relevant? (Note: An NPS representative pointed out that this is also true for NPS. Park managers are to "protect for future generations.")

- Lack of baseline data is a key issue; without it, managers do not know what they are losing and how fast. The cost of baseline data is high. Protocols for monitoring are also needed (e.g., for monitoring phenological changes and rate of increases of invasive species). A mechanism for interpretation of these data is necessary for the agency

or for managers to make informed decisions about adaptive management. (Note: An NPS representative pointed out that this is also true for NPS.)

- Managers also need guidance and acquisition policies to maintain connectivity among different public lands (i.e., FWS needs acquisition policies to maintain connections and corridors between parcels that have been separated by agriculture, etc). Again, this speaks to the need for a cohesive land acquisition strategy that reflects climate change projections. (Note: An NPS representative pointed out that this is also true for NPS. While NPS may not need to acquire more land, it may need to investigate options for providing corridors for species movement and connectivity.)

- FWS is also unprepared for the increasing pressures of using federal lands for other things, such as wind energy, bioenergy, pressure for water storage, competition for water use, and development of oil and gas resources. There will be pressure to put these installations on different public lands (FWS, BLM, and FS). A push to put things on private land may still affect refuges because animals that migrate through would be affected. (Note: An NPS representative pointed out that pressure from development is also an issue for NPS, although it is easier for NPS to say "no" than it is for FWS.)

NPS:

- The NPS management policies address individual issues, but the agency has no explicit guidance on climate change, except that NPS "can't change the weather" (i.e., practice cloud-seeding.) The Park Service's Organic Act, which created NPS and defines its mission, is very general. There is no mention in the act of ecosystems or climate change; the guidance to protect resources is implied.

- Because guidance in the Organic Act is implied, different managers have different ideas on how to interpret the Park Service's Organic Act with respect to climate change, since the act, which was created in the early part of the 20th century, does not explicitly address climate change. Therefore, some managers will attempt to address climate-related issues, and others will not. In addition, each individual park has enabling legislation that gives additional guidance along with the Organic Act. Thus, each park has its own set of mandates based on the type of park, and there is no single, coordinated approach. The public approval

process is also inconsistent. For example, if climate change is mentioned in the course of the public comment process for park general management plans, NPS addresses the issue. However, if it is not brought up, it is not addressed.

- Since federal lands are not contiguous, and there is development between habitat corridors, agencies could cooperate more, particularly with respect to planning corridors for endangered species. The Cooperative Ecosystem Study Unit (CESU) is an existing tool that has not been fully utilized but could be utilized to conduct regional-scale, cross-ownership boundary climate change effects.[36]

- More adaptation is needed in the national parks. Planners should be trained to take possible climate change into consideration. However, this may be challenging because every park has different enabling legislation. NPS currently sponsors a Climate-Friendly Parks initiative with the Environmental Protection Agency. The goal of the initiative is to educate park personnel so they can educate the public. Emissions inventories are conducted for member parks and included in Environmental Management Systems (EMS).[37] The focus is on greenhouse gas emissions mitigation, not necessarily adaptation, although bigger culverts have been suggested for under the Going-to-the-Sun Road at Glacier National Park to accommodate waters resulting from faster, more concentrated melting of snow or ice, and NPS has built portable bathhouses on some barrier islands where severe storms and flooding are problems. Also, the Cape Hatteras Lighthouse was moved in response to rising sea levels. (At the time, they called it merely "coastal erosion, but it is also a result of sea level rise, a climate change effect.)

[36]The CESU is a federal partnership between 13 federal agencies and various universities. The universities sign on to be CESUs by region and get funding from agencies. Agencies agree to work together toward common needs and sign agreements with universities for research, technical support, and outreach.

[37]An EMS is a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency.

Question 2

What are the challenges, constraints, and limitations associated with adapting to the effects of climate change for this type of federal land?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Panel members discussed multiple challenges facing land managers in the coasts and oceans ecosystem in adapting to the effects of climate change. Panel members gave the following examples of challenges based on management guidance, planning processes, and other general challenges and constraints:

Management Guidance:

- Wildlife refuges: Created under a variety of acts and executive orders. Some refuges have their own enabling legislation. The Refuge Improvement Act is one recent example in the system history that looks beyond certain species in a more holistic manner. Refuges often have no specific guidance. This issue is being raised more often in the planning process. FWS briefing statements for next 5 or 6 years, address certain places. There are rapidly developing models to project sea level rise. Also have increased consideration of climate change in land acquisition processes. This is driven by managers and planners. $20-$50 million per year for land acquisition, trying to shift paradigm inland and upland in general to catch transition zones to accommodate marsh migration. Little support from political leadership to address these issues comprehensively. No leadership example set in agencies to sit down or even use specific terms in political statements.

- Marine sanctuaries: No formal guidance, but open to talking about climate change if there are quantifiable data.

- NPS: No specific climate change-related guidance, but must base decisions on best available science. This is based on statutory guidance in the Thomas Bill.[38]

- Common theme: Guidance is bottom up, not top down. It mainly comes from constituents through the planning process.

[38]National Parks Omnibus Management Act of 1998.

Planning Process:

- Wildlife refuges: The public is starting to call for consideration of climate change in the planning process. Comprehensive Conservation Plans (CCP)—have started to address climate change impacts in more recent plans.[39]

- Climate change vulnerability issues have begun to get consideration in some planning efforts. For example, collaborating with state agencies to redefine the purposes of shellfish leasing from harvesting to conservation and buying commercial fishing licenses.

- Marine sanctuaries: Management plans are being rewritten. Each sanctuary has advisory councils that bring up concerns. Climate change has been a driving factor in the Florida Keys since the early 1990s. This process is bottom up.

- In general, the planning process is midlevel or below in the federal government—bottom-up guidance is driven by constituents. The states are taking the lead in some cases (e.g., California).

Challenges and Constraints:

- Some federal lands have static boundaries and, in some cases, very specific purposes. This limits management options.

- Global changes and local impacts: On a local scale, managing particular units, not a lot of control over the big drivers. Certain changes will happen, such as temperature increase. Local action is needed to manage these impacts. With big climate changes out of management control, managers have responsibility and jurisdiction to control the local factors that they can potentially influence. Need to look at local management regimes in light of climate change. New options need to be examined, such as buying upstream land or establishing local planning boards.

[39]Under the National Wildlife Refuge System Improvement Act of 1997 (Refuge Improvement Act), all national wildlife refuges are required to develop a CCP, which is a document that provides a framework for guiding refuge management decisions.

- Dollar limitations: FWS land acquisition dollars have declined from about $125 million in 1999 to $10 million more recently. This impacts the ability of FWS to manage the lands it has, let alone buy additional lands. Furthermore, the agency is spending more on current holdings to expand and adjust.

- Preserving ecosystem values and services: One way to do this is to build resiliency into current holdings by protecting areas that are minimally impacted, and to identify additional lands—resources that are not federally controlled, but that can be influenced through federal interaction with other landholders.

- Institutional: There is a lack of top-down leadership. The federal legislative branch has the opportunity to take the leadership role and fill the vacuum. There are also impediments within agencies. Management impediments exist between field and higher-level leadership (if any higher-level leadership exists). Conflicting agency missions—different agencies have different missions. Some agencies focus on conservation, others extraction.

- Education and public buy-in (climate literacy): Most people do not understand the long-term nature of climate and think it is too complex to understand. When they see the "debate" they do not understand the fundamentals and think there is actually uncertainty regarding whether climate change exists. This does not reflect scientific consensus. Within the scientific community, there is no debate over the reality of climate change and its human cause. The climate change issue is not on the public agenda. This issue needs to be posed by showing its impact on the economy and everyday activities. Coastal community resilience indicators and self-assessment tools are being developed to assist coastal communities to plan for impacts. Remarkable recent change in public awareness of climate change has occurred in some areas, but other areas do not have much public enthusiasm about climate change. There is an EPA study about perception, discontinuous appreciation of the issue after Hurricane Katrina. People perceive that Katrina was associated with climate change. This has recently led to a much greater appreciation of climate change.

- Lack of information: The Thomas Bill requires NPS to manage resources using the best available science. Established inventory and monitoring networks are based on bioregions. Models and indicators are needed to track ecology. Climate is playing a role. Local- and regional-scale

modeling of specific ecosystems, not artificial boundaries, is important and necessary to plan appropriately. Barriers also exist with state, local, and other land-use management agencies. When the information is available, it is easier to designate protected areas and preserve ecosystems. To demonstrate performance of reserves, more information on the functioning of systems and species connectivity and better understanding of other stressors, such as bleaching and disease, are needed. Is leadership paying attention to the information available?

- Shift from historic paradigm to looking to the future: For example, should money be spent on prescribed burning to preserve pine rockland that will not exist in 50 years? It is important to set up a system for future managers.

- Scientific debate (endless debate after science has been established as well): Gives decision makers a reason not to make a decision. Adaptive management needs to take over—needs to move with the majority of scientists, both at the management and leadership levels. For example, out of 928 papers, none disagreed with IPCC's assessment. Scientific debate is over; however, public debate is ongoing.

- Setting aside protected areas conflicts with economic goals: For example, fishery extraction is limited or prohibited in protected areas, just as timber extraction is prohibited on some terrestrial protected areas. This raises two questions: Is there an ecological limit to the production and consumption of goods and services? Is there a conflict between increasing production and consumption of goods and services (i.e., economic growth) and ecological health? If so, then protected areas and conservation lands will be encroached upon or degraded as long as economic growth ensues. This implies that biological conservation and environmental protection entails macroeconomic policy reform.

- Economy is primarily driven by fossil fuels: With fossil fuel combustion constituting the primary source of greenhouse gases, and with an economy that is 85 percent fossil-fueled, ceteris paribus, economic growth entails more global warming. Does the goal of economic growth trump the need for a stabilized climate? Does the pursuit of economic growth, which imperils the stability of global climate, likewise imperil future economic prospects?

- Need for an integrated approach: Climate change, land-based sources of pollution, habitat and hydrologic alteration, invasive species, and overfishing are the major management challenges. There is a need for integrated approaches to deal with all of these challenges. EPA completed a relative risk analysis of stressors across the country and came up with the previous factors, plus invasive species, as management challenges.

- Burden of proof to take actions: The burden is on federal land managers to prove that conservation areas work. Land managers are constantly defending themselves against consumer groups. For example, protected areas are important to sustain fish harvests. Marine reserves and limiting the taking of species ("takes") can help. In the tropics, this is much more important to demonstrate that the reserves work. In temperate and higher latitude areas, marine reserves and limiting takes do not always work because of differences in ecosystem functions due to highly mobile fish species. In tropical areas, fish are there because of the reefs. On other fishing grounds, fish are mobile; but some reserves have worked. This is known as spatial nature. In tropical areas, fish are site-attached.

- Conflict between federal and state water management: About 85 percent of existing protected waters are state waters. If resource managers can agree on commonly held conservation goals, needs, priorities, and threats, they will have more commonalities than differences: Oceans are connected. We need to transcend administrative authority barriers. All share the same threats and issues. If these were drivers of debate, jurisdictional authority issues would go by the wayside.

- Ocean/Land interface: Improve management of land-based resources as they relate to the coasts (coastal watersheds). Need to maintain critical streamflows for anadromous fisheries (e.g., Sacramento River National Wildlife Refuge for Chinook and Coastal Alaska).

Forests Ecosystem Workshop Breakout Session Responses

Forests ecosystem workshop participants from FWS, FS, and NPS identified the following management challenges and constraints:

FWS:

- Climate change will demand a paradigm shift on how FWS approaches its mission—essentially, species conservation/preservation—due to paradigm shifts in climate regime and the related impacts on species.

- The 1997 Refuge Improvement Act directs the National Wildlife Refuge System to "ensure that the biological integrity, diversity, and environmental health are maintained for the benefit of present and future generations of Americans." The impacts of climate change will impose an enormous burden on the National Wildlife Refuge System, depending on how "biological integrity, diversity, and environmental health" are interpreted.

- Examples of unprecedented change abound in the Kenai National Wildlife Refuge, Alaska, including anomalies related to fire events, glacial retreat, tree line rise, wetland decrease, species shifts, and insect infestations.[40] Other wildlife refuges may face similarly unpredictable or unexpected disturbances, so managers may need to make preparations/plans on the basis of assumptions that are fundamentally different from the past. The appropriate document for managers to develop would be a CCP.

- Many National Wildlife Refuges and Waterfowl Management Areas are inherently at risk due to small size, sensitivity (many are wetlands), and location (i.e., coastal).

FS:

- There will be a need to revisit assumptions about regeneration, management, and system resetting activities.

- Climate change will require a reexamination of the multitude of fragile partnerships developed for the protection/preservation of land use (e.g., the Northwest Partnership to secure viability of spotted owl habitat was hindered by massive fire damage).

- Climate change will require managers to work beyond administrative borders, so arrangements that encourage groups and organizations to come together are needed.

- The body of legislation that regulates day-to-day management was developed in the social context of the 1970s. Managers today are still

[40]Tree line—the point at which forest vegetation begins to shift from nontree species to tree species.

bound to backward-looking viewpoints, while climate change issues loom tomorrow.

- Of the major ongoing fire management activities, some are not being developed with climate change or long-term monitoring in mind. For example, LANDFIRE, an interagency project generated by the 2000 National Fire Plan, does not address monitoring effectively and does not incorporate the concepts of climate change.

NPS:

- Climate change may cause NPS to reexamine its role in view of its fundamental mission, which in part involves "conserving wildlife and historic objects for future generations."

- Climate change will affect the ability of NPS to fulfill its mandate to preserve certain species, which may not be able to migrate away and, therefore, will face die-off.

- Climate change will challenge NPS's ability to achieve some broad mission goals, such as maintaining visitation levels and preserving cultural resources, in view of increased climate variability, such as storms, floods, fires, and extreme heat and cold.

- Climate change will challenge NPS's ability to manage insect outbreaks and invasive species events.

Common Challenges:

- Federal land systems are fixed on the landscape, while climate has no boundaries, posing challenges for managing an administrative unit that does not move with the climate.

- In some cases, policies and laws, geared toward responding to events as they occur, constrain the ability of managers to incorporate anticipated events into planning and to incorporate climate change within the context of natural diversity.

- Managers lack risk assessment or approaches that allow for the inclusion of climate change and demographic change in planning activities.

- Political pressure to do something, regardless of whether it is likely to be effective in reducing the actual risk or whether it was appropriate for that system, can be a challenge.

- Defining "natural variability" by looking at snapshots of the past is not appropriate; regardless, the future will be different, whether it is considered "natural" or not; no accurate predictions exist; and preparing for the future in the face of this uncertainty is challenging.

- Climate change effects will exacerbate other environmental stresses and already existing problems.

- There is some degree of disconnect about the nature of agencies' mandates with respect to climate change and, accordingly, differences in the interpretation and implementation of such guidance at the management level.

- Managers operate in an administrative environment that is highly fragmented. Stakeholders include FS as well as landowners, state agencies, and industry. Climate change effects span large areas, creating problems that defy remedy along administrative lines. No one has all the information, which punctuates the importance of having infrastructure in place to develop a shared vision of issues and solutions.

- The social interface between research and management is lacking. For example, social factors play an important role in determining which fires are suppressed and which are not. Although researchers may provide rational, scientifically based recommendations to managers, legal and social constraints may take precedence.

Fresh Waters Ecosystem Workshop Breakout Session Responses

fresh waters ecosystem workshop participants identified the following management challenges and constraints:

- Various water rights laws create problems.

  - According to a USGS scientist, certain western water allocations and rights were established during a relatively wet period in the history of the United States (the wettest 15-year period in the history of the United States). As water resources become scarce, and competing demands increase, NPS and FWS land managers face pressure regarding use of water resources, and several of the land managers expressed concern over whether enough water resources would be

set aside for ecosystem functions. An FWS land manager said that the agency has a very limited ability to convincingly state water requirements to protect fish habitat and aquatic ecosystems. Land managers believed that competing demands for water resources are largest in areas of rapid development, such as Las Vegas, Nevada. Other water-stressed areas include groundwater reserves under parts of Nebraska and Kansas. Land managers believed that a collaborative effort to equitably assign water rights was necessary, otherwise public lands would suffer. Some suggested that the Congress should reassess the mandates regarding water allocation.

- A USGS representative said that it will be increasingly difficult to obtain hydrologic information from USGS because funding for the agency's stream gauging network and hydrological data is being eliminated. According to the USGS representative commenting after completion of the workshop, many core monitoring efforts are being reduced unless USGS can find funding through other, nonagency budget means. A NPS representative believed that the eastern United States already faces water challenges, and that human demand for water puts added strain on eastern aquatic ecosystems.

In addition to complexities associated with various water laws and a dearth of hydrologic data, managers face reduced management options if interrelated water supply systems are affected, and increased complexity regarding mitigation of protracted droughts or reservoir spills.

- Organic Acts and some statutory requirements are explicitly vague.

  - NPS is asked to manage land such that it is "unimpaired for the enjoyment of future generations," and FS is required to manage in order to maintain "favorable conditions of flow." An FS scientist explained that it is difficult to manage flow regimes with respect to a historic range or variability because of the added stress associated with climate change and increased demand for water resources. Many land managers believed that the mandates are vaguely written and not specific to ecological preservation. An FWS land manager said that land managers react based on statutory requirements, which presumably reflect human societal values; however, other land managers believed that the general public and the Congress do not have a clear understanding of the purpose of the federal lands.

- Management planning horizons and climate change are on different timescales.

  - NPS and FWS officials said that planning can be difficult with so much uncertainty about future climate conditions. Accountability structures that have emerged over the past decade are very short term in nature. For example, land managers are typically accountable for things on a year-to-year time frame, and "long-term" planning horizons are commonly just 10 to 15 years. An FWS land manager explained that he is required to create a general management plan on a 15-year planning horizon, which he believed was too short for incorporating management practices for addressing long-term climate change, although he also believed that decisions beyond the 10- to 15-year time frame would be very speculative. An NPS superintendent suggested that management plans may help address this timing issue by including a section on long-range issues expected beyond the time frame of the plan. For example, long-term planning in coastal areas will need to consider rising sea levels, and consider whether the management decisions being made today are also relevant for the future. This will require adaptability and will require that each management agency consider how climate change may affect its mission in the long term.

- Land management has historically been intuitive.

  - Because climate is expected to change more rapidly than in the past, managers will have a difficult time making assumptions about future conditions to justify anticipatory land management practices, and any assumptions will have to be justifiable. Managers believed that land management has historically been intuitive, and they expressed concern over their ability to react quickly if they were to reach a threshold and experience a relatively quick, dramatic change. Land managers cited the example of the whooping crane, whose population decreased to such a low level in the past that FWS had to embark on an intensive program of management. The agency is improving models to help determine continental population objectives to help make management decisions.

- Political hazards are associated with discussing climate change.

  - Land managers and scientists believed that it is not politically profitable to talk about climate change. An FWS representative said

that climate change impacts are not explicitly addressed in agency strategic plans, but may occur at a unit level, for example in the Kenai or Blackwater National Wildlife Refuges' management plans. An NPS representative agreed, saying that the agency may discuss "sea level rise" rather than referring directly to climate change. NPS has decided to talk about the effect of climate change, such as the sustainability of parks, and has implemented programs, such as "Climate Friendly Parks," to mitigate those effects.

Participants generally stated that land managers have to accept the notion of climate change in order to develop a recovery plan. For example, regarding the polar bear, land managers must decide whether to list the species under the ESA, based on what is likely to happen to the species as a result of climate change.

Grasslands and Shrublands Ecosystem Workshop Breakout Session

Grasslands and shrublands ecosystem workshop participants identified the following management challenges and constraints:

BLM:

- BLM does not have any policy from the national office to the field offices on dealing with climate change. The only offices that are having to address climate-related issues are probably in Alaska, dealing with NEPA environmental impact statements on oil and gas leases. (Note: An NPS representative pointed out that this is also true for NPS.)

- A possible entree for bringing up climate change might be through updates of the agency's planning guidance. BLM-wide monitoring policy might be another way to address for climate change, even though climate change is not mentioned directly in those documents. (Note: An NPS representative pointed out that this is also true for NPS.)

- BLM field offices address their situation with respect to current climate conditions. However, they are trying to weave in some flexibility through the concept of adaptive management so decisions can be adjusted in response to changing conditions. It might be possible to use scenario-building, in which the agency looks at different scenarios to help prepare for various possible outcomes. However, BLM does not have much predictive modeling capability, although it might be possible to contract with universities (or use the CESU tool) to acquire this expertise. (Note: An NPS representative pointed out that this is also true for NPS.)

- BLM has been involved in seed-banking for about 5 or 6 years through its fire rehab program. The agency collects native seeds for this purpose, and some of the seeds go to a botanical garden for storage.[41]

FS:

- There is no real direction trickling down of guidance from the FS Chief's level. FS talks about sustainability but does not discuss climate change per se.

- One of the barriers to managing for climate change on national grasslands is that some FS lands are intermingled with private or state lands. Therefore, even if FS buys off on climate change, it is necessary to have the private landowners on board and in agreement. Being able to manage a system with the fragmented ownership and landscapes is a challenge; it is difficult to impart an understanding of what climate change means to private landowners and having them believe it.

- The way the public involvement process works on multiple-use federal lands can really complicate discussions like adaptive management. There is a general mistrust in some circles of FS use of the adaptive management concept.

- Another challenge is that the process for planning is outpaced by the speed of scientific information coming in. Science is coming down the pike faster than it can be processed. The agency will start its planning process, and new information will come in that cannot be addressed because the planning process will not allow for it.

- Land management planning is complicated by this country's litigious society. Certain groups are able to obtain scientific information and sue the agency for taking or not taking certain actions; these groups can sue quicker than an agency can incorporate new science.

- FS may recognize that climate change is important, but the agency does not see it as urgent. A demonstration of urgency might make the agency view the issue as a priority.

[41]FWS and FS officials at the grasslands and shrublands workshop breakout session generally concurred with the BLM points made in this section.

FWS:

- Lack of staff and funding and the overall downward trend in support for conservation make it difficult for FWS managers to even maintain the status quo in terms of the work that needs to be done. (Note: An NPS representative pointed out that this is also true for NPS.)

- Seed-banking could be one adaptation option, but presently there is no direction from supervisors to do it. (Note: An NPS representative pointed out that this is also true for NPS.)

Question 3

What land management practices or approaches to planning may be considered when responding to the effects of climate change?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Panel members provided examples of steps that can be taken in land management planning that are important to consider in order to better respond to the effects of climate change:

- Planning for resilience on a large scale: Set relatively undisturbed areas aside to limit impacts. Identify more resilient communities to help preserve them for the future. Marine reserves are a promising management tool for adapting to climate change by managing for resilience. Remove the effects of fishing as a stressor. For example, Australia set aside one-third of reefs as protected areas. Showcase Marine Protected Areas[42] that are multiagency (state and federal) state partnerships as "poster children" to decision makers. Such partnerships can demonstrate the effects of reserves.

- Best practices: National Association of Counties, etc., to adopt best practices for lands management. Look at the past and the future. Prioritize investment of resources on habitats that may be impacted in the future. Consider the past, but plan for the future.

[42]A Marine Protected Area is any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein.

- Needed: A coastal manager's guide to climate change similar to *A Reef Manager's Guide to Coral Bleaching*,[43] a 2006 report on ways that local managers can help make coral systems more resilient to manage stresses during bleaching events and plan for future bleaching events. Workshops and training courses are in development. Managers need a coastal land manager's guide and training course for how to plan for, adapt to, and mitigate climate change on federal holdings.

- National Estuarine Research Reserve Conceptual Models: Climate change is important, but not the only thing that is important. Climate change creates multiple stressors, but other stressors also affect the coastal system. Emphasize cumulative stressors within the ecosystem management context. Plan needs to be in context with other stressors. Integrate watershed-level planning with coastal management adaptation.

- Manage fishing and its impacts on marine and coastal environments

- ESA critical habitat designations: Can prevent extinctions and provides land acquisition authority for the National Wildlife Refuge System.

- Legislation to create refuges: Use the following as a model to protect marine areas: wildlife (ecosystem services) first, wildlife-dependent public uses, where appropriate, based on compatibility assessments. Using the management paradigm of limiting fishes in order to limit commercial harvests. Other agencies have different missions. Need regional demonstration projects.

- Natural capital banking: Optimize the ratio of natural capital existing in a state of ecological integrity to the ratio of manufactured capital and consumer goods that flow from the stock of natural capital. Create a balanced account to optimize the public welfare. What about things that cannot easily be measured economically? Resource economists are working on this—need improved methodologies for valuing ecological services.

- Cooperative conservation approach: Beyond government jurisdiction—adopt a seamless approach for managing coastal zones and marine

[43]Paul Marshall and Heidi Schuttenberg, *A Reef Manager's Guide to Coral Bleaching* (Townsville, Australia: Great Barrier Reef Marine Park Authority, 2006).

waters that allows for adaptation to climate change (migration, etc.). Need to include public, private landowners, and interested constituents. Manage the greater ecosystem. Also need this approach for monitoring programs.

- Restore hydrology and wetlands functioning: This can be done, for example, by constructing weirs (small dams) and increasing the land's capacity to adapt to changes. Learn about anticipated future conditions and build/remove infrastructure as necessary. Remove ditches, roads, etc., as necessary. "Retreat" (i.e., moving man-made structures) is an option.

- Change incentives for building in high-risk areas, for example, by mapping erosion zones. Higher resolution coastal mapping of flood, erosion, other high-risk zones. Offer tax incentives for conservation easements or to move to different areas? In North Carolina, people can be reimbursed for destroyed coastal property, but the property will then be placed in public hands. Rolling easements (past example: Upton-Jones Amendment).[44] In Louisiana, the Federal Emergency Management Agency has provided funds to wetland mitigation projects for storm protection. This program should be expanded beyond wetlands. Mitigation pays 4:1 across the country, but 7:1 in coastal areas. The cost of adapting now would be less than paying later.

  - There is a tremendous lack of investment in adaptation at this time, but investment in the future may change this ratio. We may not be able to spend our way out of this problem.

- Florida coastal control line: Line drawn around the boundaries where overwash is expected. Setback lines in combination with building requirements and permitting in areas at risk. For example, the Maryland Critical Areas Act is intended to stop eutrophication of the bay with setbacks, but serves a similar purpose. These concepts should be enhanced using scientifically based lines.

[44]The Upton-Jones Amendment to the Housing and Community Development Act of 1987 amended the National Flood Insurance Act of 1968 to provide insurance benefits to structures in imminent danger of collapse due to coastal erosion or undermining caused by waves or water levels exceeding cyclical levels. The program had limited impact, and the Upton-Jones Amendment was repealed in 1994.

- Florida water management districts: Management boundaries are based on watershed boundaries. These districts have taxation authority. Boundaries are contiguous with natural boundaries, allowing the districts to address watershed-scale issues.

- United Kingdom Climate Impacts Program: Good model for what can be done at a national and local level to enhance adaptive capacity. This program provides a Web site (http://www.ukcip.org.uk/) and a monthly newsletter, and each political subdivision in the United Kingdom has a devoted team to help people adapt in all sectors. One potential suggestion to the Congress: Create a Climate Impacts Office, which would be distinct from Climate Change Science Program and the Climate Change Technology Program, and create a climate change extension program in every county.

- Coastal Barriers Resources Act: Private lands are demarcated as relatively immune to development. Delivery of the program is problematic due to top-down approach. This is a half-hearted fix to the problem.

- Work with insurance and financial industry to construct incentives for mitigation and adaptation. Need to also focus on what could be, not just what has already happened. Also need to include incentives for other coastal areas at risk, including New York, etc.

- Need to build a community of practice. Expand the community of practice, such as local land trusts, and expand influence.

Forests Ecosystem Workshop Breakout Session Responses

Workshop participants contributed the following ideas with regard to management options for addressing or mitigating climate change effects:

- A monitoring strategy that is affordable and reflective of some of the key vital signs of forests is needed to inform management decisions.

- One approach is to conduct vulnerability assessments to identify characteristics associated with species loss, and to pay special attention to those species most threatened.

- The Kenai National Wildlife Refuge has launched the Long-Term Ecological Monitoring Program in cooperation with FS's Forest Inventory and Analysis Program, in which vegetation data are coupled with wildlife sampling to produce a spatial explicit, comprehensive

species inventory. The program has already resulted in the identification of new species to science and the modeling of species distributions.

- The Kenai National Wildlife Refuge also helped launched the Alaska Landscape Cumulative Effects Simulator, a stock-and-flow model to which several stakeholders—public, private, and nonprofit agents, and other communities and groups—contribute. The main objective of the simulator is to provide a strategic-level land planning tool by identifying and examining landscape change drivers, including climate change, in the context of other management issues to provide an effective strategic land planning tool.

- What is needed is a national data repository and a separate Bureau of Statistics to provide a holistic portrayal of the status of the landscape. This will facilitate collaboration and address the issue that the sum of local level choices may result in a suboptimal or counterproductive aggregate outcome. In one instance, individual agency actions resulted in threatening the spotted owl in the Pacific Northwest. A holistic view also will address the issue that, although information is abundant, much of it is not comparable or compatible. Some did not agree with this approach.

- While research needs to be conducted iteratively over time to reach a level of certainty, managers need information in real time to make decisions. The needs gap may be closed by using better communication tools.

- FS tools developed for broad-scale application do not have capability at the species level, which managers would like. Developing such high-resolution models should be a research goal.

- One approach to scenario modeling is to use it to convey possibilities to the public, to change expectations and alleviate pressure on land managers, which provides more freedom to make the correct decision.

- The concept of moral hazard, the idea that climate change is inevitable, should not be used as a reason for inaction.

- The question of where to invest resources has been ignored. Should a billion dollars be put toward trying to slow the rate of climate change, fending off its effects, or adapting?

- Five basic management strategies are being submitted for consideration in an upcoming paper: (1) reduce GHGs by sequestering carbon, (2) resist climate change by legislating that the landscape remain as it has been historically (this approach is increasing in cost and is likely doomed to fail), (3) create resilient landscapes that can revert to their previous state after a disturbance, (4) respond to climate change by anticipating change and seizing opportunities, and (5) conduct triage by acknowledging priorities in conservation efforts (this approach would be legislatively challenging).

- There is a need for an agreed-upon suite of indicators that address social, economic, and ecological vital signs of the sustainability of forest lands. The research community can help identify such indicators by leveraging ongoing developmental systems, such as the Sustainable Forest Roundtable process.

- FS is testing a program that utilizes a combination of high-elevation aircraft and helicopters to produce low-cost imagery at a half-a-meter resolution that can be linked to models and indicator systems, thereby providing scalability.

- The nation's satellite system currently is not equipped to improve the problem of out-of-date National Forest land cover information. There is no operational commitment to conduct regular reporting on the actual state of land cover. It will be at least 5 to 7 years before 30-meter resolution data become available.

- Land managers are heavily dependent on technology platforms for information, but as technology changes continuity and reliability become a serious issue; there is a need for better integration of existing inventory monitoring programs that are scaled at the landscape level.

- The Healthy Forest Restoration Act has brought people together to manage fuel treatment strategically, rather than on an acre-by-acre basis.

- An ecological risk assessment framework, in which a desired outcome is identified and trade-offs discussed with stakeholders, is better than a "support-this-but-not-that" triage approach, which limits options and discussion.

Fresh Waters Ecosystem Workshop Breakout Session Responses

Land managers had some difficulty in identifying management practices for specifically addressing the effects of climate change. They said they are likely to draw on historic practices, although the frequency of the use of each practice may change. In general, they saw opportunities for public outreach and collaboration across federal agencies.

- Opportunity for public outreach and education
  - Managers of federal lands said that the federal lands with visitor centers provided an opportunity for people to learn about the benefits that protected areas provide to the public. A USGS official said that several USGS employees were told explicitly not to interpret climate trends for the public, but NPS officials said that they had more latitude for public outreach and education as part of the park interpretive experience. The management structure at each park has flexibility to include public outreach efforts, and workshop participants said that each park should take advantage of this. Land managers said that the Congress should mandate that parks incorporate public outreach and education as a low-cost, effective part of management practices. Participants also said that land management agencies should jointly fund facility investments and minimize energy use.
- Use of historic record for planning
  - A scientist from USGS suggested that land managers look at paleostudies, including the National Tree Ring Database, to understand past climate variability and hydrologic responses. Because some ecosystems have already gone through analogous changes as are expected with climate change, land managers can learn from past periods of drought during the past several hundred years. If severe droughts of the past are becoming the “norm” of the future, land managers should address this in management plans. The scientist believed that the historic record may be a better planning tool than current general circulation models, since many of the climate models are poor predictors of precipitation.
- Collaboration among federal land management agencies
  - A representative from NPS said that BLM has fragmented landscapes and migration corridors because of a mandate requiring the agency to expedite energy development. Panelists generally agreed that this

could have been avoided, if BLM were required to cooperate with other federal land management agencies as part of the energy development efforts.

- Panelists further identified "economies of scale," including examples where it is more efficient for agencies to work together. They cited the National Interagency Fire Center as a successful model of incident management (e.g., fire suppression).[45] Although an FWS representative said that collaboration among agencies can be inefficient, since agencies have differing missions and priorities. However, the panelists generally agreed that the agencies have some common interests with respect to climate change, which may necessitate the need for fire protection, cooperative snow surveys, groundwater data collection, regional model development, and data collection and dissemination, in general. An FS representative believed that USGS has a clear role to support agencies' need for water resource (hydrology) data, and to coordinate and share information. He believed that USGS was developed to address emerging needs and issues, but this function has recently been outsourced. For example, approximately 28 percent of USGS stream gauges have been eliminated over the past decade, and the current USGS long-term monitoring and research function is a user-pay, client-based system that is less useful than many university-level efforts.

- Panelists generally agreed that monitoring and research functions related to climate change are inherently governmental functions, because of the need for national-scale data that must be beyond the range of a single appropriations cycle or contract period.

- Physically manipulate the environment

  - Although land managers discussed the possibility of physically managing and manipulating an animal habitat to maintain species health in a location where the environment would no longer naturally support the species (presumably due to changed water availability),

[45]The National Interagency Fire Center is located in Boise, Idaho, and is a cooperative effort between the following organizations: BLM, the Bureau of Indian Affairs, FS, FWS, the National Association of State Foresters, NPS, the National Weather Service within NOAA, the Office of Aircraft Services within Interior, and the United States Fire Administration.

this option was not viewed as optimal because it may require considerable infrastructure investments.

- Reevaluate the concept of ecological succession

  - Experts believed that climate change impacts will result in species shifts, and may require a paradigm shift in the way that land managers think about and react to invasive species. For example, invasive species in a particular region may become the norm under a new climate regime. When treated as an invasive species, rather than part of natural ecological succession, there is a tendency to make value judgments (based on an ecological response, rate of disturbance, etc.) and fight against the species. Land managers considered what control of invasive species is likely to resemble in the future, and the degree to which managers should continue to manage (against) invasive species. An FS representative believed that land managers need to throw out the idea of what species *should* and *should not* be on a landscape, because the world (of pandemics, microbes, and seed dispersal) is changing faster than any other time in (documented) history.

- Development of adaptive management strategies

  - Managers generally agreed that the current management structure on federal lands does not provide the flexibility needed to mitigate or adapt to climate change impacts. Land management plans generally cover a 10- to 15-year time frame, although some managers considered whether they should also be looking at a 50-year time frame, and how to handle the uncertainty associated with long-term climate effects and planning.

  - FWS managers and others believed that an adaptive, or anticipatory, style of management and decision making would be necessary to reflect learning that takes place over time (e.g., with respect to climate change and ecological responses). This would require managers to state assumptions regarding the future conditions of a system and manage on the basis of those assumptions. The assumptions can later be verified against observational data and used for improving regional models.

  - According to participants, a good adaptive management framework should involve a clear set of assumptions, which are checked against

real, observed situations. For example, if a resource manager must make productive habitat for wintering populations of endangered whooping cranes, he or she should do this on the basis of assumptions of what the landscape will look like 5, 10, and 15 years in the future. Although this style of management is not specifically managing for climate change, it helps an agency meet its mission (i.e., protecting species habitat).

  - Some panelists believed that they currently lack a clear understanding of the baseline from which to adapt, because they lack adequate scientific information about their management area. However, they thought it would be useful (to the Congress) if agencies would state their assumptions about what they expect their areas to look like in the future and how that is likely to affect visitation, employment, and economic resources of these areas.

  - FWS has a successful adaptive management model for migratory birds that is highly driven by climate considerations, such as the availability and timing of water in prairie pothole regions. An FWS representative said that the model is transferable, and that the agency is moving toward adaptive management in many of its program areas.

- Possible modification of agency mission or management statutes

  - Land managers expressed concern that climate change might present such a large challenge that an agency may face difficulty in fulfilling its mission. They considered ways of incorporating climate change into a management process and believed that agencies may need to consider changing land management practices (FS, NPS) as a potential means of mitigating effects of climate change. For example, FS may consider managing in a way to specifically free up water supplies.

- Build public-private partnerships for environmental stewardship

  - An FWS representative spoke about the possibility for public-private partnerships between federal land managers and private energy companies wanting to purchase carbon credits by planting trees. For example, FWS reforested 3 to 4 million acres in the lower Mississippi valley in the past few years, at the expense of the private sector. This partnership helped FWS to meet its goal of habitat restoration and

provision of a recreation area, and the industry met its goal of carbon sequestration (carbon credits).

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

The group's responses to this question, in the general order discussed, are below:

- Conduct seed-banking (storing seeds of endangered plant species for later planting).
- Educate agency staff and the public on the significance of federal lands and how climate change might affect these lands (internal and external outreach).
- "Protect what you can"—that is, manage current stresses, such as invasive species, pests, and pathogens, because climate change will only make these worse.
- Analyze and synthesize existing information on the effects of climate change on federal lands in each ecoregion. Make a list of the lands that will likely be impacted by climate change in 25 to 100 years under various kinds of scenarios.
- Improve coordination among land agencies; interconnectivity needs to be explicitly valued where management goals could be combined to ensure sustainability. (Connect smaller land parcels to create a region of a size that enables the resilience of species. Strategic land easements or purchases could create larger corridors.)
- Adopt adaptive management scenario planning (contingency planning) for climate change.
- Quantify the following:
  - the most adverse and significant effects under Question 2, and the effects on the most vulnerable areas identified under Question 4, and
  - the reduction in the flows of goods and services due to climate changes.
- Take action at the highest levels of government to integrate climate change into planning and decision making at all federal land management agencies. Improve coordination among agencies on

management for climate change, leading to a concerted national approach (following the model of the interdepartmental Coral Reef Task Force or the Invasive Species Task Force).[46]

- Conduct baseline inventories of species on federal lands to determine their type and health. Periodically repeat monitoring on a scale that can provide feedback on changes. Have a method of interpretation that can allow managers/decision makers to develop effective land management and connectivity strategies.

- Find a specific and tangible "success story" for each agency that shows that the federal land management community is making progress to help get some traction for the climate change issue.

Question 4

What is the most important type of information (research, monitoring/measurement) needed to better understand, prepare for, and address the effects of climate change? What resources will be needed?

Coasts and Oceans Ecosystem Workshop Breakout Session Responses

Land management panel members agreed with the information needs identified with the scientific panel. See Day 1, Question 5.

Forests Ecosystem Workshop Breakout Session Responses

Forests ecosystem workshop participants identified the following as information and/or research needed to better understand and prepare for the potential climate change effects on forest ecosystems:

- Information related to biology and biogeography of forest pests and pathogens—factors that cause life cycles to accelerate, interactions with natural enemies, and phenology of infestation outbreaks

- Interactions between disturbance events and monitoring of forest establishment after disturbances, especially the potential for forest composition to change substantially

[46]The group was probably referring to the Interdepartmental Invasive Species Council established by Executive Order 13112 in 1999.

- Information on water balance, related to temperature-induced drought thresholds
- Remote sensing, especially from LANDSAT and Geostationary Operational Environmental Satellite platforms that provide indicators of seasonal to interannual stress—particularly with regard to fire and other disturbance phenomena—and related to this, a family of models that are based on actual land cover—not potential vegetation—and that are more closely integrated with decision-making models and that are spatially relevant at the 30- to 100-meter level
- High-elevation monitoring of climate, soil moisture, and streamflow
- Monitoring and assessment of the amount of residual aquifer groundwater available throughout the country
- Stream gauging network needs to be improved
- Optimize monitoring systems for early impacts
- Ecological studies of all the species likely to be engaged in responding to climate change. (One expert disagreed with this approach.)
- Role of CO_2 in water balance, vegetation density, ecosystem water-use efficiency, and the role of elevated CO_2 in ecosystem carbon storage
- Identification of thresholds and susceptible areas for fires in the future, including a map of where future events may occur
- Information regarding the direct effects of CO_2 and increases in primary productivity; experimentation that manipulates CO_2, ozone, and N levels
- Data on the impact of high CO_2 levels on root turnover rates
- A set of high-level indicators of forest health, including average temperature, precipitation, distribution, timing, and dieback
- Tune NEON for ability to detect ecological responses to climate change
- Monitoring information that integrates extreme events

- Research how people perceive the relative risk of climate change compared with federal land resources

- Phenology-monitoring network that ensures federal lands are appropriately integrated

Fresh Waters Ecosystem Workshop Breakout Session Responses

Fresh waters ecosystem workshop participants identified the following as information and/or research needed to better understand and prepare for potential climate change effects on fresh waters ecosystem:

- Need for better understanding of current anthropogenic stressors

- Stream systems in the west are managed for other purposes in ways that are likely to "trump" climate change effects that we anticipate (e.g., dams out west create a wide range of flow). Human-induced changes may "swamp" climate change effects—how should our water management practices be changed, if at all, in light of climate change? An NPS representative said that millions of dollars are spent on infrastructure on federal lands, but asked whether federal land managers are adequately addressing the effects that climate change might have on these investments in the future. Panelists suggested that the Congress may want to consider requiring that climate change be considered in environmental impact analyses (environmental impact statements, environmental assessments, etc.) required under NEPA. This could be mandated by changes in the regulations promulgated by the Council on Environmental Quality. One official commenting after completion of the workshop said that this sentiment was directed at proposed projects requiring an environmental impact statement where (1) climate is significant in the project's context and (2) the look-ahead horizon is long enough where significant climate change is projected to occur. This official said that federal agencies plan projects where NEPA is required but conditions (1) and/or (2) are not met.

- Need for better understanding of current ecological stressors

  - Existing ecological problems, such as fires, invasive species, and nitrogen deposition, may be exacerbated by climate change.

  - The panelists believed that a "model-based" capacity to think about ecological succession would be helpful in making management decisions.

- Develop a national-scale program to establish linkage between water availability and ecological demand

  - A national-scale program to establish ecological flows for rivers and wetlands would provide a knowledge base with the ability to respond to management questions—for example, regarding the amount of water needed to protect particular species, the (seasonal) timing of the water demand, and the relationship between water flow (availability) and demand. This would provide a science-based system for making management decisions regarding surface water-flow variability and the ecological response.

  - Workshop participants explained that the NEON network is dedicated to the study of phenology, or the interaction between climate and biological systems. They strongly advocated for the creation of a national phenology network dedicated to observing and recording "on-the-ground" changes over time and sharing those observations with other resource managers. One expert commenting after completion of the workshop said that NEON has not actually been established yet, and that other observatory networks, including the Critical Zone Observatory network and the Hydrologic Observatory network are also in the works. According to this expert, all of these networks are still in the "request for proposal" phase (with NEON being out in front) and all are highly vulnerable to lack of funding in the NSF budget. Another expert commenting after the completion of the workshop wanted to make clear that NEON and the national phenology network are not one and the same. The expert said that some of the same scientists are involved, but the two networks would be separately funded and managed.

- Establish consistent data collection, management, and storage and access standards

  - Several federal agencies collect ecological data, each with its own data quality standards. Workshop participants recommended that existing data be cleaned up and formatted uniformly, and that current and ongoing data collection efforts be standardized. Participants acknowledged that some data may be useful to a wide range of agencies, while other data may be agency-specific. They suggested that a monitoring program be developed to collect data on "vital signs" (of ecosystem health). An expert commenting after completion of the workshop said investment in data translation tools

designed to make data sharing easier was a better idea than enforcing some uniform data format. This expert said that encouraging data sharing preserves agency-centric creativity and control when it comes to information management, and that requiring a specific data format would be a bad idea, forcing many agencies to change their information management structure. Furthermore, the expert said that requiring a standard format would likely cost more than encouraging the development of information sharing tools using existing data formats.

- Need for regional climate models

  - Experts generally agreed that climate projection methods must be improved and that regional climate projections with accurate temperature and precipitation projections, rather than global-scale projections, would be helpful in more accurately identifying (and planning for) the likely effects of climate change. Federal land managers believed that phenological records, or documented ecological responses to changes in environmental conditions, would complement regional models and would be helpful in better understanding the relationship between projected climate change and plausible ecological responses. Although FWS collects some phenological information, it does not currently have a system to compile this information and make it readily accessible to answer questions about species' tolerance for seasonal shifts and any other possible limiting interactions. Participants agreed that hydrological and ecological models are needed to couple these systems with climate models at a scale that supports land management decision making.

- Guidance for incorporating climate change into management plans is needed

  - Most managers did not know how to build climate change into the management process, but believed that there is the need to do so. They identified the need for direction or guidance on *how* to incorporate climate change into management plans, and what set of tools may be useful in addressing climate change.

- Need for financial support

- An NPS representative referred to a previous GAO report when discussing the "decimation" of NPS's operating budget. He said that NPS has less money to fulfill its mission, and that it is difficult to assign additional resources to long-term problems, like climate change, when performance is evaluated on an annual basis.

Grasslands and Shrublands Ecosystem Workshop Breakout Session Responses

The group's responses to this question, in the general order discussed, are as follows:

- Need information on what will happen in specific regions. In particular, information is needed on flora, invertebrates, soil conditions, surface water, and groundwater. (It is very likely that this will not require new research, but rather a synthesis of information that already exists. The information needs to be packaged for a local land manager to be able to see what the global change means for him or her at the local level.)

- Managers need to better understand how the management actions of today will interact with climate change so they will know how their actions will affect either the climate itself or exacerbate the impacts of climate change.

- Need better information on temperature and precipitation changes from which models can be developed. Or vice versa—managers need better models to anticipate the temperature and precipitation change.

- Need better guidance at all levels on the effects and impacts of climate change and the appropriate agency responses to those impacts. Sometimes the appropriate response is to do nothing. The genius is knowing when that is.

Day 2: Afternoon Plenary Session

At the end of the second day, GAO Director John Stephenson convened a plenary session in which he asked all participants for ideas, from big to small, that might be of interest to the Congress. Suggestions could include ideas for future hearings or specific items of legislation that might be constraining managers' ability to act. Below are the suggestions that came out of this plenary session.

Workshop Participants' Suggestions for the Congress

- Consider the poor condition of the civilian satellite program. This program is to the point that continuity of basic earth observation is on the verge of failing.

- Examine the current body of legislation that constrains natural resource managers to manage lands/waters with respect to historical conditions (rather than in light of conditions that may be very different in the future). Review and possibly revisit specific acts as appropriate.

- Examine prescribed fire fuel management policies. Spatial, budget, and temporal targets are too narrowly defined. Land managers cannot shift resources from one area to another to meet immediate needs.

- Explore Canada's national park system as a model. Parks Canada has a very explicit ecological integrity mandate. Specifically, the Congress should add guidance to give NPS a mandate for ecological integrity, along the lines of what Parks Canada has (but do not reopen the NPS Organic Act).

- The Council on Environmental Quality should provide guidance that federal agencies should consider climate change in analyzing proposed actions in environmental documents.

- The NEPA process can be a hindrance in managing for climate change. NEPA requirements begin when an agency takes action, so there is an incentive for agencies not to take action because NEPA costs agencies money.

- The Congress should empower the Council on Environmental Quality, or a special committee, to develop a multiscale monitoring and evaluation framework (National Indicator Initiative) that could be used in existing planning efforts at the regional level. Then, these indicators should be migrated into the respective mission statements of affected federal agencies. For example, FS would deal with indicators for forests and rangeland information would be dealt with by BLM or the Natural Resources Conservation Service. Information from shared indicators that are common across the landscape would be aggregated for all to use.

- The Congress should establish a Bureau of Environmental Statistics and a central environmental data repository to be used by agencies, universities, etc.

- The Congress should enforce Title II of NEPA, which requires the administration to submit to the Congress a report on the status and trends of the nation's resources, the foreseeable trends in impacts, and the adequacy for filling the human and economic requirements along with remedies for deficiencies in resources.

- The Congress should request and fund a report detailing climate change on all federal lands. What are the impacts likely to be for all federal lands? People will then have a clear idea what scientists and land managers are talking about when there is information available about "their" federal lands. (That is, the Congress should request and fund an effort similar to the *Millennium Ecosystem Reports*.)[47]

- Develop a metric that builds on the Bureau of Economic Affairs' accounting efforts to capture the value of maintaining natural capital. There needs to be a supplementary way to account for the value that natural system services and flow of ecological services provide (i.e., develop a federal environmental accounting initiative). This can help managers identify what is being lost as a result of climate change.

- Many land management policies and regulations operate under the assumption that federal land managers manage on their own lands only (and that the effects of land management are confined to those lands). Climate change should be managed at the regional scale or above. Statutory authority and incentives are needed to work outside and beyond individual lands for the common goal of adaptation. The Southern Appalachian Biosphere Reserve is an example of such an arrangement. Some statutory authority to make such arrangements would be useful. The structure of the national fire centers and multiagency, colocated budget directors is also useful.

- There needs to be a cross-agency, cross-governmental assessment of the capability of our current EMS. How effective are current networks for measuring and predicting climate change? This network needs to be optimized to collect and analyze data that are relevant to climate change.

[47]For information on the *Millennium Ecosystem Reports*, see http://www.maweb.org/en/index.aspx.

- Federal land managers need legislative direction to account for climate change when making land management decisions.

- NOAA needs an Organic Act; this act should include language requiring direction on managing lands in anticipation of climate change.

- The Congress should promote planning at the highest level of the executive branch that recognizes the potential impacts of climate change and promotes integrated, cross-agency approaches to addressing these impacts, including a functional review of the current legal and policy frameworks that drive land management decisions.

- The Congress should direct and provide funds for federal land managers to develop prototype management documents on how to address climate change in the immediate future.

- Land managers need the ability to forecast the effects of climate change on their lands. The United States needs better short-term general circulation model forecasts. Land managers also need the ability to forecast natural resources' response to climate change.

- Land management agencies need to reconcile their divergent missions. (Note: Another panelist thought this was a bad recommendation, and that the land management agencies should continue to embrace their different missions but come together to address the impacts of climate change.)

- The moderator of the coasts and oceans breakout session referred GAO to her group's answers to Day 2, Question 3 of the workshop notes.

- Develop climate impacts offices at the county level (or through extension programs), based on the United Kingdom's climate impacts program. Each office in the United Kingdom's program has a Web site, a monthly newsletter, and a staff that helps stakeholders deal with climate change.

- The Congress and federal agencies should encourage on-the-ground entrepreneurship and creativity to address climate-related problems. These kinds of creative responses can then "bubble up" through management.

- The Congress should authorize the preparation of a "Stern Report" that focuses on the United States. (The Stern Report is a 700-page report released on October 30, 2006, in Britain, stating, among other things, that climate change will cause tremendous economic and social disruption.)

- The Congress should fund an objective assessment of the conflicts and outcomes of the Healthy Forests initiative.

- A mechanism to raise the visibility of climate change among the American people is needed. In particular, the constituents of the most politically powerful Members of Congress should be alerted to the potential negative effects of climate change—and not just on federal lands.

Four Case Study Profiles

Coasts and Oceans Ecosystem: The Florida Keys National Marine Sanctuary

Site Characteristics

We selected the Florida Keys National Marine Sanctuary, managed by NOAA, as our coasts and oceans case study. The sanctuary is part of the south Florida ecosystem. The coasts and oceans ecosystem, according to the Heinz Center, includes habitats such as coastal wetlands, coral reefs, seagrass meadows, shellfish beds, and ocean waters as far as 200 miles from the U.S. shoreline. The south Florida ecosystem consists of a mosaic of subtropical habitats connected and sustained by water.

The sanctuary is home to coral reef systems that are part of a marine ecosystem, including a variety of plants and animals. The sanctuary's extensive nursery areas, feeding grounds, and spawning grounds support a multimillion dollar commercial fishing industry that lands nearly 20 million pounds of seafood and marine products annually. Approximately 4 million visitors come to the nearby Florida Keys each year, providing tourist revenue and economic benefit to the region. FWS manages four National Wildlife Refuges in the Florida Keys. These refuges are located within the boundaries of the Florida Keys National Marine Sanctuary but are separate and distinct units from the sanctuary and managed under different authorities and mandates. One of these refuges, the National Key Deer Wildlife Refuge, is home to 22 federally listed endangered and threatened species, 5 of which are found nowhere else in the world. (The other three Keys refuges within the sanctuary's boundaries are Crocodile Lake, Great White Heron, and Key West). National Key Deer and the other refuges were established to provide habitat and protection for threatened fish, wildlife, and plants. The refuges also protect globally imperiled habitat, including pine rockland and tropical hardwood hammock.

The sanctuary's ecosystem is also closely linked to other south Florida ecosystems, including those of the Everglades and the Dry Tortugas National Parks. North of the Keys, the Everglades provides drinking water for 5 million people and supports a diverse range of flora and fauna, including 14 endangered species. Each year, more than 1 million visitors come to the Everglades National Park, managed by NPS, contributing to

the region's $13 billion annual tourism industry. Dry Tortugas National Park, which is situated more than 70 miles west of Key West, is also under the jurisdiction of NPS and includes a cluster of 7 coral reef and sand islands.

The three agencies managing these federal units—FWS, NOAA, and NPS—coordinate with one another in managing their resources. For example, FWS and NPS assisted NOAA in the development of the comprehensive management plan for the sanctuary. These federal agencies also coordinate with certain state agencies, universities, and NGOs.

Climate Change Effects

Sanctuary scientists told us that climate change may increase sea water temperatures in the area of the Florida Keys National Marine Sanctuary and may cause sea levels to rise. Climate change could have a range of ecological effects as warming sea temperatures could harm coral reefs, which are the foundation of rich marine ecosystems in the area, and rising sea levels could threaten low-lying animal and plant species. Officials also told us that climate change could result in increased storm activity, which could threaten humans as well as plant and animal species. Furthermore, officials noted that the ecological effects brought on by climate change could have a negative impact on the economic and social goods and services supported by the South Florida ecosystem.

NOAA officials told us that climate change has already contributed to the degradation of coral reefs, the key component of the complex marine ecosystems that support the Florida Keys' ecology and economy. According to NOAA scientists, if the climate—and sea temperature—warm, the reefs could be increasingly vulnerable to coral bleaching, a stress response that occurs when the corals expel the algae that live within the coral tissues and give the healthy corals their color. Bleaching, which turns the corals white, has affected the sanctuary with increasing frequency. Corals can recover from bleaching events if the stress is not too severe and long-lasting, but the stress on corals caused by coral bleaching has led to secondary problems, such as coral diseases. The corals are first stressed by the conditions that lead to coral bleaching, which is directly related to increased sea surface temperatures, and then afterward may succumb to a variety of coral diseases. A NOAA scientist told us that, as a result of climate change and seawater temperature increases, coral reefs could bleach every year, starting around midcentury. NOAA officials stated that climate-related factors, in conjunction with other environmental factors that stress the ecosystem, such as pollution, disease, and overfishing, may

make coral reefs increasingly vulnerable to bleaching and degradation. Many other species in the surrounding marine ecosystem, such as fish and crustaceans that depend on the reefs for food or shelter, may be threatened by widespread bleaching. Officials stated that, in the long term, the deterioration of coral reefs and the attendant loss of biodiversity could be "devastating."

A University of Miami scientist who has been studying coral reefs and climate change for 11 years told us that coral reefs are also vulnerable to ocean acidification, which occurs when increased carbon dioxide levels decrease carbonate ion in the seawater; carbonate ion is a substance that corals need to build their skeletons. By 2050, carbonate ion could be 34 percent less abundant, according to this scientist.

FWS officials told us that various habitats found on the Keys Wildlife Refuges may be vulnerable to climate-related changes and other factors that stress the environment. These officials stated that endangered species, such as the Key deer and Lower Keys marsh rabbit, may have greater difficulty surviving as a result. In addition, rising sea levels and increased storm surges after hurricanes that may result from climate change can cause saltwater intrusion on land, which can overwhelm sources of fresh waters that support the ecosystem's plant and animal life. Increasing salinity can change where fire occurs as well as the distribution of species, according to FWS officials.

FWS officials said that increased storm activity that may result from climate change will pose a threat not only to humans on the low-lying islands, but also to many animals—including sea turtles—which may find it difficult to lay eggs on eroded beaches. NPS officials pointed out that hurricanes, exacerbated by higher sea levels, will do more damage if they become more frequent as a result of climate change. An NPS official indicated that eight major hurricanes occurred in a 14-month period in 2004 and 2005, something that had not occurred in at least the previous 100 years.

NPS officials told us that the low-lying Everglades ecosystem is particularly vulnerable to potential sea level rise because portions of the park are currently just a few feet above sea level. These officials indicated that the ocean front is already encroaching further inland, pushing the salt content higher in border areas and traditionally fresh waters areas, a concern because many fresh waters species cannot tolerate increased salinity. NPS officials noted that increased saltwater intrusion will affect the endangered

Florida manatee, a fresh waters species, as well as the crocodile, which flourishes in brackish water. Wading birds are also vulnerable to such changes, since as salinity increases, their key food source—fish—also decreases. Other species, such as shrimp, blue crab, and spiny lobster, are likewise affected by salinity.

NOAA managers told us that the South Florida economies that depend on the reefs to support such activities as snorkeling, diving, and tourism, may be adversely affected by coral bleaching. Other economic activities, such as fishing as well as cultural resources, including Native American artifacts and historic buildings, may also be vulnerable, according to NPS officials. For example, Fort Jefferson, the 170-year-old military fort on Dry Tortugas National Park, could be severely damaged by increased frequency and intensity of hurricanes and sea level rise. Similarly, shipwrecks and other submerged artifacts valued by divers could be harmed. According to an NPS official, there may be over 1,000 shipwrecks located around the Dry Tortugas National Park.

Management Challenges

Managers with whom we spoke from all three agencies near the Florida Keys National Marine Sanctuary face some common climate change-related management challenges. For example, these managers said that they lack information about climate change, suggesting that making decisions in the face of uncertainty is difficult. NOAA managers stated that determining specific relationships between climate and its effects against a complex background of other interactive environmental stressors is nearly impossible. Therefore, prioritizing where and how to focus conservation efforts remains difficult. NOAA officials also noted that they currently lack adequate modeling and scientific information that would enable managers to predict change on a small scale, such as that occurring at the sanctuary. FWS officials stated that more research is needed in a number of areas, including acres lost to sea level rise. In addition, more monitoring of water levels, water salinity, fauna, and vegetation—especially indicator vegetation (plants that provide clues as to overall ecosystem health)—is needed. Furthermore, an NPS manager said that more information is needed to reduce uncertainty on the expected rate of sea level rise.

Another common concern expressed by these managers is a lack of climate-related guidance from their agencies' headquarters. NOAA managers, for example, indicated that the agency has no specific guidance on how to address the effects climate change, and that most of their guidance is focused on meeting the many daily challenges they face, such

as designating no-boating or no-fishing zones to protect sensitive areas. FWS officials commented that, although climate change is embedded in general discussions on ecological issues, it is not explicitly addressed; there is little or no guidance specifically on climate change. According to an NPS official, how to interpret limited guidance and deciding what, if anything, to do about the effects of climate change is difficult. Nonetheless, overall management authority is broad and gives managers some flexibility to act as they believe appropriate to protect the resources under their jurisdiction.

Officials also noted a number of planning and resource challenges to addressing the effects of climate change on their land and water units. FWS and NPS officials indicated that they operate in the context of a 10- to 20-year planning process, but that they would need at least 50 years to adapt to climate-related effects. They stated that it is unclear how to account for such a long-term issue within a short-term planning horizon. FWS officials also stated that FWS budgets are being cut, and that biologist positions are being lost. NPS officials said that funding reductions and loss of research stations pose challenges to conducting the research necessary for appropriate decision making relating to climate change issues.

NOAA officials indicated that the limitation that the agency places on discussing climate change is a significant challenge to addressing climate-related issues. NOAA officials stated that the agency's control of the message on climate change is rigid, and that, in general, the agency prefers to focus on more immediate concerns. NOAA officials further said options to address climate change at a local level are limited and reactive; the issue must be addressed at a national and global level. Likewise, NPS staff stated that, to address the effects of climate change, it is necessary to address the source—greenhouse gas emissions—at a national and international level.

Forests Ecosystem: The Chugach National Forest

Site Characteristics

We selected the Chugach National Forest in south-central Alaska as our forests ecosystem case study. According to the Heinz Center, the forests ecosystem consists of land areas of 1 acre or more that are at least

10 percent covered by trees. This includes areas in which trees are intermingled with other cover and both naturally regenerating forests and areas planted for future harvest.

The Chugach—the nation's second largest national forest—covers approximately 5.5 million acres. The Chugach is a contiguous, interconnected unit, which also includes private, state, and other federal land. It encompasses a wide variety of habitats that support over 232 vertebrate species, including brown bear, lynx, moose, wolf, and wolverine populations. However, only about 18 percent of the land area is forest vegetation and approximately 35 percent of the area is covered by perennial snow and ice. The Chugach has three distinct geographic areas: the Kenai Peninsula region (21 percent of the land area); the Prince William Sound region (48 percent of the land area); and the Copper River Delta region (31 percent of the land area). Southeast of Anchorage, the Chugach is a recreation area for activities such as fishing, wildlife-viewing, and hiking and receives approximately 8 million recreation visits per year. The Chugach also serves as a primary resource for subsistence hunting, fishing, trapping, and gathering activities for many south-central Alaskan residents. Furthermore, the forest also supports extraction activities, including mining.

The Chugach is located next to or near several other land units, including the Chugach State Park, Kenai Fjords National Park, and the Kenai National Wildlife Refuge. The Chugach's staff, therefore, coordinates with multiple stakeholders in managing the forest, including FWS, the Alaska Department of Natural Resources, and several Alaska native corporations.

Effects of Climate Change

The Chugach scientists and managers described a variety of changes currently affecting the lands they manage that may be attributable to climate change. In this regard, they attributed a number of changes in the forest ecosystem, at least in part, to the warming and drying of the climate on the Kenai Peninsula area of the forest. For example, the peninsula has been the center of a spruce bark beetle outbreak that has killed large numbers of Sitka, White, and Lutz spruce trees on 4 million acres in south-central Alaska. In lowland areas of the peninsula, lake levels have declined by as much as 1 meter, and many ponds documented in aerial photographs from the 1950s are now grassy areas with spruce and hardwood trees. In the Kenai Mountains, the tree line has risen an average of 1 meter per year during the past 5 decades. Furthermore, many glaciers in the region have been retreating since the 1850s, but the pace has greatly accelerated in

recent years in response to a warming and drying climate. For example, one large ice field in the Kenai Peninsula has lost 70 vertical feet and 5 percent in surface area in the last 50 years. As they have continued to melt and recede, the runoff from many glaciers has created glacial lakes, which capture glacial sediment and decrease the amount of sediment going into glacial rivers. As a result, the rivers are transforming from glacial, multiple channel systems to single channel meandering systems that can have considerable impacts on fish habitat, riparian and floodplain vegetation, and water quality. Officials at the Chugach also told us that they have observed an increase in the frequency of severe storm events, along with a seeming increase in lightning strikes and fires caused by lightning in recent years.

In addition to changes that the region is already experiencing, managers and scientists told us that they were concerned about a variety of potential effects from climate change that may impact the Chugach in the future. For example, although invasive species have not been a problem to date in most of Alaska, occurrences of invasive species could increase in response to disturbances associated with climate change, according to these officials. Furthermore, as habitats shift, sensitive and rare species could be adversely affected. Hydrological changes resulting from climate change could affect salmon fisheries and spawning habitat. Although the impacts are not yet known, climate change could affect tourism and recreation activities in the region, according to the Chugach officials. For example, any changes in snow cover will affect the mix of motorized versus nonmotorized vehicles permitted on forest land. In addition, tourism and property could be negatively affected by more frequent extreme events that may result from climate change, such as wildfires.

Management Challenges

Managers from both the Chugach National Forest and the Alaska Regional Office of FS told us that they were unaware of any requirements for or guidance on considering climate change in their planning and management efforts. Furthermore, due to budgetary constraints, managers at the Chugach said they have little flexibility to address the effects of climate change because climate change activities have, to date, not been funded in annual budgets. Alaska Regional Office officials added that once the budget is set by FS headquarters, individual land units do not have the flexibility to modify funding priorities.

Chugach managers also told us, however, that they can respond to the effects of climate change, but that their responses are reactive and not

predictive. However, they stated that they would face difficulty basing management decisions on forward-looking projections about the potential effects of climate change because of the lack of reliable models of future conditions in the forest. This lack of information makes it difficult to anticipate potential effects caused by climate change. However, these officials noted that better modeling and communication about risks could help them better anticipate changes.

Finally, Chugach officials told us that because climate change is a global issue, individual forests cannot effectively address climate change in a piecemeal manner. Officials with whom we met stated that any strategy to address climate change needs to be integrated across broad landscapes, not individual forests. These officials said that they hoped that the National Forest system will develop a method to monitor climate change effects on a large scale.

Fresh Waters Ecosystem: Glacier National Park

Site Characteristics

We selected Glacier National Park in northwestern Montana near the Canadian border as our fresh waters case study. The fresh waters ecosystem, according to the Heinz Center, consists of streams, rivers, lakes, ponds, reservoirs, fresh waters wetlands, groundwater, and riparian (riverbank) areas. Water sources such as glaciers and snowfields in mountain systems, according to park officials, are also considered to be part of the fresh waters ecosystem.

Encompassing more than 1 million acres, the park features forests, alpine meadows, mountains, glaciers, rivers, streams, and lakes. It is home to a number of endangered and threatened species, including bald eagles, bull trout, gray wolves, and grizzly bears. In recent years, approximately 2 million people visited the park annually. According to an estimate from the early 1990s, once the Going-to-the-Sun Road, one of the park's main attractions, opens in the spring, the daily economic benefit of the park to the surrounding region would be $1.1 million; today this figure would probably be considerably more, according to NPS.

Bordering the park are the Flathead and Lewis and Clark National Forests, managed by FS. NPS and FS cooperate on regional activities, such as wildland fire and river management. FWS also participates in the management of some wildlife resources within the park's boundaries. NPS also coordinates with USGS, which has a field research station in the park, and various Canadian organizations that oversee resources north of the U.S. border.

Climate Change Effects

A USGS scientist told us that the average temperature in western Montana has increased over the past century. While the northern hemisphere has warmed 0.6 degree Celsius during that period, the mountainous areas of the park have warmed 1.6 degree Celsius. Spring, measured by such indicators as point of maximum snow melt, initiation of first melt, and water level, is coming 3 weeks earlier now compared with the historical average. In addition, a USGS scientist mentioned that the area may be affected by extreme weather events caused by climate change. For example, forests of the intermountain west and Glacier National Park become more vulnerable to fire due to evaporative stress (drying) when more consecutive days above 90 degrees Fahrenheit are experienced. Since the early 20th century, Glacier (and western Montana) has gone from an average of 5 to approximately 20 days per year above 90 degrees Fahrenheit, with 2003 setting the record at 31 days. In addition to causing moisture stress in plants and increasing fire hazards, the increasing number of extremely hot days poses substantial human health risks, especially in regions that historically do not have air-conditioning. USGS officials also told us that physical features of the park, such as glaciers and snowpack, as well as ecological features, such as streams, forests, and alpine meadows—all of which provide habitat for a large number of species—are vulnerable to the effects of climate change. Some park infrastructure, such as roads, campgrounds, and trails, may also be vulnerable if warmer winters lead to more snow avalanches, landslides, and flooding.

According to USGS scientists, 70 to 80 percent of the western United States' drinking water comes from mountains. An NPS official stated that in the park region, precipitation patterns are changing, such that there is more rain in winter and less snow, causing winter streamflow to increase. Accordingly, snowpack has decreased by more than 30 percent. Officials explained that, with less snow and warmer winters, the timing of spring runoff can be up to 20 days earlier than in the past. Park officials expect the park to continue to receive less snow in winter on average, with more rain and midwinter melting of snowpack.

Summers in the park are expected to be drier, especially later in the season, and stream flow probably will continue to be lower than normal in late summer. Scientists stated that some mountain streams will become ephemeral (short-lived), and that the overall ability of the system to provide fresh waters to aquatic and downstream communities will likely decrease. In addition, these scientists said that, as precipitation patterns and streamflow change, the structure and function of river communities will be stressed, possibly causing the loss of species diversity. This, in turn, could have negative consequences for the downstream communities—both natural and human—that those species support.

A USGS scientist informed us that, since 1850, the number of glaciers within the park has dropped from 150 to 26, and that current trends in the rate of glacial melting in the park suggest the remaining glaciers will be gone in the next 25 to 30 years. According to scientists with whom we spoke, the loss of glaciers is symbolic of the overall changes to the natural systems in the park, including the water cycle and water temperatures.

NPS officials told us that the increasing number and severity of storms and lightning that may result from climate change may cause more forest fires, while more dead vegetation and drier conditions late in the season may feed larger, more intense wildland fires. An official also said that warmer temperatures and more severe drought may increase the risk that insects and diseases will harm already stressed trees. Greater disturbances to the park's natural systems will place native plants and animals under greater stress, and invasive (nonnative) species may be able to get a firmer hold and spread more easily, out-competing native species. According to an NPS official, warmer temperatures are expected to negatively affect mountain aquatic organisms, including insect larvae, which are an important part of the food chain as well as fish species, such as bull trout, that thrive in cold water. An NPS official explained that organisms that cannot migrate upstream to colder temperatures will not survive.

An NPS scientist noted that climate change is expected to cause vegetation in the park to migrate uphill in many places, where it is cooler, changing the ground cover in many areas of the park and affecting wildlife species that depend on those habitats. An official said that as alpine habitats warm, trees are expected to move upslope into areas that are currently treeless. Forests are already beginning to invade alpine and subalpine meadows. (Alpine refers to the zone consisting of slopes above the timberline and characterized by, among other things, the presence of low, shrubby, slow-growing woody plants.) These officials added that several animal species

may be negatively affected by the loss of alpine and subalpine habitat, including bighorn sheep, grizzly bears, mountain goats, and wolverines. They observed that because many rare plants and animals in the park are living at the edge of their range, climate change may cause some of these species in the park to die off. Officials noted that the park has already been afflicted by a mountain pine beetle infestation. This insect has decimated large areas of forest, owing to an increased vitality that has been linked, in part, to warmer temperatures.

Park and USGS officials are concerned that warmer winters resulting from climate change may lead to more avalanches and to more winter flooding, which will threaten park infrastructure. For example, they told us that there may be an increase in the frequency of heavy rainfall on snow cover, which can cause severe floods. According to these officials, if this happens, trails would need to be modified to meet such conditions, and the greater potential for weather-related infrastructure damage will require more maintenance and improvements. In addition, climate change might result in a longer park visitation season as spring comes earlier and winter comes later; this would place additional demands on park resources. For example, they said that there would be pressure for roads and facilities to stay open longer, which will require more staff and resources. These officials also said that if more fires occur, the visitor experience could be diminished by reduced air quality or limited access to fire-ravaged areas of the park, and the park and local communities could lose revenue from visitation. For example, in 2003, the Going-to-the-Sun Road was shut down for 23 days due to fire. Officials also noted that fires divert park and FS staff from their regular duties.

Management Challenges

Resource managers from FS, NPS, and USGS told us that they face several challenges in addressing climate change, including limited funds, insufficient monitoring capability, the lack of baseline information, competing priorities, the need to involve surrounding communities, and the inability at the local level to make a significant impact on a global issue, among others.

NPS and USGS officials stated that monitoring systems—programs that monitor the health of various park plants, animals, and physical features—within the park are insufficient due to lack of funding. For example, USGS, which has provided much of the monitoring effort for the park in the past, has closed down about 28 percent of stream gauges nationally. An NPS official noted that, while legislation directs NPS to

conduct and use research to support resource management decisions, programs to support their efforts, and the efforts of their other federal partners, have suffered from incomplete or partial funding due to budget shortfalls. The NPS Inventory and Monitoring program was developed to address managers' needs for better scientific information about park resources. Although one of the goals of the Inventory and Monitoring program is to create baseline inventories of basic biological and geophysical natural resources, NPS officials stated they do not have sufficient baseline information, and the program is not comprehensive enough to meet all of their information needs. In addition, because no systematic monitoring of species currently exists, it is very difficult to determine which species are at risk, determine the health of the species' populations, and develop early warning systems to predict specific effects of climate change.

According to Glacier National Park officials, a number of issues may compete with climate change for priority in receiving resources and attention. These issues include the impacts of a proposed upstream coal mine in Canada, a request from a railroad to trigger avalanches with explosives inside the park, the proliferation of noxious weeds, the deterioration of park infrastructure, and urban encroachment along the park's borders.

An NPS official expressed concern that high growth rates in the surrounding community may exacerbate some of the impacts of climate change on park resources. One of the ways in which plant and animal populations might adapt to climate change is to migrate as conditions change. For migration to occur, migration corridors must be connected to other regions. As development and land-use pressures increase on neighboring lands, these corridors will disappear, which may limit the ability of park ecosystems to adapt, according to an NPS official.

NPS officials emphasized that since climate change is a global issue, little can be done to stem the problem of climate change within the park, other than to respond, to the limited extent possible, to the symptoms of climate change through activities such as prescribing burns, reducing vegetation that may serve as kindling for forest fires, or controlling noxious weeds. However, park officials said that they are trying to address climate change—to the extent possible—by, among other actions, setting a good example in reducing the park's own greenhouse gas emissions. For example, they told us that the park is participating in the Environmental Protection Agency's Climate Friendly Parks program, which focuses on

reducing parks' greenhouse gas emissions. The park also has an Environmental Management Plan that includes a number of energy efficiency and renewable energy initiatives. In addition, the park requires the concessioners that run businesses in the park to abide by certain environmental requirements, some of which affect greenhouse gas emissions.

NPS officials also told us that there is currently no explicit guidance from NPS headquarters on addressing climate change, and that no funding or resources have been allocated directly to the issue. In addition, an NPS staff member felt that it would be useful for the park to produce a formal written position on climate change to further clarify the park's stance on the science and impacts and to outline a communication strategy for discussing the issue. NPS staff also indicated that one of the greatest values of parks such as Glacier may be in informing visitors about the potential of climate change to disrupt natural ecosystems and decrease the benefits that these systems provide to human society.

Grasslands and Shrublands Ecosystem: Bureau of Land Management Kingman Field Office, Arizona

Site Characteristics

We selected the land managed by the BLM Kingman Field Office, Arizona, as our grasslands and shrublands ecosystem case study. According to the Heinz Center, the grasslands and shrublands ecosystem comprises lands in which the dominant vegetation is grasses and other nonwoody vegetation, or where shrubs are the norm. Bare-rock deserts, alpine meadows, and Arctic tundra are included in this system as well. Also included are some pastures and haylands, which represent an overlap with the farmland system.

The field office manages approximately 2.6 million acres of public land in northwestern Arizona, including portions of the Sonoran Desert, Mojave Desert, Colorado Plateau, and six different mountain ranges. This land unit is home to a variety of wildlife, including the largest desert bighorn sheep

population in the world, the desert tortoise, and several other threatened and endangered species. The land unit receives approximately 540,000 visitors per year for a variety of recreational activities, such as camping, hunting, hiking, bird-watching, and all-terrain-vehicle 4-wheeling. It also supports economic activity through multiple types of resource extraction, most notably livestock grazing and sand, gravel, gold, and copper mining. In managing this land unit, the field office staff coordinates with several other agencies that manage adjacent land units. These agencies include FWS, NPS, the Arizona Game and Fish Department, and others.

Effects of Climate Change

In our meetings and site visits, officials described a variety of changes currently affecting the lands they manage at the BLM Kingman Field Office that may be attributable to climate change. For example, the officials said that a prolonged drought in the region had likely resulted in high mortality rates of old growth pinyon pine trees, most notably those located on south-facing mountain slopes as well as some ponderosa pines and chaparral. Ponderosa bark beetle and mistletoe infestations had also acted as stressors, contributing to the die-off of ponderosa pines.

Furthermore, according to field office staff, drought conditions in the region are causing desert scrub plant communities to convert into annual grassland communities, which are more vulnerable to fire. They said that this phenomenon has contributed to problems related to fire management. Prolonged drought acts as a stressor to native plant communities. Then, in periods of wetness, invasive species (typically, invasive annual grasses) fill in the gaps between native vegetation. Invasive species can spread and grow faster than native species. As a result, the thicker and less-evenly spaced vegetation leads to fire danger. If a fire starts, it burns much longer and hotter due to the invasive grasses. Native plant communities, such as saguaro cacti and Joshua trees are not fire resistant, so fire damages these communities and provides further environment for invasive species and increased fire danger. In some instances, according to officials, repeated fires of this nature have destroyed native plant communities, such that only invasive grasslands remain. A severe drought occurred in 2002 that resulted in the loss of perennial grass, shrubs, and trees. This drought, coupled with increased annual growth in wet years, accelerated conversion of hot deserts plant communities into annual grasslands. Should continued severe drought become the norm, this conversion can be expected to continue.

The drier climatic conditions experienced in the region have created a list of vulnerable species and natural systems on land managed by the field

office. For example, BLM scientists and resource managers told us that continuing dry conditions will likely cause changes in vegetation composition and species populations. They also said that dry conditions increase soil erosion; decrease plant productivity, resulting in less forage for cattle; decrease wildlife species abundance and diversity; decrease habitats for certain endangered species; reduce water flows in creeks and rivers; and dry up natural springs, leading to reduced water availability for wildlife (including wild burros), livestock, and riparian (riverbank) plant communities. With less precipitation, there would also be less groundwater recharge, potentially creating a situation where groundwater removal could exceed its replenishment.

Management Challenges

BLM Kingman Field Office managers with whom we met told us that they were unaware of any requirements or guidance for how to consider climate change in their planning and management efforts. In addition, field office staff said that climate change is not a priority, as partially evidenced by the fact that climate change-related activities have not been included in agency budgets. They further said that they evaluate priorities on a year-by-year basis, due to resource constraints. Because of these constraints, the field office is necessarily only addressing the highest priority issues, leaving many other issues untouched.

Another management challenge facing the field office is that much of the land it oversees is situated in a "checkerboard" pattern of land plots, alternating between public and private ownership. This pattern is primarily due to the system of railroad land grants, in which the federal government gave the companies land parcels to encourage railroad development in the region.[1] The alternating pattern of land ownership makes managing these parcels for habitat protection purposes very difficult. BLM can face public resistance when making land management decisions. For example, fire closures that restrict access to certain areas of land leads to public complaints. Land managed by the field office is also under stress due to the high level of development of lands adjacent to BLM land that has taken place over the past several years.

[1]In the mid-19th century many argued that direct financial support for internal improvements, such as railroads, was unconstitutional. Checkerboard land grant schemes, in which the government granted alternating sections of land along the proposed railroad line while retaining the other sections for eventual sale to the public, were a way to circumvent those objections.

Furthermore, field office officials told us that they have adequate management tools, such as reducing grazing-use levels, to reduce the impacts of climate change. However, they said they must show a clear pattern of historical data to make decisions or they risk opening themselves to litigation. These managers added that they would likely face challenges and opposition if they based their management actions on theoretical projections. Therefore, the managers stated that they were unsure whether they could base management actions on projected changes that may be brought about by climate change. In addition, they stated that climate change, because of its large scale, is difficult to deal with on the local level. That is, although they might be able to react to the effects of climate change on the land they manage, they are not able to control changes in the atmosphere or greater climatic patterns.

Comments from the U.S. Department of Agriculture (FS)

USDA United States Department of Agriculture | Forest Service | Washington Office | 1400 Independence Avenue, SW Washington, DC 20250

File Code: 1420
Date: JUL 10 2007

John Stephenson
Director, Natural Resources and Environment
Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Stephenson:

Thank you for the opportunity to review and comment on the Government Accountability Office (GAO) draft report # GAO-07-863, "Climate Change – Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resource." The Forest Service generally agrees with the audit recommendations. However, we believe this report does not adequately capture the scope or urgency of the agency's commitment to climate change mitigation, adaptation, and research.

Climate change continues to be a priority for the Forest Service. As stated in the Forest Service 2004-2008 Strategic Plan, "The Forest Service and its partners in land stewardship must address complex issues involving ecosystem health, biological diversity, invasive species, climate change, habitat fragmentation, and loss of open space…" Through implementation of the strategic plan, Forest Service field managers address the effects of climate change by managing for resilient ecosystems that sustain the production of public goods and services in the face of uncertain future conditions.

While we appreciate the effort to garner a field perspective, an examination of one national forest is inadequate to use as a proxy for an agency that manages diverse ecosystems across 193 million acres for multiple objectives. The draft report is correct in asserting that the Chugach National Forest does not specifically address climate change in their existing Forest Plan, which was revised in 2002. However, a broader evaluation would have revealed that 12 National Forest Plans specifically consider the effects of climate change on existing programs and local resource values. Moreover, forest plans are revised every 10-15 years to incorporate new scientific information and management strategies. Climate change mitigation and adaptation strategies will continue to be included in future revisions.

The Four Threats to the Health of the Nation's Forests and Grasslands (Four Threats) are a messaging tool to disseminate the strategic vision of the agency. The draft report notes that climate change is not listed as one of the Four Threats. However, the Four Threats emphasize two immediate consequences of climate change for land management agencies: forest fire and invasive species. The draft report rightfully gives substantial weight to invasive species and increased fire danger as dramatic effects made worse by climate change. It fails to address the effects on resources people care about such as clean water and wildlife habitat. It also fails to recognize the nexus between strategic planning and messaging efforts, like the Four Threats. Therefore, managing for climate change need not always be called "managing for climate

change." For land management agencies, it is much more important to manage for the effects of climate change.

To cite one example from the Chugach National Forest, the GAO report pointed out that the spruce bark beetle is endemic to the Kenai Peninsula, but drier, warmer conditions associated with climate change have increased their range and shortened their breeding cycle. In response, thousands of acres in the Chugach National Forest are treated annually to mitigate the threat posed by beetles. These actions are helping mitigate the effects of climate change. Although absent from the report, the Chugach National Forest is a lead collaborator in the interagency All Lands/All Hands project that specifically addresses these effects across all land ownerships. Numerous programs on the Chugach also exist to control invasive species, a threat also exacerbated by climate change.

The report overlooked many important aspects of the Forest Service commitment to addressing climate change. We would be remiss if we did not take the opportunity to briefly touch on some agency activities that were not addressed. The examples that follow are not a complete list, but represent the diversity of actions we are currently undertaking.

- **Forest-based carbon measurement** – Forest Service researchers are firmly established as world leaders in forest-based carbon measurement and carbon accounting. Data produced by Forest Service scientists have been incorporated into numerous greenhouse gas registries, including the Department of Energy's 1605b registry and other carbon offset programs. Groundbreaking research is now underway on the Mendocino National Forest to quantify the carbon benefit from avoided wildfire emissions on a typical forest fuel treatment project.

- **California Climate Action Registry (CCAR)** – National Forests in California are in the initial steps of joining the CCAR, a precursor to the statewide greenhouse gas emissions cap-and-trade system. The CCAR currently requires that member entities report their carbon footprint from business related activities as well as from land management activities.

- **Sustainable operations** – In addition to the land resource base, the Forest Service has also taken steps to reduce our carbon footprint from a business operations standpoint. Broad efforts in sustainable operations have led to a diverse suite of outcomes including energy efficiency upgrades in buildings and fleet. Also, the Forest Service is a member of the Department's Sustainable Operations Council, and has nominated employees to serve on each of the four working groups chartered by the Council.

- **Integration at the Department Level** – The Forest Service also participates in climate change programs under the umbrella of the U.S. Department of Agriculture (USDA). USDA's Global Change Program Office was established to ensure that climate change issues are fully integrated into research, planning, and decision-making. The Forest Service, along with other USDA agencies with climate change research or programmatic

responsibilities, participates in the USDA Global Change Task Force (GCTF). The GCTF coordinates USDA's participation in government-wide Climate Change Science Program and Climate Change Technology Program.

Climate change is a complex global issue that must be managed within a margin of uncertainty. The Forest Service through research and land management will continue to lead in the area of climate change. We appreciate the opportunity to have contributed to the GAO effort and we find two recommendations particularly helpful. These include the need to develop clear written communication for resource managers explaining how land managers should address the effects of climate change, and the need to coordinate with other Departments and agencies on resource management practices when preparing this guidance. The Forest Service will work to address clarity in communicating climate change mitigation and adaptation strategies to field units.

Sincerely,

ABIGAIL R. KIMBELL
Chief

Comments from the Department of Commerce (NOAA)

THE DEPUTY SECRETARY OF COMMERCE
Washington, D.C. 20230

July 3, 2007

Mr. John Stephenson
Director, Natural Resources
and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, D.C. 20548

Dear Mr. Stephenson:

Thank you for the opportunity to review and comment on the Government Accountability Office's draft report entitled *Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources* (GAO-07-863). On behalf of the Department of Commerce, I enclose the National Oceanic and Atmospheric Administration's programmatic comments on the draft report.

Sincerely,

David A. Sampson

Enclosure

Department of Commerce
National Oceanic and Atmospheric Administration
Comments on the Draft GAO Report Entitled
"Climate Change: Agencies Should Develop Guidance for Addressing Effects on Federal Land and Water Resources"
(GAO-07-863/July 2007)

General Comments

The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) appreciates the opportunity to review this report. We would note several broad cross government initiatives and specific NOAA management actions to address issues discussed in the report do not appear to be represented in the draft report. We note that the report, while citing the need for better modeling and observation systems, did not look at all into what the current state is of our modeling and of our observation systems. NOAA is at the forefront of global efforts to expand both observation systems and modeling capabilities. From the establishment of global scale systems such as the Global Earth Observing System of Systems (GEOSS) to building regional ocean and coastal monitoring systems, to developing the National Integrated Drought Information System (NIDIS), NOAA is at the forefront of building the monitoring systems and the models that will enable regional and ecosystem based forecasts and planning. This report is silent on these efforts, all of which are done with our federal and state and local partners. For example, there is no mention of a report being prepared by the U.S. Climate Change Science Program (CCSP): "Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources." This report is due at the end of the year and will be available online at <http://www.climatescience.gov>.

In addition, NOAA, along with Australia's Great Barrier Reef Marine Park Authority, has published a guide to coral bleaching – the *Reef Manager's Guide*. The Guide provides information on the causes and consequences of coral bleaching and management strategies to help local and regional reef managers reduce threats to coral reef ecosystems. It also outlines how local managers can manage reefs when bleaching occurs, how to respond to bleaching events and, most importantly, how to build long-term reef resilience into marine protected areas.

Implementing some of the ideas put forth in the *Reef Manager's Guide*, NOAA and its National Marine Sanctuary Program are also active participants in the steering committee for the Florida Reef Resiliency Program (FRRP). The FRRP currently is developing and testing protocols to measure the extent and impact of coral bleaching events on a broad spatial scale and is taking actions to improve the ability of coral reefs to survive the impacts of climate change. The FRRP is a multi-agency federal, state, and non governmental organization activity coordinated by The Nature Conservancy that brings together scientists, reef managers, and resource user groups to develop strategies to improve the health of

Florida's reefs and enhance the economic sustainability of reef-dependent commercial enterprises. As a part of this, NOAA and its partners have been involved in coordinating a bleaching response plan for South Florida.

NOAA's National Environmental Satellite, Data and Information Service has developed products and services designed to forecast coral bleaching conditions worldwide through integration and analysis of a vast array of satellite and ocean observing system data. These products are used locally in the Florida Keys National Marine Sanctuary by NOAA and partners to develop weekly current condition reports for use in a volunteer-based Coral Bleach Watch program developed by NOAA in collaboration with the Mote Marine Laboratory.

NOAA Response to GAO Recommendations

The draft GAO report states, "To better enable federal resource management agencies to take into account the existing and potential future effects of climate change on federal resources,"

Recommendation 1: "We recommend that the Secretaries of Agriculture, the Interior, and Commerce, in consultation with the Directors of Forest Service; Bureau of Land Management, Fish and Wildlife Service, and National Park Service; and the Administrator of NOAA, respectively, develop clear written communication to resource managers that explains how managers are to address the effects of climate change on federal resources in their management actions and planning efforts and identifies how managers are to obtain any site-specific information that may be needed to implement these efforts."

NOAA Response: NOAA concurs with this recommendation. As applicable, NOAA will work toward clarifying written communication to resource managers to explain how they are to address the effects of climate change on federal resources in their management actions and planning efforts and identify how managers are to obtain any site-specific information that may be needed to implement these efforts.

Recommendation 2: "In addition, we recommend that federal resource management agencies work together to share best practices when developing such written communication, while recognizing the unique missions, objectives, and responsibilities of each agency."

NOAA Response: NOAA concurs with this recommendation. NOAA currently works with relevant federal resource management agencies on a range of climate change and land management issues. NOAA will continue in these efforts and, as applicable, strive to share best practices moving forward.

Comments from the Department of the Interior (BLM, FWS, and NPS)

THE ASSOCIATE DEPUTY SECRETARY OF THE INTERIOR
WASHINGTON

JUL 19 2007

Mr. David Walker
Comptroller General
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Comptroller General Walker,

The Department of the Interior has reviewed the draft U.S. Government Accountability Office (GAO) report entitled, "Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources" (GAO-07-863). We commend your staff for highlighting the challenges faced by our Agency managers in carrying out our responsibilities identified in a diverse set of statutes.

The Department manages one in every five acres of land in the United States. In addition, the dams operated by Interior supply water to more than 31 million people and to farmers who generate nearly two-thirds of the Nation's produce. The Department also manages leases from which one-third of the Nation's domestic energy supplies are produced. Fulfilling these responsibilities requires significant public engagement, science drawn from many disciplines, and careful balancing of multiple goals.

The draft GAO report identifies four ecosystem types for analysis (forest, coast and ocean, fresh water, and grasslands and shrub lands). All four of them are present in the mix of resources managed by the Department of the Interior. The comments below address issues within that context.

Background

The subject of climate change has generated ongoing discussions for many years. As stewards of our public resources, Interior monitors and adjusts to new influences while maintaining consistent and continuous management of an extensive, diverse, and dynamic inventory of natural resources. Department of the Interior scientists and managers have been conducting research and monitoring land and water resources to identify and assess the challenges we face, including the effects of a changing climate.

As your draft report notes, the Intergovernmental Panel on Climate Change released a report in April of this year that points to reliable evidence of the effects of climate change on natural systems. Even before the release of that report, Secretary Kempthorne had determined that the Department of the Interior should take affirmative steps to assess the effects on our public lands arising from climate change and develop a process for anticipating and addressing those effects. To that end, he asked Deputy Secretary Lynn Scarlett to convene a task force of experienced career employees, seasoned managers, and senior policy personnel to study climate change because of its possible effects on our ability to be good

stewards of wildlife, national parks, water, and other resources. This is a high priority for both Departmental leaders and employees in the field. The Task Force involves nearly a hundred people, including the Department's assistant secretaries and other top leaders as well as career scientists, park superintendents, refuge managers, and others from across the country.

Since the first meeting of the Task Force in April, the team has been identifying the effects of a changing climate on water flows, sea coasts and sea ice, permafrost, wildlife, vegetation, etc. The Task Force is evaluating the science currently used by the Department and exploring how new science can be focused to provide the information needed by our land, water, and infrastructure managers. We are also looking at the best ways to convey relevant information among our bureaus so that everyone is working from the most current and reliable data, analysis and predictive models when managing public lands.

Interior's Climate Change Task Force has three subcommittees --one on legal and policy issues; a second on land and water management issues; and a third to address the scientific issues of climate change specifically related to Interior's responsibilities.

DOI Task Force Activities

The Task Force is examining how possible climate changes would affect disaster management, water resource management, and habitat management. It is evaluating new responses to manage our changing landscapes. The challenge of setting priorities requires a careful assessment of our resources, the most likely impacts, the laws governing our actions, and the quality of data and analysis we must rely on to adapt to new conditions.

As documented in the draft GAO report, many parks, refuges, and other conservation areas were created to preserve a specific mix of species and resources within specific boundaries. The Department is considering whether *in situ* conservation is possible within current, fixed boundaries if species composition is changing, or whether we should pursue additional conservation strategies. For example, will we need to change how we define the concept of invasive species if plant and animal species shift on the landscape in response to climate change?

Interior's presence along the coast is also significant, with extensive areas of shoreline managed by the National Park Service and the Fish & Wildlife Service. The Task Force is examining what steps should be taken as freshwater coastal habitats turn more saline if ocean levels rise. We must also consider how we can help the Nation manage its water resources if rainfall and snowmelt patterns change.

The Department will continue to focus on wetland management, both for the environmental benefits that result and because coastal wetlands and sea marshes serve as *horizontal levees*, absorbing and reducing impacts from coastal storms.

Other examples of challenges before the Climate Change Task Force include:

- Evaluating the management of Interior's facilities and fleet to identify additional opportunities for energy conservation and renewable energy.
- Exploring whether global and regional climate modeling can be scaled to the point that it can be used to manage parks, refuges, and dams controlled by the Department.
- Examining information needs and whether new types of monitoring might strengthen our understanding of on-the-ground trends in water availability and timing of flows, vegetative patterns, movement of species, and other factors.
- Assessing the extent and consequences of exotic grass species expansion on BLM lands, such as the impact on erosion and fire suppression.
- Assessing opportunities for carbon sequestration – both geologic and biologic – on public lands.

The report produced by GAO begins to explore the complexity faced by a Department that manages such a diverse and significant portfolio of public resources.

Draft GAO Report Themes

Throughout the GAO report, a few phrases merit specific attention. The report references conditions "caused at least in part by climate change." We are only now beginning to determine with a reasonable level of certainty which observed phenomena result from cyclic weather variation and which represent sustained shifts in climate. As observed in the draft GAO report, "some changes will occur quickly and will be readily apparent, while others will occur gradually and will be less apparent in the near-term." As we better comprehend these changes, we are evaluating the appropriate management regimes. We are proceeding with careful deliberation in the face of emerging information about the likely scope, duration, and nature of changes in both climate and associated ecosystem effects. We are devoting significant effort toward identifying and using the best available information to choose the best course of action.

The GAO report also notes that we "have not made climate change a high priority." The Department has numerous statutory obligations and responsibilities. In fulfilling these goals, we have placed a high priority on developing renewable energy sources; improving energy efficiency and use of alternative energies at our facilities across the Nation; pioneering carbon sequestration through reforestation in the southeast; and advancing scientific research regarding glaciers, sea ice, paleo-climate records, and related subjects. In the context of water management, we have sought state-of-the-science information on changing precipitation patterns. These efforts have been incorporated into our ongoing and diverse resource management efforts. These efforts have borne fruit. Since 2003, the Department has achieved reductions in energy intensity of 15 percent. Renewable energy makes up nearly 15 percent of our energy portfolio, significantly greater than use of renewable energy by the Nation as a whole. Also the Department has budgeted $27 million in the U.S. Geological Survey for global climate change research

in 2008. In carrying out it's responsibilities as a manager of one in five acres and extensive natural and cultural resources, the Department utilizes adaptive management and routinely takes actions to mitigate impacts of climate change. In addition, the Fish and Wildlife Service has been conducting carbon sequestration with reforestation activities in concert with industry and non-profit partners for several years.

As the GAO report notes, various DOI bureaus have collected information, assessed impacts, and taken incremental steps to adjust to those impacts most likely resulting from climate change. Our Task Force is assessing these efforts so that we have a more complete understanding of our actions and opportunities.

The GAO report underscores the need for more effective and timely communication of our efforts to address climate change. We agree. Secretary Kempthorne initiated the Climate Change Task Force to make sure that the subject of climate change is being addressed throughout the Department, in a comprehensive fashion, and with the full support of the executive management team. The breadth of involvement and enthusiasm of the personnel throughout the Department working on this issue will help ensure that the Department effectively generates climate science in areas of our expertise; contributes to greenhouse gas mitigation through carbon sequestration and other measures; and develops adaptation strategies to reduce the adverse impacts of climate change. We are committed to keeping personnel within the Department involved and informed.

The draft GAO report states that, "In order to plan and manage for climate change, these resource managers stated that agencies would have to change how they approach their missions because addressing climate change would require managers to anticipate potential change in their planning processes, as opposed to using historic data to react to observed changes."

Developing accurate modeling and determining the weight to put on modeling in relationship to use of historic data is a serious concern currently under review within the Task Force. To date, many of the models needed to make effective decisions at the local and regional levels have not been developed. The Task Force brings managers with years of experience into a collaborative environment where historic data, current modeling, statutory obligations, and public expectations can all be used to develop dynamic management tools to help us effectively manage public lands and waters. As noted in the draft GAO report, we will need to provide direction on how to implement these new tools as they are developed and validated. Our Task Force is looking at this issue.

The GAO draft report also highlights the importance of accurate baseline inventories of plants and animals in order to properly manage the species we are charged with conserving. The Task Force is evaluating how we might set priorities for generating essential information to create our baseline assessments.

We are confident that Interior's Climate Change Task Force will set the stage for this Department to respond to the effects of climate change on the lands and waters we manage. The Task Force has already identified virtually all of the major issues described in the draft GAO report and has highlighted a number of additional considerations that we will need to consider. We will be using the information in the final GAO report to make sure we are addressing concerns that we share with GAO and that are being reported to the Congress.

The enclosure provides additional technical comments which, we hope, will assist you in preparing the final report.

Sincerely,

James E. Cason

James E. Cason

Enclosure

GAO Contact and Staff Acknowledgments

GAO Contact

John B. Stephenson (202) 512-3841 or stephensonj@gao.gov

Staff Acknowledgments

In addition to the contact named above, Vincent P. Price, Assistant Director; Marc Castellano; John Healey; Ian Jefferies; Anne K. Johnson; and Joseph D. Thompson were major contributors to this report. Kisha Clark, John Delicath, Heather Holsinger, Richard Johnson, Karen Keegan, Carol Kolarik, David Marwick, Micah McMillan, Jean McSween, and Anne O. Stevens also made important contributions.

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