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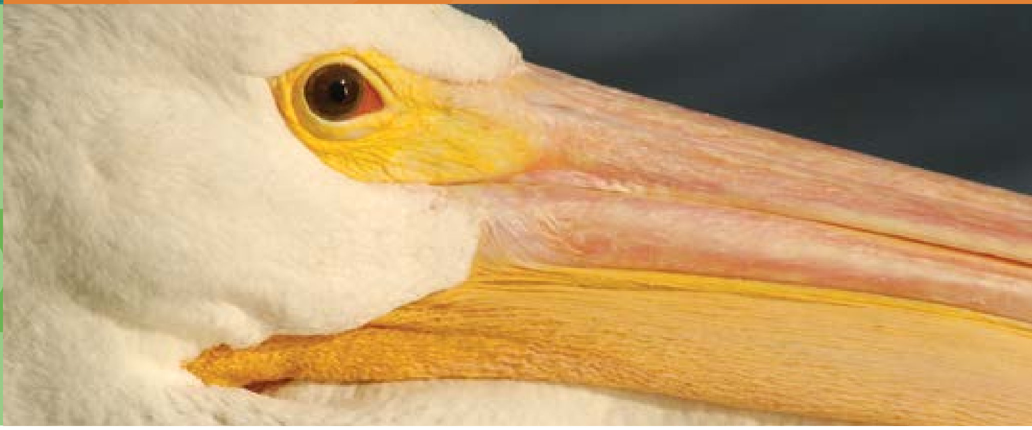

NATIONAL *fish, wildlife & plants* CLIMATE ADAPTATION STRATEGY

National Fish, Wildlife and Plants Climate Adaptation Strategy

RECOMMENDED CITATION

National Fish, Wildlife and Plants Climate Adaptation Partnership.

2012.

National Fish, Wildlife and Plants Climate Adaptation Strategy.

Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service.

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National Fish, Wildlife and Plants Climate Adaptation Strategy

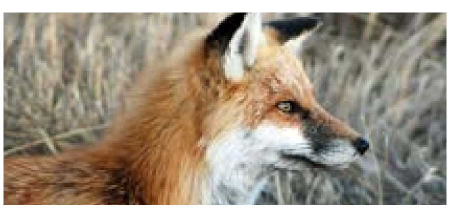
AUTHORS

National Fish, Wildlife, and Plants Climate Adaptation Partnership

Inside

The purpose of the *National Fish, Wildlife and Plants Climate Adaptation Strategy* is to **inspire** and **enable** natural resource administrators, elected officials, and other decision makers to take action to adapt to a changing climate. **Adaptation actions** are vital to sustaining the nation's ecosystems and natural resources—as well as the human uses and values that the natural world provides.

GARY WISE



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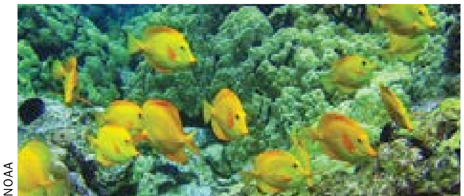

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NIGHT SKY: OKLAHOMA DEPARTMENT OF WILDLIFE CONSERVATION

Preface

Our climate is changing, and thes
are already impacting the nation’s
natural resources and the people,
unities, and economies that deper

e changes
s valuable
comm-
nd on them.

These impacts are expected to increase with continued changes in the planet's climate system, putting many of the nation's valuable natural resources at risk. Action is needed now to reduce these impacts (including reducing the drivers of climate change) and help sustain the natural resources and services the nation depends on.

The observed changes in climate have been attributed to the increasing levels of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere, which have set in motion a series of changes in the planet's climate system. Far greater changes are inevitable not only because emissions will continue, but also because CO_2 stays in the atmosphere for a long time. Even if further GHG emissions were halted today, alterations already underway in the Earth's climate will last for hundreds or thousands of years. If GHG emissions continue, as is currently more likely, the planet's average temperature is projected to rise by 2.0 to 11.5 degrees Fahrenheit by the end of the century, with accompanying major changes in extreme weather events, variable and/or inconsistent weather patterns, sea level rise, and changing ocean conditions including increased acidification.

Safeguarding our valuable living resources in a changing climate for current and future generations is a serious and urgent problem. Addressing the problem requires action now to understand current impacts, assess future risks, and prepare for and adapt to a changing climate. This *National Fish, Wildlife and Plants Climate Adaptation Strategy* (hereafter *Strategy*) is a call to action–a framework for effective steps that can be taken, or at least initiated, over the next five to ten years in the context of the changes to our climate that are already occurring, and those that are projected by the end of the century. It is designed to be a key part of the nation's larger response to a changing climate, and to guide responsible actions by natural resource managers, conservation partners, and other decision makers at all levels. The *Strategy* was produced by federal, state, and tribal representatives and has been coordinated with a variety of other climate change adaptation efforts at national, state, and tribal levels.

> *The overarching goal of the* Strategy *is a simple one: to inspire, enable, and increase meaningful action that helps safeguard the nation's natural resources in a changing climate.*

The overarching goal of the *Strategy* is a simple one: to inspire, enable, and increase meaningful action that helps safeguard the nation's natural resources in a changing climate. Admittedly, the task ahead is a daunting one, especially if the world fails to make serious efforts to reduce emissions of GHGs. But we can make a difference. To do that, we must begin now to prepare for a future unlike the recent past.

Because the development of this adaptation *Strategy* will only be worthwhile if it leads to meaningful action, it is directly aimed at several key groups: natural resource management agency leaders and staff (federal, state, and tribal); elected officials in both executive and legislative government branches (federal, state, local, and tribal); leaders in industries that depend on and can impact natural resources, such as agriculture, forestry, and recreation; and private landowners, whose role is crucial because they own more than 70 percent of the land in the United States.

The *Strategy* should also be useful for decision makers in sectors that affect natural resources (such as agriculture, energy, urban development, transportation, and water resource management), for conservation partners, for educators, and for the interested public, whose input and decisions will have major impacts on safeguarding the nation's living resources in the face of climate change. The *Strategy* also should be useful to those in other countries dealing with these same issues and those dealing with the international dimensions of climate adaptation.

USFWS

Executive Summary

FISH, WILDLIFE, AND PLANTS PROVIDE jobs, food, clean water, storm protection, health benefits and many other important ecosystem services that support people, communities and economies across the nation every day. The observed changes in the climate are already impacting these valuable resources and systems. These impacts are expected to increase with continued changes in the planet's climate system. Action is needed now to help safeguard these natural resources and the communities and economies that depend on them.

"...develop a national, government-wide strategy to address climate impacts on fish, wildlife, plants, and associated ecological processes."

—DEPARTMENT OF THE INTERIOR, ENVIRONMENT, AND RELATED AGENCIES APPROPRIATIONS ACT, 2010

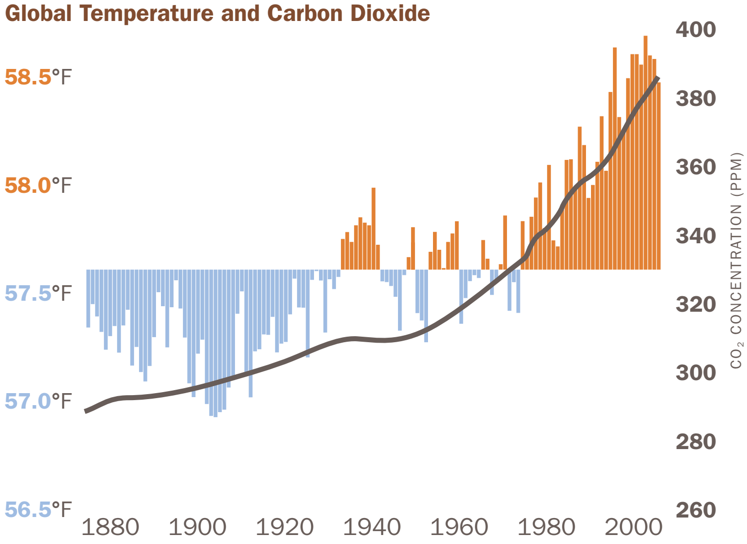
Measurements unequivocally show that average surface air temperatures in the United States have risen two degrees Fahrenheit (°F) over the last 50 years. The science strongly supports the finding that the underlying cause of these changes is the accumulation of heat-trapping carbon dioxide (CO_2) and other greenhouse gases (GHG) in the atmosphere. If GHG emissions continue unabated, the planet's average temperature is projected to rise by an additional 2.0 to 11.5 °F by the end of the century, with accompanying increases in extreme weather events, variable and/or inconsistent weather patterns, sea levels and other factors with significant impacts on natural environments and the vital services they provide.

Faced with a future climate that will be unlike that of the recent past, the nation has the opportunity to act now to reduce the impacts of climate change on its valuable natural resources and resource-dependent communities and businesses. Preparing for and addressing these changes in the near term can help increase the efficiency and effectiveness of actions to reduce negative impacts and take advantage of potential benefits from a changing climate (climate adaptation). In 2009, Congress recognized the need for a national government-wide climate adaptation strategy for fish, wildlife, plants, and ecosystems, asking the Council on Environmental Quality (CEQ) and the U.S. Department of the Interior (DOI) to develop such a strategy. CEQ and DOI responded by assembling an unprecedented partnership of federal, state, and tribal fish and wildlife conservation agencies to draft the document. More than 90 diverse technical, scientific, and management experts from across the country participated in drafting the technical content of the document.

The result is *The National Fish, Wildlife and Plants Climate Adaptation Strategy* (hereafter *Strategy*). The *Strategy* is the first joint effort of three levels of government (federal, state, and tribal) that have primary authority and responsibility for the living resources of the United States to identify what must be done to help these resources become more resilient, adapt to, and survive a warming climate. It is designed to inspire and enable natural resource managers, legislators, and other decision makers to take effective steps towards climate change adaptation over the next five to ten years. Federal, state, and tribal governments and conservation partners are encouraged to read the *Strategy* in its entirety to identify intersections between the document and their mission areas and activities.

The *Strategy* is guided by nine principles. These principles include collaborating across all levels of government, working with non-government entities such as private landowners and other sectors like agriculture and energy, and engaging the public. It is also important to use the best available science—and to identify where science and management capabilities must be improved or enhanced. When adaptation steps are taken, it is crucial to carefully monitor actual outcomes in order to adjust future actions to make them more effective, an iterative process called adaptive management. We must also link efforts within the U.S. with efforts internationally to build resilience and adaptation for species that migrate and depend on areas beyond U.S. borders. Finally, given the size and urgency of the challenge, we must begin acting now.

Global Temperature and Carbon Dioxide



Global annual average temperature from 1901–2000, indicating a clear long-term global warming trend. Orange bars indicate temperatures above and blue bars indicate temperatures below the average. The black line shows atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm).

SOURCE: USGCRP 2009. GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES.

Climate Change Impacts on Natural Systems

The *Strategy* details the current and expected future impacts of climate change on the eight major ecosystem types in the United States (Chapter 2). For example, warmer temperatures and changing precipitation patterns are expected to cause more fires and more pest outbreaks, such as the mountain pine beetle epidemic in western forests, while some types of forests will displace what is now tundra. Grasslands and shrublands are likely to be invaded by non-native species and suffer wetland losses from drier conditions, which would decrease nesting habitat for waterfowl. Deserts are expected to get hotter and drier, accelerating existing declines in species like the Saguaro cactus.

Climate change is expected to be especially dramatic in the Arctic. Temperature increases in northern Alaska would change tussock tundra into shrublands, leading to increased fire risk. In addition, the thawing of frozen organic material in soils would release huge amounts of GHGs, contributing to climate change. In coastal and marine areas, the loss of sea ice and changing ocean conditions are threatening key species such as walrus, ice seals and polar bears as well as the lifestyles and subsistence economics of indigenous peoples.

Rivers, streams, and lakes face higher temperatures that harm coldwater species like salmon and trout, while sea level rise threatens coastal marshes and beaches, which are crucial habitats for many species, such as the diamondback terrapin and the piping plover.

Since water can absorb CO_2 from the air, the rising levels of the gas in the atmosphere and accompanying absorption into the oceans have caused ocean waters to become 30 percent more acidic since 1750. Acidification is already affecting the reproduction of organisms such as oysters. As the pH of seawater continues to drop, major impacts on aquatic ecosystems and species are expected.

USFWS/JOEL GARLICH-MILLER

Loss of arctic ice means loss of valuable habitat for many marine species.

Climate Change Adaptation Strategies and Actions

The *Strategy* describes steps that can be taken to address these impacts and help conserve ecosystems and make them more resilient (Chapter 3). Proposed strategies and actions along with checklists to monitor progress are organized under seven major goals in the *Strategy*:

1 | Conserve and connect habitat

2 | Manage species and habitats

3 | Enhance management capacity

4 | Support adaptive management

5 | Increase knowledge and information

6 | Increase awareness and motivate action

7 | Reduce non-climate stressors

Many proposed actions describe types of conservation activities that management agencies have traditionally undertaken but that will continue to be useful in a period of climate change. Other actions are designed specifically to respond to the new challenges posed by climate change.

An extremely important approach for helping fish, wildlife, and plants adapt to climate change is conserving enough suitable habitat to sustain diverse and healthy populations. Many wildlife refuges and habitats could lose some of their original values, as the plants and animals they safeguard are forced to move into more hospitable climes. As a result, there is an urgent need to identify the best candidates for new conservation areas (including refugia and corridors of habitat that allow species to migrate), and areas where habitat restoration can promote resiliency and adaptation of species and ecosystem functions.

In addition to traditional habitat restoration and protection efforts, this *Strategy* envisions innovative opportunities for creating additional habitat. For example, the U.S. Department of Agriculture (USDA) works with farmers and ranchers to cost-share conservation practices that benefit at-risk, threatened, or endangered species, such as the lesser prairie chicken. These efforts may be useful in responding to climate change as well as other existing conservation challenges. Similarly, adjusting rice farming practices in Louisiana could provide valuable new resources for a variety of waterfowl and shorebirds whose habitat is now disappearing because of wetland loss and sea level rise.

It is also possible to use applied management to make habitats and species more resistant to climate change so they continue to provide sustainable cultural, subsistence, recreational, and commercial uses. For example, managing stream corridors to preserve functional processes and reconnect channels with well-vegetated floodplains may help to ensure a steady supply of groundwater recharge that maintains coldwater species even when air temperatures rise. Floodplains serve as vital hydrologic capacitors, and may become even more important in many parts of the country as more precipitation falls as rain instead of snow. Protecting and restoring stream habitats to maintain more narrow and deep stream beds and riparian shade cover can also help keep water temperatures cool in a warming climate.

Climate change adaptation requires new ways of assessing information, new management tools and professional skills, increased collaboration across jurisdictions, and review of laws, regulations, and policies to ensure effectiveness in a changing world. Climate change impacts are occurring at scales much larger than the operational scope of individual organizations and agencies, and successful adaptation demands strong collaboration among all jurisdictions. Landscape Conservation Cooperatives (LCCs), migratory bird and other Joint Ventures (JVs), National Fish Habitat Partnerships (NFHPs), and other existing and emerging partnerships are useful vehicles to promote diverse collaboration across larger scales. Because of the dependence of Native Americans, Alaska Natives and other groups on their natural resources for their economic and cultural identity, climate change is a threat not only to those natural resources, but also to the traditions, the culture, and ultimately, the very health of the communities themselves. Indigenous communities possess traditional ecological knowledge (TEK) and relationships with particular resources and homeland areas, accumulated through thousands of years of history and tradition, which make them highly sensitive to, and aware of, environmental change. Alaska provides an excellent example of not only how TEK can be successfully integrated into management activities, but also how this knowledge can be collected, used, and protected in a respectful and culturally-sensitive manner, benefitting both indigenous and non-indigenous communities.

Reducing existing stressors on fish, wildlife, and plants may be one of the most effective, and doable, ways to increase resilience to climate change.

It will frequently be difficult to predict how individual species and ecosystems will react to climate change. Adaptation in the face of uncertain impacts requires coordinated observation and monitoring, information management and decision support systems, and a commitment to adaptive management approaches. Coordinated information management systems, such as the National Ecological Observatory Network and the Integrated Ocean Observing System, that link and make available the data developed by separate agencies or groups have a critical role to play in increasing access to and use of this information by resource managers, planners, and decision makers. Vulnerability assessments are key steps to help managers develop and prioritize adaptation efforts and inform management approaches.

Additional research and modeling efforts are needed to increase knowledge about the specific impacts of climate change on fish, wildlife, plants, and habitats and their adaptive capacity to respond. The use of models has already produced valuable information for planning for climate change impacts, and more refined models at temporal and spatial scales appropriate to adaptation are required. Methods to objectively quantify the value of ecosystem services provided by well-functioning ecosystems also are needed. For example, there may be fewer salmon for commercial and recreational harvest, as well as for traditional ceremonial and cultural practices of indigenous peoples.

Adaptation efforts will be most successful if they have broad support and if key groups are motivated to take action themselves. Efforts to increase awareness and motivate action should be targeted toward elected officials, public and private decision makers, groups that are interested in learning more about climate change, private landowners, and natural resource user groups. Engaging these stakeholders early and repeatedly to increase awareness of climate change, to develop integrated adaptation responses, and to motivate their participation is key to making this *Strategy* work.

Reducing existing stressors on fish, wildlife, and plants may be one of the most effective, and doable, ways to increase resilience to climate change. Many existing non-climate stressors may be exacerbated by climate change. In particular, avoiding, reducing and addressing the ongoing habitat degradation (e.g., pollution, loss of open space) associated with human development is critical and requires collaboration with land-use planners and private land owners. Taking steps to reduce stressors not related to climate, such as fighting invasive species like water hyacinth, can help natural systems cope with the additional pressures imposed by a changing climate.

Integration and Implementation

The *Strategy* emphasizes that actions to help fish, wildlife, plants, and natural systems adapt to climate change can be coordinated with measures taken in other sectors, such as agriculture, energy, water, and transportation, to increase the benefits for all sectors (Chapter 4). One example of an action that benefits multiple sectors and ecosystems is better management of stormwater runoff, which not only reduces risks of flooding in cities, but also reduces the threat that toxic algal blooms will affect aquatic ecosystems.

The *Strategy* is designed to build upon and complement the growing number of adaptation and conservation efforts and programs (Chapter 5) at local, state, regional and national levels. Examples include the U.S. Global Change Research Program (USGCRP), which produces the National Climate Assessment (NCA) every four years; the Interagency Climate Change Adaptation Task Force (ICCATF) that provides a venue to communicate and help coordinate U.S. federal agency adaptation efforts; State Wildlife Action Plans; EPA regional initiatives such as the Great Lakes Restoration Initiative; and the work of the LCCs. Implementing the *Strategy* will require coordination and collaboration among these and many other entities. The *Strategy* calls for creation of a coordination body to oversee its implementation and engage with conservation partners.

USFWS

The *Strategy* is a call to action. We can take effective action to reduce risks and increase resiliency of valuable natural resources. Unless the nation begins a serious effort to undertake this task now, we risk losing priceless living systems—and the benefits and services they provide—as the climate changes.

CH.1 About the *Strategy*

THE PURPOSE OF THE *National Fish, Wildlife and Plants Climate Adaptation Strategy* (hereafter *Strategy*) is to inspire and enable natural resource administrators, elected officials, and other decision makers to take action to help the nation's valuable natural resources and people that depend on them adapt to a changing climate.

The Strategy *identifies major goals and outlines strategies and actions needed to attain those goals.*

1.1 A Broad National Effort

Adaptation actions are vital to sustaining the nation's ecosystems and natural resources—as well as the human uses and values that the natural world provides. The *Strategy* explains the challenge ahead and offers a guide for actions that can be taken now, in spite of remaining uncertainties over how climate change will impact living resources. It further provides guidance on longer-term actions most likely to promote natural resource adaptation to climate change. Because climate adaptation cuts across many boundaries, the *Strategy* also describes mechanisms to increase collaboration among all levels of government, conservation organizations, and private landowners.

The *Strategy* focuses on preparing for and reducing the most serious impacts of climate change and related non-climate stressors on fish, wildlife, and plants. It places priority on addressing impacts for which there is enough information to recommend sensible actions that can be taken or initiated over the next five to ten years in the context of climate change projections through the end of the century. Further, it identifies key knowledge, technology, information, and governance gaps that hamper effective action. While the *Strategy* is focused on adaptation rather than mitigation (or reduction) of GHGs, it includes approaches that may also have mitigation benefits.

The *Strategy* is not a detailed assessment of climate science or a comprehensive report of the impacts of climate change on individual species or ecosystems; an abundant and growing literature on those

topics already exists (IPCC AR4 2007, USGCRP 2009, Parmesan 2006). It is not a detailed operational plan, nor does it prescribe specific actions to be taken by specific agencies or organizations, or specific management actions for individual species. Rather, this is a broad national adaptation strategy: it identifies major goals and outlines strategies and actions needed to attain those goals. It describes the "why, what, and when" of what the nation must do to assist our living resources to cope with climate change. The "who, where, and how" of these strategies and actions must be decided through the many existing collaborative processes for management planning, decision-making, and action. In addition, the development of strategies and actions for this document was not constrained by assumptions of current or future available resources. The implementation of recommended strategies and actions, and the allocation of resources towards them, are the prerogative of the *Strategy* audience, (e.g., decision makers).

Federal, tribal, state, and local governments and conservation partners have initiated a variety of efforts to help prepare for and respond to the impacts of climate change on the nation's natural resources and the valuable services they provide. This *Strategy* is designed to build on and assist these efforts across multiple scales and organizations. These entities are encouraged to identify areas of the *Strategy* that bear on their missions and work collaboratively with other organizations to design and implement specific actions to reduce the impacts of climate change on fish, wildlife, and plants.

In order for the *Strategy* to be effectively implemented, progress should be periodically evaluated and the *Strategy* reassessed and updated through the same sort of collaborative process as was employed in the production of this first effort. The *Strategy* calls for formation of a coordinating body with representation from federal, state, and tribal governments meet semi-annually to promote and evaluate implementation and to report progress annually.

1.2 Origin and Development

Over the past decade, there have been an increasing number of calls by government and non-governmental entities for a national effort to better understand, prepare for and address the impacts of climate change on natural resources and the communities that depend on them. These calls helped lay the foundation for development of this *Strategy*.

For example, in 2007, the U.S. Government Accountability Office (GAO) released a study entitled "Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources," recommending that guidance and tools be developed to help federal natural resource managers address and incorporate climate change into their resource management efforts (GAO 2007). In 2008, the USGCRP released the report *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources* that called for and identified new approaches to natural resource management to increase resiliency and adaptation of ecosystems and resources (CCSP 2008c). In addition, a coalition of hunting and fishing organizations published reports in 2008 and 2009 on the current and future impacts of climate change on fish and wildlife and called for increased action to help sustain these resources in a changing climate (Wildlife Management Institute 2008, 2009).

Congress asked CEQ and DOI to develop a national strategy to "…assist fish, wildlife, plants, and related ecological processes in becoming more resilient, adapting to, and surviving the impacts of climate change" as part of the 2010 Appropriations Bill for the Department of the Interior and Related Agencies (U.S. Congress 2010). Acting for DOI, the U.S. Fish and Wildlife Service (FWS) and CEQ then invited the National Oceanic and Atmospheric Administration (NOAA) and state wildlife agencies, with the New York State Division of Fish, Wildlife, and Marine Resources as their lead representative, to co-lead the development of the *Strategy*. In October of 2010, the ICCATF endorsed the development of the *Strategy* as a key step in advancing U.S. efforts to adapt to a changing climate.[1]

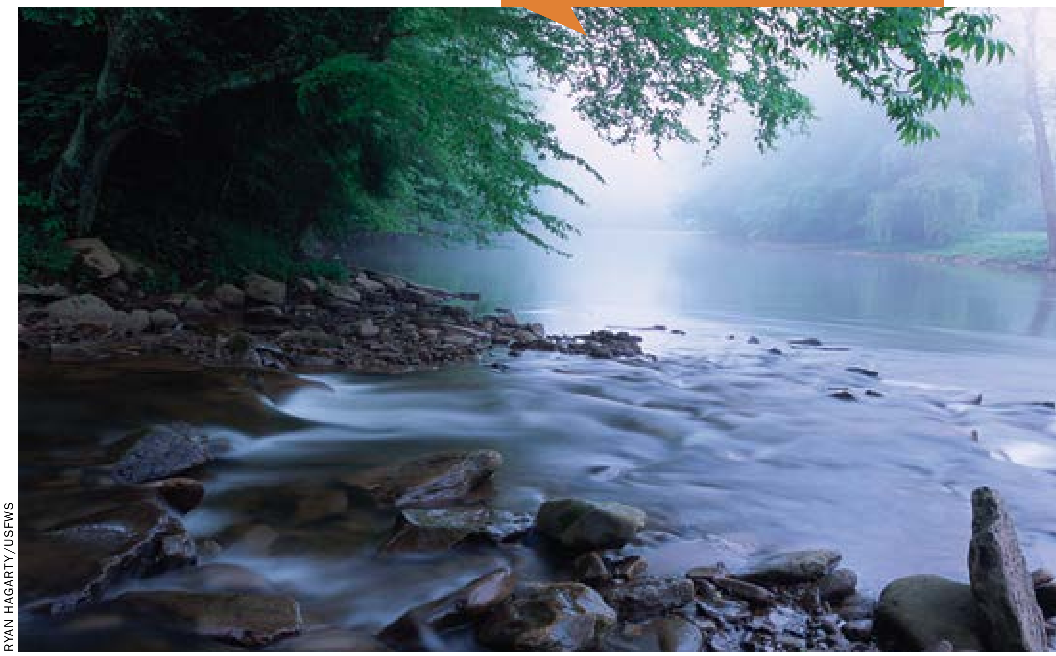
A 22-person Steering Committee was formed in January 2011, and includes representatives from 15 federal agencies with management authorities for fish, wildlife, plants, or habitat, as well as representatives from five state fish and wildlife agencies and two intertribal commissions. The Committee charged a small Management Team, including

1 See "Progress Report of the Interagency Climate Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. <www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf>

representatives of the FWS, NOAA, the Association of Fish and Wildlife Agencies (AFWA, representing the states), and the Great Lakes Indian Fish and Wildlife Commission, to oversee the day-to-day development of the *Strategy*. The Management Team was asked to engage with a diverse group of stakeholders, as well as to coordinate and communicate across agencies and departments.

In March of 2011, the Management Team invited more than 90 natural resource professionals (both researchers and managers) from federal, state, and tribal agencies to form eight Technical Teams, each centered around a major U.S. ecosystem type. These Teams, which were co-chaired by federal, state, and tribal representatives, worked over the next eight months to provide technical information on climate change impacts and to collectively develop the strategies and actions for adapting to climate change. The Management Team worked to identify and distill the primary approaches common across ecosystems into the seven overarching goals, discussed in detail in Chapter 3.

Unless the nation begins a serious effort to undertake adaptation efforts now, we risk losing priceless living systems—and the benefits and services they provide—as the climate changes.



RYAN HAGARTY/USFWS

1.3 The Case for Action

1.3.1 The Climate is Changing

Measurements and observations show unequivocally that the Earth's climate is currently in a period of unusually rapid change. The impacts of climate change are occurring across the United States. For example:

- Average air temperature has increased two degrees Fahrenheit (°F) and precipitation has increased approximately five percent in the United States in the last 50 years;
- Average global ocean temperatures have increased nearly 0.4°F since 1955;
- The amount of rain falling in the heaviest storms is up 20 percent in the last century, causing unprecedented floods;
- Extreme events like heat waves and regional droughts have become more frequent and intense;
- Hurricanes in the Atlantic and eastern Pacific have gotten stronger in the past few decades;
- Sea levels have risen eight inches globally over the past century and are climbing along most of our nation's coastline;
- Cold season storm tracks are shifting northward;
- The annual extent of Arctic sea ice is shrinking rapidly; and
- Oceans are becoming more acidic.

All of these changes have been well documented and described in the report: *Global Climate Change Impacts in the United States* (USGCRP 2009), the primary scientific reference on climate change science for this document. Moreover, the changes are harbingers of far greater changes to come.

The science strongly supports the finding that the underlying cause of today's rising temperatures, melting ice, shifting weather, increasing ocean acidification and other changes is the accumulation of heat-trapping carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere (IPCC AR4 2007, USGCRP 2009, NRC 2010). Because CO_2 remains in the atmosphere for many years, CO_2 that has already been emitted will continue to warm the Earth (and contribute to ocean acidification) for decades or centuries to come (Wigley 2005). Meanwhile, GHG emissions continue, increasing the concentrations of these gases in the atmosphere. Our future climate will be unlike that of the recent past. Traditional and proven approaches for managing fish, wildlife, plants, ecosystems, and their human uses may no longer be effective given the scale and scope of climate-driven changes.

Observed Changes to Ecosystems and Species

AFWA

Species are **shifting their geographic ranges**, often moving poleward or upwards in elevation. For instance, geese that formally wintered along the Missouri River in Nebraska and South Dakota now seem to migrate only as far south as North Dakota, to the dismay of waterfowl hunters (*Wildlife Management Institute 2008*). These shifts may also bring wildlife into more densely populated human areas, creating situations of human-wildlife conflict. In addition, some marine species are also shifting both location and depth (Nye et al. 2009).

BILL LYNCH

The phenology, such as **spring blooming, is changing** (Post et al. 2001). This could affect whether or not plants are successfully pollinated (the pollinators might come at the wrong time), or whether or not food is available when needed. For example, in the Rocky Mountains, the American robin (see Appendix D for a list of scientific names of species mentioned in the text) is now arriving up to two weeks earlier than it did two decades ago. However, the date of snow melt has not advanced, so food resources may be limited when the birds arrive (Inouye et al. 2000).

NOAA

Since water absorbs CO2, the **oceans are becoming more acidic**, affecting the reproduction of species such as oysters (Feely et al. 2008). The pH of seawater has decreased since 1750, and is projected to drop much more by the end of the century as CO2 concentrations continue to increase (USGCRP 2009). Although not technically climate change, this additional impact of the accumulation of CO2 in the atmosphere is expected to have major impacts on aquatic ecosystems and species.

SHELLEY ELLIS/NWF

Different species are responding differently to changes in climate, leading to **decoupling of important ecological relationships** (Edwards and Richardson 2004). For example, changes in phenology for Edith's checkerspot butterfly are leading to mismatches with both caterpillar host plants and nectar sources for adult butterflies, leading to population crashes in some areas (Parmesan 2006).

JOHN LYONS

Habitat loss is increasing due to ecological changes associated with climate change, such as sea level rise, increased fire, pest outbreaks, novel weather patterns, or loss of glaciers. For example, habitat for rainbow trout in the southern Appalachians is being greatly reduced as water temperatures rise (Flebbe et al. 2006).

BROME MCCREARY

Declines in the populations of species, from mollusks off the coast of Alaska to frogs in Yellowstone, are being attributed to climate change (Maclean and Wilson 2011).

TIM TORRELL

The **spread of non-native species** as well as diseases, pests, contaminants, and parasites are becoming more common. For instance, warmer temperatures are enabling a salmon parasite to invade the Yukon River, causing economic harm to indigenous peoples and the fishing industry (Kocan et al. 2004). Also, the increasing threats of wildlife diseases due to non-native species include diseases transmissible between animals and humans, which could negatively impact native species, domestic animals, and humans (Hoffmeister et al. 2010).

1.3.2 Impacts to Fish, Wildlife, and Plants

Given the magnitude of the observed changes in climate, it is not surprising that fish, wildlife, and plant resources in the United States and around the world are already being affected. The impacts can be seen everywhere from working landscapes like tree farms and pastures to wilderness areas far from human habitation (Parmesan 2006, Doney et al. 2012). Although definitively establishing cause and effect in any specific case can be problematic, the overall pattern of observed changes in species' distributions and phenology (the timing of life events) is consistent with biologists' expectations for a warming climate (Parmesan 2006, Doney et al. 2012). As the emissions of GHGs and the resulting climate changes continue to increase in the next century, so too will the effects on species, ecosystems, and their functions (USGCRP 2009). Human responses to the challenge of climate change will also affect, perhaps substantially, the natural world. Furthermore, climatic change and the human response to it are also likely to exacerbate existing stressors like habitat loss and fragmentation, putting additional pressure on our nation's valued living resources (USGCRP 2009).

CASE STUDY

Hotter summers threaten eastern brook trout

Heat stress is the biggest threat to cold water fish species and brook trout are particularly sensitive.

CHUCK KRUEGER/GREAT LAKES FISHERY COMMISSION

THE WEST FORK OF THE KICKAPOO RIVER in western Wisconsin is an angler's paradise. Its cool, shaded waters and pools abound with native brook trout. But brook trout require cold water to reproduce and survive—and water temperatures are already rising. By the end of this century, the self-sustaining population in the West Fork could be gone. In fact, up to 94 percent of current brook trout habitat in Wisconsin could be lost with a 5.4 °F increase in air temperature (Mitro et al. 2010). Although climate change has not caused the loss of any brook trout populations to date, the warming effects on air temperature is projected to significantly reduce the current range of brook trout in the eastern United States.

The threat is not limited to Wisconsin or to brook trout. Climate change is viewed as one of the most important stressors of fish populations, and coldwater fish species are especially susceptible to rising temperatures. Declining populations would have serious ecological and economic consequences, since these fish are key sources of nutrients for many other species and provide major fishing industries in the Northeast, Northwest, and Alaska (Trout Unlimited 2007).

In some cases, adaptation measures may help reduce the threat. The first step is measuring stream water temperatures and flow rates to identify which trout habitats are at greatest risk. Monitoring efforts have already shown that some trout streams are at lower risk because they have water temperatures far below lethal limits, while other streams are not likely to see increases in water temperatures even when air temperatures rise, since adequate amounts of cool groundwater sustain the stream's baseflow in summer. This information enables fisheries managers to focus on the streams and rivers that are at greater risk from climate change and from changing land use that would decrease groundwater discharge rates. In some streams, these deteriorating conditions are unlikely to be reversed.

In other streams, adaptation strategies can be implemented to reduce stream water temperatures such as planting trees and other streambank vegetation for shade, or restoring stream channel morphology to reduce solar heating. For example, managing stream corridors to preserve functional processes and reconnect channels with well-vegetated floodplains may help to ensure a steady supply of groundwater recharge that maintains coldwater species even when air temperatures rise. Floodplains serve as vital hydrologic capacitors, and may become even more important in many parts of the country as more precipitation falls as rain instead of snow.

Protecting and enhancing water infiltration rates on land is another adaptation strategy that can increase cooler groundwater discharge rates during the critical summer low flow conditions.

This "triage" stream assessment approach is similar to how accident or battlefield responders work, where efforts are focused on those most likely to respond to treatment. Thus, limited funding is directed toward streams that are at higher risk from the effects of rising temperatures, and on streams where adaptation actions are more likely to have a positive impact.

1.3.3 Ecosystem Services

Natural systems are of fundamental value and benefit to people. Natural environments provide enormously valuable, but largely unaccounted for, services that support people as well as other species (NRC 2004, NRC 2012, PCAST 2011). The materials and processes that ecosystems produce that are of value to people are known as "ecosystem services" and can be organized into four general categories (Millennium Ecosystem Assessment 2005):

- *Provisioning Services*, including food, water, medicines, and wood.
- *Regulating Services*, such as climate regulation, flood suppression, disease/pest control, and water filtration.
- *Cultural Services*, such as aesthetic, spiritual, educational, and recreational services.
- *Supporting Services*, such as nutrient cycling, soil formation, pollination, and plant productivity.

Economic contributions of ecosystem services have been quantified in some areas. For example, hunting, fishing, and other wildlife-related recreation in the United States (an example of provisioning and cultural services) is estimated to contribute $122 billion to our nation's economy annually (DOI and DOC 2006). The U.S. seafood industry—most of which is based on wild, free-ranging marine species—supported approximately 1 million full-and part-time jobs and generated $116 billion in sales impacts and $32 billion in income impacts in 2009 (NMFS 2010). Marine recreational fishing also contributes to coastal areas as an economic engine; in 2009, approximately 74 million saltwater fishing trips occurred along U.S. coasts, generating $50 billion in sales impacts and supporting over 327,000 jobs (NMFS 2010). Aquatic habitat and species conservation alone contributes over $3.6 billion per year to the economy in the U.S., and supports over 68,000 jobs (Charbonneau and Caudill 2010). Americans and foreign visitors made some 439 million visits to DOI-managed lands in 2009. These visits (an example of a cultural service) supported over 388,000 jobs and contributed over $47 billion in economic activity.

Natural environments provide enormously valuable services and goods that benefit humans and other species.

> *The U.S. seafood industry—most of which is based on wild, free-ranging marine species—annually supports approximately 1 million full-and part-time jobs.*

This economic output represents about eight percent of the direct output of tourism-related personal consumption expenditures for the United States for 2009 and about 1.3 percent of the direct tourism related employment (DOI 2011). Every year, coastal habitats such as coral reefs, wetlands, and mangroves help protect people, infra-structure and communities from storms, erosion, and flood damage worth billions of dollars (DOI and DOC 2006, CCSP 2009a).

The continuance or growth of these types of economic activities is directly related to the extent and health of our nation's ecosystems and the services they provide.

Natural resources provide a wide variety of other types of benefits and services to people and communities every day, many of which are not traded in markets and are sometimes difficult to monetize. For example, forests help provide clean drinking water for many cities and towns. Coastal habitats such as coral reefs, wetlands, and mangroves help protect people and communities from storms, erosion, and flood damage (DOI and DOC 2006, CCSP 2009a). For many people, quality of life depends on frequent interaction with wildlife. Others simply take comfort in knowing that the wildlife and natural places that they know and love still survive, at least somewhere.

For many Native Americans and rural Americans, wild species and habitats are central to their very cultural identities as well as their livelihoods. The animals and plants that are culturally important to these communities have values that are difficult to quantify and weigh in monetary terms; but this makes them no less valuable to people.

Over the past two decades the emerging environmental marketplace has been delivering evidence that at least some ecosystem services can be partially captured in markets. The buying, selling, and trading of ecosystem services as commercial commodities is now routinely occurring. Carbon credits, wetland credits, emission reduction credits, and species credits represent voluntary improvements in air and water quality and supply, land use and waste management, as well as biodiversity protection. These commodities are now exchanged across a number of recognized regional, national, and international platforms. Because these credits have achieved measureable monetary value representing incremental improvements in ecological health and integrity, they shed some light on the overall value of ecosystem services. For example, the total global value of tradable ecological assets (water, carbon, and biodiversity) exceeded $250 billion in 2011 (Carroll and Jenkins 2012).

Despite growing recognition of the importance of ecosystem functions and services, they are often taken for granted, undervalued, and overlooked in environmental decision-making (NRC 2012). Thus, choices between the conservation and restoration of some ecosystems and the continuation and expansion of human activities in others have to be made in recognition of this potential for conflict and of the value of ecosystem services. In making these choices, the economic values of the ecosystem goods and services must be known so that they can be compared with the economic values of activities that may compromise them (NRC 2004, NRC 2012).

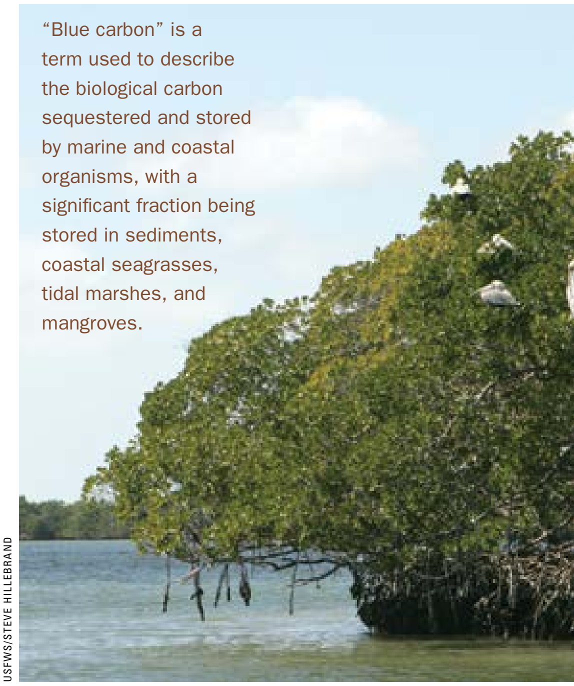
Where an ecosystem's services and goods can be identified and measured, it will often be possible to assign values to them by employing existing economic valuation methods. However, some ecosystem goods and services resist valuation because they are not easily quantifiable or because available methods are not appropriate, reliable, or fully developed. Economic valuation methods can be complex and demanding, and the results of applying these methods may be subject to judgment, uncertainty, bias, and market imperfections. There is also the risk that, where not all values can be estimated, those that can be valued lead to management that harms the overall system in pursuit of maximizing only that portion of its values (e.g., replacing natural wetland communities with monotypic wetlands to maximize water purification).

However, if policymakers consider benefits, costs, and trade-offs when making policy decisions, then monetization of the value of ecosystem services is essential. Failure to include some measure of the value of ecosystem services in benefit-cost calculations will implicitly and erroneously assign them a value of zero. In brief:

» If the benefits and costs of an adaption action or policy are to be evaluated, the benefits and costs associated with changes in ecosystem services should be included along with other impacts to ensure that ecosystem effects are adequately considered in policy evaluation.

» Economic valuation of changes in ecosystem services should be based on the total economic value framework, which includes both use and nonuse values.

» The valuation exercise should focus on changes in ecosystem goods or services attributable to a policy action, relative to a baseline.



"Blue carbon" is a term used to describe the biological carbon sequestered and stored by marine and coastal organisms, with a significant fraction being stored in sediments, coastal seagrasses, tidal marshes, and mangroves.

USFWS/STEVE HILLEBRAND

Some actions, like strategies that preserve or enhance the carbon sequestration capacity of an ecosystem, can serve to mitigate or reduce the emission of GHGs while also improving the adaptive capacity of the ecosystem (i.e., providing multiple ecosystem services). While the *Strategy* is not focused on mitigation per se, it includes strategies and actions that serve mitigation as well as adaptation goals. Unlike actions to mitigate the impacts of climate change (which often require coordinated actions at various levels of government), adaptation decisions are largely decentralized. They will be made to a large extent in well-established decision-making contexts such as private sector decision-making or public sector planning efforts. Some adaptations will benefit the public and as such, may be provided by the local, state, tribal,

or federal government. These adaptation decisions can be evaluated using traditional tools such as cost-benefit analysis. In certain circumstances, ethnographic research may prove more useful than cost-benefit analysis in understanding perceived public benefits. Private sector decisions are likely to be evaluated using standard investment appraisal techniques, for example, calculating the net present value of an adaptation investment, analyzing its risks and returns, or determining the return on capital invested.

A full accounting of ecosystem services has yet to be done for any ecosystem. Nevertheless, as climate change influences the distribution, extent, and composition of ecosystems, it will also affect the spectrum of services and economic value those ecosystems provide.

1.3.4 Adaptation to Climate Change

While addressing the causes of climate change (i.e., mitigation) is absolutely necessary, mitigation will not be sufficient to prevent major impacts due to the amount of GHGs that have already been emitted into the global atmosphere. Society's choices of what actions to take in the face of climate change can either make it harder or easier for our living resources to persist in spite of climate change. Effective action by managers, communities, and the public is both possible (see Chapter 3) and crucial.

Adaptation in the climate change context has been specifically defined as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC WGII 2007). Adaptation in the biological context has a somewhat different meaning. In essence, biological adaptation refers both to the process and the products of natural selection that change the behavior, function, or structure of an organism that makes it better suited to its environment. The factors that control the rate of biological adaptation (e.g., population size, genetic variability, mutation rate, selection pressure, etc.) are rarely under full control of human action. Much as people might like, human intervention will not be able to make species adapt to climate change. But our actions can make such adaptation more or less likely.

CASE STUDY

What happens to Tribal identity if birch bark vanishes?

CLIMATE CHANGE MODELS SUGGEST that by 2100, the paper birch tree may no longer be able to survive throughout its range in the United States (Prasad et al. 2007). This would be not just an ecological loss, but a devastating cultural loss as well. Some species are so fundamental to the cultural identity of a people through diverse roles in diet, materials, medicine, and/or spiritual practices that they may be thought of as cultural keystone species (Garibaldi and Turner 2004). The paper birch is one such example.

Paper birch bark has been indispensable for canoes, sacred fires, and as a substrate to grow fungi for medicines. It was used for food storage containers to retard spoilage, earning it the nickname of the "original Tupperware™".

CHARLIE RASMUSSEN

It is an extremely durable material and is still used as a canvas on which traditional stories and images are etched, contributing to the survival of Native culture and providing a source of revenue. Indeed, birch bark is crucial for the economic health of skilled craftspeople who turn it into baskets and other items for sale to tourists and collectors. Paper birch is central to some of the great legends of the Anishinaabe or Ojibwe peoples (also known as Chippewa).

These rich cultural and economic uses and values are at risk if the paper birch tree disappears from the traditional territories of many U.S. tribes. Already, artisans in the Upper Midwest are concerned about what they believe is a diminishing supply of birch bark.

Until adaptive management strategies are developed and implemented, managers will have to rely on identifying suitable areas to serve as refugia where culturally significant numbers of the species can survive.

The science and practice of adaptation to climate change is an emerging discipline that focuses on evaluating and understanding the vulnerability and exposure that natural resources face due to climate change, and then preparing people and natural systems to cope with the impacts of climate change through adaptive management (Glick et al. 2011a). The ability of populations, species, or systems to adapt to a changing climate is often referred to as their adaptive capacity.

Because climate change is a long-term problem, both the level and timing of adaptation decisions is important. Both sets of decisions—level and timing—will be made under uncertainty about the precise impacts of climate change. Timing decisions should recognize the following:

» Early action may be more cost effective in situations where long-lived infrastructure investments such as water and sanitation systems, bridges, and ports are being considered. In these cases, it is likely to be cheaper to make adjustments early, in the design phase of the project, rather than incur the cost and inconvenience of expensive retrofits.

» Early adaptation actions will be justified if they have immediate benefits, for example, by mitigating the effects of climate variability. In addition, adaptation actions that have ancillary benefits such as measures to preserve and strengthen the resilience of natural ecosystems might also be justified in the short-term.

Three general types of adaptation responses illustrate points along a continuum of possible responses to climate change:

Resistance	Resilience	Transformation
Ability of a system to remain essentially intact or unchanged as climate changes	Ability of a system to recover from a disturbance, returning to its original state.	The change in a system's composition and/or function in response to changes in climate or other factors.

STEVE HILLEBRAND/USFWS

Uncertainties regarding the future of climate change are inherent and unavoidable but this should not stop us from taking action now.

Application of the adaptation approaches described in this *Strategy* must carefully consider whether the desired outcome in any given situation should be to try to increase the resistance of a natural system to climate change, to attempt to make it more resilient in the face of climate change, or to assist its transformation into a new and different state—or to achieve some combination of all three outcomes (Hansen and Hoffman 2011).

CASE STUDY

Climate change on the Kenai Peninsula

RICHEY/USFWS

FOR A GLIMPSE OF THE DRAMATIC changes that a warming climate may bring to the entire nation, look no farther than Alaska's seven million-acre Kenai Peninsula. Here, warmer temperatures have increased over-winter survival and boosted populations of spruce bark beetle, enabling the pest to devastate four million acres of forest on the peninsula and south-central Alaska over a 15-year period (Berg et al. 2006).

Meanwhile, the treeline has risen an unprecedented 150 feet (Dial et al. 2007); the area of wetlands has decreased by six to 11 percent per decade (Klein et al. 2005, Berg et al. 2009, Klein et al. 2011); the Harding Icefield, the largest glacial complex in the United States, has shrunk by five percent in surface area and 60 feet in height (Rice 1987, Adageirsdottir et al. 1998); and available water has declined 55 percent (Berg et al. 2009). The fire regime is also changing: late summer canopy fires in spruce are being replaced by spring fires in bluejoint grasslands, and a 2005 wildfire in mountain hemlock was far different from any previous fire regime (Morton et al. 2006).

While these changes are already sobering, even greater changes lie ahead, according to projections from spatial modeling. As the climate continues to warm and dry, the western side of the peninsula could see an almost catastrophic loss of forest. Salmon populations—and the communities that depend on salmon—are projected to suffer because of higher stream temperatures (Mauger 2011) and increased glacial sediment (Edmundson et al. 2003). Overall, 20 percent of species may vanish from the peninsula in the worst case scenario.

Is adapting to this rapidly changing climate possible? Some communities are already taking positive steps. For instance, state and local agencies are replanting beetle-killed areas that have become grasslands with white spruce and non-native lodgepole pine to reduce fire hazards for nearby cities and communities.

The Kenai National Wildlife Refuge, Kenai Fjords National Park, Chugach National Forest, and the University of Alaska Anchorage are developing a climate vulnerability assessment in 2012 for the Kenai Peninsula and adjacent mainland. Plans are underway to develop interagency strategies for developing retrospective and prospective options (Magness et al. 2011) for adapting to climate change effects on the Kenai Peninsula. The geographic discreteness of the peninsula, the substantial lands under federal management, and the documentation of dramatic climate change impacts combine to make Kenai an ideal laboratory to explore the effectiveness of various adaptation measures.

Deciding what to do requires examining the institutions, laws, regulations, policies, and programs that our nation has developed to maintain our valuable resources and the many benefits they provide.

It requires evaluating the management techniques that the conservation profession and other sectors (such as agriculture, energy, housing and urban development, transportation, and water resources) have developed over time, as well as considering new approaches where necessary

Perhaps most of all, it requires communicating our shared social values for wild living things and the ecosystems in which they live. Those social values can form the basis of cooperative intervention.

1.4 Purpose, Vision, and Guiding Principles

In 2009, the FWS launched a series of Conservation Leadership Forums to bring together leaders in the conservation community to discuss what a *Strategy* should include and how it should be developed. That effort, and others, produced a purpose, a vision, and guiding principles for developing this first national climate change adaptation strategy.

PURPOSE

Inspire and enable natural resource professionals and other decision makers to take action to conserve the nation's fish, wildlife, plants, and ecosystem functions, as well as the human uses and values these natural systems provide, in a changing climate.

VISION

Ecological systems will sustain healthy, diverse, and abundant populations of fish, wildlife, and plants. These systems will provide valuable cultural, economic, and environmental benefits in a world impacted by global climate change.

GUIDING PRINCIPLES

An unprecedented commitment to collaboration and communication is required among federal, state, and tribal governments to effectively respond to climate impacts. There must also be active engagement with conservation organizations, industry groups, and private landowners. These considerations and the following principles guided the development of the Strategy:

Build a national framework for cooperative response.
Provide a nation-wide framework for collective action that promotes collaboration across sectors and levels of government so they can effectively respond to climate impacts across multiple scales.

Foster communication and collaboration across government and non-government entities.
Create an environment that supports the development of cooperative approaches among government and non-government entities to adapting to climate change while respecting jurisdictional authority.

Engage the public.
To ensure success and gain support for adaptation strategies, a high priority must be placed on public outreach, education, and engagement in adaptation planning and natural resource conservation.

Adopt a landscape/seascape based approach that integrates best available science and adaptive management.
Strategies for natural resource adaptation should employ: ecosystem-based management principles; species-habitat relationships; ecological systems and function; strengthened observation, monitoring, and data collection systems; model-based projections; vulnerability and risk assessment; and adaptive management.

Integrate strategies for natural resources adaptation with those of other sectors.
Adaptation planning in sectors including agriculture, energy, human health, and transportation may support and advance natural resource conservation in a changing climate.

Focus actions and investments on natural resources of the United States and its Territories.
But also acknowledge the importance of international collaboration and information-sharing, particularly across our borders with Canada and Mexico. International cooperation is important to conservation of migratory resources over broad geographic ranges.

Identify critical scientific and management needs.
These may include new research, information technology, training to expand technical skills, or new policies, programs, or regulations.

Identify opportunities to integrate climate adaptation and mitigation efforts.
Strategies to increase natural resource resilience while reducing GHG emissions may directly complement each other to advance current conservation efforts, as well as to achieve short- and long-term conservation goals.

Act now.
Immediate planning and action are needed to better understand and address the impacts of climate change and to safeguard natural resources now and into the future.

WHAT IS...?

Risk Assessment

A risk assessment is the process of identifying the magnitude or consequences of an adverse event or impact occurring, as well as the probability that it will occur (Jones 2001).

Vulnerability Assessment

Vulnerability assessments are science-based activities (research, modeling, monitoring, etc.) that identify or evaluate the degree to which natural resources, infrastructure, or other values are likely to be affected by climate change.

Adaptive Management

Adaptive management involves defining explicit management goals while highlighting key uncertainties, carefully monitoring the effects of management actions, and then adjusting management activities to take the information learned into account (CCSP 2009b).

SOUTH CAROLINA DEPT. OF NATURAL RESOURCES

Deciding how best to address ecosystem changes due to climate change will require a cooperative effort by federal, state, and tribal government agencies.

1.5 Risk and Uncertainty

Climate change presents a new challenge to natural resource managers and other decision makers. The future will be different from the recent past, so the historical record cannot be the sole basis to guide conservation actions. More is being learned every year about how the climate will change, how those changes will affect species, ecosystems, and their functions and services, and how future management and policy choices will exacerbate or alleviate these impacts. This uncertainty is not a reason for inaction, but rather a reason for prudent action: using the best available information while striving to improve our understanding over time.

An important approach for dealing with risk and uncertainty is the iterative process of adaptive management. Adaptive management is a structured approach toward learning, planning, and adjustment where continual learning is built into the management process so that new information can be incorporated into decision-making over time without delaying needed actions. Carefully monitoring the actual outcomes of management actions allows for adjustments to future activities based on the success of the initial actions.

A variety of tools and approaches can help managers deal with risk and reduce uncertainty, thus, informing managers about how climate change may affect particular systems or regions. Improved climate modeling and downscaling can help build confidence in predictions of future climate, while climate change vulnerability assessments can help to identify which species or systems are likely to be most affected by climate changes. Well-designed monitoring of how species and natural systems are currently reacting to climate impacts and to adaptation actions will also be a critical part of reducing uncertainty and increasing the effectiveness of management responses. These tools and approaches can all inform scenario planning, which involves anticipating a reasonable range of future conditions and planning management activities around a limited set of likely future scenarios. In addition, other approaches aim to identify actions that are expected to succeed across a range of uncertain future conditions such as reducing non-climate stressors or managing to preserve a diversity of species and habitats.

Another important component of managing risk and uncertainty is to better integrate existing scientific information into management and policy decisions. This requires that research results be accessible, understandable, and highly relevant to decision makers. In addition, decision support tools that help connect the best available science to day-to-day management decisions should continue to be developed, used, and improved, and research priorities should be linked to the needs of managers on the ground.

It is important to remember that natural resource management has always been faced with uncertainty about future conditions and the likely impacts of a particular action. The adaptation strategies and actions in this *Strategy* are intended to help natural resource managers and other decision makers make proactive climate change-related decisions today, recognizing that new information will become available over time that can then be factored into future decisions.

CH.2 Impacts of Climate Change & Ocean Acidification

THE UNITED STATES HAS ALREADY experienced major changes in climate and ocean acidification and additional changes are expected over time. This chapter discusses current and projected impacts of increasing GHGs on fish, wildlife, and plant species, and then provides more detailed information on impacts within eight major types of ecosystems in the United States: forest, shrubland, grassland, desert, Arctic tundra, inland water, coastal, and marine ecosystems.

2.1 GHG-induced Changes to the Climate and Ocean

The magnitude and pace of climate changes will depend on the rate of GHG emissions and the resulting atmospheric GHG levels (USGCRP 2009). These changes are already having significant impacts on the nation's natural resources, the valuable services they provide, and the communities and economies that depend on them. These impacts may be driven by a combination of GHG and climate-related factors.

Increases in atmospheric and ocean CO_2

- The concentration of CO_2 in the atmosphere has increased by roughly 35 percent since the start of the industrial revolution (USGCRP 2009).
- The oceans absorb large amounts of CO_2 from the atmosphere and as atmospheric CO_2 has increased, so has the concentration of CO_2 in the oceans. Between 1751 and 1994, surface ocean pH is estimated to have decreased from approximately 8.25 to 8.14, representing an increase of almost 30 percent in "acidity" in the world's oceans (IPCC AR4 2007). Ocean pH is projected to drop as much as another 0.3 to 0.4 units by the end of the century (Orr et al. 2005, NRC 2010).

» As a result of human activities, the level of CO_2 in the atmosphere has been rapidly increasing. The present level of approximately 390 parts per million (Tans and Keeling 2011) is more than 30 percent above its highest level over at least the last 800,000 years (USGCRP 2009). In the absence of strong control measures, emissions projected for this century would result in a CO_2 concentration approximately two to three times the current level (USGCRP 2009).

Changes in air and water temperatures

» Average air temperatures have increased more than 2 °F in the United States over the last 50 years (more in higher latitudes) and are projected to increase further (USGCRP 2009).

» Global ocean temperatures rose 0.4 °F between 1955 and 2008 (IPCC WGI 2007).

» Arctic sea ice extent has fallen at a rate of three to four percent per decade over the last 30 years. Further sea ice loss, as well as reduced snowpack, earlier snow melt, and widespread thawing of permafrost, are projected (USGCRP 2009).

» Global sea level rose by roughly eight inches over the past century, and has risen twice as fast since 1993 as the rate observed over the past 100 years (IPCC WGI 2007). Local rates of sea level change, however, vary across different regions of the coastal United States. Changes in air and water temperatures affect sea level through thermal expansion of sea water and melting of glaciers, ice caps, and ice sheets.

Changes in temperature can lead to a variety of ecologically important impacts, affecting our nation's fish, wildlife, and plant species. For example, a recent analysis showed that many rivers and streams in the United States have warmed by approximately .2 °F – 1.4 °F per decade over the past 50 to 100 years, and will continue to warm as air temperatures rise (Kaushal et al. 2010). The increasing magnitude and duration of high summer water temperatures will increase thermal stratification in rivers, lakes, and oceans, may cause depletion of oxygen for some periods and enhance the toxicity of contaminants, adversely impacting coldwater fish and other species (Noyes et al. 2009).

Changes in timing, form, and quantity of precipitation

» On average, precipitation in the United States has increased approximately five percent in the last 50 years, with regional trend variability (USGCRP 2009).

» Models suggest northern (wet) areas of the United States will become wetter, while southern (dry) areas of the country will become drier (USGCRP 2009).

As mean global temperature increases, the capacity of the atmosphere to hold water vapor increases, resulting in alterations in precipitation patterns. The combination of changes in temperature and precipitation impacts water quantity, water quality, and hydrology on a variety of scales across ecosystems (USGCRP 2009). These changes vary regionally. The Northeast and Midwest are experiencing higher precipitation and runoff in the winter and spring, while the arid West is seeing less precipitation in spring and summer (USGCRP 2009). In areas of high snowpack, runoff is beginning earlier in the spring, causing flows to be lower in the late summer. These changes in precipitation combined with increased temperatures are also expected to increase the instance and severity of drought, the conditions of which can lead to an increase in the frequency and intensity of fires. Climate change has already been linked to an increase in wildfire activity (Westerling et al. 2006, Littell et al. 2009). For example, during the extreme drought suffered by Texas in the summer of 2011, the state experienced unprecedented wildfires.

PAM MORRIS

Climate change is predicted to increase the number and severity of storm events.

Changes in the frequency and magnitude of extreme events

» Extreme weather events such as heat waves, flooding, and regional droughts have become more frequent and intense during the past 40 to 50 years (USGCRP 2009).

» Rain falling in the heaviest downpours has increased approximately 20 percent in the past century (USGCRP 2009).

» Hurricanes have increased in strength (USGCRP 2009).

According to the USGCRP (2009), over the past few decades, most of the United States has been experiencing more unusually hot days and nights, fewer unusually cold days and nights, and fewer frost days. Droughts are also becoming more severe in some regions. These types of extreme events can have major impacts on the distribution, abundance, and phenology of species, as well as on ecosystem structure and function. Extreme storm events also may result in intense and destructive riverine and coastal flooding. Over the next century, current research suggests a decrease in the total number of extratropical storm events but an increase in number of intense events (Lambert and Fyfe 2006, Bengtsson et al. 2009).

Changes in atmospheric and ocean circulation

- Warming of the atmosphere and ocean change the location and intensity of winds, which affect surface ocean circulation (Colling 2001, Blunden et al. 2011).
- Changes in ocean circulation patterns will change larval dispersal patterns (Cowen and Sponaugle 2009) and the geographic distributions of marine species (Block et al. 2011).

Changes in atmospheric and ocean circulation can affect both the marine environment as well as continental weather. By studying ocean sediment cores, scientists can learn about paleoclimatic conditions, which will provide insights about how dynamic and sensitive ocean circulation can be under different climatic conditions.

2.2 Existing Stressors on Fish, Wildlife, and Plants

Fish, wildlife, plants, and ecosystem processes are threatened by a number of existing stressors. Many of these stressors will be exacerbated by climate change, while some may reduce a species' ability to adapt to changing conditions. While the magnitude of climate change is expected to vary regionally, the overall vulnerability of some ecosystems may be primarily driven by the severity of these non-climate stressors. Resource managers must consider climate impacts in the context of multiple natural and human-induced changes that are already significantly affecting species, habitats, and ecosystem functions and services, including habitat loss, fragmentation and degradation, invasive species, overuse, pollution, and disease. Increasing our understanding of how climate change combines with multiple stressors to affect species, ecosystems, and ecological processes in complex and synergistic ways is needed to help inform and improve adaptation planning. After all, management will have to deal with the cumulative impacts of all stressors affecting a species if conservation efforts are to be successful.

Habitat fragmentation, loss, and degradation

Habitat fragmentation, loss, and degradation have been pervasive problems for natural systems and are expected to continue. For example, grasslands, shrublands, and forests are being converted to agricultural uses. Desert systems are stressed by overgrazing and off-highway vehicles. Tundra and marine ecosystems are being affected by energy and mineral exploration and extraction, and coastal ecosystems are experiencing extensive development. Adding changes in climate to habitat fragmentation will put species with narrow geographic ranges and specific habitat requirements at even greater risk than they would otherwise be. Range reductions and population declines from synergistic impacts of climate and non-climate stressors may be severe enough to threaten some species with extinction over all or significant portions of their ranges.

For example, the Rio Grande cutthroat trout, a candidate for listing under the Endangered Species Act (ESA), is primarily threatened by habitat loss, fragmentation, and impacts from non-native fish (FWS 2008). However, the habitat of the Rio Grande cutthroat is likely to further decrease in response to warmer water temperatures, while wildfire and drought impacts are likely to increase in response to climate change, further exacerbating the non-climate stressors on the species (FWS 2011).

WHAT IS...?

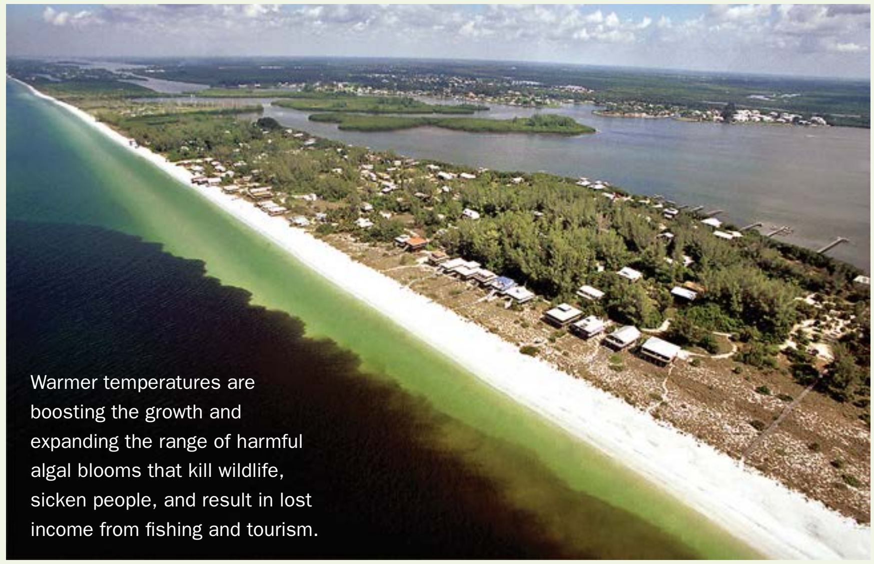
Non-Climate Stressors

In the context of climate adaptation, non-climate stressors refer to those current or future pressures impacting species and natural systems that do not stem from climate change, such as habitat loss and fragmentation, invasive species, pollution and contamination, changes in natural disturbance, disease, pathogens, and parasites, and over-exploitation.

> Ecosystems and the biodiversity they embody constitute *environmental capital* on which human well-being heavily depends....It has become increasingly clear, however, that biodiversity and other important components of the environmental capital producing these services are being degraded by human activities, and that the degradation of this capital has already impaired some of the associated services, with significant adverse impacts on society.
>
> —THE PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY (PCAST) 2011.

CASE STUDY

Harmful algal blooms



Warmer temperatures are boosting the growth and expanding the range of harmful algal blooms that kill wildlife, sicken people, and result in lost income from fishing and tourism.

NOAA

IN THE PAST THREE DECADES, harmful algal blooms (HABs) have become more frequent, more intense, and more widespread in freshwater, estuarine, and marine systems (Sellner et al. 2003). These blooms are taking a serious ecological and economic toll. Algal blooms may become harmful in multiple ways. For example, when the algae die and sink, bacteria consume them, using up oxygen in the deep water. This is a problem especially during calm periods, when water circulation and reoxygenation from the atmosphere are reduced. Increases in the nutrients that fuel these blooms have resulted in an increasing number of massive fish kills. Another type of harmful bloom happens when the dominant species of algae such as those of Cyanobacteria (commonly known as blue-green algae) produce potent nerve and liver toxins that can kill fish, seabirds, sea turtles, and marine mammals. These toxins also sicken people and result in lost income from fishing and tourism. The toxic HABs do not even provide a useful food source for the invertebrate grazers that are the base of most aquatic food webs.

The cause of the increasing number of blooms? One of them is climate change (Moore et al. 2008, Hallegraeff 2010). Warmer temperatures are boosting the growth of harmful algae (Paerl and Huisman 2008, Jöhnk et al. 2008). More floods and other extreme precipitation events are increasing the runoff of phosphorus and other nutrients from farms and other landscapes, fueling the algae's growth. The problem is only expected to get worse. By the end of the 21st century, HABs in Puget Sound may begin up to two months earlier in the year and persist for one month later compared to today—increasing the chances that paralytic toxins will accumulate in Puget Sound shellfish (Moore et al. 2011). In addition, the ranges of many harmful algal species may expand, with serious consequences. For example, a painful food-borne illness known as ciguatera, caused by eating fish that have dined on a toxin-producing microalga, is already becoming much more common in many tropical areas. Global warming will increase the range of the microalga—and the threat of poisoning.

It is possible, however, to successfully combat some HAB problems. One key strategy is reducing the flow of nutrients into waterbodies. Proven steps include adding effectively sited buffer strips beside streams or restoring wetlands to absorb nutrient pollution before the nutrients can reach streams, rivers, lakes, and oceans. For example, USDA Natural Resources Conservation Services' recent focus on improving soil health through the agriculture producers' voluntary implementation of a variety of Soil Health Management Systems will serve to optimize the reduction of sediment and nutrients to waterbodies. In addition, better detection and warning systems can reduce the danger to people.

Invasive species

Globalization and the increasing movement of people and goods around the world have enabled pests, pathogens, and other species to travel quickly over long distances and effectively occupy new areas. Historic invaders such as chestnut blight, Dutch elm disease, kudzu, and cheatgrass changed forever the character of our natural, rural, and urban landscapes. Climate change has already enabled range expansion of some invasive species such as hemlock woolly adelgid and will likely create welcoming conditions for new invaders. The buffelgrass invasion has forever changed the southwestern desert ecosystems by crowding out native plants and fueling frequent and devastating fires in areas where fires were once rare (Betancourt et al. 2010). Species such as zebra and quagga mussels, Asian carp, and kudzu already cause ecological and economic harm, such as competition for habitat, decreases in biodiversity, and predation of native species. In Guam, the brown tree snake (an invasive species introduced from the South Pacific after World War II) has caused the extirpation of most of the native forest vertebrate species, thousands of power outages, and widespread loss of domestic birds and pets (Fritts and Leasman-Tanner 2001, Vice et al. 2005).

TOWNEPOST NETWORK

Zebra mussels are particularly invasive, disrupting ecosystems and clogging pipes and waterways.

These invasions of new species are also getting a boost from land-use changes, the alteration of nutrient cycles, and climate change (Vitousek et al. 1996, Mooney and Hobbs 2000). Climate change can shift the range of invasive species, serve as the trigger by which non-native species do become invasive, and introduce and spread invasive species through severe weather events such as storms and floods. Species that have already colonized new areas in the United States may become more pervasive with changing conditions. For example, some invasive species like kudzu or cheatgrass may benefit when CO_2 concentrations increase or historical fire regimes are disturbed (Dukes and Mooney 1999). In addition, poison ivy, another injurious species (though native), may not only increase with the increase in CO_2, but is also likely to increase its production of urushiol, the oil in poison ivy that causes a rash for many people (Ziska et al. 2007). Early detection and a rapid coordinated response should be employed to contain invasive species (National Invasive Species Council 2008).

WHAT IS...?

Invasive Species

Invasive species are defined in Executive Order 13112 as alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. These are typically non-indigenous or non-native species that adversely affect the habitats and ecosystems they invade. These effects can be economic, environmental, and/or ecological. In addition, some native species can become destructive in certain ecological contexts such as with range expansions, while many non-native species do not negatively affect natural systems. Today, climate change may be redefining traditional concepts of native and non-native, as species move into new areas in response to changing conditions.

Over-use and destructive harvest practices

Over-use of America's fish, wildlife, and plants has also had major impacts. Some species have been lost from certain areas, while others have gone completely extinct. For example, overfishing of commercial and recreational fish stocks in some regions has had negative impacts on fish stocks, fish assemblages, and the communities and economies that depend on them. Some fishing methods can also damage habitats important to those and other species, and bycatch can have significant impacts on non-target species (NMFS 2011). A variety of laws, regulations and management efforts exist to address these existing stressors, including the implementation of rebuilding plans for over-fished fish stocks (NMFS 2009a), the designation and protection of essential fish habitats (NMFS 2009b), and implementation of bycatch reduction programs (NMFS 2011).

Pollution

Climate change can alter temperature, pH, dilution rates, salinity, and other environmental conditions that in turn modify the availability of pollutants, the exposure and sensitivity of species to pollutants, transport patterns, and the uptake and toxicity of pollutants (Noyes et al. 2009). For example, increasingly humid conditions could result in the increased use of fungicides (increased quantity), whereas altered pH can change the availability of metals (increased biological availability). In cases where climate change affects transport patterns of environmental pollutants, pollutants may reach and accumulate in new places, exposing biota to risk in different habitats. Climate change effects on uptake and toxicity can be the result of direct increases in the toxicity of some chemicals or increased sensitivity in the target species. Sensitivity can be increased due to general metabolic stress due to environmental changes or inhibition of physiological processes that govern detoxification.

Many pathogens are sensitive to changes in temperature, rainfall, and humidity, and climate change may result in increasing pathogen development and survival rates, disease transmission, and host susceptibility.

Pathogens

Many pathogens of terrestrial and marine taxa are sensitive to temperature, rainfall, and humidity making them sensitive to climate change. The effect of climate change may result in increasing pathogen development and survival rates, disease transmission, and host susceptibility. Although most host-parasite systems are predicted to experience more frequent or severe disease impacts under climate change, a subset of pathogens might decline with warming, releasing hosts from a source of population regulation. Detectable effects of climate change on disease include the geographic range expansion of the protistan parasite *Perkinsus marinus*, which causes Dermo disease in oysters, moving up the eastern seaboard as water temperatures have warmed (Ford 1996, Cook et al. 1998). Similarly, increased run-off from land has caused the spread of *Sarcocystis neurona*, a protozoan parasite in fecal waste from the invasive Virginia opossum, resulting in an increased infection rate in marine mammals including sea otters (Miller et al. 2010). Factors other than climate change—such as changes in land use, vegetation, pollution, or increase in drug-resistant strains—may also contribute to these range expansions. To improve our ability to predict epidemics in wild populations, it will be necessary to separate the independent and interactive effects of multiple climate drivers on disease impacts (Harvell et al. 2002). Another key concern is the entry of pathogens to fish and wildlife via legal wildlife trade which is not well monitored. Smith et al. (2009) found that of the approximately 200 million individual animals imported to the USA every year—many for the exotic pet trade, less than 14 percent are identified to the species level and more than half the individuals are only identified to the level of class.

Summary

Resource managers have worked long and hard to reduce the impact of these existing stressors in their management strategies. But as climate change will likely exacerbate these existing human-induced pressures on natural systems, one of the most successful strategies for increasing the resilience of fish, wildlife, and plants to a changing climate may be reducing the impact of these non-climate stressors (see Goal 7). For instance, warmer water temperatures have already caused many fish stocks off the northeast coast to shift northward and/or to deeper depths over a 40-year period (Nye et al. 2009). As populations move to new locations, fishing effort adjustments may be necessary to ensure sustainable populations.

DAVE MENKE/USFWS

There is high variability in the vulnerability and responses of organisms to climate change, leading to winners (i.e., species positively impacted) and losers (i.e., species negatively impacted).

In extreme cases, species have abandoned migration altogether, while in other cases species are now migrating to new areas where they were previously only occasional vagrants.

2.3 Climate Change Impacts on Fish, Wildlife and Plants

A changing climate can affect growth rates, alter patterns of food availability, and shift rates and patterns of decomposition and nutrient cycling. Changes can be driven by one or multiple climate-related factors acting in concert or synergistically and can alter the distribution, abundance, phenology, physiology and behavior of species, and the diversity, structure, and function of ecosystems. One forecast that seems certain is that the more rapidly the climate changes, the higher the probability of substantial disruption and unexpected events within natural systems (Root and Schneider 1993). The possibility of major surprises increases the need for adaptive management—where actions and approaches are flexible enough to be adjusted in the face of changing conditions.

Species and populations likely to have greater sensitivities to climate change include those with highly specialized habitat requirements, species already near temperature limits or having other narrow environmental tolerances, currently isolated, rare, or declining populations with poor dispersal abilities, and groups especially sensitive to pathogens (Foden et al. 2008). Species with these traits will be even more vulnerable if they have a small population, a low reproductive rate, long generation times, low genetic diversity, or are threatened by other factors. For example, the southwestern willow flycatcher may be considered especially vulnerable as it is currently endangered, especially sensitive to heat, primarily dependent on a habitat type projected to decline, and reliant on climate-driven environmental cues that are likely to be altered under future climate change (Glick et al. 2011a). For these reasons, maintaining rare or already threatened or endangered species will present significant challenges in a changing climate, because many of these species have limited dispersal abilities and opportunities (CCSP 2008c).

In addition, migratory species are likely to be strongly affected by climate change, as animal migration is closely connected to climatic factors, and migratory species use multiple habitats, sites, and resources during their migrations. In extreme cases, species have abandoned migration altogether, while in other cases species are now migrating to new areas where they were previously only occasional vagrants (Foden et al. 2008). However, an ability to move and utilize multiple habitats and resources may make some migratory species relatively less vulnerable. Similarly, many generalist species such as white-tailed deer or feral hogs are likely to continue to thrive in a changing climate (Johnston and Schmitz 2003, Campbell and Long 2009). International collaboration and action is critical to increasing the resilience and adaptation of species that cross and depend on areas beyond U.S. borders (e.g., migratory birds, many marine fishes, mammals, sea turtles etc.).

Climate impacts will vary regionally and by ecosystem across the United States (see Figures 1 and 2). Understanding the regional variation of impacts and how species and ecosystems will respond is critical to developing successful adaptation strategies. Examples of current and projected climate change impacts on ecosystems are summarized in Table 1.

The following sections are intended to summarize current knowledge on impacts of climate change on fish, wildlife, and plants within each of the major types of ecosystems within U.S. jurisdictions. Within each ecosystem type, a number of individual climate factors are listed and their direct effects on biota are discussed. However, many of the observed impacts are the result of climate factors acting in combination, as well as the combination of impacts across the ecosystem. While the individual effects are serious in themselves, it is the potential interactions of them—their cumulative effects through ecosystem processes that will likely lead to the greatest risk, both in potential magnitude of effects and in our uncertainty regarding the direction and magnitude of changes. For example, in marine systems, changes in community composition and food web structure resulting from the shifts in ecological niches for individual species are likely to be the largest influence of climate change (Harley et al. 2006). Single-factor studies will likely under-predict the magnitude of effects (Fabry et al. 2008, Perry et al. 2010).

In addition, impacts are not confined to a single ecosystem, nor do ecosystems have fixed boundaries. While this *Strategy* describes climate change impacts to distinct ecosystems, in actuality, vulnerability assessments and adaptation plans and actions should take into account the connections between ecosystems. For example, the mixing zone between the land and sea is affected by climate impacts to freshwater, coastal, and marine ecosystems, and adaptation strategies will need to address these multiple ecosystems.

CASE STUDY

Range shifts in a changing climate

SHELLEY ELLIS/NWF

ALL ACROSS THE COUNTRY, species are already on the move in response to climate change. For example, the range of the Edith's checkerspot butterfly has shifted northward almost 60 miles, with population extinctions seen along the southern range (Parmesan 2006). Species such as the red fox are increasingly able to move into previously inhospitable northern regions, which may lead to new competition and pressures on the Arctic fox (Killengreen et al. 2007). In Yosemite National Park, half of 28 species of small mammals (e.g., pinyon mouse, California vole, alpine chipmunk, and others) monitored showed substantial (500 meters on average) upward changes in elevation, consistent with an increase in minimum temperatures (Moritz et al. 2008).

Species are shifting in marine environments as well. In the Northeast United States, two-thirds of 36 examined fish stocks shifted northward and/or to deeper depths over a 40-year time period in response to consistently warmer waters (Nye et al. 2009). Similarly, in the Bering Sea, fish have moved northward as sea ice cover is reduced (Mueter and Litzow 2008). In the California Current ecosystem, shifts in spatial distribution were more pronounced in species that were commercially exploited, and these species may be more vulnerable to climate variability (Hsieh et al. 2008).

These types of range shifts are already widespread—indeed, in one analysis up to 80 percent of species analyzed were found to have moved consistent with climate change predictions (Parmesan and Yohe 2003).

Range shifts are not always negative: habitat loss in one area may be offset by an increase elsewhere such that if a species is able to disperse, it may face little long-term risk. However, it is clear that shifting distributions can lead to a number of new challenges for natural resource managers such as the arrival of new pests, the disruption of ecological communities and interspecies relationships, and the loss of particularly valued species from some areas. In addition, barriers to movement (such as development, altered ecosystems, or physical barriers like dams, fences, or roads) can keep species from reaching newly appropriate habitat. Other barriers are naturally occurring, such as those experienced by mountain-dwelling species that are limited in up-slope migration by the mountaintop, island species limited in migration by water depths, or aquatic and marine species limited by land barriers. Goal 1 of the Strategy describes the importance of providing linkages and corridors to facilitate connectivity while working to monitor and manage the movement of invasive species, pests, and pathogens.

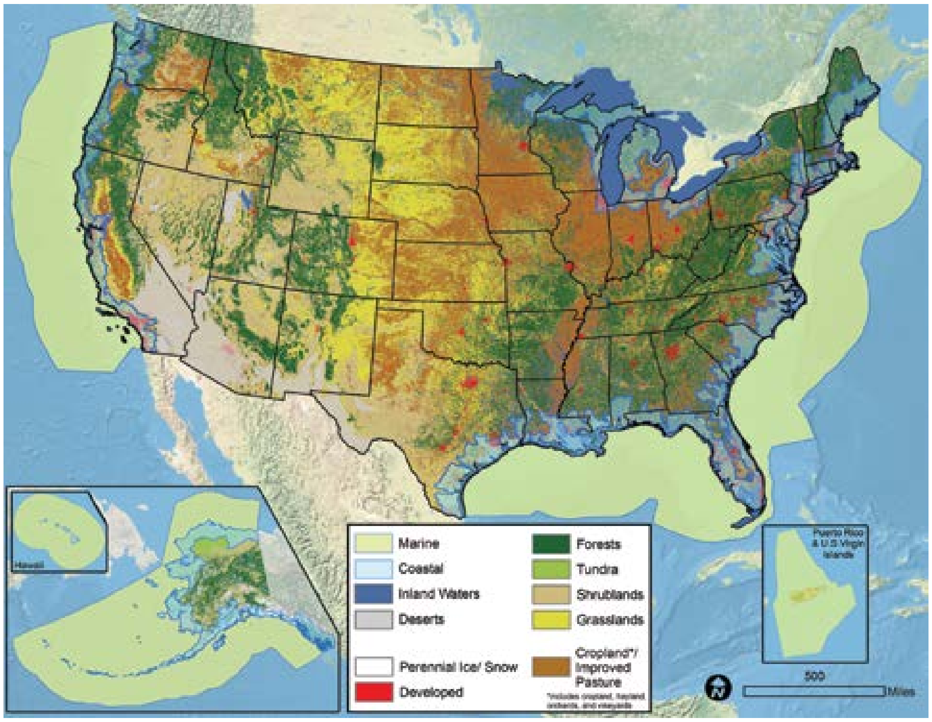


Figure 1: The distribution of the eight major ecosystems (forests, grasslands, shrublands, deserts, tundra, inland waters, coastal, and marine systems) described in the *Strategy*. Cropland (including cropland, hayland, vineyards, and orchards) and improved pasture, and developed areas are also shown.

Data source: Multi-Resolution Land Characterization (MRLC) Consortium National Land Cover Database (NLCD) 2006 (continental U.S, Hawaii), MRLC Consortium NLCD 2001 (Alaska), analysis by USGS EROS data center; NOAA's Coastal Geospatial Data Project and U.S. Maritime Zones, analysis by NOAA; USGS 1;250,000 hydrologic units of the United States.

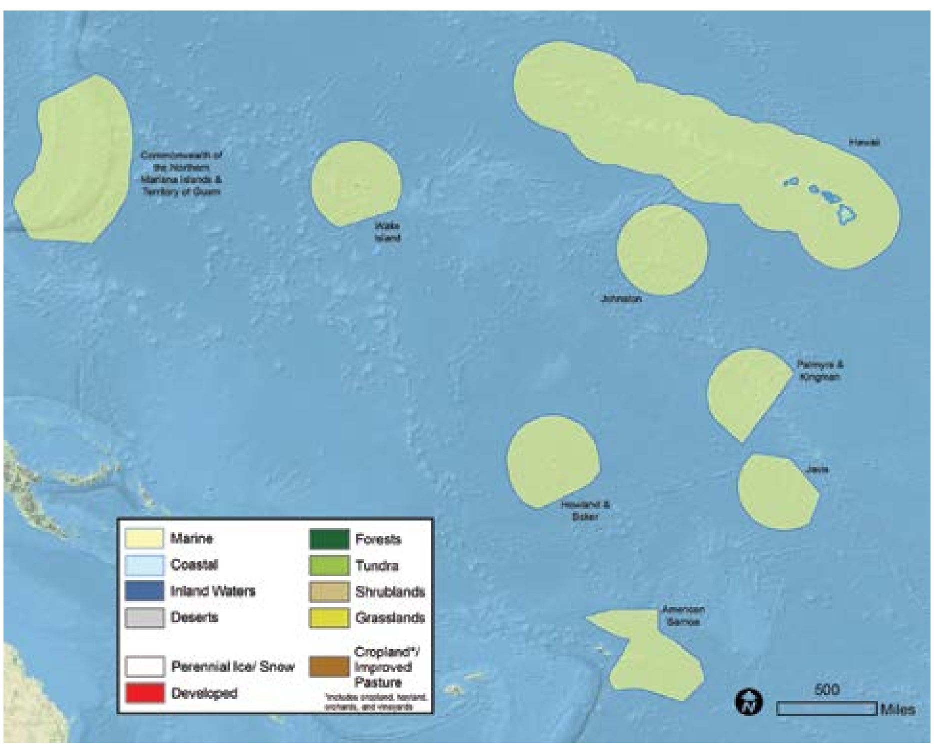


Figure 2: The distribution of the eight major ecosystems (forests, grasslands, shrublands, deserts, tundra, inland waters, coastal, and marine systems) described in the Strategy for the U.S. territories in the Pacific. Cropland (including cropland, hayland, vineyards, and orchards) and improved pasture, and developed areas are also shown. See Figure 1 for data sources.

temperature increases

INCREASING LEVELS OF GREENHOUSE GASES ON U.S. ECOSYSTEMS & SPECIES: OBSERVED & PROJECTED ECOLOGICAL CHANGES

Major Changes	Forests	Shrublands	Grasslands	Deserts	Tundra	Inland Waters	Coastal	Marine
Increased temperatures U.S. average temperatures have increased more than 2 °F in the last 50 years, and are projected to increase further. Global ocean temperatures rose 0.4 °F between 1955 and 2008.	» Increase in forest pest damage » Changing fire patterns » Longer growing season » Higher evapo-transpiration/ drought stress	» Increased fire frequency may favor grasses over shrubs » Increased evapo-transpiration/ intensified water stress » Spread of non-native species	» Spread of non-native plants and pests » Changing fire patterns	» Elevated water stress » Mortality in heat-sensitive species » Possible desert expansion » Spread of non-native species	» Higher water stress » Changing plant communities » Longer growing season » Invasion by new species » Increased fire » More freeze-thaw-freeze events » Changes in sub-nivean temp. (underneath the snow pack)	» Expansion of warm-water species » Depleted O_2 levels » Stress on coldwater species » Increased disease/ parasite susceptibility » More algal blooms	» Increase of salt marsh/ forested wetland vegetation » Distribution shifts » Phenology changes (e.g., phytoplankton blooms) » Altered ocean currents and larval transport into/out of estuaries	» Coral mortality » Distribution shifts » Spread of disease and invasives » Altered ocean currents and larval dispersal patterns » New productiv-ity patterns » Increased stratification » Lower dissolved O_2
Melting sea ice/ snowpack/ snow melt: Arctic sea ice extent has fallen 3–4% per decade over the last 30 years, and further loss is predicted. In terrestrial habi-tats, reduced snowpack, earlier snow melt, and widespread glacier melt and permafrost thawing are predicted.	» Longer frost-free periods » Increase in freeze/thaw events can lead to icing/ covering of winter forage » Decreased sur-vival of some insulation-dependent pests	» Reduced snowpack leads to hydro-logical changes (timing and quantity)	» Reduced snowpack leads to hydro-logical changes (timing and quantity)	» Reduced snowpack leads to hydro-logical changes (timing and quantity)	» Thawing permafrost/ soil » Hydrological changes » Terrain instability » Vegetation shifts » Longer snow-free season » Contaminant releases	» Snowpack loss changes the tempera-ture, amount, duration, dis-tribution and timing of runoff » Effects on coldwater and other species » Loss of lake ice cover	» Loss of anchor ice and shore-line protection from storms/ waves » Loss of ice habitat » Salinity shifts	» Loss of sea ice habitats and dependent species » Changes in distribution and level of ocean » Changes in ocean carbon cycle » Salinity shifts
Rising sea levels: Sea level rose by roughly 8" over the past cen-tury, and in the last 15 years has risen twice as fast as the rate observed over the past 100 years. Sea level will continue to rise more in the future.	 USFWS/STEVE HILLEBRAND				» Salt water intrusion » Loss of coastal habitat to erosion	» Inundation of freshwater areas » Groundwater contamination » Higher tidal/ storm surges	» Inundation of coastal marshes/low islands » Higher tidal/ storm surges » Geomorphology changes » Loss of nesting habitat » Beach erosion	» Loss of coral habitats » Negative impacts on many early life stages
Changes in circulation patterns: Warming of the atmosphere and ocean can change spatial and temporal pat-terns of water movement and stratification at a variety of scales.	 UNITED NATIONS FOOD AND AGRICULTURE ORGANIZATION/DANILO CEDRONE					Altered productivity and distribution of fish and other species with changes in lake circulation patterns	Altered productivity, survival, and/or distribution of fish and other estuarine dependent species	Altered produc-tivity, survival, and/or distribu-tion of fish and other species (particularly early life his-tory stages)

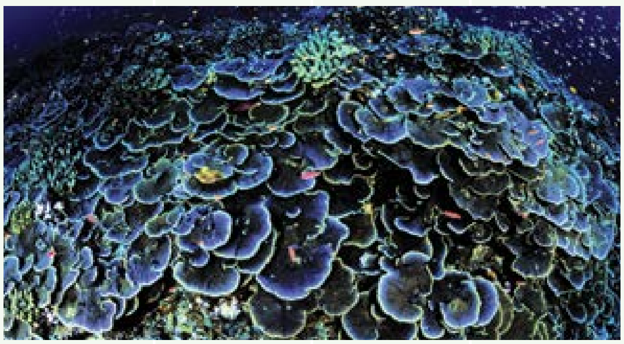
precipitation increases

INCREASING LEVELS OF GREENHOUSE GASES ON U.S. ECOSYSTEMS & SPECIES: OBSERVED & PROJECTED ECOLOGICAL CHANGES

Major Changes	Forests	Shrublands	Grasslands	Deserts	Tundra	Inland Waters	Coastal	Marine
Changing precipitation patterns Precipitation has increased approximately 5% in the last 50 years. Predictions suggest historically wet areas will become wetter, and dry, drier.	» Longer fire season » Changes in fire regime » Both wetter and drier conditions projected	» Dry areas getting drier » Changing fire regimes	» Invasion of non-native grasses and pests » Species range shifting » Changes in fire regime	Loss of riparian habitat and movement corridors	» More icing/ rain-on-snow events affect animal movements and access to forage » Increased fire	» Changing lake levels » Changes in salinity, flow	» Changes in salinity, nutrient, and sediment flows » Changing estuarine conditions may lead to hypoxia/anoxia » New productivity patterns	» Changes in salinity, nutrient and sediment flows » New productivity patterns
Drying conditions/drought Extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.	» Decreased forest productivity and increased tree mortality » Increased fire	» Loss of prairie pothole wetlands » Loss of nesting habitat » Increased fire	» Loss of prairie pothole wetlands » Loss of nesting habitat » Invasion of non-native grasses » Increased fire	» Increased water stress » Increased susceptibility to plant diseases	» Moisture stressed vegetation » Loss of wetlands » Fish passage issues	» Loss of wetlands and intermittent streams » Lower summer base flows » Decreased lake levels	» Changes in salinity, nutrient and sediment flows » Shifting freshwater input to estuaries	» Changes in salinity, nutrient and sediment flow » New productivity patterns
More extreme rain/weather events Rain falling in the heaviest downpours has increased approximately 20% in the past century. Hurricanes have increased in strength. These trends are predicted to continue.	» Increased forest disturbance » More young forest stands	More variable soil water content	Changing pest and disease epidemiology	Higher losses of water through run-off	More landslides/ slumps	» Increased flooding » Widening floodplains » Altered habitat » Spread of invasive species/ contaminants	» Higher waves and storm surges » Loss of barrier islands » Beach erosion » New nutrient and sediment flows » Salinity shifts; » Increased physical disturbance	» Higher waves and storm surges » Changes in nutrient and sediment flows » Impacts to early life stages » Increased physical disturbance

carbon dioxide increases

INCREASING LEVELS OF GREENHOUSE GASES ON U.S. ECOSYSTEMS & SPECIES: OBSERVED & PROJECTED ECOLOGICAL CHANGES

Major Changes	Forests	Shrublands	Grasslands	Deserts	Tundra	Inland Waters	Coastal	Marine
Increase in atmospheric CO_2 The concentration of CO_2 in the atmosphere has increased by roughly 35% since the start of the industrial revolution.	» Increase forest productivity/ growth in some areas » Insect pests may be affected » Changes in species composition	» Spread of exotic species such as cheatgrass » Impacts on insect pests » Changes in species composition	» Declines in forage quality from increased C:N ratios » Insect pests may be affected » Changes in species composition	» Increased productivity of some plants » Changes in communities » Increased fire risk	» Increased productivity of some plant species » Changes in plant community composition	» Increased growth of algae and other plants » Changes in species composition and dominance	» Increased terrestrial, emergent, and submerged plant productivity	» Increased plant productivity
Ocean acidification The pH of seawater has decreased significantly since 1750, and is projected to drop much more by the end of the century as CO_2 concentrations continue to increase.	 USFWS/JIM MARAGOS						» Declines in shellfish and other species » Impacts on early life stages	» Harm to species (e.g., corals, shellfish) » Impacts on early life stages » Phenology changes » Loss of the planktonic food base for critical life stages of commercial fishes

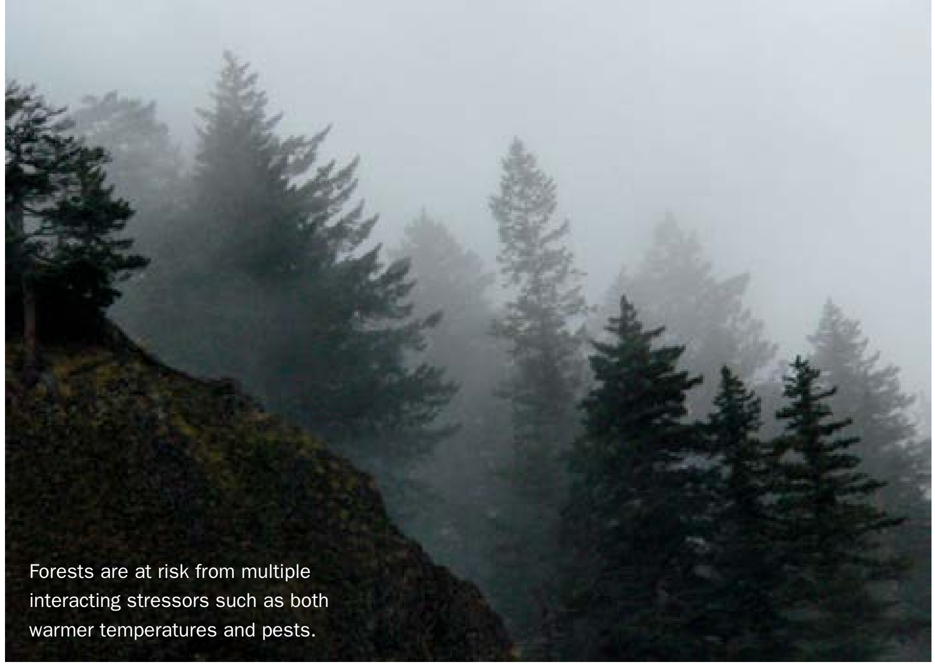
*This table is intended to provide examples of how climate change is currently affecting or is projected to affect U.S. ecosystems and the species they support, including documented impacts, modeled projections, and the best professional judgment of future impacts from Strategy contributors. It is not intended to be comprehensive, or to provide any ranking or prioritization. Climate change impacts to ecosystems are discussed in more detail in sections 2.3.1-2.3.8, and in online ecosystem specific background papers (see Appendix A).
**References: See IPCC AR4 2007, USGCRP 2009. See IPCC AR4 2007, USGCRP 2009, others in Chapter 2.

2.3.1 Forest Ecosystems

Approximately 750 million acres of the United States is forest, both public and private (Heinz Center 2008), including deciduous, evergreen, or mixed forests. This includes embedded natural features such as streams, wetlands, meadows, and other small openings, as well as alpine landscapes where they occur above the treeline (see Figure 1). Changing climate can affect forest growth, mortality, reproduction, and eventually, forest productivity and ecosystem carbon storage (McNulty and Aber 2001, Butnor et al. 2003, Thomas et al. 2004).

Atmospheric CO_2

National and regional scale forest process models suggest that in some areas, elevated atmospheric CO_2 concentrations may increase forest productivity by five to 30 percent (Finzi et al. 2007). Wetter future conditions in some areas may also enhance the uptake of carbon by ecosystems. However, other regions may experience greater than 20 percent reduction in productivity due to increasing temperatures and aridity. In some areas of the United States, higher atmospheric CO_2 may lead to greater forest water-use efficiency, while in other areas, higher evapotranspiration may result in decreased water flow (McNulty and Aber 2001). Species in today's highly fragmented landscape already face unprecedented obstacles to expansion and migration (Thomas et al. 2004), which may magnify the climate change threat to forests.



Forests are at risk from multiple interacting stressors such as both warmer temperatures and pests.

JANE PELLICCIOTTO

WHAT IS...?

Forest Carbon Sequestration

According to the U.S. Forest Service, terrestrial carbon sequestration is the process by which atmospheric CO_2 is taken up by trees, grasses, and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliage, and roots) and soils (U.S. Forest Service 2009). Reducing CO_2 emissions from deforestation and forest degradation (known internationally as REDD/REDD+) and restoring forested land cover in areas where it has been lost could play a major role in efforts to constrain the further increase of CO_2 in the atmosphere.

Although the destruction and conversion of tropical rainforests accounts for the majority of the buildup in greenhouse gasses (GHGs) from global land-use changes (IPCC AR4 2007), forests in North America are responsible for taking 140 to 400 million tons of carbon from the atmosphere and storing it in organic material each year. Because land-use changes and human population growth are expected to continue, the management of boreal and other North American forests for carbon sequestration is an important component in adapting and responding to climate change (Birdsey et al. 2007).

In the continental United States, land-use management can be utilized as a means of contributing to GHG sequestration efforts. For example, the National Wildlife Refuge System has conducted a number of projects restoring forested land cover in various refuges, and there is potential for many more such projects. In addition, no-till agriculture may reduce the emissions of CO_2 from the breakdown of organic matter in soils, and broader utilization of this cropping technique in the American agricultural sector could make a substantial contribution to limiting emissions of CO_2 (Paustian et al. 2000). Also, opportunities to protect U.S. tropical forests in Hawaii, Puerto Rico, and elsewhere as well as habitats such as coastal marshes may provide dual benefits of carbon sequestration and habitat protection.

Temperature Increases and Water Availability

In general, boreal type forest or taiga ecosystems are expected to expand northward or upward at the expense of Arctic and alpine tundra, and forests in the northwestern and southeastern United States might initially expand, although uncertainties remain (Iverson et al. 2008). Within temperate and boreal forests, increases in summer temperatures typically result in faster development and reproductive success of insects as well as changes in timing of development. As a result, these insects may interact with plant and wildlife species in different and sometimes problematic ways (Asante et al. 1991, Porter et al. 1991). Conversely, decreases in snow depth typically decrease overwinter survival of insects that live in the forest litter and rely on insulation by snow (Ayers and Lombardero 2000). Drier conditions in the southern United States and elsewhere could lead to increased fire severity and result in decreases in ecosystem carbon stocks (Aber 2001, Westerling et al. 2006, Bond-Lamberty et al. 2007). Similarly, prolonged drought may lead to decreases in primary production and forest stand water use (Van Mantgem et al. 2009). Drought can also alter decomposition rates of forest floor organic materials, impacting fire regimes and nutrient cycles (Hanson and Weltzin 2000). Changes in temperature, precipitation, soil moisture, and relative humidity can also affect the dispersal and colonization success of other forest pathogens, which may impact forest ecosystem biodiversity among other important indicators of forest health (Brasier 1996, Lonsdale and Gibbs 1996, Chakraborty 1997, Houston 1998).

Disturbances and Extreme Events

Disturbances such as wildfires, wind storms, and pest outbreaks are important to forests. Climate change is anticipated to alter disturbance frequency, intensity, duration, and timing, and may cause extreme changes in forest structure and processes (Dale et al. 2000, Running 2008). For example, predictive models suggest that the seasonal fire severity rating will increase by 10 to 50 percent over most of North America, which has the potential to overshadow the direct influences of climate on species distribution and migration (Flannigan et al. 2000). Certain forest systems, such as ponderosa pine forests, may be less resilient to fire disturbance because of the laddering effect young trees, which developed during periods of infrequent fire occurrence, have on increasing the severity of fires (Climate Impacts Group 2004). Climate-related changes in fire incidence may also increase associated mercury emissions from fires in boreal forests, presenting a growing threat to aquatic habitats and northern food chains (Turetsky et al. 2006). Friedli et al. (2009) suggest that a warming climate in boreal regions, which contain large carbon and mercury pools, will increasingly contribute to local and global mercury emissions due to more frequent and larger, more intense wildfires.

While projections of hurricane response to climate change are still uncertain, models agree on a possible increase in the intensity of Atlantic hurricanes (USGCRP 2009). If hurricane intensity increase, then more forests could be set back to earlier successional stages in areas susceptible to hurricanes (Lugo 2000).

CASE STUDY

Bark beetle outbreaks in warmer winters


TERRY TYSON

FROM BRITISH COLUMBIA TO NEW MEXICO, forests are being devastated at unprecedented levels by an epidemic—caused by a tiny insect called the mountain pine beetle. The beetles lay their eggs under the bark of trees, and in the process, infect the trees with fungus. When the eggs hatch, the combination of fungal infection and feeding by the beetle larvae kill the trees.

Bark beetles and pine trees have co-existed for eons. Regular outbreaks of beetles causing forest death are normal, but nothing like those now being seen. So why has the beetle suddenly become so destructive? In the past, sub-zero winter temperatures kept beetle populations in check by directly killing the insects. Cold temperatures also kept the beetle from extending its range farther north and to higher elevations (Amman 1974).

Warming temperatures over the last few decades, however, has enabled more beetles to survive the winter and to move to higher elevations and northward to regions like British Columbia. They have rapidly colonized areas that were previously climatically unsuitable (Carroll et al. 2003). Because these new areas had not previously experienced beetle outbreaks, they contained mature stands of trees, which are particularly susceptible. In addition, warmer summer temperatures have sped up the life cycle of the beetle, enabling it to complete more generations per year (Carroll et al. 2003). All these changes have resulted in unprecedented forest death. The current outbreak in British Columbia, for instance, is 10 times larger in area and severity than all previous recorded outbreaks (Kurz et al. 2008).

This massive loss of trees poses major challenges to forest and ecosystem managers. But there are steps that can be taken to reduce the negative impacts and prevent spreading. According to the U.S. Forest Service, the governments of British Columbia and Alberta, in an attempt to avoid further eastward expansion and potential invasion of the boreal jack pine forests, implemented an aggressive control program to suppress beetle populations east of the Rocky Mountains through felling and burning infested trees. Since its inception in 2004, the program has managed to keep beetle populations from expanding (RMRS 2009).

2.3.2 Shrubland Ecosystems

Shrublands of various types and sizes occur throughout the United States and total approximately 480 million acres (Heinz Center 2008) (see Figure 1). Shrublands are landscapes dominated by woody shrub species, often mixed with grasses and forbs (non-woody flowering plants). They provide habitat for numerous native plant and animal species. Sagebrush habitats alone support more than 400 plant species and 250 wildlife species (Idaho National Laboratory 2011), including 100 birds and 70 mammals (Baker et al. 1976, McAdoo et al. 2003). Climate change will increase the risk to shrubland species because many already live near their physiological limits for water and temperature stress.

Atmospheric CO_2

Increased CO_2 can lead to changes in species distribution and community composition in the shrublands. For example, the spread of invasive cheatgrass has likely been favored by rising CO_2 concentrations, which has been shown to benefit species, such as cheatgrass, that utilize a particular type of photosynthesis (known as C3 photosynthesis) (D'Antonio and Vitousek 1992, Larrucea and Brussard 2008). In contrast, warmer and drier conditions may favor plants that utilize a different photosynthetic system (C4).

Temperature Increases

Since 1980, western U.S. winter temperatures have been consistently higher than the previous long-term averages, and average winter snow packs have declined (McCabe and Wolock 2009). Higher temperatures associated with climate change are likely to intensify water stress through increased potential evapotranspiration (Hughes 2003). The increase in temperature also further benefits invasive cheatgrass, which thrives in hot, open, fire-prone environments and crowds out native shrubland species, and may alter fire regimes. These types of changes in community composition may impact shrubland species like the greater sage grouse (Aldridge et al. 2008).

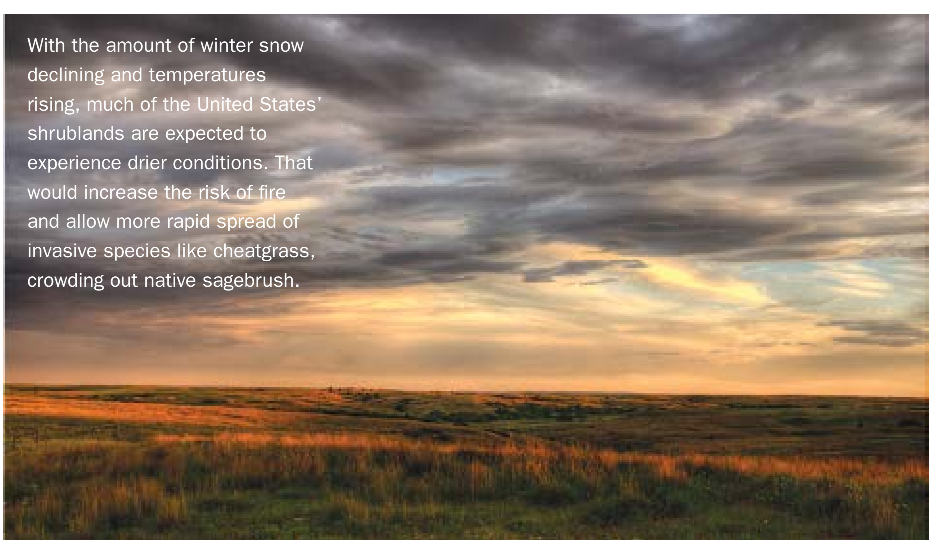
Water Availability

As a result of warmer temperatures, the onset of snow runoff in the Great Basin is currently 10 to 15 days earlier than it was 50 years ago. This has resulted in significant impacts on the downstream use of the water (Ryan et al. 2008), though periods of higher than average precipitation have helped to offset declining snow packs (McCabe and Wolock 2009). Changes in snow packs can reduce the forage available for grazing wildlife, as well as the livestock carrying capacity on working lands. Climate changes in shrubland areas can be complex: in areas where both a reduction in total annual rainfall and increased intensity of individual precipitation events are projected, wet areas are likely to become wetter while dry areas may become drier. More intense rainfall events without increased total precipitation can lead to lower and more variable soil water content, and reduce above-ground net primary production. However, some regions, such as the Great Basin, are projected to become both warmer and possibly wetter over the next few decades (Larrucea and Brussard 2008).

2.3.3 Grassland Ecosystems

Grasslands, including agricultural and grazing lands, cover about 285 million acres of the United States, and occur mostly between the upper Midwest to the Rocky Mountains and from Canada to the central Gulf Coast (CEC 1997, Heinz Center 2008). Grassland vegetation is very diverse, and includes many grass species mixed with a wide variety of wildflowers and other forbs. Grassland types include tallgrass, shortgrass, and mixed-grass systems. They also have embedded features such as the shallow, ephemeral wetlands known as prairie potholes and playas, which are openings in the prevailing grassland matrix that dot the Great Plains (see Figure 1). Grassland function is tied directly to temperature, precipitation and soil moisture; therefore, climate change is likely to lead to shifts in the structure, function, and composition of this system. Grasslands also store significant amounts of carbon, primarily in the soil (IPCC WGII 2007).

BEN DAVIS



With the amount of winter snow declining and temperatures rising, much of the United States' shrublands are expected to experience drier conditions. That would increase the risk of fire and allow more rapid spread of invasive species like cheatgrass, crowding out native sagebrush.

CHASE FOUNTAIN

Grasslands include tallgrass prairie, cattle pastures, and ephemeral prairie pothole wetlands that function as the primary breeding grounds for ducks. The warmer, drier conditions expected from climate change will likely dry up wetlands, speed the invasion of non-native grasses and pests, bring more fires, and reduce the quality of forage for livestock and wildlife.

Atmospheric CO_2

Increased CO_2 levels may affect the grassland system in multiple ways. For example, forage quality may decline due to increases in the carbon to nitrogen ratios of plant material, resulting in lower crude protein content (Milchunas et al. 2005). In addition, plants that utilize C3-type photosynthesis (e.g., cheatgrass) stand to benefit from increased atmospheric CO_2 (D'Antonio and Vitousek 1992, Larrucea and Brussard 2008), while C4 species are more efficient at using water under hot, dry conditions and may respond favorably to increased water stress and lower soil moisture conditions. One CO_2 enrichment experiment on shortgrass prairie showed a 20-fold increase in cover of a C3 shrub over C4 grass cover (Morgan et al. 2007), while other reports show an advantage for C4 over C3 grasses in a CO_2-enriched, warmer environment (Morgan et al. 2011). The future distribution of these species will no doubt be influenced by the interaction of CO_2, available moisture, and temperature, which may produce grassland communities with altered species compositions.

Temperature Increases and Water Availability

In recent decades, average temperatures have increased throughout the northern Great Plains, with cold days occurring less often and hot days more often (DeGaetano and Allen 2002). Precipitation has increased overall (Lettenmaier et al. 2008). Future changes projected for the Great Plains include increasing average annual temperatures from approximately 1.5 to 6 °F by mid-century to 2.5 to 13 °F by the end of the century. More frequent extreme events such as heat waves, droughts, and heavy rains; and wetter conditions north of the Texas Panhandle are also projected (USGCRP 2009). However, the projected increases in precipitation are unlikely to be sufficient to offset overall decreases in soil moisture and water availability due to increased temperature and water utilization by plants as well as aquifer depletion (USGCRP 2009).

Climate change is expected to stress the sensitive prairie pothole habitat with increasing temperatures and changing rainfall patterns, which will alter rates of evaporation, recharge, and runoff in these pond systems (Matthews 2008). Recent modeling projects that the prairie pothole region of the Great Plains will become a much less resilient ecosystem, with western areas (mostly in Canada) likely becoming drier and eastern areas (mostly in the United States) having fewer functional wetlands. These changes are likely to reduce nesting habitat and limit this "duck factory" system's ability to continue to support historic levels of waterfowl and other native wetland-dependent species (Johnson et al. 2010). In addition to the significant ecological consequences, this could mean fewer ducks for waterfowl hunters across the United States.

Temperature changes are also likely to combine with other existing stressors to further increase the vulnerability of grasslands to pests, invasive species, and loss of native species. For example, populations of some non-native pests better adapted to a warmer climate are projected to increase, while native insects may be able to reproduce more quickly (Dukes and Mooney 1999).

2.3.4 Desert Ecosystems

Deserts are characterized by temperate climates having low annual rainfall, high evaporation, and large seasonal and diurnal temperature contrasts. The hot desert systems of the United States include the Mohave, Sonoran, and Chihuahuan Deserts (note that the so-called "cold deserts" including much of the Great Basin, are covered in this *Strategy* under Shrublands, see Figure 1). This definition includes embedded features such as "sky islands," wetlands, and mosaics of grasses and shrubs. Desert systems harbor a high proportion of endemic plants, reptiles, and fish (Marshall et al. 2000). Desert ecosystems are particularly susceptible to climate change and climate variability because slight changes in temperature, precipitation regimes, or the frequency and magnitude of extreme events can substantially alter the distribution and composition of natural communities and services that arid lands provide (Archer and Predick 2008, Barrows et al. 2010).

Temperature Increases

Like most of the rest of the United States, the arid West and Southwest have been warming over the last century. Climate models project that these areas will continue to warm a further 3.6 to 9.0 °F by 2040 to 2069 in the summer months (AZ CCAG 2006), while parts of southern Utah and Arizona have already seen greater than average increases in temperature (e.g., 3 to 5 °F; USGCRP 2009). Most models project drying, increased aridity, and continued warming in the deserts, as well as increased severity and duration of droughts (USGCRP 2009). Higher temperatures and decreased soil moisture will likely reduce the stability of soil aggregates, making the surface more erodible (Archer and Predick 2008). Other trends include widespread warming in winter and spring, decreased frequency of freezing temperatures, a longer freeze-free season, and increased minimum winter temperatures (Weiss and Overpeck 2005).

Water Availability

The southwest has experienced the smallest increase in precipitation in the last 100 years of any region in the coterminous United States (CCSP 2008c). Precipitation is projected to increase slightly in the eastern Chihuahuan Desert but decrease westward through the Sonoran and Mojave Deserts (Archer and Predick 2008). Overall water inputs are expected to decline due to the combined effects of reduced total precipitation, elevated water stress in plants at higher temperatures, and greater run-off losses associated with increased frequencies of high intensity convectional storms (Archer and Predict 2008). Declining rainfall may eliminate wetlands, especially in marginally wet habitats such as vernal pools and in near-deserts. Varied rainfall and higher temperatures will also likely exacerbate existing stressors coming from recreation, residential, and commercial development and improper livestock grazing (Marshall et al. 2000).

Although precipitation-fed systems are most at risk, groundwater-fed systems in which aquifer recharge is largely driven by snowmelt may also be heavily affected (Burkett and Kusler 2000, Winter 2000). Reductions in water levels and increases in water temperatures will potentially lead to reduced water quality and decreased dissolved oxygen concentrations (Poff et al. 2002). Decreased water availability and expanded development will also impact desert riverine and riparian ecosystem function and disrupt movement corridors through the desert, which provide important habitat for arid land vertebrates and migratory birds (Archer and Predick 2008).

Many desert plants and animals already live near their physiological limits for water and temperature stress. For example, diurnal reptiles may be particularly sensitive due to their sedentary behavior and occurrence in very hot and dry areas (Barrows 2011). When compounded by persistent drought, climate change creates conditions that favor drought-tolerant species, leading to new species compositions of natural communities (CCSP 2009b). For example, Saguaro density and growth has declined with drought and reduced perennial shrub cover, and the range and abundance of this charismatic species will likely decline as well. Similarly, the abundance and range of nonnative grasses will most likely increase in future climates, including the spread of cheatgrass and buffelgrass (Enquist and Gori 2008). These and other non-native species have significantly altered fire regimes, increasing the frequency, intensity, and extent of fires in the American Southwest (D'Antonio and Vitousek 1992, Brooks and Pyke 2002, Heinz Center 2008).

CHASE FOUNTAIN

Temperatures in the arid West and Southwest have already climbed more than the U.S. average, and climate models project this trend to continue. Many cacti and other plant and animal species are already living near their physiological limits for water and temperature stress; many may not survive the coming changes in climate.

CASE STUDY

Cactus vulnerability

JANE PELLICCIOTTO

CACTI MAY BE AN ICONIC SYMBOL of the arid American desert, but this symbol faces an increasingly uncertain future. Adapted to hot, dry environments such as those found in the southwestern deserts of the United States, most cacti species have very specific habitat requirements that also make them highly vulnerable to climate change and susceptible to small changes in their environment. Another key vulnerability is potential disruption of associated species interactions under climate change. For example, many cacti depend on other species for pollination, to provide habitat, or to protect them from herbivores. Changes in climate may result in mismatches in time or space between the cacti and other species upon which they depend.

While helping these species adapt will be challenging, the first key management step is figuring out which species are the most vulnerable and which might be able to survive or even thrive in a climate-changed world. One such assessment is already underway. NatureServe is seeking to develop Climate Vulnerability Indices for over a hundred cactus species found in the Sonoran, Mojave, and Chihuahuan deserts. This process includes assessing a species' exposure and sensitivity to climate change through several factors, which are combined into a categorical vulnerability score. For example, in the Chihuahuan Desert, most cactus species assessed were either moderately (43 percent), highly (21 percent) or extremely (four percent) vulnerable to climate change (Hernández et al. 2010).

These types of vulnerability indices highlight the need for continued research on how climate change is likely to impact particular species and can help to establish priorities for adaptation activities. They are also tools to better inform management plans and conservation activities. In addition, vulnerability assessments may also help us identify those instances when viable adaptation measures simply may not be available.

Disturbances and Extreme Events

An increased frequency of extreme weather events such as heat waves, droughts, and floods is projected (Archer and Predick 2008, IPCC 2011). For example, climate change is projected to increase the frequency and intensity of storm events in the Sonoran Desert (Davey et al. 2007). This will result in longer dry periods interrupted by high-intensity rainstorms, and has the paradoxical effect of increasing both droughts and floods. Erosive water forces will increase during high-intensity runoff events, and wind erosion will increase during intervening dry periods (Archer and Predick 2008).

2.3.5 Arctic Tundra Ecosystems

Arctic tundra is the ecological zone of the polar regions of the Earth, occurring mainly north of the Arctic Circle and north of the boreal forest zone. Alpine tundra is the ecological zone occurring above treeline even in the non-polar regions of the Earth (see Case Study on Alpine Tundra). This section focuses on the much more extensive Arctic tundra. Arctic tundra is characterized by an absence of trees, and occurs where tree growth is limited by low temperatures and short growing seasons. In the United States, Arctic tundra ecosystems represent 135 million acres on the North Slope and west coast of Alaska (Gallant et al. 1995, Heinz Center 2008) (see Figure 1). In most areas, soils are underlain by permanently frozen ground, known as permafrost, with a shallow thawed layer of soil that supports plant growth in the summer. Alaska's tundra contains one of the largest blocks of sedge wetlands in the circumpolar Arctic (one quarter of global distribution) and provides breeding grounds for millions of birds (more than 100 species). Climate-driven changes in the tundra ecosystem are already being observed, and include early onset and increased length of growing season, melting of ground ice and frozen soils, increased encroachment of shrubs into tundra, and rapid erosion of shorelines in coastal areas (Hinzman et al. 2005, Richter-Menge and Overland 2010).

Atmospheric CO_2

Fire is predicted to increase in the Arctic tundra if the climate continues to warm (Krawchuck et al. 2009). This has the potential to release carbon that has taken decades to store, in a matter of hours, increasing the amount of CO_2 in the atmosphere (Hansen and Hoffman 2011, Mack et al. 2011). Melting permafrost and increased biological activity, coupled with saturated soil conditions will, and are, liberating increased amounts of carbon dioxide as well as methane and nitrous oxide to the atmosphere (O'Connor et al. 2010). In addition, the thawing of frozen organic material stored in tundra soils will release huge amounts of GHGs such as CO_2 and methane into the atmosphere, contributing to climate change (Schaefer et al. 2011) and exacerbating climate change in a way that none of the global climate change models have taken into account.

Temperature Increases

Climate is changing worldwide, but the Arctic has already warmed at a rate almost twice the global average (ACIA 2004). Spring snow melt has been occurring earlier as temperatures increase, leading to an earlier "green-up" of plants. A longer snow-free season also leads to local landscape warming that contributes to further climate change (Hinzman et al. 2005). Increased frequency of freeze-thaw-freeze events are another by-product of warming winter temperatures in the Arctic and sub-Arctic. Historically, fires have been common in northwestern Alaska short shrub tundra and rare in northern Alaska tussock tundra, but a change to tall shrub tundra will likely result in an increase in fire frequency in both systems (Higuera et al. 2008, 2011). A positive feedback relationship can result, as soils tend toward warmer and drier conditions after fire, promoting shrub growth and a more fire-prone landscape (Racine et al. 2004).

Analysis of satellite images has shown an increase in greenness in arctic Alaska over the last three decades indicating increased plant cover (Hinzman et al. 2005). Other studies have documented recent advancement of trees and tall shrubs onto tundra, which is expected to continue (Lloyd et al. 2003, Tape et al. 2006). Similarly, Arctic specialist animals may face increased competition as less cold-tolerant species expand their ranges northward (Martin et al. 2009). For example, the arctic fox may suffer if competitors such as red foxes continue to increase in abundance.

STEVE CHASE/USFWS

The most dramatic climate change in the United States is occurring in Alaska. Already, permafrost is thawing, fires are increasing, and shrubs and trees are replacing sedge wetlands and grasses.

CASE STUDY

Cimate change in alpine tundra systems

LYNETTE SCHIMMING

SPECIES ADAPTED TO LIFE IN THE ALPINE zone are often highly specialized for survival in cold temperatures, desiccating winds, and sparse soil and vegetation. In addition, alpine species are often endemic, restricted to only one area, because they have been isolated for thousands of years on "sky islands," high peaks surrounded by warmer lowlands.

In alpine systems, snow is of particular importance as it influences plant phenology, growth, and species composition. With warmer temperatures, more precipitation falls as rain rather than snow and the timing of snowmelt advances earlier in the spring. While warming temperatures allow for a longer growing season, earlier green-up and loss of winter frost hardiness expose plants to more killing frosts in the spring. If the insulating blanket of snow is thinner and lasts less time, then there is less protection for alpine plants and animals in the winter and soil temperatures will be lower (Wipf et al. 2009). Species will have different responses to climate warming, but research suggests that greater temperatures and advanced snowmelt could harm alpine systems and the species that depend on them.

The American pika, which lives in high elevation areas, is an example of a species very vulnerable to climate change. This small rabbit-like creature has a warm fur coat and high body temperature to survive winters without hibernating, and dies if its internal temperature increases even a few degrees. It is estimated that local pika extinctions in the Great Basin have been five times as high in the last ten years as they were in the previous century, and the low-elevation boundary for this species is moving upslope by almost 150 meters per decade (Beever et al. 2011).

Temperatures in the alpine areas of the western United States have risen faster in the past quarter century than temperatures in the lowlands (Diaz and Eischeid 2007). With warming temperatures, many plant and animal species have migrated uphill and northward (Parmesan and Yohe 2003, Moritz et al. 2009). This presents a vivid image of plant and wildlife species migrating uphill until they reach the last summits and literally, run out of room. Even if their habitats do not disappear entirely, their species ranges will become smaller, because mountain peaks are smaller than mountain bases. Smaller ranges will decrease species' genetic diversity and increase the risk of extinction.

The Köppen climate classification system maps climatic regions of the world, defining the alpine tundra climate by using the widely accepted critical threshold of an average temperature below 50 °F during the warmest month of the year. Diaz and Eischeid (2007) found that the amount of area in the western continental United States with an alpine tundra climate decreased by 73 percent during the previous two decades. This indicates that almost three quarters of the alpine tundra is out of equilibrium with the current climate, meaning it is a stressed ecosystem and little of it is likely to persist in its present form into the future.

Water Availability

While precipitation is generally expected to increase in the future, models project a generally drier summer environment due to higher air temperatures, increased evaporation, and increased water use by plants (SNAP 2008). Changes in overall water balance strongly affect this habitat, where water remains frozen most of the year. Fish will be affected by higher water temperatures and by the changes in precipitation, soil moisture, soil and water chemistry, and drainage related to permafrost degradation (Martin et al. 2009). Similarly, changes in water flow, water chemistry, turbidity, and temperature could cause physiological stress to species that cannot adapt to the new conditions. Some Arctic fish species migrate between marine and freshwaters, while others remain in freshwater throughout their life history, and involve movements from limited overwintering habitat to spawning and feeding habitat. These fish species will suffer if climate-driven stream changes prevent fish passage (Martin et al. 2009).

Thawing Permafrost

Increasing seasonal melting of ground ice and frozen soils (permafrost) is already measurably altering habitats and water distribution on the landscape, allowing new hydrologic patterns to form (Jorgenson et al. 2006). Because of warming in western Alaska, permafrost has become absent or thin and discontinuous, and more changes are expected such as lake drying (Yoshikawa and Hinzman 2003). Large mammals such as caribou and muskoxen suffer when access to forage is hampered by deep snow pack or a hard snow crust, caused by winter thaw-freeze-thaw or rain-on-snow events which are expected to increase in a warmer climate (Martin

Increasing global air temperatures and changing precipitation patterns are raising water temperatures and changing stream flows, affecting such ecosystem processes as productivity and decomposition and disrupting food web relationships.

et al. 2009). Changes in the quantity and quality of forage may also have profound effects on mammal populations, while wildlife pests and diseases are projected to increase their northern range limits (Martin et al. 2009). Warmer summers, a longer open water season, and delayed freeze-up would likely improve reproductive success for some bird species, though warmer summers could also cause drying of the wetland habitats and aquatic food sources that many birds rely upon. While birds time their breeding primarily to the solar calendar, increasing water temperature may cause aquatic insects to hatch earlier, resulting in a mismatch in timing.

Loss of permafrost and/or erosion may also affect the mobilization of pollutants from historical waste disposal sites, sewage lagoons, former military sites, mine tailings storage areas, and oil storage pits (Macdonald et al. 2003). Peatlands throughout the arctic and subarctic have accumulated carbon and trace elements such as mercury for thousands of years (Rydberg et al. 2010). Increased permafrost melt and erosive processes may enhance transport of mercury to Arctic lakes and coastal zones (Macdonald et al. 2003). Thawing of permafrost and the subsequent export of carbon and mercury to freshwater systems has been documented in Sweden and is thought to present a growing threat throughout the circumpolar region (Rydberg et al. 2010).

Sea Level Rise

Particularly in western Alaska, large areas of low-lying coastal plain bird habitat are predicted to disappear within this century, due to sea level rise and storm surges. This degradation may only be partially offset by increased sedimentation rates and tectonic rebound in some areas.

Additionally, the vast shallow wetlands of coastal plain tundra are sensitive to changes that could lead to drying. Any intrusion of saline water into formerly fresh systems results in rapid and dramatic change in vegetation (Martin et al. 2009).

Sea Ice Change

Summer sea ice has receded dramatically near northern and western Alaska in recent decades. The lack of near-shore ice in summer has made the shoreline more vulnerable to storm-induced erosion, reducing the value of these areas as wildlife habitat (Hinzman et al. 2005). In some areas, erosion rates have doubled since the middle of the last century (Mars and Houseknecht 2007). Decreasing sea ice is causing more polar bears to den and forage on land rather than on the sea ice. As a result, they can experience negative encounters with grizzly bears and humans.

2.3.6 Inland Water Ecosystems

Inland waters range from ephemeral pools and intermittent streams to large regional and national features such as the Great Lakes, Mississippi River, Ogallala aquifer, and Everglades. Inland waters are non-tidal (starting at the head of tide) and include natural features such as wetlands, rivers, and lakes, as well as artificial and human-altered waterbodies such as ponds, reservoirs, canals, and ditches (Cole 1994, see Figure 1). These waters and associated riparian areas provide habitats to support a broad range of aquatic and terrestrial wildlife and vegetation, and provide ecological connectivity. Increasing global air temperatures and changing precipitation patterns are raising water temperatures and changing stream flows, affecting such ecosystem processes as productivity and decomposition and disrupting food web relationships.

Temperature Increases

A recent analysis showed that many rivers and streams in the United States have warmed by approximately .2 °F–1.4 °F per decade over the past 50 to 100 years, and will continue to warm as air temperatures rise (Kaushal et al. 2010). Water temperature affects the physiology, behavior, distribution, and survival of freshwater organisms, and even slight changes can have an impact (Elliott 1994). Water temperature increases will allow the geographic area suitable for warm-water aquatic species to expand (Eaton et al. 1995, Eaton and Sheller 1996, Pilgrim et al. 1998, Poff et al. 2002, Rieman et al. 2007, Rahel and Olden 2008, Williams et al. 2009). The number of streams with temperatures suitable for warm-water fish and other freshwater organisms is projected to increase

USFWS/MATT POOLE

Many of the nation's lakes, rivers, and streams are expected to warm, and lake levels are expected to change. Coldwater fish like trout and salmon will be adversely affected, while warmer water species will expand their range.

by 31 percent across the United States (Mohseni et al. 2003). This would likely mean a concomitant decline of coldwater fisheries habitat.

These temperature increases will harm some inland water species. For example, one long-term study showed that a 1.2 °F increase in stream temperature caused coho salmon fry to emerge from the gravel six weeks earlier and move to the ocean two weeks earlier. This causes lower survival rates due to a mismatch in timing with peak prey abundance in the ocean (Holtby et al. 1990). Higher temperatures and more severe droughts also dry up streambeds and wetlands, harming species such as waterfowl (Johnson et al. 2005). Temperature increases could lead to changes in predation. For instance, it is projected that there would be a four to six percent increase in per capita consumption of salmonids by smallmouth bass and walleye for every 1.8 °F increase of annual river temperatures near the Bonneville Dam on the Columbia River (Rahel and Olden 2008). Warming temperatures also increase the susceptibility of organisms to disease, and may allow diseases to spread for longer periods and reproduce more quickly. For example, low flows and warmer waters contributed to a massive fish kill from a parasite infestation among spawning Chinook salmon in the Klamath River in September 2002 (CADFG 2008).

Water Availability

Precipitation changes in the United States are projected to vary regionally. Higher precipitation and runoff in the winter and spring are expected in the Northeast and Midwest, and decreasing precipitation and runoff are expected in the arid West in spring and summer (USGCRP 2009). In areas of high snowpack, runoff is beginning earlier in the spring and stream flows are lower in the late summer. This affects flow-dependent species and estuarine systems and reduces habitat area and connectivity while increasing water temperature and pollution levels. In contrast, higher flows and frequent storms can create wider floodplains, alter habitat, increase connectivity, displace riparian and bottom-dwelling species, or further distribute invasive species (Le Quesne et al. 2010). Changing flood and freshwater runoff patterns can impact critical life events such as the spawning and migration of salmon. Increased evaporation of seasonal wetlands and intermittent streams can also destabilize permanent waterbodies and cause a loss of habitat or a shift in species composition (Le Quesne et al. 2010).

CASE STUDY

Water losses under climate change

BETWEEN 2000 AND 2010, the worst drought ever recorded since Euro-American settlement hit the Colorado River Basin. Water levels in Lake Mead dropped to record lows. The drought not only threatened the supply of water to cities like Las Vegas, it also harmed the ecosystems and riparian areas that support countless fish, plants, and animals and endangered species, like the humpback chub and the southwestern willow flycatcher.

Climate models project that the decade-long drought that gripped the region may become the normal climate instead of the rare exception, perhaps as soon as the end of the 21st century (Barnett and Pierce 2009, Rajagopalan et al. 2009). The threat is being taken seriously by the Bureau of Reclamation, which has developed a plan that brings all stakeholders together in an attempt to balance human needs for water while providing sufficient flows and habitat for sustainable fish, wildlife, and plant populations.

Similar challenges must be faced around the nation. Long-term records at Anvil Lake, a groundwater-fed lake in northern Wisconsin, highlight the importance of water levels to fish, wildlife, and plant species. Over centuries, the lake's water level has risen and fallen. However, Anvil Lake's water level became progressively lower during each succeeding dry period, especially during the most recent dry period (WICCI 2011). In the future, any water loss through evapotranspiration associated with warmer temperatures would be expected to exacerbate any drought effect in similar aquatic systems.

These examples hold an important lesson for adaptation strategies. To help plants, wildlife, and ecosystems adapt to a changing climate, it is not enough to focus just on the natural world. Ensuring that ecosystems have enough water in regions expected to experience more droughts will require working with farmers, municipalities, energy industries, among others, to reduce the overall demand for this increasingly scarce resource.

In addition to their hydrologic importance, climate-related melting of glaciers can release stored persistent organic pollutants (e.g., pesticides and industrial chemicals like polychlorinated biphenyls (PCBs)) that were deposited during the period of heavy use in the mid-twentieth century (Blais et al. 2001, Bogdal et al. 2009, Schmid et al. 2011) into freshwater systems, with subsequent uptake by biota (Bettinetti et al. 2008, Bizzotto et al. 2009).

Lake Stratification

Ice cover on freshwater systems is sensitive to climate changes (Magnuson 2002). Higher air and water temperatures shorten lake ice cover seasons, increase evapotranspiration and thermal stratification, and increase winter productivity of lake systems. In shallow lakes these changes will increase winter oxygen levels and favor predator fish such as northern pike over a diverse community of fish species adapted to depleted oxygen levels (WICCI 2011). In contrast, deeper, less productive lakes in the northern United States could face lower oxygen levels in bottom waters during the summer as prolonged warm weather lengthens thermal stratification periods, isolating bottom waters from oxygen exchange. Depleted oxygen throughout the entire zone of bottom waters would harm coldwater fish such as lake trout and cisco.

GERALD BARNHART

Climate change impacts such as warming water, decreased flows, and depleted oxygen levels are predicted to stress fish populations and impact recreational fishing.

Lake Level Change

Great Lakes water levels are expected to decrease significantly due to climate-driven changes in precipitation and evapotranspiration (USGCRP 2009, Angel and Kunkel 2010). Lower water levels will lead to desiccation of coastal habitats that do not (or cannot) migrate with retreating shoreline, likely stressing fish species that rely on wetlands as nursery habitat. Shorebirds may also experience a loss of nesting habitat as beaches may become overrun by opportunistic invasive species such as *Phragmites.* At the same time, new wetlands may be formed as a result of accretion in other areas. A decrease in the extent and duration of lake ice will also affect lake species and habitats. For example, lake ice enhances the over-winter survival of fish eggs and protects shoreline habitat from erosion during winter storms (ASCE 1999). Longer periods without lake ice cause greater evaporation and can increase lake-effect snows if air temperature is favorable for snow (Lofgren et al. 2002).

Disturbance and Extreme Events

As the climate warms, altered precipitation patterns may manifest as heavy storms that punctuate extended periods of hot, dry weather, yielding floods. Heavy storms will also cause increased run-off with associated erosion, sedimentation, and pollution. Increased tidal and storm surges will also affect freshwater ecosystems, especially with increases in hurricane and typhoon intensities (IPCC WGII 2007). Tidal and storm surges can cause oxygen depletion, changes in salinity, mud suffocation, and turbulence (Tabb and Jones 1962).

WHAT IS...?

Sea Level Rise

As water warms, it expands, and the ocean surface rises. Sea level rise is highly variable regionally and local sea level rise is affected by multiple factors, including local geography and geology, such as rising or sinking land. Additional sea level rise is caused by the melting of inland glaciers and continental ice sheets, including those in Greenland and Antarctica, with recent studies placing the lower end of the range of sea level rise closer to 23 inches by the end of the century (Rahmstorf 2010).

NOAA

Coastal ecosystems are expected to experience climate impacts including sea and lake level changes, increased storm surges, and changes in precipitation patterns and subsequent delivery of freshwater, nutrients, and sediment. These changes could bring about the loss of the barrier islands, coral reefs, and coastal wetlands that help protect communities and industries from storms.

2.3.7 Coastal Ecosystems

The Pacific, Atlantic, Arctic, Gulf of Mexico, and Great Lakes coastal systems, for the purposes of the *Strategy*, extend seaward to mean lower-low water and include all lands that drain directly into an estuary, ocean (including the entirety of off-shore islands), or Great Lake (see Figure 1). They include the waters and sub-tidal zones of estuaries, semi-enclosed bays, and lagoons, as well as emergent and wooded wetlands, open water and aquatic beds, and unconsolidated and rocky shorelines. Given that coastal ecosystems inherently exist at an ecological interface, these areas also may encompass portions of other ecosystems described in the *Strategy*. In addition to increases in air and water temperature, coastal ecosystems will experience climate impacts that include: sea and lake level changes; increases in storm surge; alterations in precipitation patterns and subsequent delivery of freshwater, nutrients, pathogens, and sediment; changes in intensity of coastal storms; changes in water chemistry; and changes in sea ice.

Temperature Increases

Average global land and sea surface temperatures are continually increasing with 2010 being the hottest on record (Bluden et al. 2011). Nearshore water temperatures are similarly increasing. Temperature changes affect coastal species phenology, including key events such as the spring phytoplankton bloom, plant germination and turtle nesting, and may also cause species range shifts (Harley et al. 2006, Hoegh-Guldburg and Bruno 2010). While coastal salt marshes and forested wetlands could experience increased growth due to warmer temperatures, they could also cause expansion of invasive species and disease pathogens.

In estuarine environments, increased water temperature will affect water column stratification and eutrophication; and could cause range shifts. Extreme changes may also stress organisms to the point of mortality. In addition, warmer temperatures will exacerbate low summer oxygen levels (such as those in mid-Atlantic estuaries and the Gulf of Mexico) due to increased oxygen demand and decreased oxygen solubility (Najjar et al. 2000). Similarly, increasing temperature can increase exposure to metals by increasing respiration rates of many ectotherms such as fish (Ficke et al. 2007).

> *In Alaska, rapid warming has led to severe shoreline erosion due to longer seasons without ice cover. These and other changes have made the coast far more vulnerable to wind and wave damage.*

For high islands, such as those in Hawaii, warmer temperatures will increase stress on forest species, including birds, plants, and insects, which need cool, moist conditions to survive. In Alaska, rapid warming has led to severe shoreline erosion due to longer seasons without ice cover as well as to land subsidence due to permafrost melt and sea level rise. These changes have made the coast far more vulnerable to wind and wave damage (Larsen and Goldsmith 2007). The impacts of warmer temperatures on the Alaskan coast also are felt by the indigenous people who live there and depend on the natural resources of the coastal ecosystem.

Changes in Sea Ice

As a result of warming temperatures, Arctic sea ice has been decreasing in extent throughout the second half of the 20th century and the early 21st century (Maslanik et al. 2007, Nghiem et al. 2007, Comiso and Nishio 2008, Alekseev et al. 2009, AMSA 2009). The summer of 2007 saw a record low, with 2011 sea ice extent being second lowest compared with 2007 (Perovich 2011). Warming water temperatures and loss of sea ice are fundamentally changing the behavior, condition, survival, and interactions of Arctic marine mammals (Kovacs et al. 2010, Wassmann et al. 2011).

As sea ice thins and retreats farther north, walrus, which rely on sea ice to rest on between foraging bouts, and polar bears, which need sea ice to hunt seals, will either be displaced from essential feeding areas or forced to expend additional energy swimming to land-based haul-outs (Callaway et al. 1999, Stirling et al. 1999, Laidre et al. 2008, Stirling and Parkinson 2009). Climate-related changes in timing of sea ice breakup have been linked to polar bear dietary changes in western Hudson Bay, Canada, with an inferred increase in consumption of open water (harp and harbor) seals relative to ice-associated seals (particularly bearded seals). Dietary changes were in turn related to an increase in contaminants such as PCBs, but a decrease in dichlorodiphenyltrichloroethane, which is commonly known as DDT (McKinney et al. 2009).

In the Chukchi Sea, the loss of summer sea ice has reduced haul-out habitat for walrus, resulting in tens of thousands of walrus hauling out on land for the first time on record (Moore and Gill 2011).

Reduced sea ice and increasing temperatures have led to breeding phenology shifts in kittiwakes over a 32-year period (Byrd et al. 2008). Changing ice conditions are threatening lifestyles and subsistence economics of indigenous peoples as well, such as by making trips to hunting grounds longer and more hazardous (Forbes et al. 2011). For example, residents of Alaska Native communities rely on sea ice to ease their travel to the hunting grounds for whales, ice seals, walrus and polar bears. Krupnik et al. (2010) identify numerous effects of climate change that challenge and threaten local adaptive strategies, including times and modes of travel for hunting, fishing and foraging.

Reduced sea ice is also likely to increase marine shipping and transport in the Arctic, enhance access to rich resource reserves including oil, gas, coal, and various minerals, and alter fishing patterns (ACIA 2005, AMSA 2009). Potential natural resource issues related to these activities may include changes in noise and disturbance, ship strikes of large marine mammals, marine debris incidence, pollution incidents, and/or introduction of invasive species (AMSA 2009).

Sea Level Rise and Coastal Inundation

Sea level rise is a key driver of coastal geomorphologic change. The immediate effects of sea level rise are the submergence and increased inundation of coastal land and increased salinity in estuaries and coastal rivers. Additional physical effects include increased erosion, changes in geomorphology, and saltwater intrusion in groundwater and into tidal freshwater marsh systems. Sea level rise also will exacerbate flooding

The increasingly long swim from sea ice to shore poses risks for walruses, especially to females and young who face further hardships onshore where they compete for food and can be trampled by larger males.

events ranging from spring tides to tropical or extratropical storms, and will cause inland penetration of storm surge into areas not accustomed to inundation. These areas will likely experience flooding more often. Increased coastal flooding and inundation may result in release of contaminants from coastal soils, sediments, and infrastructure and increased exposure of fish, wildlife, and plants to these pollutants. While sea level changes have occurred repeatedly in the geologic past, changes of similar magnitude have not occurred since construction of modern human infrastructure along coastal areas, and the accelerated pace of sea level rise in the 20th and 21st centuries raises questions about how coastal ecosystems will respond (USGCRP 2009).

To preserve the current acreage of tidal wetlands, either wetlands need to keep pace with sea level rise or migrate inland to adjacent lands that are undeveloped. The success of wetland migration depends on the availability and slope of an upland corridor, the pace of the sea level rise, erosion rates, and the potential for wetland accretion (CCSP 2009a). Other important factors that affect wetland response to sea level rise are

salinity, sediment dynamics, nutrient input, and the habitats and species present. In populated coastal areas, wetland migration is often constrained by land development and shoreline stabilization measures. These conditions can result in the crowding of foraging and bank-nesting birds and the loss of crucial coastal habitat for certain species such as the diamondback terrapin, which requires both marsh and beach habitats (Shellenbarger Jones et al. 2009). Marsh islands are already being lost in the Mid-Atlantic due to sea level-related flooding and erosion, which threatens island nesting bird species (Shellenbarger Jones et al. 2009). In addition, the degradation and loss of tidal marshes affect estuarine habitat, production of commercially important fish and shellfish species, and flood attenuation, key ecosystem services for coastal communities.

Seawalls protect areas of human habitation from the action of storm surges and sea level rise. But they also inhibit animal movement and the exchange of sediment between land and sea. Current seawalls may be unable to cope with the projected increases in water levels.

FLICKR/CONESPIDER

CASE STUDY

Atlantic coast piping plover habitat conservation

USFWS

DECISIONS REGARDING COASTAL management, such as stabilization, retreat, and beach nourishment will strongly influence the effects of sea level rise on the Atlantic Coast piping plover, a threatened beach-nesting bird protected under the ESA. Piping plovers breed from Maine to North Carolina, and favor wide, gently sloping ocean beaches with blowouts, washovers, ephemeral pools, and sparse vegetation.

Federal and state agencies, nongovernmental organizations, and academic institutions are collaborating to couple a model of piping plover habitat evolution with a model of piping plover nest density and distribution. The habitat evolution model relates changes in physical habitat, such as topography, shoreline position, and vegetation, to changes in sea level and storminess (Gutierrez et al. 2011). A Bayesian approach is being used and is particularly well-suited to understanding and responding to climate change because future conditions, including results of habitat management experiments, are uncertain. Empirical data will be used to update and improve model forecasts. Model predictions will be used to develop sea level rise-related piping plover habitat conservation recommendations that can be implemented by land managers and inform regulatory authorities. Case studies incorporating explicit measures to preserve resilience of piping plover habitat to sea level rise into management plans for specific locations will demonstrate potential applications. Collaborators anticipate that model results may be readily translated to inform habitat management for other sensitive beach-strand species, such as least terns, American oystercatchers, Wilson's plovers, and seabeach amaranth (a federally threatened plant species).

Sea level rise may also result in the inland movement of seawater, shifting the tidal influence zone of streams and rivers upstream and permanently inundating downstream riparian/coastal portions with brackish water (Riggs and Ames 2003). In the United States, these impacts are already apparent in freshwater swamps along the Louisiana and Florida coasts (IPCC 1997, Bowman et al. 2010, Migeot and Imbert 2011). In Florida, mangroves have advanced 0.93 miles inland over the last 50 years (Rivera-Monroy et al. 2011), and another 10 to 50 percent of the freshwater sawgrass prairie will be transformed to salt marsh or mangroves by 2100 (Kimball 2007). Salinity increases in formerly fresh or brackish surface waters and saltwater intrusion of shallow coastal groundwater aquifers will also result from sea level rise (USGS 2010). This may threaten systems such as tidal freshwater forested wetlands that support a variety of wildlife species and critical drinking water sources, especially in island ecosystems (Huppert et al. 2009). Sea level rise also threatens small and low-lying islands with erosion or inundation (Baker et al. 2006, Church et al. 2006, USGCRP 2009), many of which support high concentrations of rare, threatened, and endemic species (Baker et al. 2006). As noted in the previous section (Inland Water Ecosystems) Great Lakes levels are expected to decrease, having different shoreline and habitat effects from ocean coasts that will experience rising water levels.

Water Availability

Changes in precipitation will primarily impact coastal systems through changes in quantity, timing, intensity, and quality of freshwater flow into estuarine systems. The quantity of freshwater will affect salinity gradients and nutrient inputs, while changes in peak flow timing could affect phenology and migration cues. Changes in the timing and amount of freshwater, nutrient, and sediment delivery will also impact estuarine productivity. For example, changes in flow regimes may affect the abundance and distribution of suspension feeders, such as mussels, clams, and oysters, which could in turn alter food web dynamics as well as water clarity (Wildish and Kristmanson 1997). Increases in flow, turbidity, and eutrophication could also impact submerged aquatic vegetation due to reduced light penetration (Najjar et al. 2000), as well as organisms that rely on this habitat for food and shelter. These impacts of precipitation changes in estuaries will likely be exacerbated by non-climate stressors such as freshwater demand and extraction, eutrophication, and hypoxia.

CASE STUDY

Coastal habitat conservation on agricultural lands

KEITH WELLER/USDA

Conservation easements meet the needs of interested owners of working farms, ranches, timberlands, sporting properties and recreational lands, who wish to protect valuable natural resources while retaining ownership of the property.

ENHANCED MANAGEMENT OF agricultural wetlands along our coasts represents an important opportunity to accommodate waterbirds displaced by wetland loss from sea-level rise.

For example, the wet coastal prairie along the Gulf Coast of Texas and Louisiana is extremely important for wetland wildlife, as are farmland such as rice fields which also provide wet, early successional habitat. But rising sea levels are expected to inundate many of these lands. Conservation programs authorized under the Food, Conservation, and Energy Act of 2008 (known to many as the Farm Bill) such as the Wildlife Habitat Incentives Program (WHIP), the Environmental Quality Incentives Program (EQIP), and the Wetlands Reserve Program (WRP) are able to compensate landowners willing to amend tillage and flooding practices to accommodate targeted waterbirds such as fall-migrating shorebirds, and wintering and spring-migrating waterfowl. These programs work with landowners to ensure critical wildlife habitat on private lands is not lost when species need it most.

Another approach is to proactively protect land that lies next to important coastal wetlands. In Pacific Northwest estuaries, for instance, Ducks Unlimited is leading an effort to protect farmland adjacent to tidal wetlands to allow for future marsh migration inland by purchasing easements (e.g., development rights) from a willing farmer. This may ensure that vital marsh habitat still exists if sea levels rise enough to submerge the existing coastal wetlands. Restoring wetlands on lands like farmlands that have not been filled and developed with buildings and hard infrastructure is a cost effective and feasible adaptation strategy.

Disturbances and Extreme Events

Increased storm wind strength due to elevated sea surface temperatures could lead to increases in wave height and storm surge (Scavia et al. 2002) and would be magnified by a higher sea level. The primary impacts associated with more intense storm systems include increased flooding and erosion. More intense storms, coupled with common manmade ecosystem alterations such as shoreline stabilization measures that impede or eliminate long-shore transport could lead certain barrier islands (and their habitats) to fragment and disappear instead of migrating and rebuilding. Impacts to coastal and estuarine beaches would affect biota such as: microscopic invertebrates that are critical to the food web; horseshoe crabs that rely on beaches for egg deposition; and migratory shorebirds that feed on the eggs, such as the red knot (Shellenbarger Jones et al. 2009). Shifts in the seasonal distribution of major storm events could also affect plants, wildlife, and fish. For example, an increase in the number or intensity of storms during the spring and early summer could substantially affect breeding success of coastal birds such as the piping plover. More infrequent but intense precipitation events can also lead to scouring of sediment and vegetation during peak flows, redistribution of sediment, resuspension of contaminated sediments, as well as increased pollutants from events such as combined sewer overflows.

Elevated CO_2 and Ocean Acidification

While not a climate change impact per se, ocean acidification is associated with increasing atmospheric CO_2 and will cause changes to many key biological processes in coastal and marine systems. For example, increased acidity in estuaries will affect shellfish species that use carbonate minerals to build their shells, as these minerals are more readily dissolved in lower pH environments (USGCRP 2009). Elevated CO_2 concentrations are also expected to increase photosynthesis and productivity for many plants, such as mangroves and emergent and submerged vegetation. These increased growth rates may be reduced in areas that experience additional stress due to coastal pollution, which can also exacerbate the effects of ocean acidification (Adam 2009).

CASE STUDY

Coastal carbon sequestration

"BLUE CARBON" IS A TERM USED to describe the biological carbon sequestered and stored by marine and coastal organisms with a significant fraction being stored in coastal sediments by coastal seagrasses, tidal marshes, and mangroves. These coastal habitats can sequester and store carbon at high rates equivalent or higher than those of tropical forests (Hopkinson et al. 2012).

JANE PELLICCIOTTO

When degraded or disturbed, these systems release carbon dioxide (CO_2) into the atmosphere or ocean. Currently, carbon-rich coastal ecosystems are being degraded and destroyed at a global average of 2 percent annually, resulting in significant emissions of CO_2 and the loss of carbon sequestration services, which contribute to climate change. Mangrove areas alone lost 20 percent of global cover between 1980 and 2005 (Giri 2011, Spalding et al. 2010). Carbon continues to be lost from the most organic soils in coastal areas. For instance, analysis of the agricultural soils of Sacramento's San Joaquin Delta, a diked and drained former tidal wetland, documents emissions of CO_2 at rates of 5 to 7.5 million tons of CO_2 each year, or 1 percent of California's total greenhouse gas emissions. Each year, an inch of organic soil evaporates from these drained wetlands, leading to releases of approximately 1 billion tons of CO_2 over the past 150 years (Crooks et al. 2009, Deverel and Leighton 2010, Hatala et al. 2012).

Similar emissions are likely occurring from other converted wetlands along the East and Gulf Coasts of the United States. Conservation and improved management of these systems brings climate change mitigation benefits in addition to increasing their resiliency and significant adaptation value to coastal species and communities (Crooks et al. 2011, McLeod et al. 2011). Developing a better understanding of blue carbon science and ecosystem management issues has implication for future climate adaptation strategies as well as coastal habitat conservation.

2.3.8 Marine Ecosystems

For the purposes of the *Strategy*, marine ecosystems extend from shore to 200 miles seaward or the nearest international boundary (see Figure 1). The area seaward of 3 miles, generally referred to as the U.S. Exclusive Economic Zone (EEZ), is the largest EEZ in the world spanning 3.4 million square nautical miles of ocean, an area 1.7 times the land area of the continental United States. The *pelagic* (open water) and *benthic* (bottom) habitats support species ranging from microscopic planktonic organisms that comprise the base of the marine food web through kelp and seagrass beds to a wide range of invertebrates and vertebrates. The two primary consequences of increased atmospheric CO_2 in marine ecosystems are increasing ocean temperatures and ocean acidity (Doney et al. 2012). Increasing temperatures produce a variety of changes in marine ecosystems including rising sea level, increasing ocean stratification, decreased oxygen availability, extent of sea ice, and altered patterns of ocean circulation, storms, precipitation, and freshwater input (Doney et al. 2012). These and other changes in ocean physical and chemical conditions impact ocean species (e.g., primary production, phenology, species distribution, species interactions, community composition) which in turn can impact human communities and economies that depend on marine ecosystems for jobs, food, and other services.

USFWS/JIM MARAGOS

Increased ocean temperatures are already impacting marine ecosystems through changes in physical conditions, primary productivity, and species distributions.

Temperature Increases

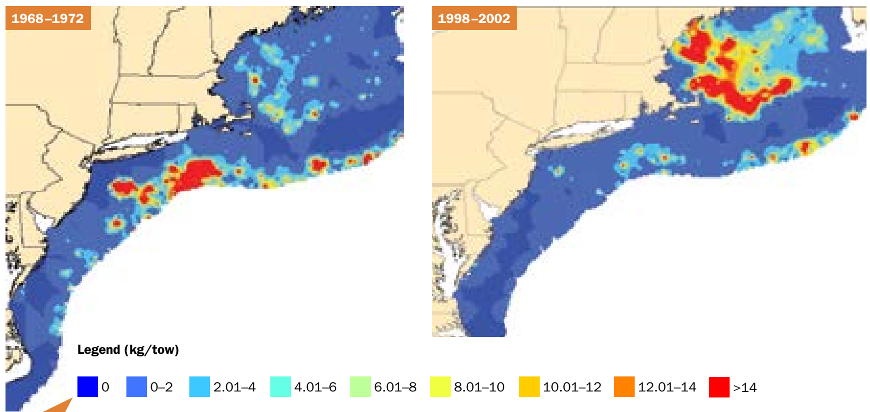
Between 1955 and 2008, it is estimated that 84 percent of the heat gained by the planet has been stored in the world's oceans, resulting in a global ocean temperatures rise of 0.4 °F, with much greater changes observed in some locations such as the Atlantic basin (Levitus et al. 2009, IPCC WGI 2007). The physical consequences of such warming include sea level rise, increased stratification of the water column, decreased oxygen levels and changes in ocean circulation. Warming sea temperatures also boost the energy available to initiate and intensify hurricanes and typhoons, and storm intensity is expected to increase as sea surface temperatures rise (IPCC WGI 2007).

Increasing ocean temperatures and the other associated changes in ocean conditions have a variety of impacts on fish, wildlife, and plants at multiple levels. These impacts range from changes in metabolic rates and energy budgets of individuals to changes in ecological processes such as productivity, species interactions, and even toxicity of compounds found in marine systems (Schiedek et al. 2007, Doney et al. 2012). Increasing air temperatures can also affect the growth and survivorship of early life history stages of some marine species whose larvae or juveniles use estuaries and other near-shore habitats as nursery areas (Hare and Able 2007). For example, increasing winter temperatures along coastal areas could increase the juvenile survivorship of these estuarine dependent species resulting in northward shifts in their distribution. Some warmer water marine fishes, such as the Atlantic croaker have already shifted their distributions poleward with warming ocean temperatures, and may also increase in growth and abundance in a changing climate (Nye et al. 2009, Hare et al. 2010).

Between 1955 and 2008, it is estimated that 84 percent of the heat gained by the planet has been stored in the world's oceans.

CASE STUDY

Shifting spatial distributions of U.S. fish stocks



Red hake distributions in the Gulf of Maine have been moving northward. As shown above, the highest biomass of these fish (shown in red) were located significantly further north in 1998–2002 than they were from 1968–1972. Historically there were high densities of this species in waters off the coast of New Jersey and Long Island, but now there are fewer fish in these areas. Source: Nye et al. 2009

THE UNITED STATES IS FORTUNATE to have programs in most regions that have been monitoring the distribution and abundance of commercial and recreational fish stocks (fish and macroinvertebrate species), protected species (e.g., marine mammals, sea turtles) and oceanic conditions (e.g., Integrated Ocean Observation System) consistently on an annual or interannual basis for some time. This information is not only essential for management of these valuable resources—it has also been critical to detecting shifts in spatial distribution of U.S. fish stocks and other species with changes in ocean conditions over time. Several studies using these data have found large distributional shifts in marine fish in the California Current Ecosystem (Hsieh et al. 2008), Bering Sea (Mueter and Litzow 2008), and the Northeast United States (Nye et al. 2009).

In the Northeast, two-thirds of 36 examined fish stocks shifted northward and/or to deeper depths over a 40-year time period in response to consistently warm waters (Nye et al. 2009). The figure below shows the past and present spatial distribution of a commercially important fish species, red hake, as an example of shifts that have been observed in this area. Surf clams in this area also suffered higher mortality in recent warm years and are now found only at deeper depths (Weinberg 2005). Similarly, in the Bering Sea, fish have moved northward as sea ice cover is reduced and the amount of cold water from melting sea ice is reduced (Mueter and Litzow 2008). In both cases, fishers have to travel further and set their nets to deeper depths, increasing the costs associated with fishing. In both ecosystems, fish stocks are shifting closer to the borders of neighboring Canada and Russia, requiring coordinated monitoring and assessment of key stocks. In the California Current ecosystem, shifts in spatial distribution were more pronounced in species that were commercially exploited, and these species may be more vulnerable to climate variability (Hsieh et al. 2008).

Combined, these studies stress the importance of tracking the impacts of climate change on marine species and incorporating that information into management plans and actions to prevent over-use, enhance recovery, and promote resilience of marine species and the communities and economies that depend on them in a changing climate.

As discussed previously, species can respond to temperature changes by migrating poleward or toward deeper depths, reducing their climate niche within their existing range, evolving, or going extinct (Mueter and Litzow 2008, Cheung et al. 2009, Nye et al. 2009, Overholtz et al. 2011). These individual responses lead to new combinations of species that will interact in unpredictable ways. Between 2000 and 2100, warming in the North Pacific is projected to result in a 30 percent increase in the area of the subtropical biome, while areas of the equatorial upwelling and temperate biomes will decrease by 28 percent and 34 percent, respectively (Polovina et al. 2011).

Changes in Sea Ice

Sea ice plays an important role in reducing the ocean-atmosphere exchanges of heat, moisture, and other gases, with implications for the global climate. These complex interactions and feedback systems cause the Arctic Ocean to be extremely sensitive to warming, with consequent changes in atmospheric circulation, vegetation, and the carbon cycle, with impacts both within and beyond the Arctic. The Intergovernmental Panel on Climate Change (IPCC) (2007) projections suggest that the Arctic may be virtually ice-free in the summer by the late 21st century. However, the previous projections are from coupled air-sea-ice climate models that tend to overestimate ice thickness, and hence some experts predict an ice-free Arctic in summer could occur as early as 2030 (Stroeve et al. 2008). Melting of sea ice and seabed permafrost is also a consequence of atmospheric and ocean warming, and will produce associated physical, chemical, and biological changes, including increased stratification in the water column. Variation in the spatial extent of sea ice and timing of the spring retreat has strong effects on the productivity of the Bering Sea ecosystem. For example, the timing of the spring phytoplankton bloom is directly tied to the location of the sea ice edge over the Bering Sea shelf (Stabeno et al. 2001).

Changes in Circulation Patterns

Ongoing warming of the atmosphere and the ocean could cause major changes for key water masses and the processes they control. A change in the intensity and location of winds, such as the Westerlies moving northward in the Atlantic, will change surface ocean circulation. Currents such as the thermohaline circulation, which is driven by temperature and salinity gradients, can also be significantly affected by the warming climate. For instance, the circulation of deep ocean currents in the Atlantic and Pacific Oceans could slow. These large scale changes in circulation could have localized impacts such as increased ocean stratification and alterations to upwelling and coastal productivity, which in turn will change the availability of essential nutrients and oxygen to marine organisms throughout the water column. In addition, changes in ocean circulation patterns will change larval dispersal patterns (Cowen and Sponaugle 2009) and the geographic distributions of marine species (Block et al. 2011).

CASE STUDY

Ocean acidification and West Coast oyster production

NOAA

IN 2007 AND 2008, two of the three major West Coast oyster hatcheries discovered that their Pacific oyster larvae were dying. It did not happen all the time, so researchers set out to understand why. Was something wrong in the water pumped from the sea into the hatcheries? By testing the water, researchers discovered a telltale pattern. The larvae died only when upwelling off the coast brought deep, cold water to the surface—and into the hatcheries (Feely et al. 2008). This cold water was low in calcium carbonate, the basic material in oyster shells. Without enough dissolved calcium carbonate (in a form known as aragonite), the oyster larvae struggled to survive.

The finding pointed to the ultimate culprit—the same rising CO_2 levels in the atmosphere that cause climate change. When CO_2 concentrations increase in the air, the ocean absorbs more CO_2. That increases the acidity of the water. Higher acidity (lower pH), in turn, means that the water cannot hold as much dissolved calcium carbonate. Compounding the issue is the fact that cold water, like that found on the bottom of the ocean, cannot dissolve as much calcium carbonate as warmer water can. Thus, the acidic cold water that is churned up during upwelling is especially harmful to the oyster larvae.

The hatcheries figured out ways around the problem. One of them measured concentrations of dissolved CO_2 in the seawater and pumped in water only when it was above a pH level of 7.75 (typically late in the day after plankton had lowered water CO_2 levels through photosynthesis). The other hatchery moved its intake from deep to shallow water.

But these steps do not solve the larger, far more significant problem—the increasing acidification of the oceans. Over the last six years, the difficulties faced by the hatcheries in rearing Pacific oyster larvae have been paralleled by poor supplies of naturally produced seed oysters in Willapa Bay, Washington—the most important oyster-producing bay on the West Coast. Acidification is already having a serious effect on the West Coast's $80 million per year oyster industry, which employs thousands of people in economically depressed coastal communities (PCSGA 2010). If the acidification of the oceans is the cause, then the problem will just get worse. Not just oysters will be at risk, but also the basic food webs in the oceans because so many species use calcium carbonate to build shells and skeletons.

Elevated CO_2 Levels and Ocean Acidification

Increased ocean acidification associated with increasing atmospheric CO_2 concentrations will directly and indirectly impact physiological and biological processes of a wide variety of marine organisms such as growth, development, and reproduction (Le Quesne and Pinnegar 2011). Ocean acidification decreases the concentration of dissolved carbonate that is available for uptake by calcifying organisms. A more acidic environment can reduce the calcification rate of many shell-forming marine organisms including oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. Even the most optimistic predictions of future atmospheric CO_2 concentrations (such as stabilization at 450 parts per million) could cause coral reefs to no longer be sustainable (Hoegh-Guldberg et al. 2007, Veron et al. 2009), bivalve reefs to slow or even stop developing, and large areas of polar waters to become corrosive to shells of some key marine species.

There also are expected to be major effects on phytoplankton and zooplankton that form the base of the marine food chain. On the organismal level, a moderate increase in CO_2 facilitates photosynthetic carbon fixation of some phytoplankton groups. It also enhances the release of dissolved carbohydrates, most notably during the decline of nutrient-limited phytoplankton blooms. On the ecosystem level, these responses influence phytoplankton species composition and succession, favoring algal species which predominantly rely on CO_2 utilization (Riebesell 2004). These effects will then have cascading impacts on productivity and diversity throughout the ocean food web.

CASE STUDY

Rising ocean temperatures and coral reef bleaching

Rising sea temperatures and ocean acidification are threatening the whole coral reef ecosystem.

DAVID BURDICK, COURTESY OF NOAA

CORAL REEFS ARE ONE OF THE MOST productive ecosystems on Earth. At the heart of the coral reef's success is a symbiotic relationship between coral and microscopic algae within the living coral. The coral provides the nutrients that the algae need to capture carbon dioxide (CO_2) through photosynthesis. The algae, in turn, provide coral with the carbon they need to build their skeletons—and thus, the reef itself.

When sea temperature rises just a degree or more and stays that way for extended periods, the relationship between coral and algae begins to breakdown. The coral expel their algae, a process called bleaching (since without the colorful algae the coral is bone white). Over the past 20 years, periods of increased sea temperatures and coral bleaching events are becoming more frequent and widespread (Marshall and Schuttenberg 2006). Usually, healthy reefs are able to recover from bleaching events. However, the severity of these events is increasing as are other human-caused threats to coral reefs (e.g., over-fishing, pollution, and sedimentation). In 2005, up to 90 percent of shallow-water corals in the British Virgin Islands bleached in response to increased water temperatures (Wilkinson and Souter 2008). Frequent bleaching has profound effects on corals and can ultimately lead to mortality.

Bleaching isn't the only threat to coral. Rapid increases in the atmospheric CO_2 concentration, and thus, ocean acidification, may be the final insult to these ecosystems. The absorption of atmospheric CO_2 by the world's oceans contributes to chemical reactions which ultimately reduce the amount of carbonate making it unavailable to coral to build their skeletons (Hoegh-Guldberg et al. 2007). Water quality improvements, particularly controlling nutrient inputs, can bolster reef resilience to bleaching (Wooldridge and Done 2009) and implementation of existing laws may help mitigate ocean acidification effects on nearshore habitats (Kelly et al. 2011).

There are a variety of efforts underway to try to protect coral reefs by making them more resilient to climate change (Marshall and Schuttenberg 2006). The Nature Conservancy has started a Reef Resilience program, working in the Florida Keys in partnership with the State of Florida, the National Oceanic and Atmospheric Administration, and Australia's Great Barrier Reef Marine Park Authority, to understand the non-climate factors that adversely affect coral reefs such as damage from charter and private vessels and improper erosion control. The hope is that by reducing these non-climate stressors, the coral will be better able to resist being bleached when sea temperatures increase. A related approach, being studied by scientists at the University of Miami, Australia Institute of Marine Science, and elsewhere, is actively inoculating corals with algal symbionts that are resistant to higher water temperatures.

2.4 Impacts on Ecosystem Services

As noted in Section 1.3.3, species and ecosystems provide a wide range of important products and services to the nation, including jobs, food, clean water, protection from storms, recreation, and cultural heritage. These natural resources and ecological systems are a significant source of economic activity and wealth. Climate change is likely to affect the spectrum of ecosystems services. In some cases or for some periods, these changes may be positive as with expanded growing zones for some agricultural crops in the northern latitudes, or with the expansion of warm-water fisheries. On balance, however, the scientific community has warned that an increase in global average temperature above 4 ^{0}F risks dangerous interference with the climate system and many adverse impacts on natural systems and the wealth they generate (IPCC AR4 2007). Recall that the current range of estimates for global average temperature increase by 2100 is 2.0 to 11.5 ^{0}F (USGCRP 2009).

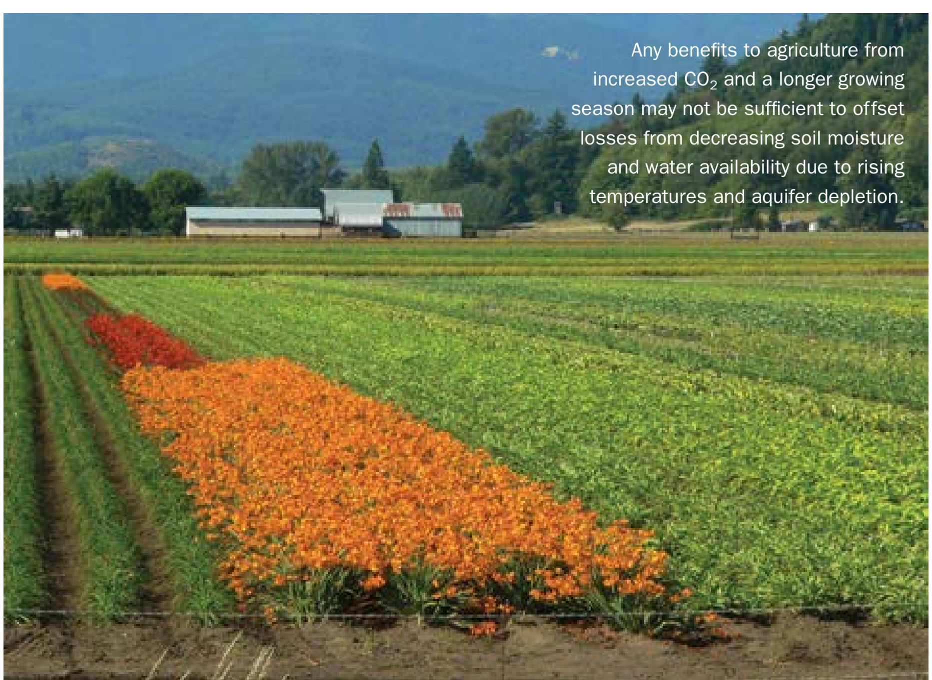
The products and services that natural resources provide support millions of jobs and billions of dollars in economic activity (DOI and DOC 2006, NMFS 2010, DOI 2011). As a result, the impacts from climate change on species and ecosystems are expected to have significant implications for America's communities and economies. In some cases, the implications could be positive and in other cases negative. The timing of any of these changes is uncertain. For example, changes in distribution, productivity, and health of forests from increased drought, fires or other climate-related factors (e.g., spread of pests or invasive species) will have direct consequences for both global carbon sequestration and the forest products industry, as well as fire risk and sedimentation of water sources, and will also influence other uses of forested ecosystems such as recreation and non-timber products. Changes in productivity of ocean ecosystems could have major impacts on fish stocks, fisheries and the communities and economies that depend on them world-wide.

The products and services that natural resources provide support millions of jobs and billions of dollars in economic activity.

Agriculture is a fundamental component within the grassland system matrix, and is also sensitive to climate changes. The same stressors that affect grasslands affect agriculture, and can decrease crop yields (Ziska and George 2004). Research suggests that crop plant responses to increasing CO_2 are varied, and it is therefore difficult to determine overall direct impacts of CO_2 (Taub 2010). However, there are numerous climate change impacts on temperature extremes and precipitation patterns that will likely have a substantial impact on vegetation and crop production.

Mapped boundaries of plant hardiness zones will change, and the list of agricultural and horticultural crops suited to particular areas will also change. The benefits from increased CO_2 and a longer growing season may not be sufficient to offset losses from decreasing soil moisture and water availability due to rising temperatures and aquifer depletion. Decreasing agricultural yields per acre could also increase pressure for the conversion of more acres of native grasslands to agriculture (USGCRP 2009). The decrease in agricultural soil moisture and water availability due to rising temperatures and aquifer depletion makes soil conservation vital. Climate change may cause reduction in precipitation and, in turn, induce soil moisture limitations in pasturelands (CCSP 2008d).

JANE PELLICCIOTTO



Any benefits to agriculture from increased CO_2 and a longer growing season may not be sufficient to offset losses from decreasing soil moisture and water availability due to rising temperatures and aquifer depletion.

CASE STUDY

A species that may thrive in a changing climate

VIRGINIA MARINE RESOURCES COMMISSION

ONE SPECIES WHICH MAY BENEFIT from marine climate change and a conservative management regime is the Atlantic croaker, which inhabits the coastal Atlantic of the United States and supports a commercial and recreational fishery worth approximately $9 million per year. Annual fish surveys along the East Coast have recorded croaker populations expanding northward since 1975. Recent research suggests that its range expansion is due to a combination of increasing sea surface temperature and a constant fishing pressure or catch level by anglers. Spawning occurs in the coastal waters during the late summer, fall, and winter. Between 30-60 days after spawning, larvae enter the estuaries of the Mid-Atlantic region to overwinter and grow to juveniles. Juvenile survival during the winter is determined by water temperature with cold water adversely affecting recruitment to the fishery.

Using sea surface temperature forecasts from an ensemble of global climate models, researchers have projected increased recruitment of juveniles in estuaries leading to more adult fish (Hare et al. 2010). If fishing pressure remains relatively low, the croaker fishery is expected to shift northward 60-250 miles as sea surface temperatures increase and new estaurine habitat becomes available. The study also suggests that under some future climate conditions, croaker populations could grow to levels sufficient to support increased fisheries.

Some benefits provided by well-functioning inland water and coastal ecosystems will also change or be lost due to climate change impacts, especially when compounded with other stressors such as land-use change and population growth. For example, there may be fewer salmon for commercial and recreational harvest, as well as for traditional ceremonial and cultural practices of indigenous peoples. Coastal marshes and mangroves provide clean water, groundwater recharge, and act as natural buffers against storms, absorbing floodwaters and providing erosion control with vegetation that stabilizes shorelines and absorbs wave energy. If those habitats are degraded and/or destroyed, then adjacent inland communities will have less protection from sea level rise, and may experience more direct storm energy and flooding (NC NERR 2007). Tidal marshes and associated submerged aquatic plant beds are important spawning, nursery, and shelter areas for fish and shellfish (e.g., commercially important species like blue crab), serve as nesting habitat for birds, and provide invertebrate food for shorebirds. At least 50 percent of commercially-valuable fish and shellfish depend upon estuaries and nearshore coastal waters in at least one life history stage (Lellis-Dibble et al. 2008); others reported estuarine dependency for approximately 85 percent of commercially-valuable fish and shellfish (NRC 1997).

In marine systems, large scale changes to biogeochemical processes, ocean currents, and the increased acidification of ocean waters are expected to have profound impacts on marine ecosystems including coral reef communities and their associated fisheries and tourism industries (Hoegh-Guldberg et al. 2007, Doney et al. 2012). Shifts of fish stocks to higher latitudes and deeper depths may force fishers to travel farther and spend more time in search of fish, or to undertake the costly task of updating infrastructure to effectively harvest the changing mixture of fish stocks. Fishery agencies will also have to update regulatory measures to conform to these new stock boundaries. Ocean acidification could have significant impacts on aquaculture industries and fisheries by affecting growth and survival of shellfish and many other species. Melting sea ice is also changing transportation routes, oil and gas exploration and extraction, fishing, and tourism in the Arctic, which in turn could impact the fish, wildlife, and plants in this region through a variety of mechanisms, including increased noise associated with increases in shipping (AMSA 2009).

The effects that climate change will have on marine aquaculture are not fully understood, but it is likely that there will be both positive and negative effects. For example, warmer temperatures may increase growth of some species, but decrease that of others, emphasizing the need for vulnerability assessments and adaptation planning that can reduce negative impacts and promote positive effects where possible (De Silva and Soto 2009). Climate change will directly affect aquaculture's choice of species, location, technology, and production costs (Hall et al. 2011). Direct impacts may include rising ocean levels, more frequent extreme weather events, changes in rain patterns, and distribution of diseases and parasites. The more subtle effects are even harder to gauge; for example, the effects that climate change may have on ocean currents, inshore salinities, and water mixing patterns; which may in turn affect aquatic productivity, fishmeal supply and global trade, or the incidence of harmful algal blooms (FAO 2010).

CH.3 Climate Adaptation Goals, Strategies & Actions

SEVEN GOALS to help fish, wildlife, plants, and ecosystems cope with the impacts of climate change were developed collectively by diverse teams of federal, state, and tribal technical and management experts, based on existing research and understanding regarding the needs of fish, wildlife, and plants in the face of climate change.

*The **goals** represent tools within the conservation toolbox.*

*Their **strategies** and **actions** should be taken or initiated over the next five to ten years.*

*Each goal has helpful **checklists** to chart milestones.*

3.1 How It Works

It is important to emphasize that all seven of these goals describe types of conservation activities that management agencies have traditionally undertaken, some for much of their history. In this sense, these goals represent tools within the conservation toolbox. What this *Strategy* seeks to do is assist the management community to better understand the application of these tools that may be most effective in a period of climate change. In other words, this *Strategy* seeks to integrate with and build upon existing management programs. These goals are intended to be implemented with full recognition of the existing rights and obligations of those who implement and will be impacted by the activities. For example, United States treaties and federal court decisions require consultation with tribal governments to ensure activities do not inadvertently lead to a diminishment of natural resources located on Indian lands, or treaty-protected natural resources, or in a diminishment of tribal access to those resources. And the resilience and adaptation of species that depend on areas outside U.S. borders will require continued collaboration and action with international partners.

Each goal identifies a set of initial strategies and actions that should be taken or initiated over the next five to ten years. Actions under various individual goals are interrelated and interdependent. To the extent possible, actions within goals are listed in sequential order; but goals are not. It is more useful to think of goals as sectors within which the appropriate actions are progressing in logical sequence. The “Actions” were compiled from Technical Team submissions

determined to be broadly applicable to the eight major U.S. ecosystem types considered in this document. In addition, examples of more detailed “Ecosystem-specific Actions” were also developed by the Technical Teams, in order to illustrate how these approaches could be carried out in particular ecosystems. A set of these specific actions most relevant to each ecosystem is available in the eight ecosystem-specific background papers referenced in Appendix A and posted online at *www.wildlifeadaptationstrategy.gov.*

A short-term progress check list is offered under each goal. These checklists are composed of items that can serve as useful milestones of progress toward the achievement of the relevant goal. Not every action has a corresponding checklist item and not every item on the checklist is a specific action under that goal. Each of the items in these lists could be achieved or initiated over the next five to ten years by pursuing the strategies and actions under each goal. Accomplishing these items will show real progress in implementing the *Strategy*. While adaptation planning for biological resources is still a new endeavor, it is important to recognize that work on all of these goals is already underway. This *Strategy* attempts to build on the excellent work of pioneering state governments, federal agencies, tribes, conservation partners, private landholders, and others who have been leading the way on adaptation. Many of the Case Studies found throughout the *Strategy* highlight some of these ongoing efforts.

The management challenge will not be to keep current conservation areas as they are, but rather ensure there is a network of habitat conservation areas that maximizes the chances that the majority of species will have sufficient habitat somewhere.

ROGER SMITH

Goals-at-a-Glance

Goal 1: Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate.

Sustaining a diversity of healthy populations over time requires conserving a sufficient variety and amount of habitat and building a well-connected network of conservation areas to allow the movement of species in response to climate change.

Goal 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.

Incorporating climate change information into fish, wildlife, and plant management efforts is essential to safeguarding these valuable natural resources.

Goal 3: Enhance capacity for effective management in a changing climate.

Climate change adaptation requires new ways of assessing information, new management tools and professional skills, increased collaboration across jurisdictions, and a review of laws, regulations, and policies.

Goal 4: Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.

Coordinated observation, information management, and decision support systems can help management strategies to be adaptive and adjust to changing conditions.

Goal 5: Increase knowledge and information on impacts and responses of fish, wildlife, and plants to a changing climate.

Research must be targeted to address key knowledge gaps and needs, and findings must be rapidly incorporated into decision support tools available to natural resource managers and other decision makers.

Goal 6: Increase awareness and motivate action to safeguard fish, wildlife, and plants in a changing climate.

Climate change adaptation efforts will be most successful if they have broad popular support and if key groups and people (such as private landowners) are motivated to take action.

Goal 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

Reducing existing threats such as habitat degradation and fragmentation, invasive species, pollution, and over-use can help fish, wildlife, plants, and ecosystems better cope with the additional stresses caused by a changing climate.

LARRY KRUCKENBERG

Goal 1

Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate.

STUDIES OF PAST PERIODS of climate change and their effects on species and ecosystems help us understand what may happen in the future. The major lesson from the recent fossil record of the transition from the last Ice Age to the current inter-glacial period is that when climate changes, each species responds in its own way (Hunter et al. 1988).

This Strategy attempts to build on the excellent work of pioneering state governments, federal agencies, tribes, conservation partners, private landholders, and others who have been leading the way on adaptation.

Species found living together in one climate may not live together in another, and vice versa. Thus, the natural community types recognized today, such as spruce-fir forests of the North, hemlock-beech forests of the Northeast, or tallgrass prairie of the Midwest, will not simply move northward or upslope. Instead, the species composition of these communities will change.

This observation has many implications for our conservation efforts in the current period of climate change. Many existing conservation areas, such as Sequoia National Park or the National Elk Refuge, were established largely to protect specific natural communities or species. As the climate continues to change and each species responds individually, these areas may lose the specific communities or species they were established to protect. For example, Joshua trees are projected to be virtually eliminated from most of the southern portions of its current range by the end of the century, including Joshua Tree National Park (Cole et al. 2011). Conservation areas will likely also gain new species, including in some cases, species equally in need of conservation. The management challenge will not be to keep current conservation areas as they are, but rather ensure there is a network of habitat conservation areas that maximizes the chances that the majority of species will have sufficient habitat somewhere. This will be a major challenge, both in knowing what will constitute "habitat" for any particular species in the future, and in dealing with biosphere scale dynamics that have now been unleashed that may be beyond management's ability to redress (e.g., ocean acidification).

Another lesson of past periods of climate change is that not all species will survive. Managers will need to come to terms with the need to make hard choices about the investment of limited resources and the likelihood of success.

Many of our nation's imperiled species (both those currently listed either as Threatened or Endangered as well as many other species that may eventually be considered for listing) do not occur in existing conservation areas. Indeed, the major threat to many species on the U.S. Endangered Species List is the loss of habitat caused when the habitat they depend on is converted to a different use. Climate change will make the problem worse—and will make the need for new conservation areas more urgent. The most robust approach to

helping fish, wildlife, and plants adapt to climate change is to conserve enough variety and amount of habitat to sustain diverse and healthy (e.g., viable, abundant) populations as landscapes and seascapes are altered by climate change. Major reviews of climate change conservation management options generally identify increased habitat conservation and/or establishing or restoring habitat connectivity as the top or among the top options to pursue (Mawdsley et al. 2009, Heller and Zavaleta 2009). We will need well-connected networks of conservation areas to allow for the movement of species in response to climate change. Selecting areas that will be both resilient and able to capture the broadest range of species is an important challenge.

It needs to be emphasized that, as used here, the term "conservation area" does not imply anything about ownership. A conservation area is simply any area that is managed, at least in part, to maintain some element of natural diversity. In this sense, a Conservation Reserve Program (CRP) lease on a farm in Iowa defines a conservation area as much as a conservation easement on privately owned timberland in Maine, a State Game Land in Pennsylvania, or a National Wildlife Refuge in Florida. These are examples of very different kinds of conservation areas, but each is an important component in the overall effort to conserve adequate habitat for our Nation's living resources. This *Strategy* makes no presumption about the best way of securing additional conservation areas (e.g., lease, conservation easement, fee acquisition, etc.), only that climate change will demand that we increase and perhaps accelerate collective efforts to do so. But simply creating new networks of conservation areas or acquiring more land to be protected in perpetuity will not be enough. Biologists and conservation land managers also must manage these conservation areas in innovative and flexible ways, as species and ecosystems respond and adjust (often in unpredictable fashion) to climate change. Flexible tools such as re-designation or exchanges of some existing public lands and the creation of additional types and/or numbers of conservation easements, leases, and incentives for private landowners will be essential.

The first step to meeting this challenge is identifying the best candidates for conservation areas. Given that natural community types will be changing as each species responds to climate change in its own way, identifying "future" habitat types and the best areas to represent them will prove challenging. Areas will need to be selected through the use of existing and new information and tools, such as inventories, gap analyses, mapping (including geophysical as well as biological features (Beier and Brost 2010, Anderson and Ferree 2010), vulnerability assessments, and geophysical and biological modeling (such as Species Distribution Models). Geographic Information Systems techniques, climate models, and inventory data can assist federal, state, tribal, and local agencies, as well as industry and private land owners in setting collective priorities for conservation and connectivity. Coordinating the efforts of many agencies and landowners will be a daunting process, but is a critical part of doing the job effectively and efficiently.

Increasing the number, quality, and size of conservation areas can increase the opportunities for individual species to adapt to climate change, and also make

KENTKENUCKY DEPARTMENT OF FISH & WILDLIFE RESOURCES

it more likely that native biodiversity will be conserved. Some species' habitat under climate change may be well outside their current or historic range. Healthy and biologically diverse ecosystems are likely to better withstand or adjust to the impacts of climate change. Increasing the number (redundancy) and distribution of protected fish, wildlife, and plant populations is important for the same reason. Establishing larger and more hospitable conservation areas for species to transition to will also increase opportunities for species to create new assemblages of species that are better able to persist in a dynamic climate.[2, 3]

Another challenge will be providing corridors between conservation areas so that species can freely move to new locations with suitable habitat. Protecting and restoring large blocks of habitat and using linkages and corridors to develop networks for movement will facilitate connectivity. Riparian corridors, such as floodplains, are useful as a conduit

2 See "For Landowners" at <www.fws.gov/endangered>

3 See "Programs & Services" at <www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs>

for migratory species and for providing access to water. In addition, appropriate transitory or "stopover" habitat for migratory species can promote biological connectivity between non-physically connected areas. Private landowners, land trusts and government agencies such as energy, transportation, and water resources agencies will be critical partners in creating these ecological connections. At the same time, managers must also guard against enabling movement of invasive and overabundant species, pests and pathogens.

Because human development in the United States has been so extensive, some of the habitat necessary for a comprehensive network of conservation areas will need to be restored. In the context of a period of climate change, ecological restoration will not necessarily be about attempting to restore specific species or combinations of species, but rather about restoring the conditions that favor healthy, diverse, and productive communities of species. Key components of such restoration can include promoting or mimicking natural disturbance regimes like fire; managing issues like in-stream flows, water withdrawals, and stormwater runoff; and addressing poorly-sited infrastructure, such as roads in floodplains and sensitive coastal areas. Effective restoration will require applying protocols and techniques that anticipate a range of future conditions, including different species compositions, caused by climate change and that can facilitate adaptation.

Alternatively, cultural and structural conservation practices applied to working agricultural and forest lands can provide a means of helping some species adapt to climate change. For example, improving the sustainability of working ranchlands, such as is being done through the NRCS Sage-Grouse Initiative, can ensure that these lands remain in grass that supports both ranching livelihoods and wildlife species associated with grassland and shrubland habitats, rather than being degraded by development, tillage, woody species encroachment or other stressors.

Overall, single jurisdiction or single interest approaches to land and water protection are not sufficient to deal with the landscape-scale changes being driven by climate change, and in some instances, may even be counter-productive. Fish, wildlife, and plant conservation agencies, local governments, tribes, and private conservation interests must work together in a coordinated way to build an ecologically-connected network of conservation areas.

CASE STUDY

Making salmon populations more resilient

AS A SPECIES THAT REQUIRES COLD, fast flowing streams for spawning, salmon could be hard hit by climate change. Indeed, climate models project widespread, large increases in air and stream temperatures in Washington State (Mantua et al. 2009), where much of the nation's key salmon habitat is located. Combined with anticipated declines in stream flows, higher temperatures would threaten not just the salmon, but also the immensely valuable industries, cultural traditions, and ecosystems that depend on the species.

TIM TORRELL

As a result, there is a need to map streams throughout the salmon's range to figure out which ones are most likely to stay cold with sufficient water flow (Mantua et al. 2009). The Washington Climate Change Impacts Assessment describes steps that can be taken to maintain good salmon habitat even in a changing climate, including:

- limit the amount of water that can be withdrawn from streams for irrigation or other purposes, especially in times of high temperatures and low stream flow;
- protect undercut banks and deep stratified pools, where water temperatures are lower;
- restore vegetation along streams, which cools the water and reduces sediment and pesticide levels;
- release cold water from large storage reservoirs during summer; and
- remove dams and other barriers so that cooler, protected headwaters flow more swiftly downstream, and salmon can swim upstream farther and faster.

Some of these strategies are already being implemented as part of the effort to protect and restore endangered salmon species. For example, two aging dams on the Elwha River are being removed, giving salmon access to 60 miles of high elevation, coldwater rivers, and streams in Olympic National Park. The availability of that additional, diverse habitat will increase salmon resilience (Waples et al. 2009).

Meanwhile, the Columbia Basin Water Transactions Program is tackling the problem of low stream flows. By taking such actions as acquiring water rights and leasing water, the program is able to reduce water withdrawals at critical times. In another example, the USDA Conservation Reserve Enhancement Program (CREP) and National Oceanic and Atmospheric Administration's Pacific Coastal Salmon Recovery fund are helping to restore vegetation in riparian zones. This restoration not only helps protect streams from rising temperatures and sediment, it also provides greater inputs of leaf litter and large logs that support stream food webs and create habitat diversity.

Strategy 1.1: Identify areas for an ecologically-connected network of terrestrial, freshwater, coastal, and marine conservation areas that are likely to be resilient to climate change and to support a broad range of fish, wildlife, and plants under changed conditions.

ACTIONS

1.1.1: Identify and map high priority areas for conservation using information such as species distributions (current and projected), habitat classification, land cover, and geophysical settings (including areas of rapid change and slow change).

1.1.2: Identify and prioritize areas currently experiencing rapid climate impacts (e.g., the coastline of Alaska, low-lying islands, and high alpine tundra).

1.1.3: Assess the potential of species to shift ranges, and prioritize conservation efforts taking into account range shifts and accounting for ecosystem functions and existing and future physical barriers.

1.1.4: Establish and maintain a comprehensive, inter-jurisdictional inventory of current conservation areas and candidate high priority conservation areas in order to coordinate future conservation efforts.

1.1.5: Re-prioritize conservation targets of existing land and water conservation programs in light of areas identified in 1.1.1.and listed in 1.1.4 and 1.4.2.

Strategy 1.2: Secure appropriate conservation status on areas identified in Action 1.1.1 to complete an ecologically-connected network of public and private conservation areas that will be resilient to climate change and support a broad range of species under changed conditions.

ACTIONS

1.2.1: Conserve areas identified in Action 1.1.1 that provide high priority habitats under current climate conditions and are likely to be resilient to climate change and/or support a broad array of species in the future.

1.2.2: Conserve areas representing the range of geophysical settings, including various bedrock geology, soils, topography, and projected climate, in order to maximize future biodiversity.

CASE STUDY

Building connectivity in New Jersey

Climate change could threaten amphibian species through increased flooding as well as drying.

USFWS/GARY STOLZ

IF CURRENT LOW-LYING COASTAL AREAS in New Jersey are flooded by spring high tides, as expected with sea level rises caused by climate change (Titus and Richman 2001), many amphibians will no longer be able to migrate up the Cape May Peninsula. That could threaten the viability of species like the state-endangered eastern tiger salamander and Cope's gray treefrog.

The New Jersey Division of Fish and Wildlife is working to provide more habitat for these amphibians and to better connect habitats to allow migration. Such migration prevents small populations from becoming isolated, thus, preserving genetic diversity for key species (Marsh and Trenham 2001, Cushman 2006).

For many amphibians, the key habitat is the vernal pool, a temporary pond that is typically deepest in the spring. The state has been both working to preserve existing vernal pools and looking for sites where it could create new pools. The sites were picked based on such criteria as elevation above anticipated sea level rise, vicinity to other vernal pools and upland habitat, location on state protected land, proper soil characteristics, and use by a variety of species.

When the effort is complete, the state will have established a connected network of vernal pool "strongholds" that will give New Jersey's amphibians a far better chance to adapt and survive as sea levels rise.

1.2.3: Build back-up redundancy into the network of conservation areas by protecting multiple examples of the range of priority areas identified in Action 1.1.1.

1.2.4: Work with partners at landscape scales to strengthen and maximize use of existing conservation programs, particularly the conservation title of the Farm Bill, conservation easement tax incentives, the private lands programs focused on endangered species, and other federal and state private lands incentive programs to conserve private lands of high conservation value, to enhance habitat values and maintain working landscapes under climate change.

1.2.5: Identify and pursue opportunities to increase conservation of priority lands and waters by working with managers of existing public lands such as military installations or state lands managed for purposes other than conservation.

Strategy 1.3: Restore habitat features where necessary and practicable to maintain ecosystem function and resiliency to climate change.

ACTIONS

1.3.1: Develop and implement restoration protocols and techniques that promote ecosystem resilience and facilitate adaptation under a range of possible future conditions.

1.3.2: Restore degraded habitats as appropriate to support a diversity of species assemblages and ecosystem structure and function.

1.3.3: Restore or enhance areas that will provide essential habitat and ecosystem services during ecosystem transitions under a changing climate.

1.3.4: Restore disturbance regimes as appropriate to emerging conditions, including instituting human-assisted disturbance where necessary (e.g., prescribed fire).

1.3.5: Develop programs to encourage resilience through restoration of habitat features that provide natural buffers.

1.3.6: Develop market-based incentives that encourage habitat restoration where appropriate.

Strategy 1.4: Conserve, restore, and as appropriate and practicable, establish new ecological connections among conservation areas to facilitate fish, wildlife, and plant migration, range shifts, and other transitions caused by climate change.

ACTIONS

1.4.1: Identify species with special connectivity needs (i.e., those that are area-limited, resource-limited, dispersal-limited, or process-limited).

1.4.2: Assess and prioritize critical connectivity gaps and needs across current conservation areas, including areas likely to serve as refugia in a changing climate.

1.4.3: Conserve corridors and transitional habitats between ecosystem types through both traditional and non-traditional (e.g., land exchanges, rolling easements) approaches.

1.4.4: Assess and take steps to reduce risks of facilitating movement of undesirable non-native species, pests, and pathogens.

1.4.5: Assess existing physical barriers or structures that impede movement and dispersal within and among habitats to increase natural ecosystem resilience to climate change, and where necessary, consider the redesign or mitigation of these structures.

1.4.6: Provide landowners and stakeholder groups with incentives for conservation and restoration of key corridor habitats through conservation programs such as those under the conservation title of the Farm Bill and landowner tools under the ESA as well as other mechanisms such as conservation easement tax incentive programs designed to protect private lands of high connectivity value under climate change.

GOAL 1 PROGRESS CHECK LIST

- ☐ Areas resilient to climate change identified;
- ☐ Gap analysis of geophysical settings completed and priority candidate areas identified;
- ☐ Desired ecological connectivity among conservation areas identified;
- ☐ Baseline comprehensive inventory of conservation areas completed;
- ☐ Suite of land protection tools (designations, exchanges, acquisitions, easements, leases, incentives) evaluated and updated;
- ☐ Protocols for incorporating climate change into ecological restoration efforts developed and implemented;
- ☐ Begin conserving and/or restoring high priority areas for fish, wildlife, and plants under climate change.

USFWS/RYAN HAGERTY

Goal 2

Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.

AS DESCRIBED IN CHAPTER 1, humans depend upon and derive multiple benefits from fish, wildlife, plants, and their habitats. Our living resources are vital for ceremonial, spiritual, and subsistence practices by indigenous peoples; recreational activities such as sport fishing, hunting, birding, and nature photography; and commercial interests such as fisheries, wood products, and food production. They are part of the core fabric of America, providing livelihoods, cultural identity, and boundless opportunities.

> *Maximizing the chances for species to adapt to climate change likely includes maintaining a full range of genetic diversity across managed plant and animal populations.*

The United States has a highly developed set of management agencies and authorities that work to maintain our existing living resources and the many uses and benefits they provide. Virtually all of these agencies have sophisticated management plans for the species and areas under their jurisdiction. Some of these plans have incorporated climate change considerations. For example, some 17 states have already developed or are in the process of developing climate adaptation strategies for their fish, wildlife, and plant resources. At the federal level, the FWS, the National Park Service, and the U.S. Forest Service have all developed climate change strategies for their agencies (see Chapter 5 for a more detailed discussion of ongoing adaptation planning). Nonetheless, many other agencies and most of the specific resource plans agencies are responsible for do not yet take climate change into account. This deficiency must be addressed, because managing for the *status quo* is no longer sufficient. We must build on our legacy of conservation action and begin to integrate climate adaptation strategies and actions into existing species and conservation area management plans if species and ecosystems are to survive and thrive in an uncertain future (see Glick et al. 2011a and Poiani et al. 2011 for a discussion of applicable methods).

Management plans and programs must consider species' abilities to adapt to climate change. They must also consider the ability of habitats to be resilient in the face of climate change, not necessarily in the sense of maintaining their current species composition, but in the sense of their overall functionality. Maximizing the chances for species to adapt to climate change likely includes maintaining a full range of genetic diversity across managed plant and animal populations. Some species may need more direct management, such as captive breeding. In other cases, managers may need to consider whether human interventions such as translocation or assisted relocation are appropriate. Because some of these actions may be new and potentially controversial, they need to be fully explored before moving forward, and collaborative, deliberative, and flexible decision-making will be critical.

Continued development and application of ecosystem based approaches to natural resource management is also a key step in this process. This approach grew out of broad acknowledgement that successful management required multi-dimensional, multispecies, and multi-sector approaches across broader time and spatial scales than was previously practiced. The scale and scope of climate change impacts on natural and human communities make this type of approach even more essential for sustaining ecosystem functions in a changing world.

Strategy 2.1: Update current or develop new species, habitat, and land and water management plans, programs and practices to consider climate change and support adaptation.

ACTIONS:

2.1.1: Incorporate climate change considerations into new and future revisions of species and area management plans (e.g., North American Waterfowl Management Plan, National Forest Plans, State Wildlife Action Plans, and agency-specific climate change adaptation plans such as federal agency adaptation plans required by E.O. 13514) using the best available science regarding projected climate changes and trends, vulnerability and risk assessments, scenario planning, and other appropriate tools as necessary.

2.1.2: Develop and implement best management practices to support habitat resilience in a changing climate.

2.1.3: Identify species and habitats particularly vulnerable to transition under climate change (e.g., wetlands, cool-water to warm-water fisheries, or cool season to warm season grasslands) and develop management strategies and approaches for adaptation.

2.1.4: Review and revise as necessary techniques to maintain or mimic natural disturbance regimes and to protect vulnerable habitats consistent with emerging conditions.

2.1.5: Review and revise as necessary existing species and habitat impact avoidance, minimization, mitigation, and compensation standards and develop new standards as necessary to address impacts in a manner that incorporates climate change considerations.

2.1.6: Review permitting intervals in light of the scope and pace of climate change impacts.

2.1.7: Review existing management frameworks and identify ways to increase the ability of stakeholders to adapt their actions to climate variability and change while preserving the integrity and sustainability of natural resources, habitats, and ecosystems.

2.1.8: Utilize the principles of ecosystem-based management and green infrastructure.

2.1.9: Develop strategic protection, retreat, and abandonment plans for areas currently experiencing rapid climate change impacts (e.g., coastline of Alaska and low-lying islands).

Strategy 2.2: Develop and apply species-specific management approaches to address critical climate change impacts where necessary.

ACTIONS:

2.2.1: Use vulnerability and risk assessments to design and implement management actions at species to ecosystem scales.

2.2.2: Develop criteria and guidelines that foster the appropriate use, and discourage inappropriate use of translocation, assisted relocation, and captive breeding as climate adaptation strategies.

2.2.3: Where appropriate, actively manage populations (e.g., using harvest limits, seasons, translocation, captive breeding, and supplementation) of vulnerable species to ensure sustainability and maintain biodiversity, human use, and other ecological functions.

USFWS/DAVE MENKE

diversity by protecting diverse populations and genetic material across the full range of species occurrences.

ACTIONS

2.3.1: Develop and implement approaches for assessing and maximizing the potential for maintaining genetic diversity of plant and animal species.

2.3.2: Protect and maintain high quality native seed sources including identifying areas for seed collection across elevational and latitudinal ranges of target species.

2.3.3: Develop protocols for use of propagation techniques to rebuild abundance and genetic diversity for particularly at-risk plant and animal species.

2.3.4: Seed bank, develop, and deploy as appropriate plant materials for restoration that will be resilient in response to climate change.

2.3.5: Develop ex-situ living collections with partners such as botanic gardens, arboreta, zoos, and aquaria.

CASE STUDY

Seed banking in a changing climate

CLIMATE CHANGE MAY BRING THE LOSS of major populations of plants—or even entire species. One of the key approaches for boosting a species' chances of surviving in a changed world is maintaining the species' genetic diversity.

Both of these issues can be addressed by collecting and banking seeds and other plant materials. An extensive seed bank can save species that go extinct in the wild, preserve the genetic diversity needed for other species to cope with a changed environment, and provide the seed needed for restoration projects.

Such a preservation effort is now underway. In 2001, Congress directed the Interagency Plant Conservation Alliance to develop a long-term program to manage and supply native plant materials for various federal land management restoration and rehabilitation needs. Working with hundreds of partners in federal, tribal, and state agencies, universities, conservation groups, native seed producers, and others, the program has now collected seeds from more than 3,000 native plant species in the United Sates.

Global networks, such as the Global Strategy for Plant Conservation and the Gran Canaria Declaration on Climate Change and Plant Conservation, also exist to protect plants. These are both important documents that can be used in the development of criteria and guidelines for plants.

Graphic adapted from BLM/Interagency Native Plant Materials Development Program

Strategy 2.3: Conserve genetic

GOAL 2 PROGRESS CHECK LIST

- ☐ Species requiring active intervention identified;
- ☐ Genetic conservation issues identified;
- ☐ Fire and other disturbance regimes managed to better suite emerging conditions;
- ☐ Criteria and guidelines developed for translocation, assisted relocation, and captive breeding;
- ☐ Vulnerability and risk assessments and scenario planning used to guide species management decisions;
- ☐ Best management practices developed and initiated;
- ☐ Species and area management plans updated;
- ☐ State Wildlife Action Plans updated to include climate adaptation;
- ☐ Agency specific climate change adaptation plans developed and integrated with other appropriate plans;
- ☐ Seed banks and living collections developed consistent with planning.

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Goal 3

Enhance capacity for effective management in a changing climate.

CLIMATE CHANGE ADAPTATION REQUIRES altering existing or developing new ways of assessing information, new management tools, and new professional skills. Natural resource agency professionals need accessible opportunities to learn about climate-related species, habitat, and ecosystem changes as well as how to identify the most promising strategies to conserve fish, wildlife, and plant populations and functioning ecosystems.

It is becoming increasingly important to train wildlife professionals on how to incorporate climate change into their management practices.

While well-trained in ecology and applied resource management, many managers have not yet had the opportunity to learn about and understand how climate change "changes the rules" about conservation of fish, wildlife, and plants. These professionals require training to enhance their capacity and confidence to understand the impacts of climate change and to design and deliver effective climate adaptation programs.

Climate change impacts are occurring at scales much larger than the operational scope of individual organizations and agencies, and successful adaptation to climate change demands a strong collaboration among all jurisdictions charged with fish, wildlife, and plant conservation, both domestic and international.

Although some regionally integrated, multi-jurisdictional climate change adaptation programs and plans exist, more are needed. Collaborative efforts will result in more informed, relevant, and creative solutions for all stakeholders. Federal, state, and tribal resources managers should work together with their partners across jurisdictions and regional scales (including international borders) to provide context and coordination for species and conservation area management in the context of climate change scenarios. Current institutional disconnects and barriers can hamper our ability to manage fish, wildlife, plants, and ecosystems across jurisdictions. This is an opportunity for practitioners to network their capacities to be more effective and efficient in terms of monitoring, data sharing, data development, and adaptive management. Existing and emerging partnerships and organizations (e.g., LCCs, Climate Science Centers (CSCs) JVs, Regional Integrated Sciences and Assessments (RISAs), NFHPs, regional ocean governors' alliances, AFWA, the Association of State Wetland Managers, and others) provide useful forums for multiple jurisdictions and partners to better work together to define, design, and deliver sustainable landscapes at a regional scale.

Many fish, wildlife, and plant conservation laws, regulations, and policies were developed without the current understanding of climate change. These legal and policy foundations should be reviewed to identify opportunities to improve, where appropriate, their usefulness to address climate change considerations. This review process should assure that these legal foundations assist, and do not impede, adaptation efforts. Appropriate regulatory tools and

adequate enforcement will be important to reduce existing stressors on fish, wildlife, and plants. It is also essential that programs are reviewed to maximize the utility of existing conservation funding and to increase the priority of climate change adaptation work.

Strategy 3.1: Increase the climate change awareness and capacity of natural resource managers and other decision makers and enhance their professional abilities to design, implement, and evaluate fish, wildlife, and plant adaptation programs.

ACTIONS

3.1.1: Build on existing needs assessments to identify gaps in climate change knowledge and technical capacity among natural resource professionals.

3.1.2: Build on existing training courses and work with professional societies, academicians, technical experts, and natural resource agency training professionals to address key needs, augment adaptation training opportunities, and develop curricula, a common lexicon, and delivery systems for natural resource professionals and decision makers.

3.1.3: Develop training on the use of existing and emerging tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, decision support tools, and adaptive management).

3.1.4: Develop a web-based clearinghouse of training opportunities and materials addressing climate change impacts on natural resource management.

3.1.5: Encourage use of interagency personnel agreements and interagency (state, federal, and tribal) joint training programs as a way to disperse knowledge, share experience and develop interagency communities of practice about climate change adaptation.

3.1.6: Support and enhance web-based clearinghouses of information (e.g., www.CAKEX.org, etc.) on climate change adaptation strategies and actions targeted towards the needs of resource managers and decision makers.

3.1.7: Increase scientific and management capacity (e.g., botanical expertise) to develop management strategies to address impacts and changes to species.

3.1.8: Develop training materials to help managers and decision makers apply climate knowledge to the administration of existing natural resource and environmental laws and policies.

CASE STUDY

Sea level rise in Delaware

A RISING SEA COMBINED with sinking land creates a watery future. The state of Delaware is experiencing both, with relative sea levels to rise at the rapid rate of one inch every eight years (NOAA 2009). That is a big problem in a state where more than 10 percent of the land lies less than eight feet above sea level and no spot is farther than 35 miles from the Atlantic Ocean, Delaware Bay, or Delaware River. Residences, communities, and industries are at risk. In fact, the state is already experiencing worrisome coastal flooding. Breaches in the sandy shoreline at Prime Hook National Wildlife Refuge, for instance, have allowed saltwater into freshwater marshes that provide important waterfowl habitat.

Keenly aware of the threat, the state of Delaware has created a Sea Level Rise Initiative to understand the impacts of sea level rise, prepare for inundation in some areas, respond where necessary, and keep the public informed. Prime Hook National Wildlife Refuge is collaborating with the state of Delaware to implement short-term adaptation strategies to address inundation and saltwater intrusion into freshwater impoundments by re-establishing the shoreline.

GREG THOMPSON / USFWS

Strategy 3.2: Facilitate a coordinated response to climate change at landscape, regional, national, and international scales across state, federal, and tribal natural resource agencies and private conservation organizations.

ACTIONS

3.2.1: Use regional venues, such as LCCs, to collaborate across jurisdictions and develop conservation goals and landscape/seascape scale plans capable of sustaining fish, wildlife, and plants.

3.2.2: Identify and address conflicting management objectives within and among federal, state, and tribal conservation agencies and private landowners, and seek to align policies and approaches wherever possible.

3.2.3: Integrate individual agency and state climate change adaptation programs and State Wildlife Action Plans with other regional conservation efforts, such as LCCs, to foster collaboration.

3.2.4: Collaborate with tribal governments and native peoples to integrate traditional ecological knowledge and principles into climate adaptation plans and decision-making.

3.2.5: Engage with international neighbors, including Canada, Mexico, Russia, and nations in the Caribbean Basin, Arctic Circle, and Pacific Ocean to help adapt to and mitigate climate change impacts in shared trans-boundary areas and for common migratory species.

3.2.6: Foster interaction among landowners, local experts, and specialists to identify opportunities for adaptation and to share resources and expertise that otherwise would not be available to many small landowners.

CASE STUDY

Traditional ecological knowledge

JEFF NICHOLS

INDIGENOUS COMMUNITIES POSSESS traditional ecological knowledge (TEK) and relationships with particular resources and homeland areas, accumulated through thousands of years of history and tradition, which make them highly sensitive to, and aware of, environmental change. TEK can be defined as the "holistic, evolving practices and beliefs passed down through generations about the relationships of living beings to their environment" (Swinomish 2010). This knowledge is place-specific and includes the relationships between plants, animals, natural phenomena, landscapes, and phenology that are used for regular practices like hunting, fishing, trapping, and forestry (Rinkevich et al. 2011).

Because of the dependence of American Indians and Alaska Natives on their natural resources for their economic and cultural identity, climate change is a threat not only to those natural resources, but also to the traditions, the culture, and ultimately, the very health of the communities themselves. TEK holds great value with respect to climate change assessment and adaptation efforts, by helping to understand climatic impacts on a wide variety of ecological processes and ecosystems, at various scales (Nabhan 2010). Governments and organizations, from the Intergovernmental Panel on Climate Change to DOI, are increasingly recognizing the value of TEK as a complement to research for developing a comprehensive response to climate change impacts, both in indigenous and non-indigenous communities (DOI 2010, Anisimov et al. 2007). Despite this gradually increasing acknowledgement, the status and trust obligations related to TEK have yet to receive comprehensive treatment.

Alaska Natives are already facing the effects of climate change head on. For example, due to erosion rates and increased climate change effects (e.g., sea ice retreat, permafrost melt, storm effects) the village of Newtok, home to the Qaluyaarmiut people, has begun relocation plans (Feifel and Gregg 2010). The Qaluyaarmiut are avid fishermen and depend on the natural environment for subsistence. The American Indian Alaska Native Climate Change Working Group represent a broad alliance of indigenous communities, tribal colleges, scientists, and activists, who work together to empower indigenous climate change adaptation. Indigenous educational institutions are critical vehicles for nurturing indigenous environmental knowledge and scientific capacity, and can be leaders of regional indigenous responses to climate change (Upham 2011).

In addition to working groups that focus on indigenous climate issues, TEK is already being utilized by other management entities in Alaska. The U.S. Fish and Wildlife Service and the State of Alaska Department of Fish and Game collect and use TEK for research and monitoring fish populations and their responses to climate and environmental change (Rinkevich et al. 2011). The response to certain environmental disasters and the justification of listing the polar bear as a threatened species both relied on the inclusion of TEK to understand and document historical ecological characteristics (Rinkevich et al. 2011). The relationships developed in Alaska are an excellent example of not only how TEK can be successfully integrated into management activities, but also how this knowledge can be collected, used, and protected in a respectful and culturally-sensitive manner.

Strategy 3.3: Review existing federal, state and tribal legal, regulatory and policy frameworks that provide the jurisdictional framework for conservation of fish, wildlife, and plants to identify opportunities to improve, where appropriate, their usefulness to address climate change impacts.

ACTIONS

3.3.1: Review existing legal, regulatory and policy frameworks that govern protection and restoration of habitats and identify opportunities to incorporate the value of ecosystem services and improve, where appropriate, the utility of these frameworks to address climate change impacts.

3.3.2: Review existing legal, regulatory and policy frameworks and identify opportunities to develop or enhance, where appropriate, market-based incentives to support restoration of habitats and ecosystem services impacted by climate change. Identify opportunities to eliminate disincentives to conservation and adaptation.

3.3.3: Review existing legal, regulatory and policy frameworks and identify opportunities to improve, where appropriate, compensatory mitigation requirements to account for climate change.

3.3.4: Review existing legal, regulatory and policy frameworks that govern floodplain mapping, flood insurance, and flood mitigation and identify opportunities to improve their usefulness to reduce risks and increase adaptation of natural resources and communities in a changing climate.

3.3.5: Review existing legal, regulatory and policy tools that provide the jurisdictional framework for conservation of fish, wildlife, and plants to identify existing provisions that provide climate change adaptation benefits.

3.3.6: Continue the ongoing work of the Joint State-Federal Task Force on Endangered Species Act Policy to ensure that policies guiding implementation of the ESA provide appropriate flexibility to address climate change impacts on listed fish, wildlife, and plants and to integrate the efforts of federal, state, and tribal agencies to conserve listed species.

3.3.7: Initiate a dialogue among all affected interests about opportunities to improve the usefulness of existing legal, regulatory, and policy frameworks to address impacts of sea level rise on coastal habitats.

Strategy 3.4: Optimize use of existing fish, wildlife, and plant conservation funding sources to design, deliver, and evaluate climate adaptation programs.

ACTIONS

3.4.1: Prioritize funding for land and water protection programs that incorporate climate change considerations.

3.4.2: Review existing federal, state, and tribal grant programs and revise as necessary to support funding of climate change adaptation and include climate change considerations in the evaluation and ranking process of grant selection and awards.

3.4.3: Collaborate with state and tribal agencies and private conservation partners to sustain authorization and appropriations for the State and Tribal Wildlife Grants Program and include climate change criteria in grant review process.

3.4.4: Collaborate with agricultural interests and businesses to identify potential impacts of climate change on crop production and identify conservation strategies that will maintain or improve ecosystem services through programs under the conservation title of the Farm Bill or other vehicles.

3.4.5: Review existing conservation related federal grants to tribal agencies and revise as necessary to provide funding for tribal climate adaptation activities.

3.4.6: Develop a web-based clearinghouse of funding opportunities available to support climate adaptation efforts.

GOAL 3 PROGRESS CHECK LIST

- ☐ Natural resource professional training needs identified;
- ☐ Climate adaptation training collaboratives established;
- ☐ Core curricula for climate adaptation established;
- ☐ Training opportunity and accessibility increased;
- ☐ Interagency personnel assignments expanded;
- ☐ Regional collaboratives engaged to serve as venues for inter-jurisdictional collaboration on climate change adaptation;
- ☐ Legal, regulatory, and policy frameworks regarding key conservation statues reviewed and as necessary, updated;
- ☐ Floodplain maps updated;
- ☐ Dialogue initiated to improve implementation of existing legal policy frameworks, regulations, and policies to respond to climate impacts;
- ☐ Criteria to include climate change adaptation in existing conservation grant programs developed;
- ☐ Criteria for including climate change adaptation needs in resource allocation developed;
- ☐ Funding allocations reviewed/revised in light of climate change priorities.

JENNY LEFF

Goal 4

Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.

THERE IS UNCERTAINTY REGARDING the specific impacts of climate change on natural resources. There is also much to be learned about the effectiveness of management actions to mitigate these impacts. To improve understanding of adaptation options, it is important to support the development and use of long-term data series, information systems, and decision support tools.

Vulnerability assessments and scenario planning can inform and enable management planning and decision-making under uncertainty.

The use of these tools, best professional judgment, and stakeholder involvement is critical to the design and implementation of management approaches to promote climate change adaptation. The continuous learning principles of adaptive management should be used to monitor the response to management actions, evaluate effectiveness, gain new knowledge, and improve and inform future management decisions. When coupled with research on specific impacts to fish, wildlife, plants, and habitats and their response to climate change (Goal 5), managers will be better equipped to implement effective management actions.

Inventory, monitoring, and observation systems should be maintained, addressed, and where needed, coordinated to enable resource managers to monitor and identify changes in ecological baselines from the species to the ecosystem level, and to prioritize and develop adaptation plans and actions. Monitoring and tracking key ecological variables can provide early warnings of pending change, and is essential to evaluating and improving adaptation responses over time. The National Ecological Observatory Network is an example of such an effort to deploy instrumentation at sites to measure key ecosystem variables arrayed across important environmental gradients. Other such systems include, but are not limited to, the Forest Inventory and Analysis, the Natural Resource Assessment, the Breeding Bird Survey, the National Wetlands Inventory, Integrated Ecosystem Assessments, the Integrated Ocean Observing System and many others. Monitoring systems, especially those that meet local to regional needs, will allow managers and other decision makers to evaluate the efficacy of management actions. International efforts are critical to monitor and track climate impacts on species that migrate to and depend on areas beyond U.S. borders. Where existing systems do not meet all management needs, additional programs may need to be developed.

While observation systems provide critical data for resource managers, those data have far greater utility when processed, analyzed, and made available as readily useable information. The need for information management and increased access to information is well-documented (Glick et al. 2011b). A multi-disciplinary approach to link and

make available data currently developed by separate agencies or groups will increase access to and use of this information by resource managers, planners, and decision makers.

Vulnerability assessments are important science-based tools that inform adaptation planning by identifying, quantifying, or evaluating the degree to which natural resources or other values are likely to be affected by changing climatic conditions. They may focus on natural resources, communities, species, sites, regions, sectors, or other values or targets, and should consider both current and future impacts. Vulnerability is generally defined as a combination of sensitivity to change, likely exposure to changing conditions, and the capacity to adapt to those changes over time (IPCC AR 4 2007). Vulnerability assessments should address all three factors. These types of assessments can help managers develop and prioritize adaptation strategies as well as inform management approaches.

Tools, such as vulnerability and risk assessments and scenario planning, can inform and enable management planning and decision-making under uncertainty. Identifying, developing, and employing these types of tools will help managers facilitate adaptation of individual species, increase habitat resilience, and help identify where changes to the built environment may conflict with ecosystem needs.

Strategy 4.1: Support, coordinate, and where necessary develop distributed but integrated inventory, monitoring, observation, and information systems at multiple scales to detect and describe climate impacts on fish, wildlife, plants, and ecosystems.

ACTIONS

4.1.1: Synthesize existing observations, monitoring, assessment, and decision support tools as summarized by the U.S. Global Change Research Program Ecosystem Working Group. Conduct a knowledge-gap analysis of existing observation networks, indicators, monitoring programs, remote sensing capabilities, and geospatial data necessary to define priorities.

4.1.2: Use available long-term monitoring programs at appropriate scales (local to international) as baselines for population and migration changes that could be affected by climate change (e.g., International Waterfowl Surveys).

4.1.3: Work through existing distributed efforts (e.g., NCA, National Estuarine Research Reserve System's system-wide monitoring program, State Natural Heritage Programs, National Wildlife Refuge System and National Park Service inventory and monitoring programs) to support integrated national observation and information systems that inform climate adaptation.

4.1.4: Expand and develop as necessary a network of sentinel sites (e.g., tribal lands, National Estuarine Research Reserves, and National Wildlife Refuges) for integrated climate change inventory, monitoring, research, and education.

4.1.5: Develop consensus standards and protocols that enable multi-partner use and data discovery, as well as interoperability of databases and analysis tools related to fish, wildlife, and plant observation, inventory, and monitoring.

4.1.6: Develop, refine, and implement monitoring protocols that provide key information needed for managing and conserving species and ecosystems in a changing climate.

4.1.7: Use existing or define new indicators at appropriate scales that can be used to monitor the response of fish, wildlife, plants, and ecosystems to climate change.

4.1.8: Promote a collaborative approach to acquire, process, archive, and disseminate essential geospatial and satellite-based remote sensing data products (e.g., snow cover, green-up, surface water, wetlands) needed for regional-scale monitoring and land management.

4.1.9: Collaborate with the National Phenology Network to facilitate monitoring of phenology; create an analogous National Population Network to catalog changes in distribution and abundance of fish, wildlife, and plants that have been identified as most vulnerable to climate change.

4.1.10: Identify and develop a lessons learned/success stories list of multi-partner data development, analysis, and dissemination efforts.

USFWS/GREG WANNER

Strategy 4.2: Identify, develop, and employ decision support tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, strategic habitat conservation approaches, forecasting, and adaptive management evaluation systems) via dialogue with scientists, managers (of natural resources and other sectors), economists, and stakeholders.

ACTIONS

4.2.1: Develop regional downscaling of Global Climate models to conduct vulnerability assessments of living resources.

4.2.2: Develop, disseminate, and utilize geophysical and biological modeling (such as Species Distribution Models).

4.2.3: Conduct vulnerability and risk assessments for habitats and priority species (threatened and endangered species, species of greatest conservation need, and species of socioeconomic and cultural significance).

4.2.4: Define national standards and criteria to identify fish, wildlife, plants, and ecosystems most vulnerable to climate change impacts.

4.2.5: Synthesize vulnerability assessments across jurisdictions to provide regional assessments.

4.2.6: Engage scientists, resource managers, economists, and stakeholders in climate change scenario planning processes, including identification of a set of plausible future scenarios associated with climate phenomena and socio-economics likely to significantly impact fish, wildlife, and plants.

4.2.7: Ensure the availability of and provide guidance for decision support tools (e.g., NOAA's Digital Coast, Sea Level Affecting Marshes Model (SLAMM), etc.) that assist federal, state, local, and tribal resource managers and planners in effectively managing fish, wildlife, and plants in a changing climate.

4.2.8: Use observation and monitoring systems in an adaptive management framework to evaluate the effectiveness of specific management actions and adapt management approaches appropriately.

4.2.9: Develop a central repository for sharing experiences and reporting progress in implementing the Strategy in order to share information across implementing agencies and partners and to inform future iterations of the Strategy.

GOAL 4 PROGRESS CHECK LIST

- ☐ Public/private collaborative convened to build nationally integrated inventory, monitoring, observation and information systems to inform climate change adaptation actions;
- ☐ Existing public and private inventory, monitoring, observation, and information systems linked and information systems assessed, linked, and made available;
- ☐ Data collection standards for common set of climate change metrics established;
- ☐ Coordinated sentinel sites identified, linked, and as necessary, established to monitor climate change impacts and responses;
- ☐ Targeted monitoring of fish, wildlife, plants, and their habitats for the effects of climate change initiated;
- ☐ Federal, state, and tribal managers provided with access to natural resources information and other necessary data;
- ☐ Evaluation of existing and new climate adaptation plans uses observation and monitoring systems;
- ☐ Regionally downscaled climate projections produced where appropriate;
- ☐ Standardized climate change scenarios developed;
- ☐ Models for climate change impacts to species and habitats improved or developed;
- ☐ Framework of tools for managing under uncertainty developed;
- ☐ Vulnerability and risk assessments conducted for priority species.

CASE STUDY

Sentinel site monitoring

The innovative approaches to sentinal site monitoring provide a framework that can be applied to inform the climate change management dialogue.

GABI ESTILL/ELKHORN SLOUGH NERR

CRAFTING AN EFFECTIVE CLIMATE adaptation strategy is difficult without having good data on the impacts of climate change. Collecting that vital information, in turn, requires observing and measuring what is happening at specific locations over many years. In 2008, the National Estuarine Research Reserve System (NERRS) began establishing such so-called "sentinel sites" to learn how estuarine habitats respond to sea level change.

One of those sentinel sites is the Elkhorn Slough Reserve in California's Monterey Bay. The area began losing some of its tidal wetlands more than 100 years ago when dikes and water control structures began to decrease tidal exchange and to many portions of the estuary. An artificial mouth to the estuary created in 1946 to accommodate a new harbor also contributed to wetland loss. Now, sea level rise is further threatening this valuable estuarine ecosystem. At the same time, the estuary is under stress from eutrophication, groundwater withdrawals, and other factors.

To understand the complex effects of these stressors, the NERRS is intensely monitoring the ecosystem. Researchers are recording surface water levels, testing water quality, and measuring changes occurring in tidal marsh plants, and submerged aquatic vegetation. They are also monitoring the amounts of sediment in the wetlands and changes in land elevation.

So far, the project has documented a worrisome trend. The marshes appear to be sinking, and this subsidence greatly decreases their resilience to future sea level rise. Eventually, rising sea levels will increase the vulnerability of a railroad line, a power plant, and a number of adjacent farms to flooding and coastal erosion. The monitoring data will be informing the adaptation measures that are taken to reduce vulnerability.

USFWS/LARRY JERNIGAN

Goal 5

Increase knowledge and information on impacts and responses of fish, wildlife, and plants to a changing climate.

THE DESIGN AND DELIVERY of fish, wildlife, and plant climate change adaptation programs is also hampered by lack of detailed knowledge about specific impacts of climate change on fish, wildlife, plants, and habitats and their adaptive capacity to respond.

The services associated with healthy ecosystems, including clean water, healthy habitats, and desirable living and recreational environments are invaluable.

It is important to note that despite a growing foundation of information, many uncertainties and gaps remain in our understanding about the current and future impacts of climate change and ocean acidification on natural resources and ecosystems.

Focused research on developing a clear set of indicators that could be used to track and assess the impacts of climate change and the effectiveness of adaptation efforts over time is still in its infancy but has been growing in recent years. Additional basic research to develop, improve, and integrate information from physical monitoring systems, satellites, and national weather service systems is needed to better understand how the climate is changing.

Knowledge gaps regarding impacts on species and ecosystems will need to be addressed. Existing research collaborations such as the USGCRP can enable natural resource managers and other decision makers to focus and prioritize research. There are many critical areas where increased basic understanding is needed to anticipate and help reduce the impacts of climate change on fish, wildlife, and plants including how climate change will alter the effects of pollutants and other existing stressors in ecosystems, and how species will respond to changes in climatic and non-climatic factors. New findings should be rapidly incorporated into decision support tools (e.g., state-and-transition models) and made available to managers, as well as into climate change adaptation planning, delivery, and evaluation. By improving the state of knowledge, managers can better develop novel and anticipatory adaptation strategies.

The use of models to project potential changes in weather patterns and natural systems has already generated a great deal of useful information to help us plan for future climate impacts, especially at large scales. Additional and more refined models at temporal and spatial scales appropriate to climate adaptation objectives established by natural resource managers are required. Development of models to predict how changes in climate variables (e.g., temperature, humidity, atmospheric CO_2) impact habitat and fish, wildlife, and plant abundance and distribution is a priority and should initially focus on processes that are already occurring and that act on short (i.e., decadal) time scales.

Most Americans appreciate the aesthetic values that healthy populations of fish, wildlife, and plants offer, and many have a cultural, recreational, or economic association with wildlife and wild places. Few, however, fully understand the services that well-functioning ecosystems provide to society or what the full cost of replacing those services would be. Methods should be developed to objectively quantify the value of ecosystem services and to understand potential impacts from climate change to these important services. Once these values are quantified, they can be considered in better economic decision-making processes.

Strategy 5.1: Identify knowledge gaps and define research priorities via a collaborative process among federal, state, tribal, private conservation organization, and academic resource managers and research scientists.

ACTIONS

5.1.1: Increase coordination and communication between resource managers and natural and social scientists through existing forums (e.g., National Science Foundation (NSF), USGCRP, NCA, USDA, Cooperative Ecosystem Studies Units, CSCs, LCCs, JVs, RISAs, Associations of Fish and Wildlife Agencies, State Wetlands Managers, State Floodplain Managers, Coastal States Organization, National Estuarine Research Reserve Association, and others) to ensure research is connected to management needs.

CASE STUDY

Plants and their pollinators

USFWS/LAURA PERLICK

MORE THAN 75 PERCENT OF FLOWERING plants, which provide a bounty of fruits, seeds, nuts, and nectar for wildlife, depend on pollinators. As the climate changes, plants will grow in different places and bloom at different times. That raises a high-stakes question: Will pollinators follow? If they cannot, then vital ecological relationships could be severed.

The U.S. Fish and Wildlife Service's Arizona Ecological Services Field Office and the Merriam-Powell Center for Environmental Research at Northern Arizona University are trying to answer this question. In the mountains of San Francisco Peaks north of Flagstaff, Arizona, teams of researchers are conducting extensive surveys of plant-pollinator relationships at five different sites.

This collaborative study is looking across ecosystems from the desert foothills up to the highest mountain peaks, collecting both ecological and climate data, and capturing changes in ecological relationships over time.

5.1.2: Bring managers and scientists together at the appropriate scales to prioritize research needs that address resource management objectives considering a changing climate.

5.1.3: Encourage agencies with scientific assets and expertise to participate in and contribute to regional dialogues about actions needed to meet management-driven science needs.

5.1.4: Participate in research planning for relevant programs of agencies (e.g., NSF, NOAA, state agencies, and local governments), and intergovernmental forums (e.g., Conservation of Arctic Flora and Fauna working group of the Arctic Council) to ensure inclusion of research relevant to missions of agencies and resource managers.

5.1.5: Based on priority conservation needs identified by resource managers, develop national, and as appropriate, regional research agendas identifying key high level questions for which more fundamental research is needed to enable development of management applications or decision support tools; and facilitate consultation among major science funding agencies to maximize incorporation of these needs into funding opportunities and work plans.

5.1.6: Prioritize research on questions relevant to managers of near-term risk environments (e.g., low-lying islands, alpine systems and high-elevation headwaters, coral reefs, and glaciated areas) or highly vulnerable species.

5.1.7: Prioritize research and methods development for the valuation of ecosystem services and the role these services play in ameliorating climate change impacts on people and communities.

Strategy 5.2: Conduct research into ecological aspects of climate change, including likely impacts and the adaptive capacity of species, communities and ecosystems, and their associated ecosystem services, working through existing partnerships or new collaborations as needed (e.g., USGCRP, NCA, CSCs, RISAs, and others).

ACTIONS

5.2.1: Produce regional to subregional projections of future climate change impacts on physical, chemical, and biological conditions for U.S. ecosystems.

5.2.2: Support basic research on life histories and food web dynamics of fish, wildlife, and plants to increase understanding of how species are likely to respond to changing climate conditions and identify survival thresholds.

5.2.3: Identify and address priority climate change knowledge gaps and needs (e.g., species adaptive capacity, risk and rewards of assisted relocation, climate change synergy with existing stressors).

5.2.4: Conduct research on the propagation and production of native plant materials to identify species or genotypes that may be resilient to climate change.

5.2.5: Accelerate research on establishing the value of ecosystem services and potential impacts to communities from climate change (e.g., loss of pollution abatement or flood attenuation; climate regulation by forests and wetlands through carbon sequestration, oxygen production, and CO_2 consumption; and pollination by insects, birds, and mammals).

5.2.6: Identify pollutants likely to be affected by climate change and accelerate research on their effects on fish, wildlife, and their habitats, including contaminant effects that will likely increase vulnerability to climate change.

Strategy 5.3: Advance understanding of climate change impacts and species and ecosystem responses through modeling.

ACTIONS

5.3.1: Define the suite of physical and biological variables and ecological processes for which predictive models are needed via a collaborative process among state, federal, and tribal resource managers, scientists, and model developers.

5.3.2: Improve modeling of climate change impacts on vulnerable species, including projected future distributions and the probability of persistence.

5.3.3: Develop models that integrate the potential effects of climate and non-climate stressors on vulnerable species.

5.3.4: Develop and use models of climate-impacted physical and biological variables and ecological processes at temporal and spatial scales relevant for conservation.

5.3.5: Provide access to current climate data and ensure alignment with data management and decision support tools at agency and departmental levels.

GOAL 5 PROGRESS CHECK LIST

- ☐ Working groups are developed that share data, expertise, and responsibilities for addressing research needs;
- ☐ Initial inventory of knowledge gaps completed;
- ☐ Research agenda developed;
- ☐ Research to address priority knowledge gaps initiated;
- ☐ Regional and subregional projections of climate change impacts completed;
- ☐ Protocols and methods for valuing ecosystem services developed;
- ☐ Approaches to improve validity of projections of future climate and improve linkage of atmospheric/climate models to ecological impact models developed.

BILL LYNCH

KEITH WELLER/USDA

Goal 6

Increase awareness and motivate action to safeguard fish, wildlife, and plants in a changing climate.

ADAPTATION EFFORTS WILL BE MOST SUCCESSFUL if they have broad support and if key groups and people are motivated to take action themselves. Resources should be targeted toward elected officials, public and private policy makers, groups that are interested in learning more about climate change issues, private landowners, and natural resource user groups.

Engaging stakeholders early and repeatedly is key to making this Strategy *work.*

Helping stakeholders understand the concept of uncertainty and decision-making in the context of uncertainty are also important and integral parts of adaptive management.

Engaging stakeholders early and repeatedly to increase awareness of the threats from climate change, to gather input in developing appropriate, integrated adaptation responses, and to motivate their participation and action is key to making this *Strategy* work.

The concept of ecosystem services is gaining traction among elected officials and policy makers, but not enough is being done to translate the concept into action. Communicating science-based information on the socio-economic value of ecosystem services to public and private decision makers and opinion leaders should be accomplished by using real examples.

Development and implementation of effective adaptation policies and practices requires that interested constituencies and key stakeholders understand the fundamentals of climate change adaptation. Practical education and outreach efforts and opportunities for participation should be developed and implemented whenever possible.

Strategy 6.1: Increase public awareness and understanding of climate impacts to natural resources and ecosystem services and the principles of climate adaptation at regionally- and culturally-appropriate scales.

ACTIONS

6.1.1: Develop focused outreach efforts and materials aimed at local, state, tribal, and federal government authorities; land and water managers; economic policy decision makers; zoning and transportation officials; etc. on ecosystem services, climate impacts to fish, wildlife, plants, and ecosystems, the impacts of other local stressors, and the importance of adaptation planning.

6.1.2: Develop outreach efforts and materials to other key audiences, such as the private sector (e.g., agriculture, forestry, etc.), cultural leaders, and private land managers that provide information on existing conservation incentive programs.

6.1.3: Identify and partner with key stakeholder groups (e.g., conservation and environmental organizations, hunting and angling groups, trade associations, outdoor manufacturers and retailers) to help develop and distribute key climate change and adaptation messages tailored for their interest groups as well as the broader public.

6.1.4: Incorporate information about potential climate change impacts to ecosystem services in education and outreach activities.

6.1.5: Increase public awareness of existing habitat conditions and the benefits of building resiliency of those habitats.

Strategy 6.2: Engage the public through targeted education and outreach efforts and stewardship opportunities.

ACTIONS

6.2.1: Identify and make opportunities available for public involvement to aid in the development of focused outreach materials.

6.2.2: Use public access points, nature centers, and hunting and fishing regulation guides to inform tourists, visitors, and recreational users of climate change impacts to and adaptation strategies for fish, wildlife, and plants.

6.2.3: Develop specific programs and/or modify existing programs (e.g., bird and amphibian surveys) to motivate action and engage citizens in monitoring impacts of climate change on the landscape (e.g., citizen science monitoring for detection of invasive species, nature center programs, etc.).

6.2.4: Make research and monitoring information regarding climate impacts to species and natural systems accessible and easily understood to the public and other partners (e.g., commercial fisheries, etc.).

6.2.5: Develop educational materials and teacher trainings for K-12 classrooms linked to state education standards on impacts and responses to climate change.

6.2.6: Develop collaborations with zoos, museums, aquariums, botanic gardens, arboreta, and other organizations and universities to increase communication and awareness of impacts and responses to climate change.

6.2.7: Develop core messaging and recommended strategies to communicate the *Strategy* within participating organizations, local associations and clubs (e.g., garden clubs), and with the public.

6.2.8: Develop strategy to assess effectiveness of communication efforts and modify as appropriate.

Strategy 6.3: Coordinate climate change communication efforts across jurisdictions.

ACTIONS

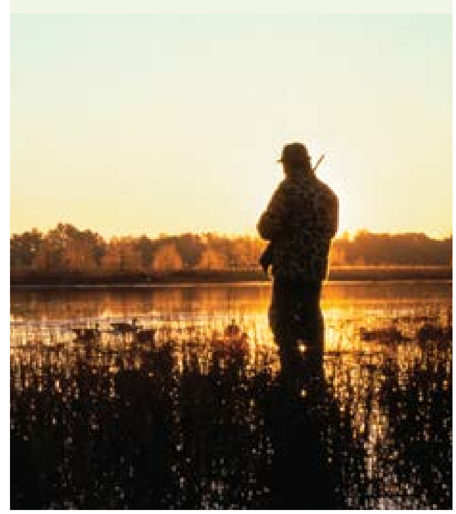
6.3.1: Develop, implement, and strengthen existing communication efforts between federal agencies, with states and tribes to increase awareness of the impacts and responses to climate change.

6.3.2: Engage employees from multiple agencies in key climate change issues by expanding existing forums for information sharing and idea exchange, and create new forums and channels as needed.

6.3.3: Provide access to tools (web-based and others) that promote improved collaboration, interactive dialog, and resource sharing to minimize duplication of effort across jurisdictions.

GOAL 6 PROGRESS CHECK LIST

- ☐ Focused outreach to key decision makers initiated;
- ☐ Stakeholder representatives engaged in working groups related to climate change messaging;
- ☐ Improved messaging and targeting of information on fish, wildlife, and plants, ecosystem services, and climate change to key audiences developed;
- ☐ Agency-produced educational and interpretive materials and papers are developed and distributed;
- ☐ Tools designed to engage citizens in monitoring impacts of climate change developed;
- ☐ Educational curricula developed;
- ☐ Collaborations with zoos, aquaria, museums, and botanic gardens initiated;
- ☐ Workshops and communication programs increasing awareness of climate change related issues regarding fish, wildlife, and plants across agencies developed;
- ☐ Effectiveness of communications assessed.



USFWS/PAT HAGAN

USFWS/RYAN HAGERTY

Goal 7

Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

THIS *STRATEGY* IDENTIFIES ACTIONS THAT natural resource managers and others can take to address the impacts of climate change on fish, wildlife, and plants and the human uses and benefits that living systems provide. One of the most important actions is to reduce the negative impacts of existing stressors to help increase the capacity of fish, wildlife, and plants to cope with changing climate conditions.

Addressing existing stressors has been the focus of natural resource conservation and management efforts for decades, often with notable successes.

While this *Strategy* does not attempt to catalog all of those critical efforts, it is important to note that some of these existing stressors (such as habitat loss, fragmentation, and degradation, invasive species, disease, pollution, over-harvesting, destructive harvest practices (e.g., fisheries bycatch and illegal trade) are not only some of the things decision makers can control, they are also likely to interact with climate change to magnify negative impacts on fish, wildlife, and plants (Negri and Hoogenboom 2011). Indeed, the cumulative effects of these existing stressors is already a major threat to many species, some of which may not survive long enough to have a chance of adapting to climate change if existing stressors are not adequately addressed. Thus, reducing these existing stressors is both essential to maintain short-term survival for some species, but also may be some of the most effective ways to increase resilience of fish, wildlife, and plants in a changing climate. Where possible, reducing non-climate stressors should be approached with a changing climate in mind to prioritize actions and discourage maladaptive decisions.

Continued application of ecosystem based approaches to natural resource management is also a key step in this process given the scale and scope of climate change impacts on natural and human communities. The importance of conserving, restoring, and connecting suitable habitats as a way to enhance fish, wildlife, and plant resiliency has been discussed previously, and reducing and mitigating the ongoing degradation associated with human development such as pollution and loss of open space is also critical. Opportunities for collaboration should be actively pursued with land-use planners as well as major sectors such as agriculture, transportation, and water resource interests to identify common concerns and shared solutions.

As described previously, invasive species are pervasive in our environment and becoming more so every day. There are no easy ways to combat invasive species, but coordinating efforts across jurisdictions, international borders and among terrestrial and aquatic resource managers and citizen scientists can help. Greater coordination in stepping up efforts at prevention, enhancing early detection and rapid response programs, and avoiding accidental movement of invaders is essential (National Invasive Species Council 2008). Moreover, decisions regarding increasing connectivity and restoring corridors will have to be weighed with the threat of invasives and the consequences of choosing one adaptation strategy over another. In addition to the threats from invasive species, climate stresses are causing some native pests and pathogens as well as pollution exposure to become increasingly problematic and this will need to be considered when management plans are developed.

CASE STUDY

Fighting the spread of water hyacinth

INTRODUCED INTO THE UNITED STATES in the late 1890s from South America, water hyacinth has spread rapidly across the southeastern United States, and today is already a major pest. This floating plant produces vast, thick mats that clog waterways, crowding out native plants and making boating, fishing, and swimming almost impossible.

Because water hyacinth cannot survive when winter temperatures drop below freezing, climate change will only make the problem worse. Rising temperatures will allow this pest to invade new areas, and the plant will likely spread north. Fortunately, there are some effective measures for fighting invasions of water hyacinth, such as utilizing weevils along with some herbicides (Mallya et al. 2001).

PHIL WHITEHOUSE

But these steps must be taken before the plant gets established, emphasizing the vital importance of planning for invasions projected in a changing climate and constantly monitoring vulnerable ecosystems for the first telltale signs of such invasions.

Strategy 7.1: Slow and reverse habitat loss and fragmentation.

ACTIONS

7.1.1: Work with local land-use planners, flood-plain administrators, and others to identify shared interests and potential conflicts in reducing and reversing habitat fragmentation and loss through established planning and zoning processes.

7.1.2: Work with farmers and ranchers to apply the incentive programs in the conservation title of the Farm Bill as well as the landowner tools under the ESA and other programs to minimize conversion of habitats, restore marginal agricultural lands to habitat, and increase riparian buffer zones.

7.1.3: Provide landowners with appropriate incentives for conservation and restoration of key habitats, such as conservation easement tax incentive programs, designed to protect private lands of high habitat connectivity value under climate change.

7.1.4: Work with water resource managers to enhance design and siting criteria for water resources infrastructure to reduce impacts and restore connectivity in floodplains and aquatic habitats.

7.1.5: Work with local and regional water management agencies to evaluate historical water quantities and base flows and develop water management options to protect or restore aquatic habitats.

7.1.6: Consider application of offsite habitat banking linked to climate change habitat priorities as a tool to compensate for unavoidable onsite impacts and to promote habitat conservation or restoration in desirable locations.

7.1.7: Consider market-based incentives that encourage conservation and restoration of ecosystems for the full range of ecosystem services including carbon storage.

7.1.8: Minimize impacts from alternative energy development by focusing siting options on already disturbed or degraded areas.

7.1.9: Identify options for redesign and removal of existing structures or barriers where there is the greatest potential to restore natural processes.

Strategy 7.2: Slow, mitigate, and reverse where feasible ecosystem degradation from anthropogenic sources through land/ocean-use planning, water resource planning, pollution abatement, and the implementation of best management practices.

ACTIONS

7.2.1: Work with local and regional land-use, water resource, and coastal and marine spatial planners to identify potentially conflicting needs and opportunities to minimize ecosystem degradation resulting from development and land and water use.

7.2.2: Work with farmers and ranchers to develop and implement livestock management practices to reduce and reverse habitat degradation and to protect regeneration of vegetation.

7.2.3: Reduce existing pollution and contaminants and increase monitoring of air and water pollution as necessary.

7.2.4: Work with water resource managers to identify, upgrade, or remove outdated sewer and stormwater infrastructure to reduce water contamination.

7.2.5: Increase restoration, enhancement, and conservation of riparian zones and buffers in agricultural and urban areas to minimize non-point source pollution.

7.2.6: Work with federal, state, and tribal environmental regulators to address potential pollution threats, including impairments to water quality.

7.2.7: Reduce impacts of impervious surfaces and stormwater runoff in urban areas to improve water quality, groundwater recharge, and hydrologic function.

7.2.8: Reduce ground and surface water withdrawals in areas experiencing drought and/or increased evapotranspiration.

7.2.9: Promote water conservation, reduce water use, and promote increased water quality via proper waste disposal.

7.2.10: Develop and implement protocols for considering carbon sequestration and storage services of natural habitats in management decisions.

7.2.11: Incorporate the recommendations and actions from the National Action Plan for Managing Freshwater Resources in a Changing Climate into water resource planning.

7.2.12: Consider the impact of logging practices on fire risk and ecosystem diversity and function.

Strategy 7.3: Use, evaluate, and as necessary, improve existing programs to prevent, control, and eradicate invasive species and manage pathogens.

ACTIONS

7.3.1: Use, integrate, and implement existing pest and pathogen risk assessment methodologies for imported organisms and establish appropriate regulations to prevent deliberate importations of pests, pathogens, or other species that are predicted to be harmful or invasive.

7.3.2: Employ a multiple barriers approach to detect and contain incoming and established invasive species, including monitoring at points of origin and points of entry for shipments of goods and materials into the United States and for trans-shipment within the country. Utilize education, regulation, and risk management tools (e.g., the Hazard Analysis and Critical Control Point process).

7.3.3: Develop national standards for collecting and reporting invasive species data to facilitate information sharing and management response.

7.3.4: Apply risk assessment and scenario planning to identify actions and prioritize responses to invasive species that pose the greatest threats to natural ecosystems.

7.3.5: Implement existing national, state and local strategies and programs for rapid response to contain, control, or eradicate invasive species, and develop new strategies as needed.

7.3.6: Assess risks and vulnerability to identify high priority areas and/or species for monitoring of invasive species and success of control methods.

7.3.7: Monitor invasive species and pathogens associated with fish, wildlife, and plant species for increased understanding of distributions and to minimize introductions.

7.3.8: Apply integrated management practices, share innovative control methodologies, and take corrective actions when necessary to manage fish, wildlife, and plant diseases and invasives.

7.3.9: Work with federal, state, regional, and county agricultural interests to identify potentially conflicting needs and opportunities to minimize ecosystem degradation resulting from pests, pathogens, and invasive species eradication, suppression, and control efforts.

Strategy 7.4: Reduce destructive capture practices (e.g., fisheries bycatch, destructive fishing gear), over-harvesting and illegal trade to help increase fish, wildlife, and plant adaptation.

ACTIONS

7.4.1: Reduce the unintentional capture (such as fisheries bycatch) of species in fishing and other capture activities.

7.4.2: Implement the 2011 U.S. National Bycatch Report recommendations (NMFS 2011) to increase information of bycatch levels, identify fisheries and/or species with potential bycatch concerns, and improve monitoring of bycatch levels over time.

7.4.3: Reduce negative impacts of capture practices and gear on important habitats for fish, wildlife, and plants.

7.4.4: Determine sustainable harvest levels in changing climate, and design, implement, and evaluate management plans and practices to eliminate over-harvest of fish, wildlife, and plants.

7.4.5: Increase efforts to monitor and reduce illegal species trade in the United States.

GOAL 7 PROGRESS CHECK LIST

- ☐ Regional and local land-use, water resource, coastal, and marine planners engaged;
- ☐ Collaboration with farmers and ranchers to review/revise livestock management practices begun;
- ☐ Nationwide inventory of outdated legacy infrastructure initiated;
- ☐ Disruptive floodplain infrastructure reduced/removed;
- ☐ Coordinated invasive species and disease monitoring system established;
- ☐ Multiple barriers to invasive species introduction in place;
- ☐ Strong import screening protocols established;
- ☐ Coordinated national invasives management actions implemented;
- ☐ Pollution/contaminant monitoring improved;
- ☐ Destructive capture practices identified and reduced.

CH.4 Opportunities for Multiple Sectors

CLIMATE CHANGE POSES SIGNIFICANT CHALLENGES for more than our nation's ecosystems. Its impacts also will be felt in cities and towns, and in sectors such as agriculture, energy, transportation and other infrastructure, housing, and water resources. The anticipated impacts to those sectors have been well documented and the threat of climate change has already prompted important adaptation efforts.

It is important to consider not only the impacts of other sectors on species and their ecosystems, but to look for opportunities for coordinated adaptation strategies that provide co-benefits.

Chicago is installing "green" roofs that put vegetation on top of buildings and "cool" pavement that reflects light to tamp down anticipated heat waves (Hayhoe and Wuebbles 2010). Keene, New Hampshire, has upgraded storm-water systems and other infrastructure after being hit by devastating floods (City of Keene, New Hampshire 2007). Native Americans are moving entire villages in Alaska and making trout habitat more resilient in Michigan (Buehler 2011). Overall, at least 17 states have or are developing climate adaptation plans. At the federal level, adaptation efforts are being coordinated by the ICCATF and are described in the October 2011 *Progress Report of the Interagency Climate Change Adaptation Task Force* (CEQ 2011).

All of these affected interests will respond to climate change impacts in their own way, and the decisions made in these sectors will ultimately impact our nation's fish, wildlife, and plants. At times, adaptation efforts taken by these sectors can conflict with the needs of ecosystems (maladaptation). For example, southwestern cities diversifying their water supplies may take vital water away from wildlife and farmers. But far more often, climate change adaptation can benefit multiple sectors. Restoring wetlands to provide more resilient habitats also can improve water quality and slow floodwaters helping downstream cities. Protecting coastal ecosystems also helps protect communities and industries from rising sea level along the coast. Moreover, research on the economics of climate adaptation shows that it can be far cheaper to invest in becoming more resilient now than to pay for damages caused by climate change later (ECA 2009).

In working to reduce climate change impacts on fish, wildlife, and plants, it

is important to consider not only the impacts of other sectors on these species and their ecosystems, but to look for opportunities for coordinated adaptation strategies that provide co-benefits. These sectors can take actions that also reduce non-climate stressors on ecosystems. For instance, precisely matching fertilizer amounts to the differing needs of each section of a field can cut overall fertilizer use and nutrient runoff, thus reducing the algal blooms that stress aquatic ecosystems and increase their vulnerability to climate change (e.g., increasing water temperatures).

It is outside the scope of this *Strategy* to describe in detail the climate change impacts on various sectors or their adaptation needs. Instead, this chapter briefly describes relevant climate impacts and recommends actions for managers in these sectors to promote co-benefits and ensure that the needs of fish, wildlife, and plants are considered in their climate adaptation efforts.

There are seven overarching climate adaptation strategies, common to all sectors, that can benefit fish, wildlife, and plant adaptation:

1 | Improve the consideration of impacts to fish, wildlife, and plants in the development of sector-specific climate adaptation strategies.

2 | Enhance coordination between sectors and natural resource managers, land-use planners, and decision makers regarding climate change adaptation.

3 | Use integrated planning to engage all levels of government (local, state, federal, and tribal) and multiple stakeholders in multi-sector planning.

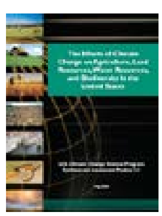
4 | Make best available science on the impact of climate change on fish, wildlife, and plants accessible and useable for planning and decision-making across all sectors.

5 | Explicitly consider natural resource adaptation in sector-specific climate adaptation planning.

6 | Improve, develop, and deploy decision support tools, technologies, and best management practices that incorporate climate change information to reduce impacts on fish, wildlife, and plants.

7 | Assess the need for, and the utility of, expanding compensatory mitigation requirements for projects that reduce ecosystem resilience.

ADDITIONAL RESOURCES ON IMPACTS TO OTHER SECTORS



National Action Plan: Priorities for Managing Water Resources in a Changing Climate (ICCATF 2011)

The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States (CCSP 2008d)

Effects of Climate Change on Energy Production and Use in the United States (CCSP 2007)

Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I (CCSP 2008b)

Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region (CCSP 2009a)

The Washington Climate Change Impacts Assessment (Climate Impacts Group 2009)

Wisconsin Initiative on Climate Change Impacts (WICCI 2011)

California Climate Adaptation Strategy (CAS) (CNRA 2009)

4.1 Agriculture

Agricultural production is the predominant land use on the American landscape. Virtually all crop (390 million acres) and pasture land (119 million acres), as well as a large fraction of rangeland (409 million acres), is privately owned by more than two million landowners and provides a livelihood to them and those who rent from them. Climate change aside, grassland species in the United States will feel more pressure over the next century as food production responds to greater demand from a larger global population and as farming technologies expand the range for planting annual crops both north and west. Further changes can be expected when drought, flood, or other climatic disruption affects crop production in Australia, Asia, or South America in the future. A successful climate change adaptation strategy for grassland species must contend with the global market forces and the associated policy responses that generate the returns to agricultural production. This represents a more formidable challenge than adapting public lands management to respond to a new stressor.

Irrigated agriculture relies heavily on surface-water diversions and groundwater pumping. Projected climate changes include less snowpack which would mean less natural springtime replenishment of water storage in the surface-water reservoirs.

JOHN CURLEY

Agricultural production is an economic activity that is uniquely sensitive to changes in precipitation and temperature and these agronomic factors are predicted to be more variable in a changing climate. Producers and governments will seek to mitigate the increased risk of shortages due to crop failure by increasing or encouraging increased production. If new technology or more nutrients and water cannot be used to satisfy increasing demand for food, open space will be used with increasing intensity for agricultural production, with pastureland converting to cropland, rangeland to pastureland and cropland, and retired marginal land to all three agricultural land uses. Expanding crop production in this way will likely increase pressures on plant and wildlife species that may also be confronting pressures resulting from a changing climate. Given the managed nature of agricultural lands and the likely expansion of cropland into grassland areas, it is critical to identify strategies to aid plant and wildlife adaptation in agriculture-dominated landscapes.

Maintaining viable grassland species populations requires adopting more wildlife friendly agricultural practices, managing the intensity of agricultural production, and selectively retiring some lands from production. Existing programs offer incentives for producers. For example, the Environmental Quality Incentives Program offers cost share for wildlife friendly livestock fencing. Other practices, like haying and grazing systems that have schedules sensitive to bird nesting seasons and integrated pest management, can make crop production more compatible with wildlife and pollinators.

Using long-term contracts and permanent easements, other programs encourage landowners to take and keep land out of crop production when doing so confers large conservation benefits. Two programs that are particularly relevant to grasslands are the Grasslands Reserve Program (GRP) and CRP. The former offers annual contract payments or lump-sum easement payment to landowners who want to maintain or enhance viable grasslands and the latter offers annual contract payments to landowners who convert cropland to grassland. Long-term contracts are particularly well-suited to climate change concerns because they can be used as "rolling easements," permitting the landscape configuration of habitat to evolve over time. The CRP has been credited for providing habitat and increasing populations of waterfowl and grassland birds that had seen long-term population declines prior to the program. Both programs employ critical elements of climate adaptation strategies such as outreach, technical assistance, and financial incentives to help landowners restore and conserve grassland ecosystems and help to mitigate the effects of climate change.

Adaptation strategies for agriculture also benefiting natural resources

- » Encourage producers to take sensitive lands out of crop production for extended periods of time and restore wildlife habitat on these lands.
- » Encourage producers to maintain grassland habitat.
- » Encourage producers to adopt agricultural production and land use strategies that are resilient under changing conditions and that benefit agriculture, fish, and wildlife.
- » Improve estimates of ecosystem services to better link conservation compensation with the environmental services producers provide.
- » Encourage producers to adopt wildlife-friendly practices.

CASE STUDY

Lesser prairie-chicken in a changing climate

THE LESSER PRAIRIE-CHICKEN, which resides mainly in the grasslands of the southern Great Plains region, is a species in trouble. The conversion of native rangelands to cropland, decline in habitat quality due to herbicide use, petroleum and mineral extraction activities, and excessive grazing of rangelands by livestock have all contributed to a significant decline in population leading to its Candidate status under the federal Endangered Species Act (NRCS 1999).


GREG KRAMOS / USFWS

Climate change is expected to make the bird's plight worse. Climate change models project that temperatures in the lesser prairie-chicken's range will climb by about 5 °F and that precipitation will decrease by more than one inch per year by 2060 (USGCRP 2009). Such changes would likely harm the lesser prairie-chicken's chances of survival.

The good news is that simple management steps can make a big difference. Under existing USDA conservation programs, farmers and ranchers are compensated to take land out of production to create wildlife habitat. In fact, a landscape-scale geospatial analysis has shown that restoring native prairie grasses and sagebrush on 10 percent of land enrolled in CRP, if properly targeted, could offset the projected population decline of lesser prairie-chicken from climate change (McLachlan et al. 2011).

4.2 Energy

Climate-related changes to fish and wildlife habitat will occur simultaneous to changes that are occurring in the energy sector. Some of these changes will have clear implications for energy production and use (CCSP 2007). Energy usage patterns are expected to change in the United States, as are population demographics that drive regional energy demand and seasonal energy needs for heating and cooling (CCSP 2007, USGCRP 2009). For instance, average warming can be expected to increase energy requirements for cooling and reduce energy requirements for heating (USGCRP 2009).

USFWS/RACHEL MOLENDA

Development of more efficient clean sources of energy remains a challenge, but is becoming increasingly important in a changing climate.

In addition to challenges in managing consumer demand for electricity, particularly during peak load periods, changes in the physical environment may affect existing generation capacity and constrain the siting of new energy generation capacity (CCSP 2007). For example, changes in precipitation and snow pack will affect the seasonality and overall generating capacity of hydroelectric power, and decreased freshwater availability and increased surface water temperatures will affect water-cooled thermoelectric power plants in some regions (USGCRP 2009). Coastal power plants in some regions could be subject to climate-related impacts from erosion, inundation, storm surges, and river flooding as sea level rises and precipitation increases, especially during severe weather events (USGCRP 2009). Changes in the intensity or frequency of severe storms could also affect the reliability of transmission infrastructure (CCSP 2007, USGCRP 2009).

Changes in the production and use of fuels for transportation, heating, and cooling must also be considered, including the increased production of biofuels. Coastal (and offshore) facilities and infrastructure for producing and distributing liquid transportation fuels could be subject to similar impacts as coastal power plants (CCSP 2007, USGCRP 2009). Changes in population demographics could also affect levels of consumption and the location of infrastructure associated with the delivery of fuels (CCSP 2007).

Decisions made within the energy sector affect fish, wildlife, and plants, as do decisions in the natural resource management sector affect the energy sector. There is considerable uncertainty as to how many species of fish, wildlife, and plants will respond to climate change effects. The migration of species, particularly those listed as threatened or endangered, or the change in status of currently healthy populations under future environmental stressors, could affect the operation and siting of existing and new energy infrastructure. The sources of energy that are used influence the rate of GHG emissions, as well as the level of stress placed on local fish, wildlife, and plant populations along the supply chain. For this reason, it is important that efforts within the energy sector and natural resources management sector are better informed.

Adaptation strategies for energy development also benefiting natural resources

- Increase consultation and better align natural resource management and energy sector climate change adaptation strategies and activities, including vulnerability assessments.
- Incentivize the siting of new large energy projects in previously disturbed areas or areas that have the least impact to fish, wildlife, and plants. Avoid areas of high ecological vulnerability and areas with limited water availability and competing water demands.
- Research and develop energy technologies that minimize climate change impacts to fish, wildlife, and plants.
- Use local and regionally appropriate approaches that incorporate adaptive management principals to develop and site renewable energy resources to reduce vulnerability and enhance the resilience of local and regional ecosystems.

Human responses to climate change in the urban environment will likely include both fortification and relocation, impacting wildlife and natural systems in a variety of ways.

Human responses to climate change in the urban environment are expected to take one of two general paths: fortification or relocation.

4.3 Housing and Urbanization

Since U.S. cities, towns and communities developed with an assumption of relatively stable climatic conditions, many U.S. municipalities and urban centers are at risk from the changing climate. This risk is exacerbated by a burgeoning urban population; 80.7 percent of the U.S. population now resides in urban areas, an increase of 12.1 percent since 2000 (U.S. Census Bureau 2012). Further, 30 percent of the U.S. population lives in a "coastline county"—and population along coasts continues to increase (U.S. Census Bureau 2010). Sea level rise and changes in temperature, precipitation, and extreme weather events will have the greatest impact on society and urban centers. Physical damage from storms, flooding, and sea level rise will threaten infrastructure and development, particularly along the coast. Changing temperatures and precipitation patterns will affect the built environment as well as resource availability (e.g., water). Increased temperatures and forest fires will reduce air quality and threaten life and property (McMahon 1999).

Human responses to climate change in the urban environment are expected to take one of two general paths: fortification or relocation. Each of these broad strategies will affect fish, wildlife, and plants in a number of ways. In response to rising sea levels and extreme precipitation events, communities may develop engineered structures, such as seawalls and levees, to protect critical assets from potential inundation. These strategies, in turn, may adversely affect surrounding landscapes, resulting in habitat loss, and the inability of fish, wildlife, and plants to respond to climate-based stressors. In the longer term, human populations will likely shift to areas with ample natural amenities while people that remain in areas without necessary resources will exert more effort to import those resources (CCSP 2008a). The shifts in human population and the use of resources can be expected to strain the ecosystem services provided by the natural environment. Increased human demand for water resources will likely reduce water availability for fish, wildlife, and plants.

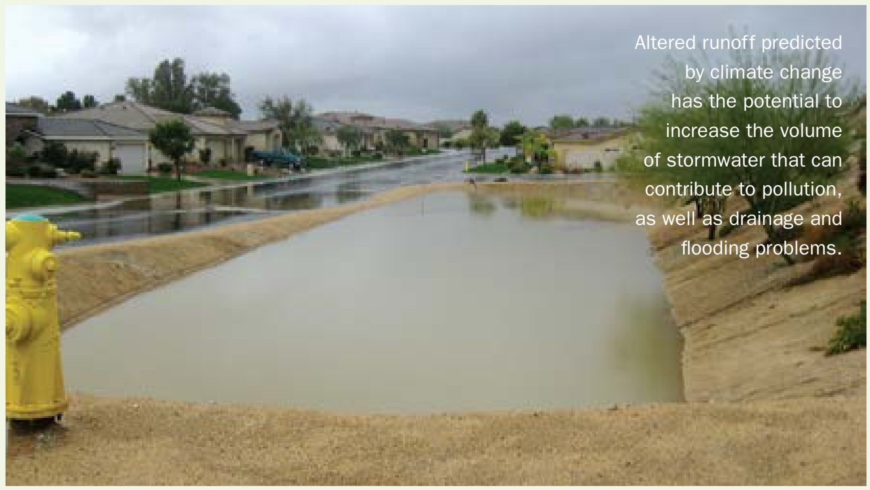
The availability of culturally, commercially, and recreationally important species for human uses (e.g., fishing, hunting, watching) will also change as species distributions respond to a changing climate and human population pressures. Availability of those species will ultimately affect subsistence and commercial use, recreation, tourism, and the economy. Also affecting the economy will be the response of harvestable resources (e.g., timber, fish) to a changing climate. Decisions made regarding development can affect fish, wildlife, and plant populations by reducing habitat availability, fragmenting habitats, and increasing multiple stressors. And conversely, development will be affected by the presence of species listed under the ESA, the number of which will likely grow due to climate change.

Adaptation strategies for community planning also benefiting natural resources

- Provide opportunities to engage many different stakeholders in land use and resource use decisions that incorporate climate change considerations.
- Anticipate changes in human demographic patterns in response to climate change, identify potential conflicts with the protection of fish, wildlife, and plants, and develop possible solutions.
- Continue current research on the valuation of ecosystem services so that communities can make better-informed decisions regarding land use and resource protection.
- Educate the public about ecosystems, ecosystem services, and anticipated climate changes, and prepare the public for projected changes.
- Develop multi-objective strategies to identify landscapes which sustain ecological values and provide human benefits through ecosystem services (e.g., urban green space which provides recreational and cooling values; restoration of native habitats and species; and promotion of native and drought tolerant species in development standards).
- Provide tools and methods that encourage communities to analyze the potential costs and benefits of adaptation strategies (i.e., fortify, accommodate, relocate) and their impact on surrounding habitats.
- Incorporate habitat migration potential into land-use planning and protect key corridors for species movement.
- Review federal programs to encourage buyouts and other mitigation measures in areas vulnerable to recurring climate change impacts.

CASE STUDY

Stormwater runoff



Altered runoff predicted by climate change has the potential to increase the volume of stormwater that can contribute to pollution, as well as drainage and flooding problems.

RAYMOND SHOBE

A MAJOR SOURCE OF POLLUTION related to development along the coastline is stormwater runoff. Runoff degrades water quality, making it an important stressor affecting resilience and sustainability of coastal habitats and species. As a result of increasing development, impervious surfaces that do not allow rain to penetrate the soils (such as parking lots, roads and rooftops) increase the amount, peak flow, and velocity of stormwater runoff, carrying pollutants into waterways and scouring streambanks. Changing precipitation patterns, especially increased frequency and intensity of heavy rains, will have a compounding effect on the amount of stormwater released into surrounding ecosystems.

Many tools are being developed to help land managers make informed decisions. For example, The National Oceanic and Atmospheric Administration's National Centers for Coastal Ocean Science at Hollings Marine Laboratory has developed a stormwater runoff-modeling tool to project the local impacts of development in a changing climate (Blair et al. 2011). Urbanized watersheds were compared with less-developed suburban and undeveloped forested watersheds to examine the relationship between land-use change and stormwater runoff and how this will be amplified under climate change.

This user-friendly and flexible tool provides a mechanism to quantify the volume of runoff and peak flow estimates under different land use and climate change scenarios. It provides an improved understanding of the impacts of development on stormwater runoff as well as the potential impacts associated with climate change in urbanized communities. Moreover, this research provides coastal resource managers with a tool to protect coastal habitat resiliency from both non-climatic stressors such as development as well as climate-associated stressors such as changing patterns of precipitation.

4.4 Transportation and Infrastructure

Transportation planners, owners, and operators face many of the same impacts and challenges of climate change as natural resource managers. Impacts of particular concern include rising sea level as well as increases in very hot days and heat waves, Arctic temperatures, intense precipitation events, and hurricane intensity (CCSP 2008b). While climate change poses threats to existing infrastructure, a changing climate likely will create new opportunities for increased Arctic transit or reduce operational costs for snow removal and maintenance.

Climate change will need to be considered in future infrastructure design, as projects are designed to stand the test of time and are built with long timeframes and local conditions in mind. Thus, it is necessary to understand how the impacts of climate change on local conditions are expected to change during the project's lifetime. Early and coordinated planning can allow transportation professionals and natural resource managers to design systems such that the goals of both can be met given a changing climate.

Natural resource and transportation agencies would benefit from increased collaboration on anticipated changes in flora and fauna patterns and potential ways to address them. Regional habitat conservation plans and strategies developed by resource agencies would provide information and a better understanding of the types of species that will be supported in the future. For example, if a transportation project is initiated with a lifetime of 20 to 40 years, advice and information from natural resource agencies is needed to ensure the right plantings for the future climate, not just current native species. These conservation plans and strategies would be used by Metropolitan Planning Organizations and state Departments of Transportation, airport planners and other transportation agencies in the development of transportation plans to avoid potential ecosystem impacts, allow advanced planning to minimize or avoid impacts, and to promote habitat resilience. Transportation agencies also could use these conservation strategies in the project development process to mitigate project effects in a more predictable, effective, and efficient manner.

The use of advanced conservation strategies and conservation banks by transportation agencies should continue to be encouraged. However, when such advanced practices are deployed, natural resource and transportation agencies should collaborate on sharing and identifying changing land use patterns to best inform locations for advanced conservation and banking decisions.

Natural resource and transportation agencies should work together to develop best practices that address the potential to use bridges, culverts, and roadway design to mitigate specific impacts such as sea level rise, precipitation, and stormwater on flora and fauna. For example, one method to deal with more intense precipitation events and resulting flooding is to increase the diameter of culverts. Larger culverts can, in some cases, also help to improve the ability of the culvert to serve as a passage for mammals, amphibians, and fish. Where both goals are being considered, the passage requirements of various animals and the geometry and geomorphology of the given stream should be taken into account in culvert design. As another example, protecting barrier islands and wetlands benefits both the natural environment and also reduces the effects of storms on the land and transportation infrastructure (roads) and operations. The Transportation Research Board has recommended a number of operational and design adaptation strategies for transportation systems responding to a variety of climate impacts.

CASE STUDY

Interagency cooperative conservation

WHILE NOT APPLICABLE TO ALL transportation agencies, Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects is an example of one existing robust program approach to help address ecosystem and species conservation given a changing climate and offers a framework for achieving greater interagency cooperative conservation. Eco-Logical is an environmental review toolkit designed to help agencies join in partnerships as catalysts for greater stakeholder cooperation and coordination through promoting a Strategic Habitat Conservation and an ecosystem approach to species and ecosystem conservation, including the integration of climate change into the conservation strategy. It is goal driven, and based on a collaboratively developed vision of desired future conditions that integrates ecological, economic, and social factors. It is applied within a geographic framework defined primarily by ecological boundaries (Brown 2006).

RICHARD WASSERMAN

Lake Mead is the largest reservoir in the United States in maximum water capacity but severe drought has caused water levels to drop.

Adaptation strategies for transportation also benefiting natural resources

- Strengthen interagency and stakeholder cooperation and coordination, particularly between transportation and natural resource planners and managers.
- Identify changing transportation demands resulting from climate change and the implications to infrastructure development.
- Use the best available habitat conservation plans to develop strategies associated with transportation projects that take into account climate change impacts to habitats and species.
- Develop best management practices (BMPs) and best designs for transportation projects to accommodate climate change effects and incorporate conservation needs at the same time.

4.5 Water Resources

Water resources are shared by fish, wildlife, plants, and many different human interests (e.g., agriculture, drinking water, manufacturing, energy). The balance of use and consumption will ultimately determine the quantity and quality of water available for species and ecosystems. Already under stress from climate change, the nation's fish, wildlife, and plant populations would be further stressed by a lack of available, high quality water resources. All decisions made regarding water resources will have a direct influence on the quantity and quality of habitat that supports both aquatic and terrestrial species.

Many of the impacts described in Section 2.3.6: Inland Water Ecosystems apply to other aspects of water resource management beyond fish, wildlife, and plants. Rising stream temperatures, altered precipitation patterns, reduced snowpack and earlier snowmelt, and saltwater intrusion are expected to impact the management of water supply, water quality, and water use. Impacts on water resources will vary between regions, as precipitation is anticipated to increase in certain areas, decrease in others, and overall become more variable with more severe drought and heavier rainfall, often occurring in the same area. Past water levels and precipitation patterns will no longer serve as indicators of future conditions as climate change creates conditions outside of historical parameters (CCSP 2008d).

Climate change impacts and adaptation needs for the water resources sector are described in much more detail in the recently published *National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate* (hereafter *Freshwater Action Plan*) (ICCATF 2011), which establishes 24 priority actions for federal agencies in managing freshwater resources in a changing climate. The *Freshwater Action Plan* identifies "ensuring adequate water supplies; protecting human life, health, and property; and protecting the quality of freshwater resources" as major challenges (ICCATF 2011). The water resources management community can build resilience to both climate and non-climate stressors by using strategies that incorporate green infrastructure and watershed-based approaches that use the ecosystem services provided by fish, wildlife, and plants. Living resources can also serve as bio-indicators of water quality or perform biofiltration, thereby improving local water quality and increasing the value of those water resources. Additionally, riparian zones and wetlands have been shown to improve water quality, reduce flooding, and sequester CO_2.

The *Freshwater Action Plan* (ICCATF 2011) provides the following recommendations that can assist the water resources sector in ensuring the continued protection of fish, wildlife, and plant resources:

Adaptation strategies for water resource management also benefiting natural resources

- Establish a planning process that includes multiple levels of government, prioritization of challenges, and considerations for other resources.
- Improve water resources and climate change information for decision-making to help move decisions beyond a reliance on past conditions.
- Strengthen assessment of vulnerability of water resources to climate change.
- Expand water use efficiency, conservation, productivity, and substitution to reduce overall demand of water.
- Support integrated water resources management through coordinated adaptive management.
- Support training and outreach to build response capability using cross-disciplinary education, instruction, and training while focusing on solutions integrated across multiple sectors.

CH.5 Integration & Implementation

THIS FIRST NATIONAL-SCALE EFFORT identifies the major strategies and initial actions needed to help our valuable living resources and the communities that depend on them address the challenges of climate change. Although the *Strategy* identifies some of the essential actions that can be taken or initiated in the next five to ten years, its success relies on additional planning and action by federal, tribal, state, and local governments and many partners.

5.1 Strategy Integration

The *Strategy* builds upon and complements many existing climate adaptation efforts. Continuation and expansion of these efforts is critical to achieving the goals of this *Strategy*.

First, many local governments and states have already begun to develop adaptation plans, either through their local land-use planning efforts, within their state fish and wildlife agencies, or more broadly across state government. For example, Washington State released the *Washington State Integrated Climate Change Response Strategy* in December 2011, which explains the climate change adaptation priorities and potential strategies and actions to address those concerns. Many other states have developed similar efforts, such as *Alaska's Climate Change Strategy* released in 2010 and the *California Climate Adaptation Strategy* released in 2009. The number of state resource agencies with climate vulnerability and adaptation efforts underway is increasing, and this *Strategy* can serve as a resource for states as well as local governments, tribes, federal agencies, and others.

Second, many multi-governmental and non-governmental partnerships already conduct sophisticated resource management planning that can incorporate climate change. Two examples are JVs[4] and the NFHAP,[5] partnerships of federal agencies, states, tribes, conservation organizations, and industry working to protect priority bird and fish habitats respectively. These efforts offer ideal opportunities to bring climate change

4 www.fws.gov/birdhabitat/JointVentures/index.shtm
5 fishhabitat.org/

information into existing resource management planning to ensure management actions advance adaptation in a changing climate. Such efforts can also draw upon a growing number of important tools and approaches for adaptation planning and action. For example, the Climate Adaptation Knowledge Exchange (CAKE),[6] a joint project from EcoAdapt and Island Press, provides detailed information and access to information, tools, and case studies on adaptation to climate.

Many tribal governments and organizations understand the need to adapt as they are already experiencing the impacts of climate change on species, habitats, and ecosystems that are vital to their cultures and economies. For example, the Swinomish Tribe in the Pacific Northwest, which depends on salmon and shellfish, has developed the Swinomish Climate Change Initiative. This effort seeks to assess local impacts, identify vulnerabilities, and prioritize planning areas and actions to address the impacts of climate change, and can serve as an example for other tribal governments.

A number of climate adaptation efforts are underway at the Federal level. Many Federal agencies have initiated efforts to assess risks and impacts of climate change, and design adaptation efforts to reduce these risks. Federal agencies with natural resource management responsibilities like DOI, NOAA, USDA, EPA, and others have initiated a wide variety of efforts to better understand, monitor, prepare for, and respond to climate change impacts in their mission areas, including targeted science, the application of new tools and assessments, and training for natural resource decision makers and partners (CEQ 2010, 2011, Pew Center 2010, 2012). Many of the strategies and actions in this *Strategy* are based in part on efforts identified, planned, or implemented by one or more other agencies (federal, state, or tribal).

The USGCRP[7] is responsible for publishing a National Climate Assessment (NCA) every four years describing the extent of climate change in the United States and its impacts. The most recent national assessment was published in 2009, and provides the scientific foundation for this *Strategy*. The next assessment in 2013 will provide new information about impacts, opportunities, and vulnerabilities. Future NCAs will provide a basis for evaluating the effectiveness of the adaptation actions in this *Strategy* and determining next steps.

In addition, the USGCRP has produced a series of 21 Synthesis and Assessment Products on the current information regarding the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes. These reports address topics such as sea level rise (CCSP 2009a), ecosystem change (CCSP 2009b), agriculture, biodiversity, land and water resources (CCSP 2008d), adaptation options for climate-sensitive systems and resources (CCSP 2008c), energy production (CCSP 2007), human health (CCSP 2008a), and transportation (CCSP 2008b).

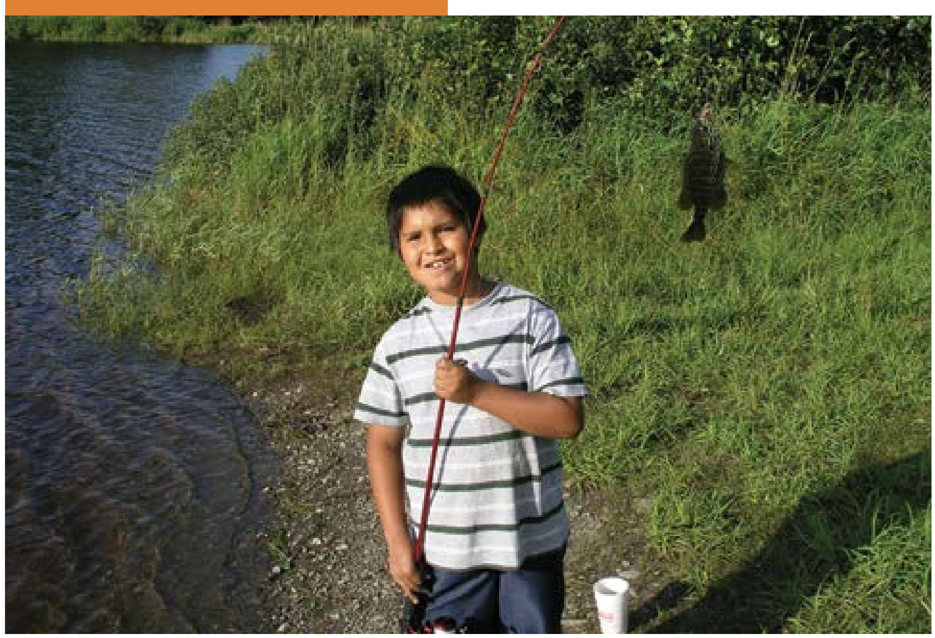
Another important entity is the ICCATF,[8] which was established in 2009 to help the federal government and partners understand, prepare for, and adapt to the impacts of climate change. The development of this *Strategy* was endorsed in the ICCATF's 2010 *Progress Report*

6 www.cakex.org

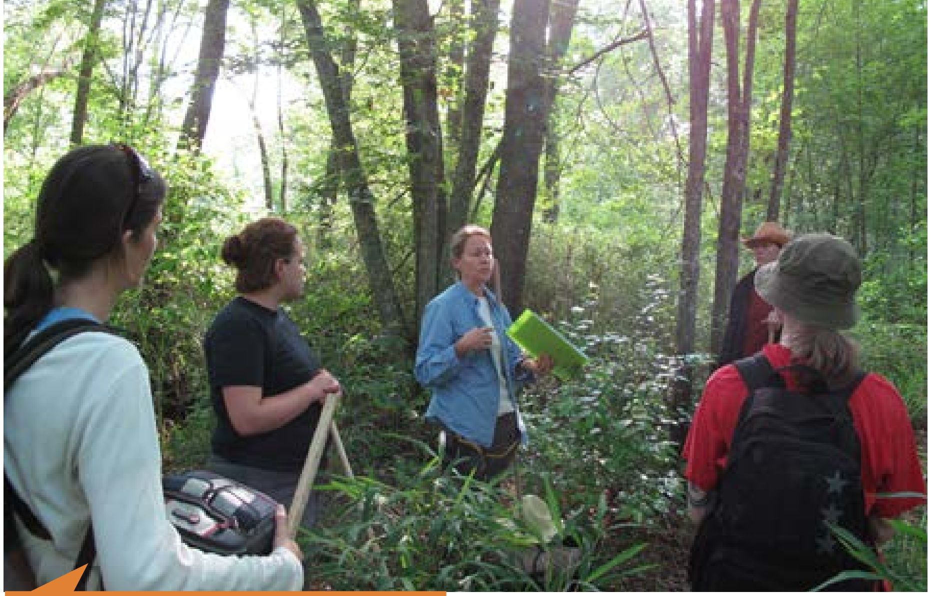
7 www.globalchange.gov

8 www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation

Planning for climate adaptation will require a team effort involving federal, state, tribal, and local governments if it is to be successful.



JOHN MILLER/AROOSTOOK BAND OF MICMACS/FRED COREY PHOTO



USFWS/GARY PEEPLES

Successful implementation will require partnerships, innovation, and passion.

to the President. The ICCATF has also launched other efforts to advance climate adaptation that both inform this *Strategy* and provide opportunities for the *Strategy's* implementation. One of these is the *Freshwater Action Plan.* Released in October of 2011, the *Freshwater Action Plan* describes the challenges that a changing climate presents for the management of the nation's freshwater resources, and recommends a set of actions federal agencies can take to help freshwater resource managers reduce the risks of climate change.

In addition, the National Ocean Council (NOC) is developing a series of actions to address the Resiliency and Adaptation to Climate Change and Ocean Acidification priority objective, one of nine priority objectives identified by the National Ocean Policy (NOP). These actions will address how the NOC will implement the NOP to respond to the challenges posed by climate change and ocean acidification. A *Draft Strategic Action Plan* outline was released for public comment in June 2011, and a draft *Implementation Plan* for the NOP was released for comment in January 2012. A final *Implementation Plan* is expected in 2012. This *Strategy* has been developed in coordination with both the *Freshwater Action Plan* and the *NOP Strategic Action Plan*, so that the three strategies support and reinforce each other.

In addition, following direction from Presidential Executive Order 13514 and the ICCATF, CEQ issued *Implementing Instructions* to all federal agencies to launch climate change adaptation planning with the first agency plans due in June 2012. This presents many opportunities for the resource management agencies involved in the development of this *Strategy* to develop their own agency-specific plans (if they have not already done so) and to interact with other agencies whose programs may influence their prospects for success. Many federal agencies have already conducted assessments of their vulnerability to climate change and are developing adaptation plans to reduce risks, respond to impacts, and take advantage of possible beneficial changes of a changing climate. This *Strategy* should serve as a useful resource to all these efforts.

5.2 Strategy Implementation

Successful implementation of this *Strategy* will take commitment and resources by government and non-government entities, and must include steps to formulate specific objectives, select and implement conservation actions, and evaluate, learn, and adjust our course of action as needed to achieve our goals in a changing world. Logical models for transitioning from the framework of the *Strategy* to more specific action plans are described by Peterson et al. (2011) and Glick et al. (2009).

SCOTT NEWHALL/TIME OUT CHARTERS

To ensure effective coordination, implementation, tracking, and updating of the *Strategy*, this report proposes the following steps:

1 **Federal, state, and tribal governments and conservation partners** should incorporate appropriate elements of the *Strategy* (goals, strategies, and actions) into their plans and actions at national to local levels (e.g., development of implementation plans by federal, state, and tribal governments).

» LCCs can play an important role in facilitating development of action plans to implement the *Strategy* that include specific objectives, actions, and commitments of resources appropriate to their geographic areas. The LCCs have a good mix of membership of state, federal, tribal and private conservation organizations, and operate at scales appropriate to successfully facilitate implementation of this *Strategy* through a collaborative process. CSCs, RISAs, and other regional collaborative efforts should incorporate appropriate elements of this *Strategy* as a resource for guiding their future science and assessment agendas and adaptation strategies.

» Many states have already incorporated climate change considerations in their State Wildlife Action Plans. Future revisions of these plans and other States' Wldlife Action Plans that lack climate change considerations should incorporate appropriate elements of this *Strategy*, AFWA's *Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans,* and other appropriate resources to design and deliver programs and actions that advance adaptation of fish and wildlife resources in a changing climate.

» Federal members of the *Strategy* Steering Committee will coordinate lead roles, responsibilities, and milestones for implementation of the *Strategy* across the federal sector.

» Federal agencies with programs that affect fish, wildlife, and plants and the habitats they depend on should ensure that ongoing agency adaptation planning efforts under Executive Order 13514 reflect and align with the recommendations, strategies, and actions of the *Strategy*.

» The ICCATF should continue to facilitate coordination and interaction among federal agencies regarding this *Strategy* and other climate adaptation planning efforts at both the national and regional level.

2 **An inter-jurisdictional coordinating body with policy maker representation and staff support** from federal, state, and tribal governments should be established. This body should meet biannually to monitor performance and evaluate implementation of the *Strategy* and report its findings to the public.

» This coordinating body will be tasked with promoting awareness, understanding, and use of the *Strategy* as a key tool in addressing climate change.

» Starting in June 2014, the coordinating body, with support from DOI, NOAA, and CEQ, should start a revision of the *Strategy,* to be completed by June 2015. This revision will incorporate information produced by the 2013 NCA.

» The coordinating body will establish a mechanism to engage representatives of non-governmental organizations, natural resource industries, private landowners, and international conservation partners to assist with *Strategy* implementation and revision.

USFWS/STEVE HILLEBRAND

- The coordinating body will work with regional conservation collaboratives such as LCCs to facilitate transition from the framework of this *Strategy* to geographically specific implementation action plans.
- The coordinating body will develop a process and tools, including the Progress Checklists of this *Strategy,* to evaluate implementation and shall include an assessment of implementation in their annual report.
- The coordinating body will work with the ICCATF to facilitate efficient communication and coordination among federal agencies and between federal agencies and state and tribal governments. The coordinating body should facilitate these interactions in a way that fosters clear, consistent, and efficient communication and avoids duplication of effort.
- The FWS, NOAA, and AFWA will collaborate to staff and support the work of the coordinating body.

This *Strategy* is the beginning of a significant collective effort to safeguard the nation's fish, wildlife, plants, and the communities and economies that depend on them in a changing climate. A challenging task lies ahead, and much remains to be learned about the specific impacts of climate change and the responses of plants, wildlife, and ecosystems.

JANE PELLICCIOTTO

New climate change and adaptation science is coming out almost daily and will help guide the way. But we know enough now to begin taking effective action to reduce risks and increase resiliency of these valuable natural resources—and we cannot afford to wait to respond to the changes we are already seeing or to prepare for those yet to come. Unless the nation begins a serious effort to undertake this task now, we risk losing priceless living systems—and the countless benefits and services they provide—as the climate inexorably changes.

This *Strategy* offers a common framework for meaningful adaptation response, and will help ensure that the nation's valuable fish, wildlife, plants, and ecosystems continue to the benefit of our nation, our communities and our economy for years to come.

Resources

INSIDE RESOURCES

Literature Cited

Aber, J. 2001. Forest processes and global environment change: The effects of individual and multiple stressors on forests. BioScience 51:735-751.

ACIA (Arctic Climate Impact Assessment). 2004. Impacts of a warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press, New York.

ACIA. 2005. Arctic Climate Impact Assessment. Cambridge University Press. 1042 pp.

Adageirsdottir, G., K.A. Echelmeyer, and W.D. Harrison. 1998. Elevation and volume changes on the Harding Icefield, Alaska. Journal of Glaciology 44:570-582.

Adam, P. 2009. Salt Marsh Restoration. *In* Coastal Wetlands: An integrated ecosystem approach. G.M.E. Perillo, E. Wolanski, D.R. Cahoon, and M.M. Brinson (eds.). Elsevier 2009. Oxford, UK.

Aldridge, C.L., S.E. Nielsen, H.L. Beyer, M.S. Boyce, J.W. Connelly, S.T. Knick, and M.A. Schroeder. 2008. Range-Wide Patterns of Greater Sage-Grouse Persistence. USGS Staff Published Research. Paper 42.

Alekseev, G., A. Danilov, V. Kattsov, S. Kuz'mina, and N. Ivanov. 2009. Changes in the climate and sea ice of the Northern Hemisphere in the 20th and 21st centuries from data of observations and modeling. Izvestiya Atmospheric and Oceanic Physics 45(6):675-686.

Amman, G. D. 1974. Population changes of the mountain pine beetle in relation to elevation. Environmental Entomology 2:541-547.

AMSA (Arctic Marine Shipping Assessment) 2009 Report. 2009. Arctic Council. April 2009, second printing.

Anderson, M.G. and C.E. Ferree. 2010. Conserving the stage: Climate change and the geophysical underpinnings of species diversity. PlosONE 5: e11554.

Angel, J.R. and K.E. Kunkel. 2010. The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. Journal of Great Lakes Research 36:51-58.

Anisimov, O.A., D.G. Vaughan, T.V. Callaghan, C. Furgal, H. Marchant, T.D. Prowse, H. Vilhjalmsson and J.E. Walsh. 2007. 2007: Polar regions (Arctic and Antarctic). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Paultikof, P.J. van der Linden and E.E. Hanson, Eds., Cambridge University Press, Cambridge, pp. 653-685.

Archer, S.R. and K. I. Predick. 2008. Climate change and ecosystems of the Southwest United States. Society of Range Management 30(3):23-28.

Asante SK., W. Danthanarayana, and H. Heatwole. 1991. Bionomics and population growth statistics of apterous virginoparae of woolly apple aphid *Eriosoma lanigerum* at constant temperatures. Entomologia Experimentalis et Applicata 60:261-270.

ASCE (American Society of Civil Engineers). 1999. Potential climate change effects on Great Lakes hydrodynamics and water quality. D. Lam and W. Schertzer (eds.). Reston, VA. 217 pp.

Ayers, M.P. and M.J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment 262:263-286.

AZ CCAG (Arizona Climate Change Advisory Group). 2006. Climate Change Action Plan, Arizona Department of Environmental Quality. Arizona, USA. 84 pp.

Baker, M.F., R.L. Eng, J.S. Gashwiler, M.H. Schroeder, and C.E. Braun. 1976. Conservation committee report on effects of alteration of sagebrush communities on the associated avifauna. Wilson Bull 88:165-171.

Baker, J.D., C.L. Littnan, and D.W. Johnston. 2006. Potential effects of sea level rise on the terrestrial habitats of endangered and endemic megafauna in the Northwestern Hawaiian Islands. Endangered Species Research 4:1-10.

Barnett, T.P. and D.W. Pierce. 2009. Sustainable water deliveries from the Colorado River in a changing climate. Proceedings of the National Academy of Sciences of the United States of America 106(18):7334-7338.

Barrows, C.W. 2011. Sensitivity to climate change for two reptiles at the Mojave-Sonoran Desert interface. Journal of Arid Environments 75(7):629-635.

Barrows, C.W., J.T. Rotenberry, and M.F. Allen. 2010. Assessing sensitivity to climate change and drought variability of a sand dune endemic lizard. Biological Conservation 143(3):731-736.

Beever, E.A, C. Ray, J.L. Wilkening, P.F. Brussard, and P.W. Mote. Contemporary climate change alters the pace and drivers of extinction. 2011. Global Change Biology 17:6, 2054–2070.

Beier, P. and B. Brost. 2010. Use of land facets to plan for climate change: Conserving the arenas, not the actors. Conservation Biology 24:701-710.

Bengtsson, L., K.I. Hodges, and N. Keenlyside. 2009. Will Extratropical Storms Intensify in a Warmer Climate? Journal of Climate 22(9):2276-2301.

Berg, E.E., J.D. Henry, C.L. Fastie, A.D. De Volder and S. M. Matsuoka. 2006. 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 227:219-232.

Berg, E.E., K.M. Hillman, R. Dial and A. DeRuwe. 2009. Recent woody invasion of wetland on the Kenai Peninsula Lowlands, south-central Alaska: a major regime shift after 18,000 years of wet Sphagnum –sedge peat recruitment. Canadian Journal of Forest Research 39:2033-2046.

Betancourt, J., T. Bean, L. Brigham, L. Frid, G. Frisvold, T. Holcombe, J. Morisette, A. Olsson, and R. Remington. 2010. Buffelgrass Invasion in the Sonoran Desert: What do we stand to lose? ACES Conference, Chandler, AZ. December 7, 2010.

Bettinetti, R., S. Quadroni, S. Galassi, R. Bacchetta, L. Bonardi, and G.Vailati. 2008. Is meltwater from Alpine glaciers a secondary DDT source for lakes? Chemosphere 73:1027-1031.

Birdsey, R.A., J.C. Jenkins, M. Johnston, and E. Huber-Sannwald, 2007. Chapter 11: North American Forests. *In* The first state of the carbon cycle report (SOCCR): The North American carbon budget and implications for the global carbon cycle. U.S. Climate Change Science Program, Synthesis and Assessment Product 2.2. 117-126 p.

Bizzotto, E.C., S. Villa and M.Vighi. 2009. POP bioaccumulation in macroinvertebrates of alpine freshwater systems. Environmental Pollution 157:3192-3198.

Blair, A., D. Sanger, A.F. Holland, D. White, L. Vandiver, and S. White. 2011. Stormwater Runoff – Modeling Impacts of Urbanization and Climate Change. Conference Paper 1111825 in Proceedings of the 2011 Annual International Meeting of the American Society of Agricultural and Biological Engineers, Louisville, KY.

Blais, J.M., D.W. Schindler, D.C.G. Muir, M. Sharp, D. Donald, M. Lafrenière, E. Braekevelt and W.M.J. Strachan. 2001. Melting Glaciers: A major source of persistent organochlorines to subalpine Bow Lake in Banff National Park, Canada. Ambio 30:410-415.

Block, B.A., I.D. Jonsen, S.J. Jorgensen, A.J. Winship, S.A. Shaffer, S.J. Bograd, E.L. Hazen, D.G. Foley, G.A. Breed, A. Harrison, J.E. Ganong, A. Swithenbank, M. Castleton, H. Dewar, B.R. Mate, G.L. Shillinger, K.M. Schaefer, S.R. Benson, M.J. Weise, R.W. Henry, and D.P. Costa. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature 475(7354):86-90.

Blunden, J., D.S. Arndt, and M.O. Baringer (eds.). 2011. State of the Climate in 2010. Bulletin of the American Meteorological Society 92(6):S1-S266.

Bogdal, C., P. Schmid, M. Zennegg, F.S. Anselmetti, M. Scheringer and K. Hungerbhler. 2009. Blast from the Past: Melting Glaciers as a Relevant Source for Persistent Organic Pollutants. Environmental Science and Technology 43:8173-8177.

Bond-Lamberty, B., S.D. Peckham, D.E. Ahl, and S.T. Gower. 2007. Fire as the dominant driver of central Canadian boreal forest carbon balance. Nature 450(7166):89-+.

Bowman, D.M.J.S., L.D. Prior, and S.C. De Little. 2010. Retreating Melaleuca swamp forests in Kakadu National Park: Evidence of synergistic effects of climate change and past feral buffalo impacts. Austral Ecology 35(8):898-905.

Brasier, C.M. 1996.Phytophthora cinnamomi and oak decline in southern Europe: environmental constraints including climate change. Annales des Sciences Forestières 53:347-358.

Brooks, M.L. and D.A. Pyke. 2002: Invasive plants and fire in the deserts of North America. *In* Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Gallery, K.E.M. and T.P. Wilson (eds.). Proceedings of the Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management, Tall Timbers Research Station, 1-14 pp.

Brown, J. W. 2006. Eco-logical: an ecosystem approach to developing infrastructure projects. Office of Project Development and Environmental Review, Federal Highway Administration, Washington, D.C., USA.

Buehler, B. 2011. Michigan Tribe and NRCS Partner to Provide Safe Fish Travel in Great Lakes Basin. United States Department of Agriculture: USDA Blog. Accessed October 13, 2011.

Burkett, V. and J. Kusler. 2000. Climate change: Potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association 36(2):313-320.

Butnor, J.R., K.H. Johnsen, R. Oren, and G.G. Katul. 2003. Reduction of forest floor respiration by fertilization on both carbon dioxide-enriched and reference 17-year-old loblolly pine stands. Global Change Biology 9: 849-861.

Byrd, V.G., W.J. Sydeman, H.M. Renner, and S. Minobe. 2008. Responses of piscivorous seabirds at the Pribilof Islands to ocean climate. Deep-Sea Research Part II 55:1856-1867.

CADFG (California Department of Fish and Game) Partnership for Interdisciplinary Studies of Coastal Oceans, Channel Islands National Marine Sanctuary, and Channel Islands National Park. 2008. Channel Islands Marine Protected Areas: First 5 Years of Monitoring: 2003-2008. Airamé, S. and J. Ugoretz (eds.). 20 pp.

Callaway, D., J. Eamer, E. Edwardsen, C. Jack, S. Marcy, A. Olrun, M. Patkotak, D. Rexford, and A. Whiting. 1999. Effects of Climate Change on Subsistence Communities in Alaska, in the proceedings for a workshop on Assessing the Consequences of Climate Change in Alaska and the Bering Sea Region, held in Fairbanks, AK, October 29-30, 1998, edited by G. Weller and P.A. Anderson, Center for Global Change and Arctic System Research, the University of Alaska Fairbanks.

Campbell, T.A., and D.B. Long. 2009. Feral swine damage and damage management in forested ecosystems. Forest Ecology and Management 257:2319-2326.

Carroll, A.L., S.W. Taylor, J. Regniere, and L. Safranyik. 2003. Effect of climate change on range expansion by the mountain pine beetle in British Columbia. The Bark Beetles, Fuels, and Fire Bibliography. Paper 195.

Carroll, N. and M. Jenkins. 2012. The Matrix 2012: Innovative Markets and Market-Like Instruments for Ecosystem Services. Ecosystem Marketplace. Available at: http://moderncms.ecosystemmarketplace.com/repository/moderncms_documents/the_matrix_5-9-12.pdf.

CCSP (U.S. Climate Change Science Program). 2007. Effects of climate change on energy production and use in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. T.J. Wilbanks, V. Bhatt, D.E. Bilello, S.R. Bull, J. Ekmann, W.C. Horak, Y.J. Huang, M.D. Levine, M.J. Sale, D.K. Schmalzer, and M.J. Scott (eds.). Department of Energy, Office of Biological and Environmental Research, Washington, DC, USA. 160 pp.

CCSP. 2008a. Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, T.J. Wilbanks, (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA.

CCSP. 2008b. Impacts of climate change and variability on transportation systems and infrastructure: Gulf Coast Study, Phase I. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. M.J. Savonis, V.R. Burkett, and J.R. Potter (eds.). Department of Transportation, Washington, DC, USA. 445 pp.

CCSP. 2008c. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Julius, S.H., J.M. West (eds.). J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors). U.S. Environmental Protection Agency, Washington, DC, USA. 873 pp.

CCSP. 2008d. The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. P. Backlund, A. Janetos, D. Schimel, J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B.A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M.G. Ryan, S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B.P. Kelly, L. Meyerson, B. Peterson, and R. Shaw. U.S. Department of Agriculture, Washington, DC, USA. 362 pp.

CCSP. 2009a. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic Region. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus (Coordinating Lead Author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (Lead Authors). U.S. Environmental Protection Agency, Washington D.C., USA. 320 pp.

CCSP. 2009b. Thresholds of Climate Change in Ecosystems. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research Fagre, D.B., C.W. Charles, C.D. Allen, C. Birkeland, F.S. Chapin III, P.M. Groffman, G.R. Guntenspergen, A.K. Knapp, A.D. McGuire, P.J. Mulholland, D.P.C. Peters, D.D. Roby, and George Sugihara. U.S. Geological Survey, Reston, VA. 156 pp.

CEC (Commission for Environmental Cooperation). 1997. Ecological regions of North America: toward a common perspective. Commission for Environmental Cooperation, Montreal, Quebec, Canada. 71 pp. Revised 2006.

CEQ (White House Council on Environmental Quality). 2010. Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. October 5, 2010.

CEQ. 2011. Progress Report of the Interagency Climate Change Adaptation Task Force: Federal actions for a climate resilient nation. October 28, 2011.

Chakraborty S. 1997. Recent advances in studies of anthracnose of stylosanthes. V. Advances in research on stylosanthes anthracnose epidemiology in Australia. Tropical Grasslands 31:445-453.

Charbonneau, J.J and J. Caudill. 2010. An Assessment of Economic Contributions from Fisheries and Aquatic Resource Conservation. U.S. Fish and Wildlife Service Business Management and Operations, Division of Economics, Arlington, VA. September 2010. 42 pp.

Cheung, W.L., V.W.Y. Lam, J.L. Sarmiento, K. Kearney, R. Watson, and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries 365:187-197.

Church, J.A., N.J. White, and J.R. Hunter. 2006. Sea-level rise at tropical Pacific and Indian Ocean islands. Global and Planetary Change 53(3):155-168.

City of Keene, New Hampshire. 2007. Adapting to climate change: planning a climate resilient community. November 2007.

Climate Impacts Group. 2004. Forest Fire and Climate. University of Washington, Seattle, Washington. July 2004.

Climate Impacts Group. 2009. The Washington Climate Change Impacts Assessment. M. McGuire Elsner, J. Littell, and L Whitely Binder (eds.). Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, Washington.

CNRA (California Natural Resources Agency). 2009. 2009 California Climate Adaptation Strategy: A report to the governor of the state of California in response to E.O. S-13-2008. 200 pp.

Cole, G.A. 1994. Textbook of Limnology. 4th Edition. Waveland Press, Inc. Prospect Heights, IL. 426 pp.

Cole, K. L., K. Ironside, J. Eischeid, G. Garfin, P. B. Duffy, and C. Toney. 2011. Past and ongoing shifts in Joshua tree distribution support future modeled range contraction. Ecological Applications, 21(1): 137–149.

Colling, A. 2001. Ocean Circulation. Oceanography Course Team. Open University. second printing. 279 pp.

Comiso, J. and F. Nishio. 2008. Trends in the sea ice cover using enhanced and compatible AMSR-E, SSM/I, and SMMR data. Journal Geophysical Research 113:C02S07.

Cook, T., Folli, M., Klinck, J., Ford, S. & Miller, J. 1998. The relationship between increasing sea-surface temperature and the northward spread of Perkinsus marinus (Dermo) disease epizootics in oysters. Estuarine, Coastal and Shelf Science 46, 587-597.

Cowen, R.K. and S. Sponaugle. 2009. Larval Dispersal and Marine Population Connectivity. Annual Review of Marine Science 1:443-466.

Crooks, S., J. Findsen, K. Igusky, M.K. Orr, and D. Brew. 2009. Greenhouse Gas Mitigation Typology Issues Paper Tidal Wetlands Restoration. Report prepared for California Climate Action Registry.

Crooks, S., D. Herr, J. Tamelander, D. Laffoley, and J. Vandever. 2011. Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems: Challenges and Opportunities. Environment Department Paper 121, World Bank, Washington, DC.

Cushman, S.A. 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biological Conservation 128:231-240

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson. 2000. The interplay between climate change, forests, and disturbances. Science of the Total Environment 262:201-204.

D'Antonio, C.M., and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63-87.

Davey, C.A., K.T. Redmond, and D.B. Simeral. 2007. Weather and Climate Inventory, National Park Service, Sonoran Desert Network. Natural Resource Technical Report NPS/SODN/NRTR—2007/044. National Park Service, Fort Collins, Colorado.

De Silva, S.S. and D. Soto. 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. *In* Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. K. Cochrane, C. De Young, D. Soto, and T. Bahri (eds.). 151-212 pp. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp.

DeGaetano, A.T. and R.J. Allen. 2002. Trends in twentieth-century temperature extremes across the United States. Journal of Climate 15(22):3188-3205.

Department of the Interior (DOI). 2010. Order No. 3289: Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources.

Department of the Interior (DOI). 2011. The Department of the Interior's economic contributions. June 21, 2011. 138 pp.

Department of the Interior (DOI), Fish and Wildlife Service, and U.S. Department of Commerce (DOC). U.S. Census Bureau. 2006. National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

Deverel, S.J. and D.A. Leighton. 2010. Historic, Recent and Future Subsidence, Sacramento- San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science, 8-1-23.

Dial, R.J., E.E. Berg, K. Timm, A. McMahon, and J. Geck. 2007. Changes in the alpine forest-tundra ecotone commensurate with recent warming in southcentral Alaska: Evidence from orthophotos and field plots, Journal of Geophysical Research 112:G04015.

Diaz, H. and J. Eischeid. 2007. Disappearing "alpine tundra" Köppen climatic type in the western United States. Geophysical Research Letters 34:L18707.

Doney, S.C., M. Ruckelshaus, J.E. Duffy, J.P. Barry, F. Chan, C.A. English, H.M. Galindo, J.M. Grebmeier, A.B. Hollowed, N. Knowlton, J. Polovina, N.N. Rabalais, W.J. Sydeman, and L.D. Talley. 2012. Climate Change Impacts on Marine Ecosystems. Annual Review of Marine Science 4:11-37.

Dukes, J.S. and H.A. Mooney. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution 14(4):135-139.

Eaton, J.G., J.H. Mccormick, B.E. Goodno, D.G. Obrien, H.G. Stefany, M. Hondzo, and R.M. Scheller. 1995. A Field Information-Based System for Estimating Fish Temperature Tolerances. Fisheries 20(4):10-18.

Eaton, J.G. and R.M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnology and Oceanography 41(5):1109-1115.

ECA (Economics of Climate Adaptation) Working Group. 2009. Shaping climate-resilient development: A framework for decision-making. Report. 159 pp.

Edmundson, J.A., T. M. Willette, J. M. Edmundson, D. C. Schmidt, S. R. Carlson, B. G. Bue, and K. E. Tarbox. 2003. Sockeye salmon overescapement (Kenai River component). Restoration Project 96258A-1. Final Report. Alaska Department of Fish and Game, Anchorage, AK. 49 pp.

Edwards, M. and A.J. Richardson. 2004. Impact of climate change on marine pelagic phonology and trophic mismatch. Nature 430(7002):881-884.

Elliott, J. 1994. Quantitative ecology and the brown trout. Oxford University Press, London.

Enquist, C. and D. Gori. 2008. Implications of recent climate change on conservation priorities in New Mexico. A Climate Change Vulnerability Assessment for Biodiversity in New Mexico, Part I: TNC and WCS. 79 pp.

Fabry, V.J., and B.A. Seibel, R.A. Feely, and J.C. Orr. 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science 65:414-432.

FAO (Food and Agriculture Organization of the United Nations) Fisheries and Aquaculture Department. 2010. The state of the world fisheries and aquaculture. Rome, Italy. 218 pp.

Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Lanson, and B. Hales. 2008. Evidence for upwelling of corrosive 'acidified' water onto the continental shelf. Science 320:1490-1492.

Feifel, K. and R.M. Gregg. 2010. Relocating the Village of Newtok, Alaska due to Coastal Erosion [Case study on a project of the Newtok Planning Group]. Retrieved from CAKE. Last updated July 2011.

Ficke, A.D., C.A. Myrick, and L.J. Hansen. 2007. Potential impacts of global climate change on freshwater fisheries. Rev. Fish Biol. Fisheries 17:581-613.

Finzi, A.C., R.J. Norby, C. Calfapietra, A. Gallet-Budynek, B. Gielen, W.E. Holmes, M.R. Hoosbeek, C.M. Iversen, R.B. Jackson, M.E. Kubiske, J. Ledford, M. Liberloo, R. Oren, A. Polle, S. Pritchard, D.R. Zak, W.H. Schlesinger, and R. Ceulemans. 2007. Increases in nitrogen uptake rather than nitrogen-use efficiency support higher rates of temperate forest productivity under elevated CO_2. Proceedings of The National Academy of Sciences 104(35):14014-14019.

Flannigan, M.D., B.J. Stocks, and B.M. Wolton. 2000. Climate change and forest fires. The Science of the Total Environment 262:221-229.

Flebbe, P., L. Roghair, and J. Bruggink. 2006. Spatial modeling to project Southern Appalachian Trout distribution in warmer climate. Transaction of the American Fisheries Society 135:1371-1382.

Foden, W., G. Mace, J.-C. Vié, A. Angulo, S. Butchart, L. DeVantier, H. Dublin, A. Gutsche, S. Stuart, and E. Turak. 2008. Species susceptibility to climate change impacts. *In* The 2008 Review of The IUCN Red List of Threatened Species. J.-C. Vié, C. Hilton-Taylor and S.N. Stuart (eds.). IUCN Gland, Switzerland.

Forbes, B.C., F. Stammler, T. Kumpula, N. Meschtyb, A. Pajunen, and E. Kaarlejärvi. 2011. Yamal reindeer breeders, gas extraction, and changes in the environment: adaptation potential of nomad economy and its limits (in Russian). Environmental Planning and Management 1(12)C:52-68.

Ford, S.E. 1996. Range extension by the oyster parasite Perkinsus marinus into the northeastern United States: response to climate change? Journal of Shellfish Research 15, 45-56.

Friedli, H.R., A.F. Arellano, S. Cinnirella and N. Pirrone. 2009. Initial Estimates of Mercury Emissions to the Atmosphere from Global Biomass Burning. Environmental Science and Technology 43:3507-3513.

Fritts, T.H., and D. Leasman-Tanner. 2001. The Brown Tree snake on Guam: How the arrival of one invasive species damaged the ecology, commerce, electrical systems, and human health on Guam: A comprehensive information source.

FWS (U.S. Fish and Wildlife Service). 2008. Endangered and threatened wildlife and plants: Status review for Rio Grande cutthroat trout. 73 Federal Register 94 (May 14, 2008) 27900-27926 pp.

FWS. 2011. Review of native species that are candidates for listing as endangered or threatened. 76 Federal Register 207 (October 26, 2011) 66370-66439 pp.

Gallant, A.L., E.F. Binnian, J.M. Omernik, and M.B. Shasby. 1995. Ecoregions of Alaska. U.S. Geological Survey Professional Paper 1567: 73 pp.

GAO (U.S. Government Accountability Office). 2007. Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources. GAO-07-863.

Garibaldi, A. and N. Turner. 2004. Cultural keystone species: Implications for ecological conservation and restoration. Ecology and Society 9(3).

Giri, C., E. Ochieng, L. Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek, and N. Duke. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20:154-159.

Glick, P., A. Staudt, and B.A. Stein. 2009. A New Era for Conservation: Review of Climate Change Adaptation Literature. National Wildlife Federation. Washington, DC.

Glick, P., B.A. Stein, and N.A. Edelson. 2011a. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, DC.

Glick, P., H. Chmura, and B. A. Stein. 2011b. Moving the Conservation Goalposts: A review of Climate Change Adaptation Literature. National Wildlife Federation Climate Change Safeguards Program, National Wildlife Federation, Washington, DC.

Gutierrez, B.T., N.G. Plant, and E.R. Thieler. 2011. A Bayesian network to predict coastal vulnerability to sea level rise. Journal of Geophysical Research-Earth Surface 116:F02009.

Hall, S.J., A. Delaporte, M.J. Phillips, M. Beveridge, and M. O'Keefe. 2011. Blue frontiers: Managing the environmental costs of aquaculture. The WorldFish Center, Penang, Malaysia.

Hallegraeff, G.M. 2010. Ocean climate change, phytoplankton community responses, and harmful algal blooms: a formidable predictive challenge. Journal of Phycology 46:220-235.

Hansen, L. and J. Hoffman. 2011. Climate savvy: adapting conservation and resource management to a changing world. Island Press.

Hanson, P.J., and J.F. Weltzin. 2000. Drought disturbance from climate change: response of United States forests. The Science of the Total Environment 262(3):205-220.

Hare, J.A. and K.W. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (*Micropogonias undulatus*). Fisheries Oceanography 16:31-45.

Hare, J.A., M.A. Alexander, M.J. Fogarty, E.H. Williams, and J.D. Scott. 2010. Forecasting the dynamics of a coastal fishery species using a coupled climate-population model. Ecological Applications 20:452-464.

Harley, C.D.G., A.R. Hughes, K.M. Hultgren, B.G. Miner, C.J.B. Sorte, C.S. Thornber, L.F. Rodriguez, L. Tomanek, and S.L. Williams. 2006. The impacts of climate change in coastal marine systems. Ecology Letters 9(2):228-241.

Harvell, D.C., C.E. Mitchell, J.R. Ward, S. Altize, A.P. Dodbson, R.S. Ostfeld, and M.D. Samuel. 2002. Climate Warming and Disease Risk for Terrestrial and Marine Biota. Science 296(5576):2158-2162.

Hatala, J.A., M. Detto, O. Sonnentag, S.J. Deverel, J. Verfaillie, and D.D. Baldocchi. 2012. Greenhouse gas (CO_2, CH_4, H_20) fluxes from drained and flooded agricultural peatlands in the Sacramento San Joaquin Delta. Agriculture, Ecosystems and Environment 150:1-18.

Hayhoe, K. and D. Wuebbles. 2010. Chicago climate change action plan: Our city. Our future. City of Chicago Climate Change Task Force.

Heinz Center (The H. John Heinz III Center for Science, Economics and the Environment). 2008. Heinz Report: Grasslands and Shrublands. The State of the Nations Ecosystems. Island Press, Washington, DC.

Heller, N.E. and E.S. Zavaleta. 2009. Biodiversity management in the face of climate change: A review of 22years of recommendations. Biological Conservation 142:14-32.

Hernández, H.M., C. Gómez-Hinostrosa, and G. Hoffmann. 2010. Is geographical rarity frequent among the cacti of the Chihuahuan Desert?. Revista mexicana de biodiversidad 81(1):163-175.

Higuera P.E., L.B. Brubaker, P.M. Anderson, T.A. Brown, and A.T. Kennedy. 2008. Frequent Fires in Ancient Shrub Tundra: Implications of Paleorecords for Arctic Environmental Change. PLoS ONE 3(3): e0001744.

Higuera, P.E., M.L. Chipman, J.L. Barnes, M.A. Urban, and F.S. Hu. 2011. Variability of tundra fire regimes in Arctic Alaska: millennial scale patterns and ecological implications. Ecological Applications, 21: 3211-3226.

Hinzman, L.D., N.D. Bettez, W.R. Bolton, F.S. Chapin, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K. Winker, and K. Yoshikawa. 2005. Evidence and implications of recent climate change in northern Alaska and other arctic regions. Climatic Change 72(3):251-298.

Hoegh-Guldberg, O. and J.F. Bruno. 2010. The Impact of Climate Change on the World's Marine Ecosystems. Science 328(5985):1523-1528.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi, and M.E. Hatziolos. 2007. Coral Reefs Under Rapid Climate Change and Ocean Acidification. Science 318(5857):1737-1742.

Hoffmeister, E., G. Moede Rogall, K. Wesenberg, R. Abbott, T. Work, K. Schuler and J. Sleeman. 2010. Climate change and wildlife health: Direct and indirect effects. U.S. Geological Survey National Wildlife Health Center. Factsheet:2010-3017.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Cananadian Journal Of Fisheries and Aquatic Sciences 47:2181-2194.

Hopkinson, C.S., Cai, W.J., and X. Hu. 2012. Carbon sequestration in wetland dominated coastal systems — a global sink of rapidly diminishing magnitude. Current Opinion in Environmental Sustainability 2012, 4:186–194.

Houston, D.R. 1998. Beech bark disease. *In* K. Britton (ed.), Exotic pests of eastern forests. USDA Forest Service 29-41.

Hsieh, C.H., C.S. Reiss, R.P. Hewitt, and G. Sugihara. 2008. Spatial analysis shows that fishing enhances the climatic sensitivity of marine fishes. Canadian Journal of Fisheries and Aquatic Sciences 65:947-961.

Hughes, L. 2003. Climate change and Australia: Trends, projections and impacts. Austral Ecology 28(4):423-443.

Hunter, M.L., Jr., G.L. Jacobson, Jr., and T. Webb III. 1988. Paleoecology and the coarse-filter approach to maintaining biological diversity. Conservation Biology 2:375-385.

Huppert, D., A. Moore, and K. Dyson. 2009. Chapter 8: Coasts: Impacts of climate change on the coasts of Washington State *In* The Washington climate change impacts assessment. Climate Impacts Group.

ICCATF (Interagency Climate Change Adaptation Task Force). 2011. National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate. Washington, DC.

Idaho National Laboratory. 2011. U.S. Department of Energy. Idaho Falls, ID.

Inouye, D.W, D. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences. USA 97:1630-1633.

IPCC (Intergovernmental Panel on Climate Change). 1997. The regional impacts of climate change: An assessment of vulnerability. R.T. Watson, M.C. Zinyowera, and R.H. Moss (eds.). Cambridge University Press, UK. 517 pp.

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (AR4). Core Writing Team, R.K. Pachauri and A. Reisinger (eds.). IPCC, Geneva, Switzerland, 104 pp.

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

IPCC, Working Group II (WGII). 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 (II). M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2011. Summary for Policymakers. *In* Intergovernmental Panel on Climate Change Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. C.B. Field, V. Barros, T.F. Stocker, D. Qin, D. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.K. Plattner, S. Allen, M. Tignor, and P.M. Midgley (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Iverson, L.R., A.M. Prasad, S.N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management 254(3):390-406.

Jöhnk, K.D., J. Huisman, J. Sharples, B. Sommeijer, P.M. Visser, and J.M. Stroom. 2008. Global Change Biology 14(3):495-512.

Johnson, W.C., B.V. Millett, T. Gilmanov, R.A. Voldseth, G.R. Guntenspergen, and D.E. Naugle. 2005. Vulnerability of northern prairie wetlands to climate change. Bioscience 55(10):863-872.

Johnson, W.C., B. Werner, G.R. Guntenspergen, R.A. Voldseth, B. Millett, D.E. Naugle, M. Tulbure, R.W.H. Carroll, J. Tracy, and C. Olawsky. 2010. Prairie Wetland Complexes as Landscape Functional Units in a Changing Climate. Bioscience 60(2):128-140.

Johnston, K., and O. Schmitz. 2003. Wildlife and climate change: assessing the sensitivity of selected species to simulated doubling of atmospheric CO_2. Global Change Biology 3(6):531-544.

Jones, R.N. 2001. An environmental risk assessment/management framework for climate change impact assessments. Natural Hazards 23:197-230.

Jorgenson, M.T., Y.L. Shur, and E.R. Pullman. 2006. Abrupt increase in permafrost degradation in Arctic Alaska. Geophysical Research Letters 33(2):L02503.

Kaushal, S.S., G.E. Likens, N.A. Jaworski, M.L. Pace, A.M. Sides, D. Seekell, K.T. Belt, D.H. Secor, and R.L. Wingate. 2010. Rising stream and river temperatures in the United States. Frontiers in Ecology and the Environment 8(9):461-466.

Kelly, R.P., M.M. Foley, W.S. Fisher, R.A. Feely, B.S. Halpern, G.G. Waldbusser, and M.R. Caldwell. 2011. Mitigating Local Causes of Ocean Acidification with Existing Laws. Science 332:1036-1037.

Killengreen, S.T., R.A. Ims, N.G. Yoccoz, K.A. Brathen, J.A. Henden, T. Schott. 2007. Structural characteristics of a low Arctic tundra ecosystem and the retreat of the Arctic fox. Biological Conservation 135(4):459-472.

Kimball. D. 2007. Statement of Dan Kimball, Superintendent, Everglades National Park. Testimony to Congress Subcommittee.

Klein, E., E.E. Berg, and R. Dial. 2005. Wetland drying and succession across the Kenai Peninsula Lowlands, south-central Alaska. Canadian Journal of Forest Research 35(8):1931-1941.

Klein, E.S., E.E. Berg, and R. Dial. 2011. Reply to comment by Gracz on “Wetland drying and succession across the Kenai Peninsula Lowlands, south-central Alaska”. Canadian Journal of Forest Research 41:425-428.

Kocan, R., P. Hershberger, and J. Winton. 2004. Ichthyophoniasis: An Emerging Disease of Chinook Salmon in the Yukon River. Journal of Aquatic Animal Health 16:58-72.

Kovacs, K.M., C. Lydersen, J.E. Overland, and S.E. Moore. 2010. Impacts of changing sea-ice conditions on Arctic marine mammals. Marine Biodiversity 41(1):181-194.

Krawhchuck, M.A., M.A. Moritz, M.A. Parisian, J. VanDorn, and K Hayhoe. 2009. Global pyrogeography: the current and future distribution of wildfire. PLoS ONE 4:1-12.

Krupnik, I., C. Aporta, S. Gearheard, G. Laidler, and L. Kielse Holm. (eds.). 2010. SIKU: Knowing Our Ice. Documenting Inuit Sea Ice Knowledge and Use. New York: Springer.

Kurz, W.A., C.C. Dymond, G. Stinson, G.J. Rampley, E.T. Neilson, A.L. Carroll, T. Ebata, and L. Safranyik. 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature 452:987-990.

Laidre, K.L., I. Stirling, L.F. Lowry, Ø. Wiig, M.P. Heide-Jørgensen, and S.F. Ferguson. 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecological Applications 18: S97-S125.

Lambert, S.J. and J.C. Fyfe. 2006. Changes in winter cyclone frequencies and strengths simulated in enhanced greenhouse warming experiments: results from the models participating in the IPCC diagnostic exercise. Climate Dynamics 26(7-8):713-728.

Larsen, P. and S. Goldsmith. 2007. How much might climate change add to future costs for public infrastructure?. Institute of Social and Economic Research, University of Alaska. UA Research Summary 8: 108 pp.

Larrucea, E.S., and P.F. Brussard. 2008. Shift in location of pygmy rabbit (Brachylagus idahoensis) habitat in response to changing environments. Journal of Arid Environments 72:1636-1643.

Le Quesne, T., J. H. Matthews, C. Von der Heyden, A. J. Wickel, R. Wilby, J. Hartmann, G. Pegram, E. Kistin, G. Blate, G. K. de Freitas, E. Levine, C. Guthrie, C. McSweeney, and N. Sindorf. 2010. Freshwater Ecosystem Adaptation to Climate Change in Water Resources Management and Biodiversity Conservation, Water Working Notes No. 28, August 2010. 74 pp.

Le Quesne, W. J. F. and J.K. Pinnegar. 2011. The potential impacts of ocean acidification: scaling from physiology to fisheries. Fish and Fisheries.

Lellis-Dibble, K.A., K.E. McGlynn, and T.E. Bigford. 2008. Estuarine Fish and Shellfish Species in U.S. Commercial and Recreational Fisheries: Economic Value as an Incentive to Protect and Restore Estuarine Habitat. U.S. Department of Commerce, National Oceanic and Atmospheric Administration National Marine Fisheries Service. NOAA Technical Memorandum NMFS-F/SPO-90.

Lettenmaier, D., D. Major, L. Poff, and S. Running. 2008. Water resources. In The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States.

Levitus, S., J.I. Antonov, T.P. Boyer, R.A. Locarnini, H.E. Garcia, and A.V. Mishonov. 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems. Geophysical Research Letters 36, L07608.

Littell, J. S., D. McKenzie, D.L. Peterson, and A. L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications19(4): 1003–1021.

Lloyd, A.H., T.S. Rupp, C.L. Fastie, and A.M. Starfield. 2003. Patterns and dynamics of treeline advance on the Seward Peninsula, Alaska. Journal of Geophysical Research 108 D2.

Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel, A.J. Eberhardt, and C.L. Luukkonen. 2002. Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCMs. Journal of Great Lakes Research 28:537-554.

Lonsdale, D. and J.N. Gibbs. 1996. Effects of climate change on fungal diseases of trees. British Mycological Society Symposium; Fungi and environmental change 20:1-19.

Lugo, A.E. 2000. Effects and outcomes of Caribbean hurricanes in a climate change scenario. Science of the Total Environment 262:243-251.

Macdonald, R.W., T. Harner, J. Fyfe, H. Loeng, and T. Weingartner, 2003. AMAP Assessment 2002: The Influence of Global Change on Contaminant Pathways to, within, and from the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xii+65 pp.

Mack, M.C., M.S. Bret-Harte, T.N. Hollingsworth, R.R. Jandt, E.A.G. Schuur, G.S. Shaver, and D.L. Verbyla. 2011. Carbon loss from an unprecedented Arctic tundra wildfire. Nature 475:489-492.

Maclean, M.D. and R.J. Wilson. 2011. Recent ecological responses to climate change support predictions of high extinction risk. Proceedings of the National Academy of Sciences. Published online before print July 11, 2011.Magness, D.R, and J.M. Morton. Submitted. Using hierarchical and competing models to increase certainty of landcover conversion in a changing climate. Journal of Fish and Wildlife Management.

Magness, D.R., J.M. Morton, F. Huettmann, F.S. Chapin III, and A.D. McGuire. 2011. A climate-change adaptation framework to reduce continental-scale vulnerability across conservation reserves. Ecosphere 2(10):212.

Magnuson, J.J. 2002. Signals from ice cover trends and variability. *In* Fisheries in a changing climate. N.A. McGinn (ed). American Fisheries Society, Bethesda, MD, 3-14 pp.

Mallya, G., P. Mjema, and J. Ndunguru. 2001. Water hyacinth control through integrated weed management strategies in Tanzania. ACIAR Proceedings 102:120-122.

Mantua, N.J., I. Tohver, and A.F. Hamlet. 2009. Impacts of climate change on key aspects of freshwater salmon habitat in Washington State. Chapter 6 *In* The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington.

Mars, J.C., and D.W. Houseknecht. 2007. Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska. Geology 35(7):583-586.

Marsh D.M. and P.C Trenham. 2001. Metapopulation dynamics and amphibian conservation. Conservation Biology 15(1):40-49.

Marshall, R.M., S. Anderson, M. Batcher, P. Comer, S. Cornelius, R. Cox, A. Gondor, D. Gori, J. Humke, R. Paredes Aguilar, I.E. Parra, and S. Schwartz. 2000. An Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion. Prepared by The Nature Conservancy Arizona Chapter, Sonoran Institute, and Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora with support from Department of Defense Legacy Program, Agency and Institutional partners. 146 pp.

Marshall P.A. and H.Z Schuttenberg. 2006. A Reef Manager's Guide to Coral Bleaching. Great Barrier Reef Marine Park Authority, Australia. 163 pp.

Martin, P.D., J. L. Jenkins, F.J. Adams, M.T. Jorgenson, A.C. Matz, D.C. Payer, P.E. Reynolds, A.C. Tidwell, J.R. Zelenak. 2009. Wildlife response to environmental Arctic change: predicting future habitats of Arctic Alaska. Report from a workshop of the same name, 17-18 November 2008. U.S. Fish and Wildlife Service. Fairbanks, Alaska. 138 pp.

Maslanik, J., C. Fowler, J. Stroeve, S. Drobot, J. Zwally, D. Yi, and W. Emery. 2007. A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss. Geophysical Research Letters 34:L24501.

Matthews, J. 2008. Anthropogenic Climate Change in the Playa Lakes Joint Venture Region: Understanding Impacts, Discerning Trends, and Developing Responses. Playa Lakes Joint Venture, Lafayette, CO. 40 pp.

Mauger, S. 2011. Stream temperature monitoring network for Cook Inlet salmon streams, 2008-2010. Cook Inlet Keeper, Homer, AK. 45 pp.

Mawdsley, J.R., R. O'Malley, and D.S. Ojima. 2009. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology 23:1080-1089.

McAdoo, J.K., B. W. Schultz, and S.R. Swanson. 2003. Habitat management for sagebrush-associated wildlife species. Fact Sheet -03-65. University of Nevada Cooperative Extension.

McCabe, G.J., and D.M. Wolock. 2009. Snowpack in the Context of Twentieth-Century Climate Variability. Earth Interactions 13:12.

McKinney, M.A., E. Peacock, and R.J. Letcher. 2009. Sea ice-associated diet change increases the levels of chlorinated and brominated contaminants in polar bears. Environmental Science and Technology 43:4334– 4339.

McLachlan, M., A. Bartuszevige, and D. Pool. 2011. Evaluating the potential of the conservation reserve program to offset projected impacts of climate change on the lesser prairie-chicken (*Tympanuchus pallidicinctus*). USDA Natural Resources Conservation Service and USDA Farm Service Agency. 50 pp.

McLeod, E., G.L. Chmura, S. Bouillon, R. Salm, M. Bjork, C.M. Duarte, C.E. Lovelock, W.H. Schlesinger, and B.R. Silliman. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Frontiers in Ecology and the Environment 9(10):552-560.

McMahon, C.K. 1999. Forest fires and smoke impacts on human health and air quality in the USA. *In*: Proceedings TAPPI International Environmental Conference April 18-21. Nashville, TN: TAPPI Press 2:443-453.

McNulty, S.G. and J.D. Aber, 2001: US national climate change assessment on forest ecosystems: An introduction. Bioscience 51:720-722.

Migeot, J., and D. Imbert. 2011. Structural and floristic patterns in tropical swamp forests: A case study from the Pterocarpus officinalis (Jacq.) forest in Guadeloupe, French West Indies. Aquatic Botany 94(1):1-8.

Milchunas, D.G., A.R. Mosier, J.A. Morgan, D.R. LeCain, J.Y King and J.A. Nelson. 2005. Elevated CO_2 and defoliation effects on a shortgrass steppe: forage quality versus quantity for ruminants. Agriculture, Ecosystems and Environment 111:166-184.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being. Synthesis. Island Press. Washington, DC.

Miller, M.A., Conrad, P.A., Harris, M., Hatfield, B., Langlois, G., Jessup, D.A., Magargal, S.L., Packham, A.E., Toy-Choutka, S., Melli, A.C., Murray, M.A., Gulland, F.M. and Grigg, M.E. 2010. A protozoal-associated epizootic impacting marine wildlife: mass-mortality of southern sea otters (Enhydra lutris nereis) due to Sarcocystis neurona infection. Veterinary Parasitology 172, 183-194.

Mitro, M.G., J.D. Lyons, and J.S. Stewart. 2010. Predicted effects of climate change on the distribution of wild brook trout and brown trout in Wisconsin streams. Proceedings of the Wild Trout X Symposium, Sept. 28-30, 2010, West Yellowstone, MT. 69-76 pp.

Mohseni, O., H.G. Stefan, and J.G. Eaton. 2003. Global warming and potential changes in fish habitat in US streams. Climatic Change 59(3):389-409.

Mooney, H.A. and R.J. Hobbs (eds.). 2000. Invasive Species in a Changing World. Island Press, Washington, DC.

Moore, S.K., V.L. Trainer, N.J. Mantua, M.S. Parker, E.A. Laws, L.E. Fleming, and L.C. Backer. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health 7(Suppl 2).

Moore, S. and M. Gill. 2011. Marine ecosystems study. Arctic report card: update for 2011. Accessed December 2011.

Moore, S.K., N.J. Mantua, and E.P. Salathe Jr. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. Harmful Algae 10:521-529.

Morgan, J.A., D.G. Milchunas, D.R. LeCain, M. West, and A.R. Mosier. 2007. Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. Proceedings of the National Academy of Sciences of the United States of America 104(37):14724-14729.

Morgan, J.A., D.R. LeCain, E. Pendall, D.M. Blumenthal, B.A. Kimball, Y. Carrillo, D. Williams, J. Heisler-White, F. A. Dijkstra, and M. West. 2011. C4 grasses prosper as carbon dioxide eliminates desiccation in warmed semi-arid grassland. Nature 476:202-205.

Moritz, C., J. Patton, C. Conroy, J. Parra, G. White, and S. Beissinger. 2008. Impact of a Century of Climate Change on Small-Mammal Communities in Yosemite National Park, USA. Science 322:261-264.

Moritz, C, J.L. Patton, C.J. Conroy, J.L. Parra, G.C. White, and S.R. Beissinger. 2009. Impact of a century of climate change on small mammal communities in Yosemite National Park, USA. Science 322:261-264.

Morton, J.M., E. Berg, D. Newbould, D. MacLean and L. O'Brien. 2006. Wilderness fire stewardship on the Kenai National Wildlife Refuge, Alaska. International J. Wilderness 12(1):14-17.

Mueter, F. J. and M. A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications 18(2):309-320.

Nabhan, G.P. 2010. Perspectives in Ethnobiology: Ethnophenology and Climate Change. Journal of Ethnobiology 30(1):1-4.

Najjar, R.G., H.A. Walker, P.J. Anderson, E.J. Barron, R.J. Bord, J.R. Gibson, V.S. Kennedy, C.G. Knight, J.P. Megonigal, R.E. O'Connor, C.D. Polsky, N.P. Psuty, B.A. Richards, L.G. Sorenson, E.M. Steele, and R.S. Swanson. 2000. The potential impacts of climate change on the mid-Atlantic coastal region. Climate Research 14(3):219-233.

National Invasive Species Council. 2008. 2008-2012 National Invasive Species Management Plan. 35 pp.

NRC (National Research Council). 1997. Striking a Balance: Improving Stewardship of Marine Areas. Washington, DC: The National Academies Press. 192 pp.

NRC. 2004. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. Washington, DC: The National Academies Press. 290 pp.

NRC. 2010. Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Washington, DC: The National Academies Press. 175 pp.

NRC. 2012. Ecosystem Services: Charting a Path to Sustainability. Washington, DC: The National Academies Press. 136 pp.

NC NERR (North Carolina National Estuarine Research Reserve). 2007. North Carolina National Estuarine Research Reserve Technical Paper Series Number 2. What Are Ecosystem Services? 2 pp.

Negri, A.P. and M.O. Hoogenboom, 2011. Water Contamination Reduces the Tolerance of Coral Larvae to Thermal Stress. PLoS ONE 6(5): e19703.

Nghiem, S., I. Rigor, D. Perovich, P. Clemente-Colon, J. Weatherly, and G. Neumann. 2007. Rapid reduction of Arctic perennial sea ice. Geophysical Research Letters 34:L19504.

NMFS (National Marine Fisheries Service). 2009a. Our Living Oceans. Report on the status of U.S. living marine resources, 6th edition. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-F/SPO-80, 369 pp.

NMFS. 2009b. Our Living Oceans: Habitat. Status of the habitat of U.S. living marine resources. Policy Maker's Summary. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-F/SPO-83, 32 pp.

NMFS. 2010. Fisheries Economics of the United States, 2009. U.S. Department of Commerce. NOAA Tech. Memo. NMFS-F/SPO-118.

NMFS. 2011. U.S. National Bycatch Report. U.S. Department of Commerce. NOAA Tech. Memo. NMFS-F/SPO-117E.

NOAA (National Oceanic and Atmospheric Administration). 2009. Sea level variations of the United States 1854-2006. Technical Report NOS CO-OPS 053, Silver Spring, MD.

Noyes, D., M. McElwee, H. Miller, B. Clark, L. Van Tiem, K. Walcott, K. Erwin, and E. Levin. 2009. The toxicology of climate change: Environmental contaminants in a warming world. Environmental International 35(6):971-986.

NRCS (Natural Resources Conservation Service). 1999. Lesser Prairie-Chicken (Tympanuchus pallidicinctus). Fish and Wildlife Habitat Management Leaflet 6.

Nye, J.A., J.S. Link, J.A. Hare and W.J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology Progress Series 393:111-129.

O'Connor, F. M., O. Boucher, N. Gedney, C.D. Jones, G.A. Folberth, R. Coppell, P. Friedlingstein, W.J. Collins, J. Chappellaz, J. Ridley and C.E. Johnson. 2010. Possible role of wetlands, permafrost, and methane hydrates in the methane cycle under future climate change: A review. Rev. Geophys. 48(4): RG4005.

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.F. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437(7059):681-686.

Overholtz, W.J., J.A. Hare, and C.M. Keith. 2011. Impacts of interannual environmental forcing and climate change on the distribution of Atlantic mackerel on the U.S. northeast continental shelf. Marine and Costal Fisheries: Dynamics, Management, and Ecosystem Science 3:219–232.

Paerl, H.W. and J. Huisman. 2008. Blooms like it hot Science 320:57-58.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637-669.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421(6918):37-42.

Paustian, K., J. Six, E.T. Elliott, and H.W. Hunt. 2000. Management options for reducing CO_2 emissions from agricultural soils. Biogeochemistry 48(1):147-163.

PCSGA (Pacific Coast Shellfish Growers Association). 2010. Shellfish production on the west coast. Compiled by the Pacific Coast Shellfish Growers Association.

Perovich, D.K. 2011. The changing Arctic sea ice cover. Oceanography 24(3):162-173.

Perry, R.I., P. Cury, K. Brander, S. Jennings, C. Möllmann, and B. Planque. 2010. Sensitivity of marine systems to climate and fishing: Concepts, issues and management responses. Journal of Marine Systems 79(3-4):427-435.

Peterson, D.L., C.L. Millar, L.A. Joyce, M.J. Furniss, J.E. Halofsky, R.P. Neilson, and T.L. Morelli. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109p.

Pew Center on Global Climate Change. 2010. Climate change adaptation: What federal agencies are doing. Washington, DC. Accessed December 2011.

Pew Center on Global Climate Change. 2012. Climate change adaptation: What federal agencies are doing (update). Washington, DC. Accessed December 2011.

Pilgrim, J.M., X. Fang, and H.G. Stefan. 1998. Stream temperature correlations with air temperatures in Minnesota: Implications for climate warming. Journal of the American Water Resources Association 34(5):1109-1121.

Poff, N.L., M.M. Brinson, and J.W. Day, Jr. 2002. Aquatic Ecosystems & Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Pew Center on Global Climate Change, Arlington, VA. 1-56 pp.

Poiani, K.A., R.L. Goodman, J. Hobson, J.M. Hoekstra, and K.S. Nelson. 2011. Redesigning biodiversity conservation projects for climate change: Examples from the field. Biological Conservation 20:185-201.

Polovina, J.J., J.P. Dunne, P.A. Woodworth, and E.A. Howell. 2011. Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. ICES Journal of Marine Science 68(6):986-995.

Porter, J.H., M.L. Parry, and T.R. Carter. 1991. The potential effects of climatic change on agricultural insect pests. Agricultural and Forest Meteorology 57:221-240.

Post, E., M.C. Forchhammer, N.C. Stenseth, and T.V. Callaghan. 2001. The timing of life-history events in a changing climate. Proceedings of the Royal Society of London Series Biological Sciences 268(1462):15-23.

Prasad, A. M., L. R. Iverson., S. Matthews., and M. Peters. 2007-ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States. Northern Research Station, USDA Forest Service, Delaware, OH.

The President's Council of Advisors on Science and Technology (PCAST). 2011. Sustaining Environmental Capital: Protecting Society and the Economy, Executive Report. Executive Office of the President, Washington, D.C.

Racine, C., R. Jandt, C. Meyers, and J. Dennis. 2004. Tundra fire and vegetation change along a hillslope on the Seward Peninsula, Alaska, USA. Arctic, Antarctic, and Alpine Research 36:1-10.

Rahel, F.J., and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22(3):521-533.

Rahmstorf, S. 2010. A new view on sea level rise. Nature reports climate change. April, 1, 2010.

Rajagopalan, B., K. Nowak, J. Prairie, M. Hoerling, B. Harding, J. Barsugli, A. Ray, and B. Udall. 2009. Water supply risk on the Colorado River: Can management mitigate? Water Resources Research 45:W08201.

Rice, B. 1987. Changes in the Harding Icefield, Kenai Peninsula, Alaska. M.S. thesis. School of Agriculture and Land Resources Management, University of Alaska, Fairbanks, AK. 116+ pp.

Richter-Menge, J., and J.E. Overland (eds.). 2010: Arctic Report Card 2010. 103 pp.

Riebesell, U. 2004. Effects of CO_2 Enrichment on Marine Phytoplankton. Journal of Oceanography 60(4):719-729.

Rieman, B.E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. Transactions of the American Fisheries Society 136(6):1552-1565.

Riggs, S.R. and D.V. Ames. 2003. Drowning the North Carolina coast: sea-level rise and estuarine dynamics. North Carolina Sea Grant, NC State University, Raleigh, NC, 152 pp.

Rinkevich, S., K. Greenwood, and C. Leonetti, 2011. Traditional Ecological Knowledge for Application by Service Scientists. U.S. Fish and Wildlife Service.

Rivera-Monroy, V.H., R.R. Twilley, S.E. Davis III, D.L. Childers, M. Simard, R. Chambers, R. Jaffe, J.N. Boyer, D.T. Rudnick, K. Zhang, E. Castaneda-Moya, S.M.L. Ewe, R.M. Price, C. Coronado-Molina, M. Ross, T.J. Smith III, B. Michot, E. Meselhe, W. Nuttle, T.G. Troxler, and G.B. Noe. 2011. The Role of the Everglades Mangrove Ecotone Region (EMER) in Regulating Nutrient Cycling and Wetland Productivity in South Florida. Critical Reviews in Environmental Science and Technology 41:633-669.

RMRS (U.S. Forest Service: Rocky Mountain Research Station). 2009. Mountain Pine Beetles in Colorado. Accessed October 2011.

Root, T.L. and S.H. Schneider. 1993. Can Large-Scale Climatic Models be Linked with Multiscale Ecological-Studies. Conservation Biology 7(2):256-270.

Running, S.W. 2008. Climate change - Ecosystem disturbance, carbon, and climate. Science 321(5889):652-653.

Ryan, M.G., S.R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, and W. Schlesinger. 2008. Land Resources. *In* The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC, USA. 362 pp.

Rydberg, J., J. Klaminder, P. Rosén and R. Bindler. 2010. Climate driven release of carbon and mercury from permafrost mires increases mercury loading to sub-arctic lakes. Science of the Total Environment 408:4778-4783.

Scavia, D., J.C. Field, D.F. Boesch, R.W. Buddemeier, V. Burkett, D.R. Cayan, M. Fogarty, M.A. Harwell, R.W. Howarth, C. Mason, D.J. Reed, T.C. Royer, A.H. Sallenger, and J.G. Titus. 2002. Climate change impacts on US coastal and marine ecosystems. Estuaries 25(2):149-164.

Schaefer, K., T. Zhang, L. Bruhwiler, and A.P. Barrett. 2011. Amount and timing of permafrost carbon release in response to climate warming. Tellus Series B-Chemical and Physical Meteorology 63(2):165-180.

Schiedek, D., B. Sundelin, J.W. Readman, and R.W. Macdonald. 2007. Interactions between climate change and contaminants. Marine Pollution Bulletin 54(12):1845-1856.

Schmid, P., C. Bogdal, N. Blüthgen, F.S. Anselmetti, A. Zwyssig, and K. Hungerbhler. 2011. The Missing Piece: Sediment Records in Remote Mountain Lakes Confirm Glaciers Being Secondary Sources of Persistent Organic Pollutants. Environmental Science and Technology 45:203-208.

Sellner, K.G., G.J. Doucette, and G.J. Kirkpatrick. 2003. Harmful algal blooms: causes, impacts and detection. Journal of Industrial Microbiology and Biotechnology 30:383-406.

Shellenbarger Jones, A., C. Bosch, and E. Strange. 2009. Vulnerable species: the effects of sea-level rise on coastal habitats. *In* Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors). U.S. Environmental Protection Agency, Washington, DC. 43-56 pp.

Smith, K.F., M. Behrens, L.M. Schloegel, N. Marano, S. Burgiel, and P. Daszak. 2009. Reducing the risks of the wildlife trade. Science 324(5927):594-595.

SNAP (Scenarios Network for Alaska Planning). 2008. Validating SNAP climate models. Accessed May 2011.

Spalding, M.D., M. Kainuma, and L. Collins. 2010. World Atlas of Mangroves. London, Earthscan, with International Society for Mangrove Ecosystems, Food and Agriculture Organization of the United Nations, The Nature Conservancy, UNEP World Conservation Monitoring Centre, United Nations Scientific and Cultural Organisation, United Nations University.

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, and J.D. Schumacher. 2001. On the temporal variability of the physical environment over the south-eastern Bering Sea. Fisheries Oceanography 10(1):81-98.

Stirling, I., N.J. Lunn, and J. Iacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climate change. Arctic 52:294-306.

Stirling, I. and C.L. Parkinson. 2009. Possible Effects of Climate Warming on Selected Populations of Polar Bears (*Ursus maritimus*) in the Canadian Arctic. ARCTIC 59(3):261-275.

Stroeve, J., M. Serreze, S. Drobot, S. Gearheard, M. Holland, J. Maslanik, W. Meier, and T. Scambos. 2008. Arctic Sea Ice Extent Plummets in 2007. EOS, Transactions AGU 89(2):13.

Swinomish Indian Tribal Community. 2010. Swinomish Climate Change Initiative Climate Adaptation Action Plan.

Tabb, D.C. and A. C. Jones. 1962. Effect of hurricane Donna on the aquatic fauna of North Florida Bay. Transactions of the American Fisheries Society 91(4):375-378.

Tans, P. and R. Keeling. 2011. Trends in Atmospheric Carbon Dioxide. NOAA Earth Systems Research Laboratory. Accessed December 2011.

Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. Global Change Biology 12(4):686-702.

Taub, D. 2010. Effects of Rising Atmospheric Concentrations of Carbon Dioxide on Plants. Nature Education Knowledge 1(8):21.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427(6970):145-148.

Titus, J.G. and C. Richman. 2001. Maps of Lands Vulnerable to Sea Level Rise: Modeled Elevations along the U.S. Atlantic and Gulf Coasts. Climate Research 18:205-228.

Trout Unlimited. 2007. Healing Troubled Waters: Preparing Trout and Salmon Habitat for a Changing Climate. Accessed October 2011.

Turetsky, M.R., J.W. Harden, H.R. Friedli, M. Flannigan, N. Payne, J. Crock, and L Radke. 2006. Wildlifes threaten mercury stocks in northern soils. Geophysical Research Letters 33:L16043.1-L16043.

Upham, L. 2011. Global climate change workshops at SKC begin next week. Char-Koosta News: the official news publication of the Flathead Indian Nation. April 21, 2011.

U.S. Census Bureau. 2010. Coastline Population Trends in the United States: 1960 to 2008. 28 pp.

U.S. Census Bureau. 2012. Growth in Urban Population Outpaces Rest of Nation, Census Bureau Reports. Newsroom. Press Release March 26, 2012.

U.S. Congress, House of Representatives. 2010. Department of the Interior, Environment and Related Agencies Appropriations Act, 2010 Conference Report. To accompany H.R. 2996. 111th Congress. First Session. Report 111-316. 76-77 pp.

U.S. Forest Service. 2009. Carbon Sequestration. U.S. Department of Agriculture. Accessed December 2011.

USGCRP (United States Global Change Research Program). 2009. Global Climate Change Impacts in the United States. T.R. Karl, J.M. Melillo, and T.C. Peterson (eds.). Cambridge University Press.

USGS (United States Geological Survey). 2010. Sea-level rise hazards and decision support: Coastal Groundwater systems. Accessed December 2011.

Van Mantgem, P.J., N.L. Stephenson, J.C. Byrne, L.D. Daniels, J.F. Franklin, P.Z. Fule, M.E. Harmon, A.J. Larson, J.M. Smith, A.H. Taylor, and T.T. Veblen. 2009. Widespread Increase of Tree Mortality Rates in the Western United States. Science 323(5913):521-524.

Veron, J.E.N., O. Hoegh-Guldberg, T.M. Lenton, J.M. Lough, D.O. Obura, P. Pearce-Kelly, C.R.C. Sheppard, M. Spalding, M.G. Stafford-Smith, and A.D. Rogers. 2009. The coral reef crisis: The critical importance of < 350 ppm CO(2). Marine Pollution Bulletin 58(10):1428-1436.

Vice, D.S., R.M. Engeman, and D.L. Vice. 2005. A comparison of three trap designs for capturing brown tree snakes on Guam. Wildlife Research 32:355-359.

Vitousek, P.M., C.M. D'Antonio, L.L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84(5):468-478.

Waples, R.S., T. Beechie, and G.R. Pess. 2009. Evolutionary History, Habitat Disturbance Regimes, and Anthropogenic Changes: What Do These Mean for Resilience of Pacific Salmon Populations? Ecology and Society 14(1):3.

Wassmann, P., C.M. Duarte, S. Agustí, and M.K. Sejr. 2011. Footprints of climate change in the Arctic marine ecosystem. Global Change Biology 17:1235-1249.

Weinberg, J.R. 2005. Bathymetric shift in the distribution of Atlantic surfclams: response to warmer ocean temperature. ICES Journal of Marine Science 62(7):1444-1453.

Weiss, J.L., and J.T. Overpeck. 2005. Is the Sonoran Desert losing its cool? Global Change Biology 11(12):2065-2077.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science 313(5789):940-943.

WICCI (Wisconsin's Changing Climate: Impacts and Adaptation). 2011. Wisconsin Initiative on Climate Change Impacts. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Wisconsin Department of Natural Resources, Madison, Wisconsin.

Wigley, T.M.L. 2005. The climate change commitment. Science 307(5716):1766-1769.

Wildish, D. and D. Kristmanson. 1997. Benthic suspension feeders and flow. Cambridge: Cambridge University Press. 409 pp.

Wildlife Management Institute. 2008. Season's End: Global Warming's Threat to Hunting and Fishing. Bipartisan Policy Center.

Wildlife Management Institute. 2009. Beyond Season's End: A Path Forward For Fish and Wildlife In An Era Of Climate Change. Bipartisan Policy Center.

Wilkinson, C. and D. Souter. 2008. Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville, 152 pp.

Williams, J.E., A.L. Haak, H.M. Neville, and W.T. Colyer. 2009. Potential Consequences of Climate Change to Persistence of Cutthroat Trout Populations. North American Journal of Fisheries Management 29(3):533-548.

Winter, T.C. 2000. The vulnerability of wetlands to climate change: A hydrologic landscape perspective. Journal of the American Water Resources Association 36(2):305-311.

Wipf, S., V. Stoeckli, and P. Bebi. 2009. Winter climate change in alpine tundra: plant responses to changes in snow depth and snowmelt timing. Springer Science + Business Media B.V. 2009. Published online, February 17, 2009.

Wooldridge, S.A., and T.J. Done. 2009. Improved water quality can ameliorate effects of climate change on corals. Ecological Applications 19:1492-1499.

Yokishikawa, K. and L.D. Hinzman. 2003. Shrinking thermokarst ponds and groundwater dynamics in discontinuous permafrost near Council, Alaska. Permafrost and Periglacial Processes 14:151-160.

Ziska, L. and K. George. 2004. Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. World Resource Review 16:427-447.

Ziska, L., R. Sicher, K. George, and J. Mohan. 2007. Rising Carbon Dioxide, Plant Biology Public Health: Potential Impacts on the Growth and Toxicity of Poison Ivy (*Toxicodendron radicans*). Weed Science 55:288-292.

FLICKR/KJELL

Appendix A: Supporting Materials

Below are supporting materials for the National Fish, Wildlife and Plants Climate Adaptation *Strategy* (hereafter *Strategy*). The supporting materials are made available to increase understanding of the development of the *Strategy* and to provide more detailed information about subjects mentioned in the *Strategy*. Each of these materials is available online on the *Strategy*'s web site: www.wildlifeadaptationstrategy.gov, or via the links listed in this appendix.

Ecosystem-Specific Background Papers

These ecosystem-specific background papers were developed by the Technical Teams (see Appendix E for a listing of the Technical Teams and their members) as source material for the *Strategy* detailing the impacts of climate change on specific ecosystems as well as adaptation strategies and actions for those systems. They are not formal appendices to the *Strategy* and have not been, nor will they be updated or revised based on either the agency or public reviews of the *Strategy*. These papers have been edited by the Management Team for length, style, and content, and the Management Team accepts responsibility for any omissions or errors. Please follow the links to access detailed information regarding climate change adaptation for specific ecosystems.

Forest Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Forest_Ecosystems_Paper.pdf

Shrubland Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Shrubland_Ecosystems_Paper.pdf

Grassland Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Grassland_Ecosystems_Paper.pdf

Desert Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Desert_Ecosystems_Paper.pdf

Arctic Tundra Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Tundra_Ecosystems_Paper.pdf

Inland Water Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Inland_Water_Ecosystems_Paper.pdf

Coastal Ecosystems

www.wildlifeadaptationstrategy.gov/pdf/Coastal_Ecosystems_Paper.pdf

Marine Water Ecosystems

www.wildlifeadaptationstrategy.gov/pdfMarine_Ecosystems_Paper.pdf

Legislation

www.wildlifeadaptationstrategy.gov/pdf/2010_Legislative_Language_for_Adaptation_Strategy.pdf

Related Resources, Reports, and Materials

Adaptive Management: The U.S. Department of Interior Technical Guide

www.doi.gov/initiatives/AdaptiveManagement/documents.html

The Technical Guide presents adaptive management as a tool to help bureaus make better decisions in the context of uncertain or incomplete information.

America's Climate Choices

nas-sites.org/americasclimatechoices

The National Research Council of the National Academies is conducting a series of coordinated activities designed to advance the U.S. response to climate change.

Animal and Plant Health Inspection Service (APHIS): National Wildlife Research Center (NWRC)

www.aphis.usda.gov/wildlife_damage/nwrc

The APHIS's NWRC can work with conservation and land and resource management agencies and organizations to address invasive species damage management.

Climate Adaptation Knowledge Exchange (CAKE)

www.cakex.org

CAKE is a joint project of Island Press and EcoAdapt. It is aimed at building a shared knowledge base for managing natural systems in the face of rapid climate change, and includes a large database of adaptation case studies, reports, and tools, as well as links to federal, state, and local adaptation plans.

Climate Change Tree and Bird Atlases

www.nrs.fs.fed.us/atlas

The tree and bird atlases examine current distributions and modeled future-climate habitats for 134 individual tree species and the distribution of 150 bird species by geographic area.

Climate Change Resource Center (CCRC)

www.fs.fed.us/ccrc/

CCRC is a reference Web site for resource managers and decision makers who need information and tools to address climate change in planning and project implementation.

Climate Forest Vegetation Simulator Projection

forest.moscowfsl.wsu.edu/climate/species/index.php

Climate-FVS is a modification to the Forest Vegetation Simulator, a stand dynamics model generally used to support forest planning, project analysis, and silvicultural prescription preparation.

Climate Science Centers (CSCs)

nccwsc.usgs.gov/csc.shtml

Regional CSCs will provide scientific information, tools, and techniques that land, water, wildlife, and cultural resource managers can apply to anticipate, monitor, and adapt to climate and ecologically-driven responses at regional-to-local scales.

U.S. Environmental Protection Agency (EPA)

www.epa.gov/climatechange/

The EPA provides a good overview of climate adaptation and links to related resources and materials.

Forecasts of Climate-Associated Shifts in Tree Species (ForeCASTS)

www.forestthreats.org/tools/ForeCASTS

The maps, known as ForeCASTS depict future suitable habitat ranges for North American tree species within the United States as well as across the globe. It uses projections of future climate in combination with the concept of fine-scale ecoregions and can ultimately be used to assess the risk to genetic integrity of North American forest tree populations.

Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers

www.nrs.fs.fed.us/pubs/40543

This document provides a collection of resources designed to help forest managers incorporate climate change considerations into management and devise adaptation tactics. It was developed in northern Wisconsin as part of the Northwoods Climate Change Response Framework project and contains information from assessments, partnership efforts, workshops, and collaborative work between scientists and managers.

ForGRAS (Forest Genetic Risk Assessment System)

www.forestthreats.org/current-projects/project-summaries/genetic-risk-assessment-system

This assessment framework serves as a tool for planning management activities and conservation efforts, for evaluating species' genetic resources, and for detecting vulnerabilities. It has the advantage of accounting for multiple threats that may result in the most severe genetic impacts.

Integrated Climate and Land Use Scenarios (ICLUS)

www.epa.gov/ncea/global/iclus

The EPA is developing scenarios broadly consistent with global-scale, peer-reviewed storylines of population growth and economic development, which are used by climate change modelers to develop projections of future climate.

Interagency Climate Change Adaptation Task Force (ICCATF)

www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation

The Council on Environmental Quality is co-chairing the ICCATF which is comprised of over 200 federal agency staff.

Intergovernmental Panel on Climate Change (IPCC)

www.ipcc.ch

The IPCC is the definitive scientific intergovernmental body tasked with reviewing and assessing the most recent scientific, technical, and socio-economic information produced worldwide relevant to the understanding of climate change. Work on the Fifth Assessment Report is currently underway.

Landscape Conservation Cooperatives (LCCs)

www.fws.gov/science/shc/lcc.html

LCCs are self-directed, applied conservation science partnerships that will support conservation at landscape scales.

MC1 Dynamic Global Vegetation Model

databasin.org/climate-center/features/mc1-dynamic-global-vegetation-model

MC1 is a widely used dynamic global vegetation model (DGVM) that has been used to simulate potential vegetation shifts in California and Alaska, all of North America, and over the entire globe under various climate change scenarios.

National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate

www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf

The Freshwater Action Plan recommends federal agency actions to aid freshwater resource managers in managing and protecting the nation's water resources.

National Ocean Policy

www.whitehouse.gov/administration/eop/oceans/policy

In July of 2010, Executive Order 13547 established a National Ocean Policy and tasked the interagency National Ocean Council with developing this strategic action plan.

National Road Map for Responding to Climate Change

www.fs.fed.us/climatechange/pdf/Roadmapfinal.pdf

The National Road Map for Responding to Climate Change was developed by the U.S. Forest Service to achieve the goal of all National Forests being in compliance with a climate adaptation and mitigation strategy. The Roadmap integrates land management, outreach, and sustainable operations accounting. It focuses on three kinds of activities: assessing current risks, vulnerabilities, policies, and gaps in knowledge; engaging partners in seeking solutions and learning from as well as educating the public and employees on climate change issues; and managing for resilience, in ecosystems as well as in human communities, through adaptation, mitigation, and sustainable consumption strategies.

Plant Protection Act (PPA)

www.aphis.usda.gov/brs/pdf/PlantProtAct2000.pdf

The PPA consolidates all or part of 10 existing U.S. Department of Agriculture plant health laws into one comprehensive law, including the authority to regulate plants, plant products, certain biological control organisms, noxious weeds, and plant pests.

Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options

www.fs.fed.us/pnw/pubs/pnw_gtr855.pdf

This guidebook created by the U.S. Forest Service contains science-based principles, processes, and tools necessary to assist with developing adaptation options for national forest lands.

Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change

www.fws.gov/home/climatechange/pdf/CCStrategicPlan.pdf

The U.S. Fish and Wildlife Service climate change strategy, titled "Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change," establishes a basic framework within which the Service will work as part of the larger conservation community to help ensure the sustainability of fish, wildlife, plants and habitats in the face of accelerating climate change.

Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment

www.habitat.noaa.gov/pdf/scanning_the_conservation_horizon.pdf

This guidance document is a product of an expert workgroup on climate change vulnerability assessment convened by the National Wildlife Federation in collaboration with the U.S. Fish and Wildlife Service.

The seed selection tool (SST)

sst.forestry.oregonstate.edu

The seedlot selection tool (SST) is a GIS mapping program designed to help forest managers match seedlots with planting sites based on climatic information.

Template for Assessing Climate Change Impacts and Management Options (TACCIMO)

www.forestthreats.org/tools/taccimo/intro

A web-based tool that provides land owners, managers, and planners with the most current climate change science available. Developed by EFETAC researchers in partnership with USDA Forest Service Southern Regional Planning, Land and Resource Management; Southern Regional Cooperative Forestry; and Western Wildland Environmental Threat Assessment Center, the TACCIMO tool compiles climate change projections, literature-based impacts and management options, and Forest Service land and resource management plans in an online database.

U.S. Global Change Research Program (USGCRP)

www.globalchange.gov

The USGCRP coordinates and integrates federal research on changes in the global environment and their implications for society.

Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans and Other Management Plans

www.fishwildlife.org/files/AFWA-Voluntary-Guidance-Incorporating-Climate-Change_SWAP.pdf

This document, which was produced by the Climate Change Wildlife Action Plan Work Group which was created as a joint work group by the Association of Fish and Wildlife Agencies Climate Change and Teaming with Wildlife Committees, provides voluntary guidance for state fish and wildlife agencies wanting to better incorporate the impacts of climate change on wildlife and their habitats into Wildlife Action Plans.

USFWS/GEORGE GENTRY

Appendix B: Glossary

Adaptation (Climate Change): adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptation (Biological): the process or the product of natural selection that changes an organism's behavior, physiological function, or anatomical structure, so that it is better suited to its environment.

Adaptive Capacity: the ability of a species to become adapted (i.e., to be able to live and reproduce) to a certain range of environmental conditions as a result of genetic and phenotypic responses.

Anthropogenic: of, relating to, or resulting from the influence of human beings on nature.

Biodiversity: the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, among species, and of ecosystems.

Bycatch: unwanted marine creatures that are caught in the nets while fishing for another species

Carbon Sequestration: the long-term storage of carbon dioxide or other forms of carbon. It has been proposed as a way to slow the atmospheric and marine accumulation of the greenhouse gas, which is released by burning fossil fuels.

Clean Water Act: the primary federal law in the United States governing water pollution. The Act established the goals of eliminating releases of high amounts of toxic substances into water, eliminating additional water pollution by 1985, and ensuring that surface waters would meet standards necessary for human sports and recreation by 1983.

Climate Change: a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions or the distribution of events around that average (e.g., more or fewer extreme weather events). Climate change may be limited to a specific region or may occur across the whole Earth.

Climate Models: quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate.

Coastal Zone Management Act: an Act of Congress passed in 1972 to encourage coastal states to develop and implement coastal zone management plans. This act was established as national policy to preserve, protect, develop, and where possible, restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations.

Conservation: Preservation, protection, or restoration of the natural environment, natural ecosystems, vegetation, and wildlife.

Conservation Partners: entities working toward the conservation of fish, wildlife, and other natural resources, which includes local governments, non-government organizations, charitable foundations, academic institutions, industries, private landowners, and other interested individuals.

Downscaling: refers to techniques that take output from global climate models and add information at smaller scales. Downscaling methods are used to obtain local-scale surface weather from global or regional-scale models.

Ecosystem: a biological environment consisting of all the organisms living in a particular area, as well as all the nonliving (abiotic), physical components of the environment with which the organisms interact, such as air, soil, water, and sunlight.

Ecosystem Function: the physical, chemical, and biological processes or attributes that contribute to the self-maintenance of the ecosystem, such as decomposition, nutrient cycling, pollination, and seed dispersal.

Ecosystem Process: A natural phenomenon in an ecosystem that leads toward a particular result.

Ecosystem Services: the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, identity, and spiritual fulfillment; and supporting services such as soil formation, photosynthesis, and nutrient cycling.

Endangered Species Act (ESA): environmental law signed on December 28, 1973, that provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend. The ESA replaced the Endangered Species Conservation Act of 1969. It has been amended several times.

Eutrophication: the movement of a body of water's trophic status in the direction of increasing biomass, by the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system.

Evapotranspiration: describes the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through its leaves.

Exclusive Economic Zone: a zone of an ocean or sea over which a state has special rights over the exploration and use of marine resources, including production of energy from water and wind. It stretches from the seaward edge of the state's territorial sea out to 200 nautical miles from its coast.

Extreme Events: includes weather phenomena that are at the extremes of the historical distribution, especially severe or unseasonal weather such as heat waves, drought, floods, storms, and wildfires.

Farm Bill: colloquial name for the primary agricultural and food policy tool of the federal government. The comprehensive omnibus bill is passed every five years or so by the United States Congress and deals with both agriculture and all other affairs under the purview of the U.S. Department of Agriculture. The formal title of each bill varies, but the current version is known as the Food, Conservation, and Energy Act of 2008.

Geomorphological Change: changes observed in landforms and the processes that shape them. The study of geomorphological change can be used to understand landform history and dynamics, and to predict future changes through a combination of field observations, physical experiments, and numerical modeling.

Globalization: refers to the increasingly global relationships of culture, people, and economic activity.

Greenhouse Gas: a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Habitat: an ecological or environmental area that is inhabited by a particular species of animal, plant, or other type of organism. It is the natural environment in which an organism lives, or the physical environment that surrounds (influences and is utilized by) a population.

Habitat Degradation: the process in which natural habitat is rendered functionally unable to support the species present. In this process, the organisms that previously used the site are displaced or destroyed, reducing biodiversity.

Habitat Fragmentation: describes the emergence of discontinuities in an organism's preferred habitat, causing population fragmentation. Habitat fragmentation can be caused by geological processes that slowly alter the layout of the physical environment or by human activity such as land conversion and road building.

Harmful Algal Blooms: a rapid increase or accumulation in the population of algae in an aquatic system forming visible patches that may harm the health of the environment, plants, or animals. They can deplete the oxygen and block the sunlight that other organisms need to live, and some algae blooms release toxins that are dangerous to animals and humans.

Hydrology: the movement, distribution, and quality of water, including the hydrologic cycle, water resources, and environmental watershed sustainability.

Hypoxia: a phenomenon that occurs in aquatic environments as dissolved oxygen becomes reduced in concentration to a point where it becomes detrimental to aquatic organisms living in the system.

Invasive Species: non-indigenous species of plants or animals that adversely affect the economy, environment, and/or ecology of the habitats and bioregions they invade.

Keystone Species: a species that has a disproportionately large effect on its environment relative to its abundance. Such species play a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community.

Maladaptation: an adaptation that, although reasonable at the time, becomes less and less suitable and more of a problem or hindrance as time goes on. It is possible for an adaptation to be poorly selected or become less appropriate or even become, on balance, more of a dysfunction than a positive adaptation over time.

Mitigation: in the context of climate change, a human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Natural Disturbance Regimes: the pattern and dynamics of disturbance events (e.g., fires, floods, landslides, etc.) that mold the structure and species composition of an ecosystem.

Natural Resources: materials and components that can be found within the environment. A natural resource may exist as a separate entity, such as fresh water and air, as well as a living organism, such as a fish, or it may exist in an alternate form which must be processed to obtain the resource, such as metal ores, oil, and most forms of energy.

Non-climate Stressors: in the context of climate adaptation, non-climate stressors refer to those current or future pressures and impacts threatening species and natural systems that do not stem from climate change, such as habitat fragmentation, invasive species, pollution and contamination, disease, and over exploitation.

Nonpoint Source Pollution: refers to both water and air pollution from diffuse sources. Nonpoint source water pollution affects a waterbody from sources such as polluted runoff from agriculture areas draining into a river or wind-borne debris blowing out to sea. Nonpoint source air pollution affects air quality from sources such as smokestacks or car tailpipes. Although these pollutants have originated from a point source, the long-range transport ability and multiple sources of the pollutant make it a nonpoint source of pollution.

Ocean Acidification: the ongoing decrease in the pH and increase in acidity of the Earth's oceans, caused by the uptake of carbon dioxide from the atmosphere.

Permafrost: soil at or below the freezing point of water (0 °C or 32 °F) for two or more years.

Phenology: the study of periodic plant and animal life cycle events and how these are influenced by seasonal and inter-annual variations in climate.

Resilience: (Current Ecological Usage) - the capacity of an ecosystem to return to its original state following a perturbation, including maintaining its essential characteristics of taxonomic composition, structure, ecosystem functions, and process rates. (Emerging Climate Change Usage)—In the emerging context of climate change, resilience might best be thought of as the ability of an ecosystem to recover from or adjust easily to change, measured more in terms of overall ecosystem structure, function, and rates and less in terms of taxonomic composition. A grassland that remains a grassland in the face of climate change could be thought of as resilient, even if its species composition is substantially altered. On the other hand, a grassland that becomes a forest in the face of climate change was not resilient: it has transformed into a new system.

Resistance: the capacity of the ecosystem to absorb disturbances and remain largely unchanged.

Restoration: (Current Ecological Usage) - the process of repairing damage to the diversity and dynamics of indigenous ecosystems, which can include promoting or mimicking natural disturbance regimes; managing issues like in-stream flows, water withdrawals, and stormwater run-off; and addressing poorly-sited infrastructure. (Emerging Climate Change Usage) - In the emerging context of climate change, restoration might best be thought of as focusing on repairing damage to such structural or functional aspects of the ecosystem as listed above, as opposed to attempting to restore the original species composition of an ecosystem.

Risk Assessment: the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat such as climate change.

Sea Level Rise: As water warms, it expands, and the ocean surface rises. The melting of inland glaciers and continental ice sheets, including those in Greenland and Antarctica, causes additional sea level rise. Sea level change is highly variable regionally. It depends on the relative increase in water levels as well as local land elevation changes caused by subsidence or uplift, and local rates of sediment accumulation. Relative sea level rise refers to a local increase in the level of the ocean due to the interaction of these factors.

Sentinel Site: A location that is selected to represent a certain, preferably large, class of ecosystems for intensive monitoring.

Socioeconomics: a word used to identify the importance of factors other than biology in natural resource management decisions. For example, if management results in more fishing income, it is important to know how the income is distributed between small and large boats or part-time and full-time fishermen.

Stakeholders: a person, group, organization, or system that affects or can be affected by an organization's actions.

Stratification: in relation to water, stratification occurs when water masses with different properties (salinity, oxygenation, density, temperature) form layers that act as barriers to water mixing. These layers are normally arranged according to density, with the least dense water masses sitting above the more dense layers.

Vulnerability Assessment: a tool used in adaptation planning for informing the development and implementation of resource management practices.

LORI IVERSON/USFWS

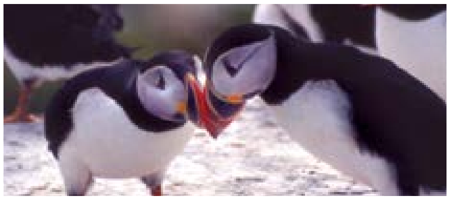
Appendix C: Acronyms

ACIA	Arctic Climate Impact Assessment
AFWA	Association of Fish and Wildlife Agencies
AMSA	Arctic Marine Shipping Assessment
ASCE	American Society of Civil Engineers
AZ CCAG	Arizona Climate Change Advisory Group
CADFG	California Department of Fish and Game
CAKE	Climate Adaptation Knowledge Exchange
CEC	Commission for Environmental Cooperation
CEQ	Council on Environmental Quality
CO_2	Carbon Dioxide
CSCs	Climate Science Centers
CCSP	U.S. Climate Change Science Program
DDT	Dichlorodiphenyltrichloroethane
DOC	Department of Commerce
DOI	Department of the Interior
ECA	Economics of Climate Adaptation Working Group
ESA	Endangered Species Act
F	Fahrenheit
FAO	Food and Agriculture Organization of the United Nations
FWS	U.S. Fish and Wildlife Service
GAO	General Accountability Office
GHG/GHGs	Greenhouse Gas/Gasses
HABs	Harmful Algal Blooms
IPCC	Intergovernmental Panel on Climate Change
ICCATF	Interagency Climate Change Adaptation Task Force
JVs	Migratory bird and other Joint Ventures
LCC	Landscape Conservation Cooperative
NC NERR	North Carolina National Estuarine Research Reserve
NCA	National Climate Assessment
NERRS	National Estuarine Research Reserve System
NFHAP	National Fish Habitat Action Plan
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOC	National Ocean Council
NOP	National Ocean Policy
NRC	National Research Council
NRCS	National Resource Conservation Service
NSF	National Science Foundation
PCB	Polychlorinated biphenyls
PCSGA	Pacific Coast Shellfish Growers Association
REDD	Reducing Emissions from Deforestation and Forest Degradation
RISAs	Regional Integrated Sciences and Assessments
RMRS	U.S. Forest Service: Rocky Mountain Research Station
SNAP	Scenarios Network for Alaska Planning
TEK	Traditional Ecological Knowledge
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
WICCI	Wisconsin's Changing Climate: Impacts and Adaptation


DAN DZURISIN

Appendix D: Scientific Names

alpine chipmunk	*Neotamias alpinus*
American oystercatcher	*Haematopus palliatus*
American robin	*Turdus migratorius*
Arctic fox	*Vulpes lagopus*
Asian carp (Bighead carp)	*Hypophthalmichthys nobilis*
Asian carp (Black carp)	*Mylopharyngodon piceus*
Asian carp (Grass carp)	*Ctenopharyngodon idella*
Asian carp (Silver carp)	*Hypophthalmichthys molitrix*
Atlantic croaker	*Micropogonias undulatus*
blue crab	*Callinectes sapidus*
brook trout	*Salvelinus fontinalis*
brown treesnake	*Boiga irregularis*
buffelgrass	*Pennisetum ciliare*
California vole	*Microtus californicus*
caribou	*Rangifer tarandus*
cheatgrass	*Bromus tectorum*
Edith's checkerspot butterfly	*Euphydryas editha*
Chinook salmon	*Oncorhynchus tshawytscha*
cisco	*Coregonus artedi*
Coho salmon	*Oncorhynchus kisutch*
Cope's gray treefrog	*Hyla chrysoscelis*
diamondback terrapin	*Malaclemys terrapin*
eastern tiger salamander	*Ambystoma tigrinum*
feral hog	*Sus scrofa*
greater sage grouse	*Centrocercus urophasianus*
grizzly bear	*Ursus arctos horribilis*
hemlock woolly adelgid	*Adelges tsugae*
horseshoe crab	*Limulus polyphemus*
humpback chub	*Gila cypha*
kelp	*Laminariales*
Kittiwake	*Rissa sp.*
kudzu	*Pueraria sp.*
lake trout	*Salvelinus namaycush*
least tern	*Sterna antillarum*
lesser prairie-chicken	*Tympanuchus pallidicinctus*
lodgepole pine	*Pinus contorta*
mountain pine beetle	*Dendroctonus ponderosae*
muskoxen	*Ovibos moschatus*
northern pike	*Esox lucius*
Pacific oyster	*Crassostrea gigas*
paper birch tree	*Betula papyrifera*
common reed	*Phragmites sp.*
pinyon mouse	*Peromyscus truei*
piping plover	*Charadrius melodus*
poison ivy	*Toxicodendron radicans*
polar bear	*Ursus maritimus*
Ponderosa pine	*Pinus ponderosa*
quagga mussel	*Dreissena rostriformis bugensis*
rainbow trout	*Oncorhynchus mykiss*
red fox	*Vulpes vulpes*
red knot	*Calidris canutus*
ring seal	*Pusa hispida*
Rio Grande cutthroat trout	*Oncorhynchus clarki virginalis*
sagebrush	*Artemisia sp.*
Saguaro	*Carnegiea gigantea*
seabeach amaranth	*Amaranthus pumilus*
silver hake	*Merluccius bilinearis*
smallmouth bass	*Micropterus dolomieu*
southwestern willow flycatcher	*Empidonax traillii extimus*
spruce	*Picea sp.*
spruce bark beetle	*Ips typographus*
surf clam	*Spisula solidissima*
walleye	*Sander vitreus*
walrus	*Odobenus rosmarus*
water hyacinth	*Eichhornia crassipes*
white spruce	*Picea glauca*
white-tailed deer	*Odocoileus virginianus*
Wilson's plover	*Charadrius wilsonia*
zebra mussel	*Dreissena polymorpha*



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