NATIONAL *fish, wildlife* & *plants* CLIMATE ADAPTATION STRATEGY

January
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Shared solutions to protect shared values

Public Review **Draft**

National Fish, Wildlife and Plants Climate Adaptation Strategy

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Preface

Our climate is changing, and these changes are already impacting the nation's valuable natural resources and the people, communities, and economies that depend on them (see Chapters 1 and 2). The observed changes in climate, in turn, have been directly correlated 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 already inevitable 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 more likely, the planet's 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, sea level rise, and acidification of our oceans. The pace and scale of these kinds of changes are expected to have major impacts on our natural resources and the communities and economies that depend on them.

The problem, therefore, is serious and urgent. The nation must prepare for and adapt to a changing climate to safeguard our valuable living resources for current and future generations. 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 currently 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 and other decision makers at all levels of government. 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. 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 energy, housing and urban development, transportation, and water systems), 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.

Executive Summary

The climate is changing, and the effects are being seen in the nation's valuable natural resources and in the economies and communities that depend on plants, animals, and ecosystems. Measurements unequivocally show that average 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, the planet's temperature is predicted to rise by an additional 2.0 to 11.5 °F by the end of the century, with accompanying increases in extreme weather events and sea levels.

Faced with a future climate that will be unlike that of the recent past, the nation has no choice but to adapt to the changes. 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 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 *Strategy*. More than 100 diverse technical and scientific experts from across the country participated in drafting the Strategy for the partnership.

> **"...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

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.

The *Strategy* is guided by nine principles. Those 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's 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's crucial to carefully monitor actual outcomes in order to adjust future actions to make them more effective, an iterative process called adaptive management. And given the size and urgency of the challenge, we must begin acting now.

The *Strategy* details how climate change is expected to affect the eight major ecosystem types in the United States (Chapter 2). Warmer temperatures and changing precipitation patterns are expected to cause more fires and more pest outbreaks like the mountain pine beetle epidemic in forests, for instance, while boreal forest will move north into 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, with temperatures in northern Alaska projected to climb 13 to 26 °F. That would change tundra into shrublands, and bring more fires. In addition, the thawing of frozen organic material in soils would release huge amounts of greenhouse gases, contributing to climate change. Rivers, streams, and lakes face higher temperatures that harm coldwater species like salmon and trout populations, while sea level rise threatens coastal marshes and beaches, which are crucial habitats for many species. Among those at risk: the diamondback terrapin and the piping plover.

Since water absorbs CO_2 from the air, the rising levels of the gas in the atmosphere have caused the oceans to become 30 percent more acidic since 1750. That's already affecting the reproduction of species like oysters. As the pH of seawater continues to drop, major impacts on aquatic ecosystems and species are expected.


Photo: AFWA

The *Strategy* describes steps that can be taken to combat these impacts and 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) conserving and connecting habitat; (2) managing species and habitats; (3) enhancing management capacity; (4) supporting adaptive management; (5) increasing knowledge; (6) Increasing awareness and motivating action; and (7) reducing stresses not caused by climate change. 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 but that will continue to be useful in a period of climate change. Others are designed to respond to the new challenges posed by climate change.

The most robust 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 more hospitable climes. As a result, there's a growing need to identify the best candidates for new conservation areas, and to provide corridors of habitat that allow species to migrate.

This *Strategy* envisions innovative opportunities for creating additional habitat. Paying farmers in the Great Plains to take some of their land out of production and then restoring prairie grass and sagebrush on the land could offset the projected population declines from climate change of the threatened lesser prairie chicken, according to one analysis. 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's 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 use. Stream and habitat restorations that narrow and deepen streams or that ensure a steady supply of cold groundwater can keep water temperatures low enough to maintain healthy trout populations even when air temperatures rise.

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. 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. Landscape Conservation Cooperatives, Migratory Bird Joint Ventures, National Fish Habitat Partnerships, and other existing and emerging partnerships are useful vehicles to promote collaboration.

Predicting how individual species and ecosystems will react to climate change will frequently be difficult. Adapting to uncertain impacts requires coordinated observation and monitoring, information management and decision support systems, and a commitment to adaptive management approaches. The National Ecological Observatory Network is one example of a coordinated observation system. Coordinated information management systems that 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 can help managers develop and prioritize adaptation efforts and inform management approaches.

New research is 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 useful information for planning for climate change impacts. 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 are needed.

Adaptation efforts will be most successful if they have broad public and political support and if key groups and people are motivated to take action themselves. Efforts to increase awareness and motivate action should be targeted toward elected officials, public and private policy 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 and action is key to making this *Strategy* work.

Reducing existing stresses on fish, wildlife, and plants can be some of the most effective, and doable, ways to increase resilience to climate change. Reducing and mitigating the ongoing habitat degradation associated with human development such as pollution and loss of open space is critical and requires collaboration with land use planners. Taking steps to reduce stresses 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.

In addition, the *Strategy* emphasizes that actions to help plants, wildlife, fish, and natural systems adapt to climate change can be coordinated with measures taken in other sectors, such as agriculture and industry, to increase the benefits for all sectors. Reducing stormwater runoff not only reduces risks of flooding in cities, for example, it also reduces the threat that toxic algal blooms will affect aquatic ecosystems.

The *Strategy* is also designed to build upon and complement many existing adaptation and conservation efforts (Chapter 4). Notable among those are the U.S. Global Change Research Program and the National Climate Assessment it produces every four years; the Interagency Climate Change Adaptation Task Force that coordinates U.S. federal agency adaptation efforts; State Wildlife Action Plans; and Landscape Conservation Cooperatives. Implementing the *Strategy* will require coordination and collaboration among these and many other entities. The *Strategy* proposes creation of a coordination body to oversee its implementation and engage with conservation partners.

Admittedly, the task ahead is a daunting one. However, we can begin to take effective action to reduce risks and increase resiliency of valuable natural resources. This *Strategy* is a call to action. 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.

Chapter 1: Introduction

The goal of the *National Fish, Wildlife and Plants Climate Adaptation Strategy* (hereafter *Strategy*) is to inspire and enable natural resource administrators, legislators and other decision makers to take action to adapt to a changing climate. Those 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. Since 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 (see Chapter 2). 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.

Photo: AFWA

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 (Parmesan 2006, IPCC AR4 2007, USGCRP 2009). 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. 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, i.e., decision makers. Rather, this is a broad national adaptation strategy: it identifies major goals and outlines more specific strategies and actions needed to attain those goals. It describes the "why, what, and when" of what the conservation community, collectively, 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.

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 fish, wildlife, and plants 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 among federal, state, and tribal fish and wildlife authorities as was employed in the production of this first effort. This report proposes that a coordinating body with representation from federal, state, and tribal governments meet semi-annually to evaluate implementation and to report progress annually.

The *Strategy* is organized into four chapters and several appendices. The first chapter explains the origins, vision, guiding principles, and development of this effort. It describes the need for action and explains how to use this document. Chapter 2 describes major current and projected impacts of climate change on the eight major ecosystem types of the United States and on the fish, wildlife and plant species those ecosystems support. Chapter 3 lays out the goals, strategies, and actions that can help fish, wildlife, plants, and ecosystems be more resilient and adapt in a changing climate. It also highlights some of the important roles and opportunities that other sectors such as agriculture, energy, and transportation have in promoting climate adaptation of fish, wildlife, and plants through their activities. Chapter 4 discusses implementation and integration, outlining how stakeholders at all levels of government can use this *Strategy* as a resource. Appendix A provides supplementary information and links to ecosystem-specific background papers that provide more depth and detail regarding climate change impacts and ecosystem-specific actions for each major ecosystem type of the United States. Additional appendices provide a glossary of terms used in the *Strategy*, a list of acronyms, a list of scientific names of species, and a roster of those involved in the development of the *Strategy*.

1.1 Origins and Development of the *Strategy*

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 incorporate and address climate change into their resource management efforts (GAO 2007). In 2008, the U.S. Global Change Research Program (USGCRP) released the report "*Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*" that called for and identified a variety of new approaches to natural resource management to increase resiliency and adaptation of ecosystems and resources (CCSP 2008b). In addition, a coalition of hunting and fishing organizations published two 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).

In 2009, Congress asked the Council on Environmental Quality (CEQ) and the Department of the Interior (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" (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 2010, the Interagency Climate Change Adaptation Task Force (ICCATF) endorsed development of the *Strategy* as a key step in advancing U.S. efforts to adapt to a changing climate[1].

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[1] http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation

A 23-person Steering Committee was formed in January 2011. The Steering Committee includes representatives from 16 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 Steering Committee charged a small Management Team including representatives of the FWS, NOAA, Association of Fish and Wildlife Agencies (AFWA, representing the states) and 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, presented at right and discussed in detail in Chapter 3.

Strategy Goals:

- Goal 1. Conserve and Connect Habitat
- Goal 2. Manage Species & Habitats
- Goal 3. Enhance Management Capacity
- Goal 4. Support Adaptive Management
- Goal 5. Increase Knowledge & Information
- Goal 6. Increase Awareness & Motivate Action
- Goal 7. Reduce Non-Climate Stressors

1.2 The Case for Action

1.2.1 The Climate is Changing

Earth's climate has changed many times over its long history. Measurements and observations show unequivocally that the Earth's climate is now in such a period of change. In 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.
- 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.
- Oceans are becoming more acidic.
- Ocean currents and upwelling patterns are changing.

All of these changes have been well documented, as 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, and other changes is the accumulation of heat-trapping carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere (IPCC AR4 2007). Because GHGs remain in the atmosphere for many years, those that have 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, and ecosystems may no longer be effective either in kind, in scale, or both.

1.2.2 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). 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 biologist's expectations for a warming climate (Parmesan 2006). 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). Furthermore, climatic changes are also likely to exacerbate existing stresses like habitat loss and fragmentation, putting additional pressure on our nation's valued living resources (USGCRP 2009).Changes that have already been observed include:

- Species are shifting their geographic ranges, often moving poleward or upwards in elevation. For instance, geese that used to winter 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).
- The timing of life history events (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 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).
- Declines in the populations of species, from mollusks off the coast of Alaska to frogs in Yellowstone, have been attributed to climate change (Maclean and Wilson 2011).
- 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 has led to mismatches with both caterpillar host

plants and nectar sources for adult butterflies, leading to population crashes in some areas (Parmesan 2006).

- 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).
- Since water absorbs CO_2, the oceans are becoming more acidic, affecting the reproduction of species like oysters (Feely et al. 2008). 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 (USGCRP 2009). Although not technically climate change, this additional impact of the accumulation of CO_2 in the atmosphere is expected to have major impacts on aquatic ecosystems and species.
- The spread of non-native species as well as diseases, pests, and parasites has become more common. For instance, warmer temperatures have enabled a salmon parasite to invade the Yukon River, causing economic harm to 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).

HOTTER SUMMERS THREATEN EASTERN BROOK TROUT

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.

Photo: M. Mitro-Wisconsin DNR

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 cold-water 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 stream bank vegetation for shade, or narrowing and deepening stream channels to reduce solar heating. 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.

1.2.3 Ecosystem Services

Living resources are of immense value and benefit to people. 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, wood, etc.
- *Regulating Services*, such as climate regulation, flood suppression, disease/pest control, or water filtration, etc.
- *Cultural Services*, such as aesthetic, spiritual, educational, and recreational services.
- *Supporting Services*, such as nutrient cycling, soil formation, pollination and plant productivity, etc.

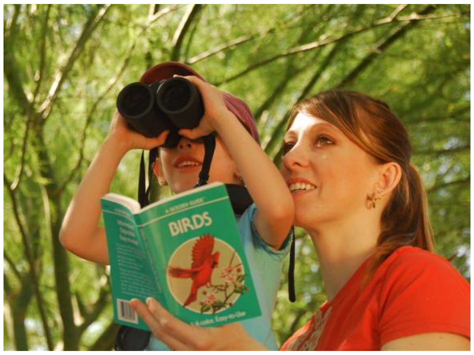


Photo: AFWA

It is possible to calculate the economic contribution associated with some of these services. For example, hunting, fishing, and other wildlife-related recreation (an example of Provisioning and Cultural services) is estimated to contribute $122 billion to our nation's economy annually (U.S. DOI and U.S. DOC 2006), while the world's fisheries (a Provisioning service), most of which are based on wild, free-ranging species, support approximately $116 billion in economic activity a year to the U.S. economy (NMFS 2010). Americans and foreign visitors made some 439 million visits to Interior-managed lands. These visits (example of a Cultural service) supported over 388,000 jobs and contributed over $47 billion in economic activity. 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 (U.S. DOI 2011). 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.

Other examples of ecosystem services, though no less real, have yet to be fully quantified economically. For example, Native Americans and other indigenous peoples around the world still depend on wild species for their livelihoods. 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 (U.S. DOI and U.S. DOC 2006). 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. The animals and plants that are culturally important to these communities have values that are difficult to quantify and weight in monetary terms.

Despite growing recognition of the importance of ecosystem functions and services, they are often taken for granted and overlooked in environmental decision-making. 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 and so that improvements to one ecosystem can be compared to those in another (NRC 2005).

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 such as the examples given above. However, some ecosystem goods and services cannot be valued because they are not quantifiable or because available methods are not appropriate or reliable. Economic valuation methods can be complex and demanding, and the results of applying these methods may be subject to judgment, uncertainty, and bias.

However, if policymakers consider benefits, costs, and trade-offs when making policy decisions, then quantification 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 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.

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 have a public good character 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. 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.

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 taken under considerable 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.

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.

WHAT HAPPENS TO TRIBAL IDENTITY IF BIRCH BARK VANISHES?

Photo: John Zasada

Climate change models suggest that by 2100, the paper birch tree may no longer be able to survive in its habitat in the upper Midwest and northeastern United States, from northern Wisconsin to Maine (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 crucial for American Indians throughout the Northeast and Alaska Native tribes since time immemorial. It provided native peoples with transportation, thanks to birch bark canoes. It was used for food storage containers to retard spoilage, earning it the nickname of the “original Tupperware™”. It was a material on which fungi was grown for medicines and for tinder in sacred fires. 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.

1.2.4 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.

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.

Three general types of adaptation responses illustrate points along a continuum of possible responses to climate change: resistance, resilience, and transformation.

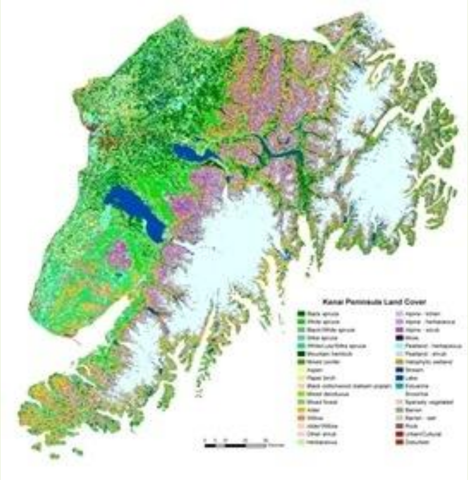
- *Resistance* is the ability of a system to remain essentially intact or unchanged as climate changes.
- *Resilience* is the ability of a system to recover from a disturbance, returning to its original state.
- *Transformation* is the change in a system's composition and/or function in response to changes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

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).

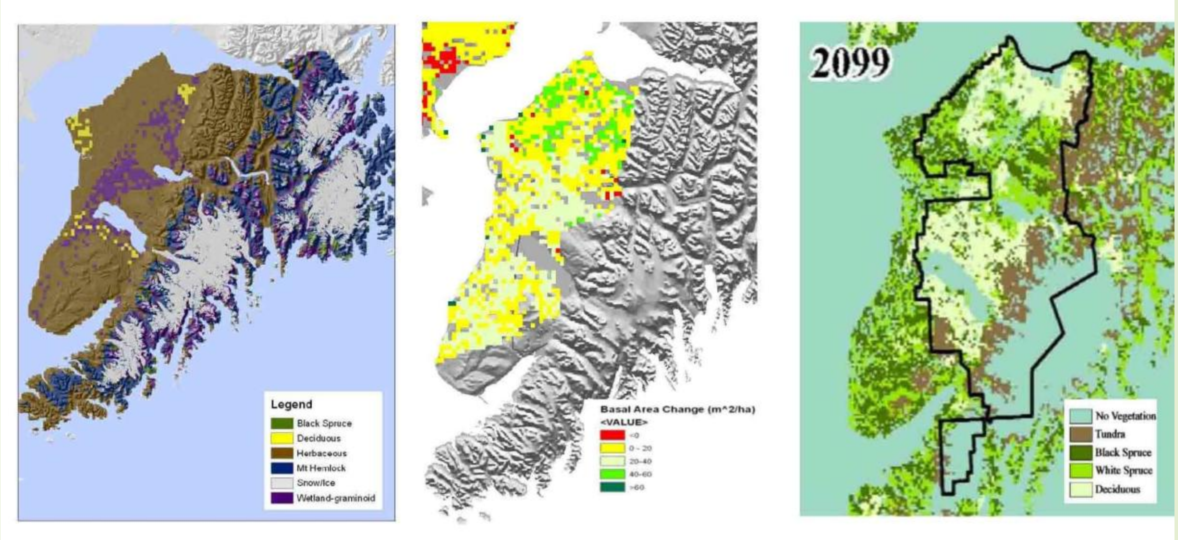
CLIMATE CHANGE IN THE KENAI PENINSULA

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 overwinter 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 (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 and increased glacial sediment. Overall, roughly 20 percent of species may vanish from the peninsula.



Current Kenai Landscape (2006)



Future scenarios of the landscape on Kenai National Wildlife Refuge, Alaska using three modeling approaches: climate envelope, fire regime shift, and forest dynamics (USFWS/John Morton)

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 National Park Service, the Forest Service, the University of Alaska Anchorage, and other agencies and groups are also exploring additional adaptation options for the Kenai Peninsula. Kenai National Wildlife Refuge will host a workshop in early 2012 to develop interagency strategies for developing reactive and anticipatory options specifically for 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.

1.3 About the *Strategy*

As discussed previously, species and habitats are already displaying changes consistent with a warming climate (Parmesan 2006). What society can or even should do about these changes is a complicated question, and involves much more than science. Deciding what to do requires considering the way existing conservation institutions describe, classify, and value nature and natural resources. It requires examining the institutions, laws, regulations, policies, and programs that our nation has developed to maintain these resources and the many benefits they provide. It requires evaluating the management techniques that the conservation profession and other sectors (such as agriculture, energy, transportation, and urban development) 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 they live in. Those social values can form the basis of cooperative intervention.

This *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. The timeframe for this first effort focuses on actions that can be taken or initiated in the next decade to help fish, wildlife, and plants adapt to changes that are currently projected to occur over the next century. Although there is great certainty about the fact of climate change, uncertainty remains about its scale, pace, and regional effects. Because new information will become available in the coming years, this adaptation strategy should be revisited, refreshed, and as necessary, revised preferably within a year or so of each successive National Climate Assessment (NCA).

Jurisdiction of State, Tribal, and Federal Agencies

Jurisdiction for conservation of fish and wildlife in the United States is shared among state, tribal, and federal governments. State governments generally have responsibility for conservation of resident fish and wildlife. For example, New York State asserts ownership and control of all fish, game, wildlife, shellfish, crustacean, and protected insects under its Environmental Conservation Law (11-0105). Other states derive their jurisdiction for fish and wildlife conservation from similar statutes or from their State Constitutions.

Tribes recognized by the United States generally have primacy for conservation of resident fish and wildlife on tribal reservation lands. In some instances, tribes also have reserved rights for harvest of fish and wildlife on non-tribal lands. Tribal jurisdiction and rights are articulated in treaties between the individual sovereign tribes and the United States.

The federal government jurisdiction for fish and wildlife conservation focuses on migratory birds, threatened and endangered species, and inter-jurisdictional and federal fisheries. The authority comes from the U.S. Constitution and such federal statutes as the Migratory Bird Treaty Act, the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), the Magnuson-Stevens Fishery Conservation and Management Act, and the Coastal Zone Management Act. However, with the exception of the MMPA, Congress has affirmed in these statutes that state jurisdiction for fish and wildlife remains concurrent with the federal jurisdiction.

Ownership and jurisdiction for conservation of plants is shared among governments and private landowners. Plants are generally owned by the underlying landowner, and landowners are essential partners for plant conservation. Many state governments and the United States government provide some protection, usually regulating the sale of plants listed as threatened or endangered under the federal ESA or various state statutes.

1.3.1 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: The purpose of the *Strategy* is to 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. Those systems will continue to provide valuable cultural, economic, and environmental benefits in a world impacted by global climate change.

Guiding Principles for the development of this *Strategy*: 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.

In light of these considerations, the development of this *Strategy* was guided by the following principles:

1. **Build a national framework for cooperative response.** Provide a framework for collective action that promotes collaboration across sectors and levels of government so they can effectively respond to climate impacts.
2. **Foster communication and collaboration across government and non-government entities.** Create an environment that supports the development of cooperative approaches to adapting to climate change while respecting jurisdictional authority.
3. **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.
4. **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 and monitoring systems; model-based projections; vulnerability and risk assessment; and adaptive management.
5. **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.
6. **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.
7. **Identify critical scientific and management needs.** These may include new research, information technology, training to expand technical skills, or new policies, programs, or regulations.
8. **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.
9. **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.

1.3.2 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.

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).

A variety of tools and approaches can help reduce uncertainty and inform 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 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 make proactive climate change-related decisions today, recognizing that new information will become available over time that can then be factored into future decisions.

Chapter 2: Impacts of Climate Change and Ocean Acidification on Fish, Wildlife and Plants

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 United States has already experienced major changes in climate and ocean acidification and additional changes are expected over time. The magnitude and pace of these 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. As a result, the pH of seawater has decreased an average of 0.1 units since 1750 (IPCC AR4 2007), which represents a 30 percent increase in acidity. 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).
- 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 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 0.2 °F between 1961 and 2003 (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). However, local rates of sea level change 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 over the past 50 to100 years (Kaushal et al. 2010), and will continue to warm 0.4 °F per decade (IPCC AR4 2007). 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). Increasing temperature is also a major driver of rising sea levels through thermal expansion.

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 (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. For example, during the extreme drought suffered by Texas in the summer of 2011, the state experienced unprecedented wildfires.

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)..

- 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, over-use, and disease.

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.

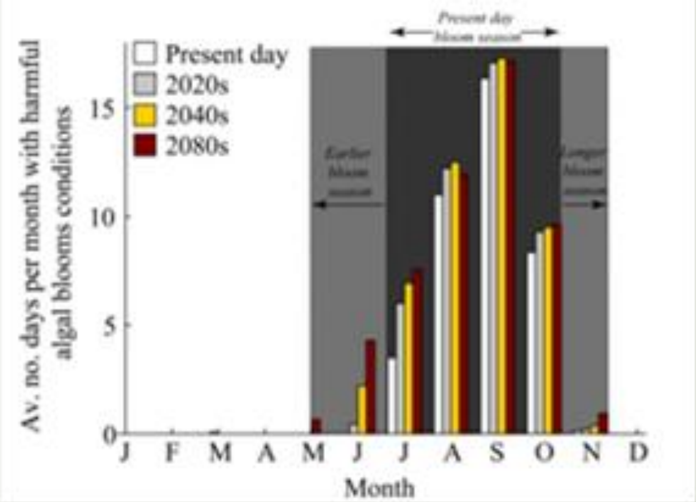
Habitat fragmentation, loss, and degradation have been pervasive problems for natural systems and are expected to continue. For example, grasslands, shrublands, and forests are being converted to agricultural uses. Desert systems are stressed by overgrazing and off-highway vehicles. Tundra and marine 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).

HARMFUL ALGAL BLOOMS

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. Warmer temperatures are boosting the growth of harmful algae (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. 2009). In addition, the ranges of many harmful algal species may expand, with serious consequences. For example, a painful foodborne 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 buffer strips beside streams or restoring wetlands to absorb nutrient pollution before the nutrients can reach streams, rivers, lakes, and oceans. In addition, better detection and warning systems can reduce the danger to people.



Projected changes to the harmful algal bloom season in Puget Sound in a future warmer climate. (NOAA/S. Moore)

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). 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 invasive 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).

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 invasive in certain ecological contexts, 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 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 harmed the resources and the communities and economies that depend on them. However, overfishing of specific stocks is not the only problem associated with fishing. Fishing methods can damage habitats and bycatch can cause significant impacts to non-target species (NOAA 2011).

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. The most detectable effects of climate change on disease relate to geographic range expansion of pathogens such as Rift Valley fever, dengue, and Eastern oyster disease. 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).

Resource managers have long worked hard to reduce the impact of these 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 reductions may be necessary to ensure sustainable populations. 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.

2.3 Climate Change Impacts on Fish Wildlife, and Plants

A changing climate can affect growth rates, alter patterns of food availability, and change 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, 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, in turn, increases the need for adaptive management strategies—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 threatened, 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 2008b).

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 to negative impacts of climate change. 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).

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, and discussed in greater detail in the following sections.

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 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).

RANGE SHIFTS IN A CHANGING CLIMATE

All across the country, species are already on the move in response to climate change. For example, Edith's checkerspot butterfly has shifted northward an average of 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 warm 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). However, movements may not always be straightforward: recent evidence suggests that some alpine plant species in the Sierra Nevada may actually be shifting their distributions "downslope" in response to changes in water availability rather than changes in temperature (Crimmins et al. 2011).

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. 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.

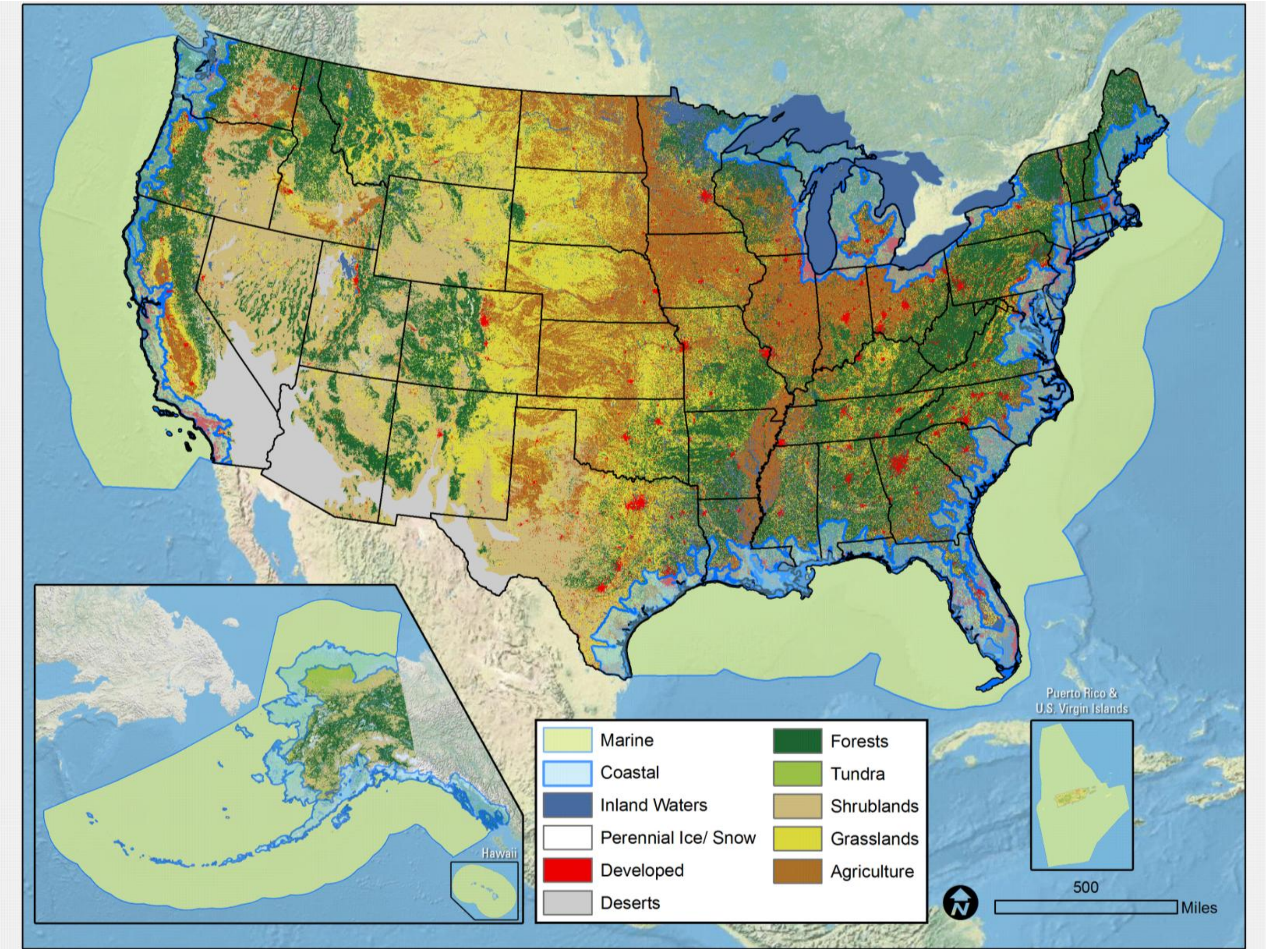


Figure 1: *The distribution of the eight major ecosystems (forests, grasslands, shrublands, deserts, tundra, inland waters, coastal, and marine systems) described in the Strategy, agriculture, and developed areas. Data source: Multi-Resolution Land Characterization (MRLC) Consortium National Land Cover 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.*

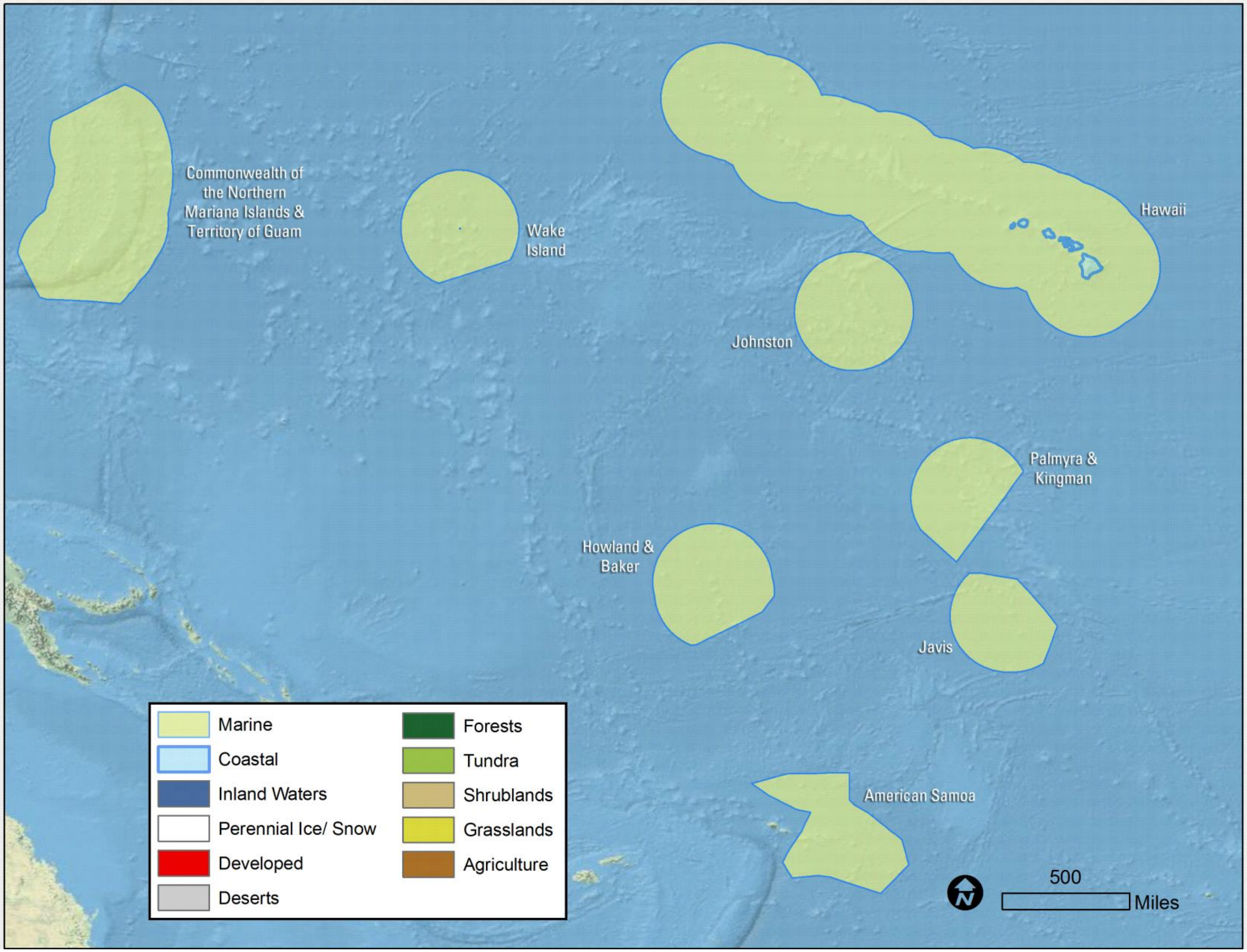


Figure 2: *The distribution of the eight major ecosystems (forests, grasslands, shrublands, deserts, tundra, inland waters, coastal, and marine systems) described in the Strategy, agriculture, and developed areas for the U.S. territories in the Pacific. See Figure 1 for data sources.*

Table 1: Examples of Observed and Projected Ecological Changes Associated With Increasing Levels of GHGs on U.S. Ecosystems and Species*

Major Changes Associated With Increasing Levels of GHGs	Examples of Observed or Predicted Ecological Changes (by Major Ecosystem Type)**							
	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 0.2 °F between 1961 and 2003.	• Increase in forest pest damage • Changing fire patterns • Longer growing season may increase productivity • Higher evapotranspiration /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	• Expansion of warm-water species • Depleted O_2 levels • Stress on cold-water species • Increased disease/parasite susceptibility • More algal blooms	• Growth of salt marshes/ forested wetlands • 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 productivity patterns • Increased stratification • Lower dissolved O_2
Melting sea ice/ snowpack/snow melt: Arctic sea ice extent has fallen at a rate of 3 to 4 percent per decade over the last 30 years, and further loss is predicted. In terrestrial habitats, 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 survival of some insulation-dependent pests	• Reduced snowpack leads to hydrological changes (timing and quantity)	• Reduced snowpack leads to hydrological changes (timing and quantity)	• Reduced snowpack leads to hydrological changes (timing and quantity)	• Thawing permafrost/soil • Hydrological changes • Terrain instability • Vegetation shifts • Longer snow-free season • Contaminant releases	• Snowpack loss changes the temperature, amount, duration, distribution and timing of runoff • Effects on coldwater and other species • Loss of lake ice cover	• Loss of anchor ice and shoreline protection from storms/waves • Loss of ice habitat • Changes in ocean carbon cycle • 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 inches over the past century, 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.	*NA*	*NA*	*NA*	*NA*	• 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 • Loss of sea turtle nesting sites
Changes in circulation patterns: Warming of the atmosphere and ocean can change spatial and temporal patterns of water movement and stratification at variety of scales.	*NA*	*NA*	*NA*	*NA*	*NA*	• 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 productivity, survival and/or distribution of fish and other species (particularly early life history stages)

Table 1 (cont.): Examples of Observed and Projected Ecological Changes Associated With Increasing Levels of GHGs on U.S. Ecosystems and Species*

Major Changes Associated With Increasing Levels of GHGs	Examples of Observed or Predicted Ecological Changes (by Major Ecosystem Type)**							
	Forests	**Shrublands**	**Grasslands**	**Deserts**	**Tundra**	**Inland Waters**	**Coastal**	**Marine**
Changing precipitation patterns: Precipitation has increased approximately 5 percent in the last 50 years. Predictions suggest historically wet areas will become wetter, while historically dry areas will become drier.	• Longer fire season • Increased frequency/severity of wildfires • Both wetter and drier conditions projected	• Dry areas getting drier • Changing fire regimes	• Invasion of non-native grasses and pests • Species range shifting • Increased fire • Loss of prairie potholes/ wetlands	• Loss of riparian habitat and movement corridors	• More icing/rain-on-snow events affect animal movements and access to forage • Changes in subnivean temperature • Increased fire	• Decreased 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	• Changes in salinity, nutrient and sediment flows • Shifting freshwater input to estuaries • New productivity patterns	• 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 percent 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

Table 1 (cont.): Examples of Observed and Projected Ecological Changes Associated With Increasing Levels of GHGs on U.S. Ecosystems and Species*

Major Changes Associated With Increasing Levels of GHGs	Examples of Observed or Predicted Ecological Changes (by Major Ecosystem Type)**							
	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 percent 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.	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	• 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

**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.*

2.3.1 Forest Ecosystems

Photo: FWS

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.

Temperature Increases and Water Availability

In general, boreal forest and taiga ecosystems are expected to move 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

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 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 per 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 throughout the system, 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.

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 (Brasier 1996, Lonsdale and Gibbs 1996, Chakraborty 1997, Houston 1998).

BARK BEETLE OUTBREAKS IN WARMER WINTERS

From British Columbia to New Mexico, forests are being devastated at unprecedented levels by an epidemic—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, causing regular outbreaks of forest death 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).

The warming 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).

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 than others because of infilling from young trees, which grew during periods of low fire frequency, increasing the severity of fires (Climate Impacts Group 2004). While projections of hurricane response to climate change are still uncertain, models agree on a dramatic increase in cyclone activity in the western North Pacific (Emanuel et al. 2008), and the intensity of Atlantic hurricanes is likely to increase as well (USGCRP 2009). If hurricane frequency and intensity increase, then a larger percentage of forests could be set back to earlier successional stages (Lugo 2000).

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.

Photo: NPS

Atmospheric CO_2

Increased CO_2 can lead to changes in species distribution and community composition in the shrublands. For example, the spread of cheatgrass has likely been favored by rising CO_2 concentrations, which has been shown to benefit species that utilize the type of photosynthesis (C3) (D'Antonio and Vitousek 1992, Larrucea and Brussard 2008) used by this species. 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 average temperature, 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 shurbland species like the greater sage grouse (Aldridge et al. 2008).

Water Availability

As a result of the warmer temperatures, the onset of snow runoff in the Great Basin is currently 10 to15 days earlier than 50 years ago, with significant impacts on the downstream use of the water (Ryan et al. 2008), though periods of higher than average precipitation have helped to offset the declining snow packs (McCabe and Wolock 2009). This 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 thus, reduce above-ground net primary production. However, some regions such as the Great Basin region are projected to become both warmer and possibly wetter over the next few decades (Larrucea and Brussard 2008).

2.3.3 Grassland Ecosystems


Photo: NPS

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). 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, as well as embedded features such as the shallow, ephemeral wetlands known as prairie potholes and playas that dot the Great Plains and the Eastern grasslands that are openings in the prevailing forest matrix (see Figure 1). Grassland function is tied directly to temperature, precipitation and soil moisture, and 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).

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 (C) 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 composition of plants and animals.

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 ºF by mid-century to 2.5 to 13 ºF 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).

LESSER PRAIRIE-CHICKEN IN A CHANGING CLIMATE

Photo: AFWA

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 ESA (NRCS 1999).

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 U.S. Department of Agriculture conservation programs, farmers and ranchers are paid 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 the Conservation Reserve Program, if properly targeted, could offset the projected population decline of lesser prairie-chicken from climate change (McLachlan et al. 2011).

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" 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


Photo: AFWA

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 2008b). 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).

CACTUS VULNERABILITY

Photo: FWS

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 habit, 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 and west 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 on p. 37). 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

Photo: FWS

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). 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 rare on Alaskan tundra, but fire frequency will likely increase as the climate warms. 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.

CLIMATE CHANGE IN ALPINE TUNDRA SYSTEMS

In 2007, researchers found a significant decline in the alpine tundra (or Köppen) ecosystem in the mountainous western United States (Diaz and Eischeid 2007). Average temperatures in the western United States have risen considerably in the last 20 years, greatly affecting alpine tundra systems. The warmest month in many of these areas has seen an average temperature rise from as low as 47.3 °F to over 50 °F (Diaz and Eischeid 2007). This phenomenon has resulted in a loss of 73 percent of area classified as alpine tundra in the last 20 years. Many of the remaining areas still classified as alpine tundra systems are experiencing average warmest month temperatures creeping towards the critical threshold of 50 °F, making it likely that with continued warming, these areas will no longer sustain alpine tundra systems in the long term (Diaz and Eischeid 2007).

In alpine systems, snow is of particular importance as it influences plant phenology, growth, and species composition (Wipf et al. 2009). Climate change also affects alpine areas as the snow -to-rain ratio decreases while the timing of snowmelt advances. While warming temperatures may allow for a longer growing season, the decrease in snow depth and earlier snowmelt will ultimately have a negative effect on many alpine plants, because the advanced snowmelt creates a higher number of frost days as well as lower soil temperatures due to lower snow cover (Wipf et al. 2009). Not every plant species has the same reaction to climate warming, but research suggests that greater temperatures and advanced snowmelt could harm alpine systems and the species that depend on them.

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 stream changes prevent fish passage (Martin et al. 2009).

ALASKA CLIMATE CHANGE WORKING GROUP

Indigenous communities possess local environmental knowledge and relationships with particular resources and homeland areas, built up through hundreds and even thousands of years of place-based history and tradition, which may make them highly sensitive to and aware of environmental change. Climate change, with its promise of unprecedented landscape-level environmental change, is a threat not only to particular resources or features, but also to the traditions, the culture, and ultimately, the very health of the community itself. Indigenous communities lend unique and important perspectives and knowledge about landscapes and climates to the overall effort to respond to climate change, and recognize that they must work together to nurture native environmental knowledge, enhance indigenous capacity to use modern scientific methods, and create indigenous climate-change leadership.

Due to climate warming impacts such as coastal erosion, increased storm effects, sea ice retreat, and permafrost melt, the village of Newtok, home to the Qaluyaarmiut people for at least 2,000 years, has begun relocation plans. The Qaluyaarmiut are avid fishermen and depend on the natural environment for subsistence. With an average erosion rate of 68 feet per year from 1953 to 2003 and the combination of all the climate warming impacts it is enduring, Newtok is no longer a sustainable long-term home for the Qaluyaarmiut people (Feifel and Gregg 2010).

Members of the American Indian Alaska Native Climate Change Working Group represent a broad alliance of indigenous communities, tribal colleges, scientists, and activists, who recognize the significance of situations like Newtok, working together to empower indigenous climate-change adaptation. They argue that indigenous educational institutions are critical vehicles for nurturing indigenous environmental knowledge and scientific capacity, and can be organizers and leaders of regional indigenous responses to climate change (Upham 2011). Indigenous working groups provide neutral ground in a relaxed setting that promotes broad participation, and often lead to consideration of a broader spectrum of resources and issues than externally driven approaches.

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 thawing or rain-on-snow events which are expected to increase in a warmer climate (Martin 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.

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. For the purposes of the *Strategy*, inland waters end at the high tide line 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


Photo: FWS

A recent analysis showed that many rivers and streams in the United States have warmed over the past 50 to 100 years (Kaushal et al. 2010), and will continue to warm up to 0.5 °F per decade, based on GHG emissions scenarios (IPCC AR4 2007). 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 by 31 percent across the United States (Mohseni et al. 2003). This would likely mean a concomitant decline of cold water 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).

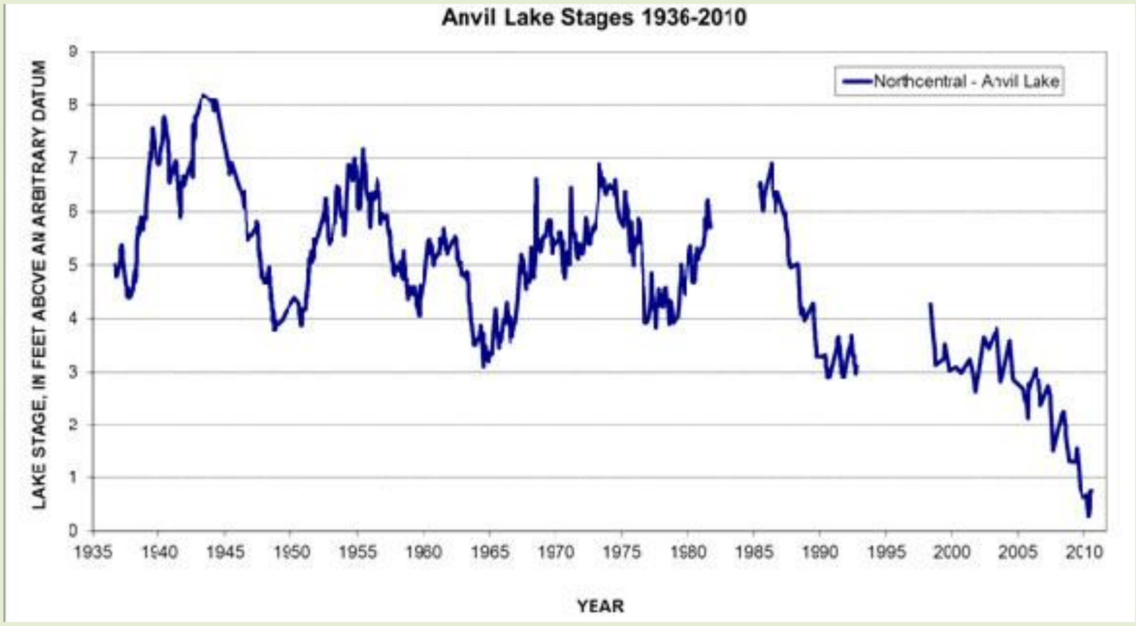
WATER LOSSES UNDER CLIMATE CHANGE

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 the increasingly scarce water.



Water levels for Anvil Lake in North central Wisconsin, 1936-2010 (WICCI 2011; USGS lake stage data)

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).

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.

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 overwinter 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/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).

2.3.7 Coastal Ecosystems

The Pacific, Atlantic, Arctic, Gulf of Mexico, and Great Lakes coastal systems, as defined for the *Strategy*, extend seaward to mean lower-low water and landward to 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. 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.

Photo: NOAA

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).

Temperature Increases

Global ocean temperatures rose 0.2 °F between 1961 and 2003 (IPCC AR4 2007). Temperature changes affect species phenology, including key events such as the spring phytoplankton bloom, plant germination and turtle nesting. Changes in temperature also can cause species range shifts (Harley et al. 2006, Hoegh-Guldburg and Bruno 2010). While warmer temperatures could cause increased growth of coastal salt marshes and forested wetlands, they could also cause expansion of invasive species and disease pathogens. Extreme changes may also stress organisms to the point of mortality. In estuarine environments, increased water temperature will affect water column stratification and eutrophication; and could cause range shifts. 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). 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). 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.

Sea Level Rise

As water warms, it expands, and the ocean surface rises. Additional sea level rise is caused by the melting of inland glaciers and continental ice sheets, including those in Greenland and Antarctica. Sea level is projected to increase 16 to 79 inches by 2090 (IPCC AR4 2007, Rahmstorf 2010); however, sea level change is highly variable regionally.

Changes in Sea Ice

Changes in the extent, thickness, condition, and duration of sea ice are direct impacts of changes in global temperature. Warming triggers loss of sea ice, creating open water conditions. These conditions in turn allow higher wave energy to reach the shoreline (particularly during storms), accelerating the rate of coastal erosion (USGCRP 2009). Retreat of sea ice will result in loss of important habitat for species that depend on the ice, such as polar bears and walrus. Similarly, 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). In addition, warmer temperatures could change food web dynamics by allowing for the migration of different predator and prey species in the Arctic (Forbes et al. 2011). Changing ice conditions are threatening lifestyles and subsistence economics of indigenous peoples as well, such as by making trips to hunting grounds more hazardous (Forbes et al. 2011). Warmer temperatures could also extend the growing season, increasing primary production in the summer.

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 will also exacerbate flooding 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. While sea-level changes have occurred repeatedly in the geologic past, 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, which is dependent on the availability and slope of an upland corridor, the pace of the rise, erosion rates, and the potential for wetland accretion (CCSP 2009a). Other important factors that affect wetland response to sea-level rise depend on the rate of sea level rise, tides, salinity, elevation, sediment dynamics, 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.

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.

ATLANTIC COAST PIPING PLOVER HABITAT CONSERVATION

Photo: Bill Byrne

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 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 Louisiana and Florida (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).

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.

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.

2.3.8 Marine Ecosystems

For the purposes of the *Strategy*, marine ecosystems extend from the coastline to 200 miles seaward or the nearest international boundary (see Figure 1). This area, generally referred to as the U.S. Exclusive Economic Zone, spans 3.4 million square nautical miles of ocean, encompassing 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 eelgrass beds to a wide range of invertebrates and vertebrates. Higher temperatures and CO_2 levels have significant impacts on marine species and ecosystems. Marine systems and taxa respond physically, chemically, and biologically to both increases in ocean temperatures and the absorption of atmospheric CO_2. This leads to changes in nutrient availability, biological productivity, reproductive success, the timing of biological processes, distributions, migrations, community structure, predator-prey relationships, and entire biomes.


Photo: NOAA

Temperature Increases

Between 1961 and 2003, it is estimated that 90 percent of the heat gained by the planet has been stored in the world's oceans resulting in a global ocean temperatures rise of 0.2 °F, with much greater changes observed in some locations such as the Atlantic basin (Levitus et al. 2005, IPCC WGI 2007). The physical consequences of such warming include sea level rise, increases in storm frequency and intensity, increased stratification of the water column, 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).

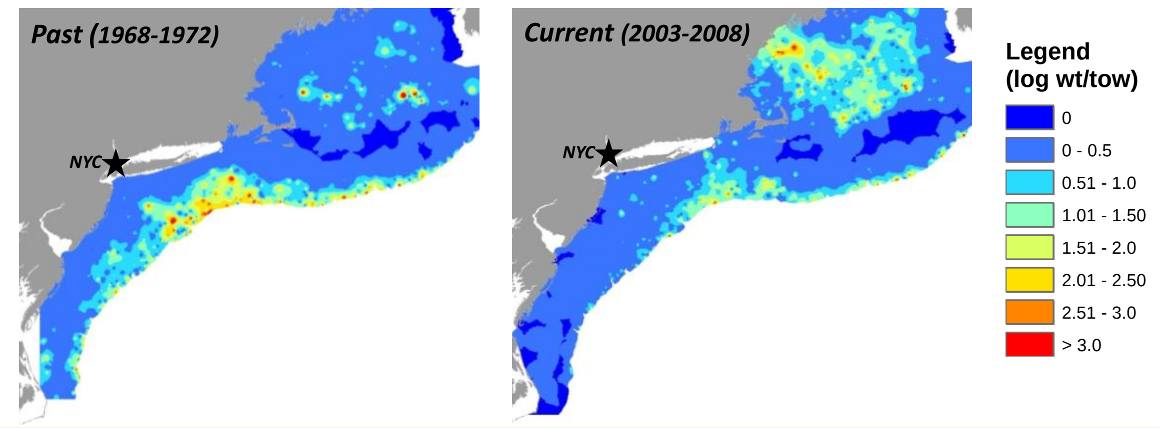
Altered patterns of wind and water circulation in the ocean environment will influence the vertical movement of ocean waters (i.e., upwelling and downwelling). This coupled with increased stratification of the water column resulting from changes in salinity and water temperature will change the availability of essential nutrients and oxygen to marine organisms throughout the water column.

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). 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.

SHIFTING SPATIAL DISTRIBUTIONS OF U.S. FISH STOCKS

The United States is fortunate to have several multispecies fish monitoring programs in its large marine ecosystems where the abundance and location of important fish and macroinvertebrate species are consistently documented each year. Without these long time series of data, shifts in spatial distribution of U.S. fish stocks would never have been detected. 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, silver 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 coordinating monitoring and assessment of key stocks. In the California ecosystem, shifts in spatial distribution were more dramatic in species that were heavily fished (Hsieh et al. 2008). Combined, these studies stress the importance in preventing overfishing in healthy stocks to enhance recovery of those at low abundance such that these shifts in spatial distribution and the resilience of these species will not be exacerbated by climate change.



Silver hake distribution in the past as compared to its present distribution (Nye et al. 2011).

As discussed previously, species can respond to temperature changes by migrating poleward or toward deeper depths, reducing their climate niche within the 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. 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). 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).

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. Species are particularly vulnerable in the Arctic, where shrinking ice cover reduces habitat and increases adult and juvenile mortality in some species. In Alaska, the melting of sea ice has forced walruses to congregate in large dense populations, which has led to many calves being crushed and a depletion of bottom food resources in the long term, due to the limited areas where they can rest between excursions for food (CEICC 2008). 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). In 2008, the polar bear was listed as a threatened species under the ESA because of a projected decline in abundance. The main cause of this projected decline is malnutrition and reduced survival resulting from the projected loss of sea ice habitat required by polar bears and their prey (e.g., ring seals). In contrast, some species may benefit from climate change, such as the Atlantic croaker (see Case Study on Atlantic Croaker, p. 51, Hare et al. 2010) while some warmer water marine fishes may grow bigger or more rapidly (Nye et al. 2009).

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). Even the most optimistic predictions of future atmospheric CO_2 concentrations (such as stabilization at 450 parts per million) could bring levels high enough to 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.

WEST COAST OYSTER PRODUCTION

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.

Ocean Currents

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 and the geographic distributions of marine species (Block et al. 2011).

CORAL REEF BLEACHING

Coral reefs are one 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 CO_2 through photosynthesis. The algae, in turn, provide coral with the carbon they need to build their skeletons—and thus, the reef itself.

Photo: NOAA/Eakin

A changing climate is threatening this symbiotic relationship and the whole coral reef ecosystem. When sea temperatures rise too much, the coral expel their alage, a process called bleaching (since the coral become whiter without their symbionts). 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). Bleaching has profound effects on corals and the loss of the symbionts can ultimately cause the bleached coral to starve to death.

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).

An effort is underway to try to protect coral reefs by making them more resilient to climate change. The Nature Conservancy has started a Reef Resilience program, working in the Florida Keys in partnership with the State of Florida, NOAA, 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 to Ecosystem Services

As noted in Section 1.2.3, species and the ecosystems they form provide a wide range of important products and services to the nation, including food, clean water, protection from storms, recreation, and cultural heritage. These natural resources and ecological systems are a significant source of economic 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.

The products and services that natural resources provide support millions of jobs and billions of dollars in economic activity. 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 and productivity of forests will have direct consequences for both global carbon sequestration and the forest products industry, and will also influence other uses of forested ecosystems such as recreation and non-timber products.

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). In the case of crop production, research suggests that crop plant responses to increasing CO_2 are varied, and therefore, it is difficult to determine winners and losers (Taub 2010). 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).

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 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, including commercially important species like blue crab, nesting habitat for birds, and 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 ecosystem services, including fisheries. 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. 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; the effects on fishmeal supply and global trade, or on incidence of harmful algal blooms (FAO 2010)

POTENTIAL BENEFITS OF CLIMATE CHANGE: ATLANTIC CROAKER FISHERY

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 $9M 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). As sea surface temperature increases the range and if fishing pressure remains relatively low, the croaker fishery is expected to shift northward 100-400 km as new estuarine habitat becomes available.

Chapter 3: Climate Adaptation Strategies and Actions

3.1 Goals, Strategies and Actions

This *Strategy* identifies seven Goals to help fish, wildlife, plants, and ecosystems cope with the impacts of climate change. As discussed in the Introduction, these Goals were developed collectively by diverse teams of federal, state, and tribal technical experts, based on existing research and understanding regarding the needs of fish, wildlife, and plants in the face of climate change.

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.

Strategy Goals:

- Goal 1. Conserve & Connect Habitat
- Goal 2. Manage Species & Habitats
- Goal 3. Enhance Management Capacity
- Goal 4. Support Adaptive Management
- Goal 5. Increase Knowledge & Information
- Goal 6. Increase Awareness & Motivate Action
- Goal 7. Reduce Non-Climate Stressors

Each Goal identifies a set of initial strategies and actions that should be taken or initiated over the next five to ten years. 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 complete set of these specific actions most relevant to each ecosystem is available in the eight ecosystem-specific background papers described further in Appendix A and posted online at *www.wildlifeadaptationstrategy.gov*.

A short-term progress check list is offered under each 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 very 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.

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. The impacts of climate change are uncertain. 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.

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 and political 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.

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. 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. For example, many existing conservation areas, such as Joshua Tree National Monument 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. They 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.

Many of our nation's imperiled species (both those currently listed as either 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 environment 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, sustainable, abundant) populations as landscapes and seascapes are altered by climate change. 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 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 (lease, easement, acquisition, other), only that climate change will demand that we increase and perhaps accelerate our 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 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, and mapping (including geophysical as well as biological features), 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 it more likely that native biodiversity will be conserved. For some species, their required 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.

The Importance of Private Lands

Over 70 percent of the land area of the United States is in private ownership (Lubowski et al. 2006). The majority of this land is either in agricultural production or classed as agricultural land (crop, pasture, forest) (Lubowski et al. 2006). In much of the continental United States (especially in the East and Midwest), privately owned lands dominate the landscape and provide valuable habitat for native fish, wildlife, and plants.

The vast majority of the nation's publicly owned land is federal, and most of it is located in the eleven western states and Alaska. The bulk of America's federal estate is open to various forms of resource development such as mining, grazing, and timber and energy production that are not always compatible with the protection of all fish, wildlife, plants, or ecological processes. Only about five percent of the land area of the United States falls into the highest categories of protection, aimed primarily at maintaining natural values (IUCN 1998). However, public lands are generally protected from conversion to urban or suburban development, and they are typically more closely managed for conservation purposes than are private lands.

Private lands do and will continue to play a vital role in the conservation of our nation's fish, wildlife, and plant resources. For example, many listed threatened and endangered species are only known to occur on private lands. In addition, because most public lands occur in isolated blocks, especially in the East and Midwest, private lands often provide the only connections between protected areas. As the climate continues to change and the geographic distributions of species continue to shift in response, private lands may become even more important, especially for providing physical connectivity across the landscape.

There are many federal and state programs that provide incentives to private landowners to manage and maintain certain natural values on their lands. Principal among these are the many programs that make up the Conservation Title of the "Farm Bill," which constitute an important set of tools for maintaining wildlife values on private lands and a suite of landowner tools available under the ESA (see "For Landowners" at http://www.fws.gov/endangered). Although clearly essential to help manage existing stressors to our fish, wildlife, and plant resources, these programs may not be fully adequate to respond to climate change. It is likely that new challenges, especially the increasing need to provide connectivity between protected areas, may demand changes or additions to these existing programs.

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. In addition, appropriate transitory or "stopover" habitat for migrating species can promote biological connectivity between non-physically connected areas. Private landowners 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 in floodplains and sensitive coastal areas. Effective restoration will require applying protocols and techniques that anticipate a range of future conditions caused by climate change and that facilitate adaptation.

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.

MAKING SALMON POPULATIONS MORE RESILIENT


Photo: Amy Gulick

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 temperature 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.

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 also describes steps that can be taken to maintain good salmon habitat even in a changing climate. Those steps include:

- limiting 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;
- protecting undercut banks and deep stratified pools, where water temperatures are lower;
- restoring vegetation along streams, which cools the water and reduces sediment and pesticide levels;
- releasing cold water from large storage reservoirs during summer; and
- removing 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 U.S. Department of Agriculture Conservation Reserve Enhancement Program and NOAA's Pacific Coastal Salmon Recovery fund are helping to restore vegetation in riparian zones. That 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 on 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 for consideration areas currently experiencing rapid climate impacts (such as the coastline of Alaska, low-lying islands, and high alpine tundra).
- 1.1.3: Assess the migration potential of species, and prioritize conservation for areas with highest migration potential, considering 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.

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.
- 1.2.3: Build 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 maximize use of existing conservation programs (e.g., easement, management, mitigation), particularly the conservation titles of the Farm Bill, 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 processes 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 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 natural disturbance regimes as appropriate, including instituting human-assisted disturbance (e.g., prescribed fire) to augment natural processes and mimic natural patterns and recurrence for specific ecological systems.
- 1.3.5: Develop programs to encourage resilience through restoration of habitat features that provide natural buffers in coastal habitats.
- 1.3.6: Develop market-based incentives that encourage habitat restoration where appropriate.

BUILDING CONNECTIVITY IN NEW JERSEY

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 when sea levels rise.

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 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 to maximize use of existing conservation programs, such as the conservation titles of the Farm Bill and landowner tools under the ESA, to protect private lands of high connectivity value under climate change.

☑ **PROGRESS CHECK LIST FOR GOAL 1:**

☐ 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;

☐ Funding allocations reviewed/revised in light of climate change priorities;

☐ Begin conserving and/or rehabilitating high priority areas for fish, wildlife, and plants under 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.

As described in Chapter 1, humans depend upon and derive multiple benefits from fish, wildlife, and plants. 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.

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, but many 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.

Management plans and programs must consider species' abilities to adapt to climate change, including 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 migration 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. The development of ecosystem based approaches to natural resource management grew out of broad acknowledgement that successful natural resource 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 existing and new management plans and practices using the best available science regarding projected climate changes and trends, vulnerability and risk assessments, and scenario planning.

— 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., cool-water to warm-water fisheries or cool season to warm season grasslands) and develop management strategies and approaches for adaptation.

— 2.1.4: Conserve or create landscape patterns with many age classes, diverse species, and seed sources.

— 2.1.5: Review and revise as necessary techniques to maintain or mimic natural disturbance regimes and to protect vulnerable habitats.

- 2.1.6: 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 associated with climate change.
- 2.1.7: Review existing management frameworks and identify ways to increase the ability of stakeholders to adapt 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.
- 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).

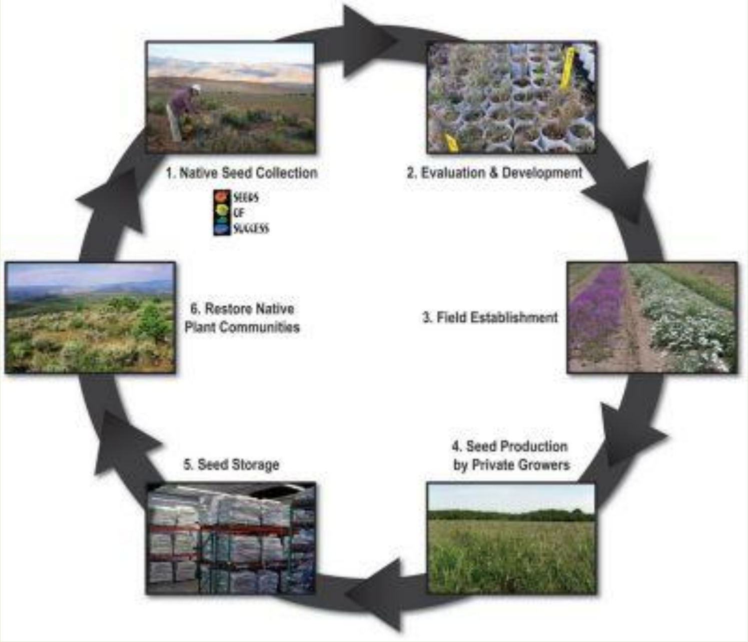
Strategy 2.2: Develop and apply species-specific management approaches to address critical climate change impacts where necessary.

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 for the use of translocation, assisted migration, 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.

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 on a changed planet is maintaining the species' genetic diversity.



Bureau of Land Management 2009. Native Plant Materials Development Program: Progress Report for FY2001-2007.

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

Strategy 2.3: Conserve genetic 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 genetic diversity of 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 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 and arboreta.

☑ **GOAL 2 PROGRESS CHECK LIST:**

☐ Co-managers (state, federal, tribal, local, international) identified and engaged;
☐ Species requiring active intervention identified;
☐ Genetic conservation issues identified;
☐ Criteria and guidelines developed for translocation, managed relocation/assisted migration, and captive breeding;
☐ Vulnerability and risk assessments and scenario planning used to guide species management decisions;
☐ Species and area management plans updated;
☐ Fire and other disturbance regimes managed to better simulate natural conditions;
☐ State Wildlife Action Plans updated to include climate adaptation;
☐ Agency specific climate change adaptation plans developed;
☐ Agency specific climate adaptation plans and regional plans integrated;
☐ Seed banks and living collections developed consistent with planning.

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. 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. Landscape Conservation Cooperatives (LCCs), Climate Science Centers (CSCs), Migratory Bird Joint Ventures (JVs), Regional Integrated Sciences and Assessments (RISAs), National Fish Habitat Partnerships and other existing and emerging partnerships 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 foundations should be reviewed to identify opportunities to improve, where appropriate, their utility for addressing 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 stresses 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.

SEA LEVEL RISE IN DELAWARE

Photo: NOAA

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, 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 stabilizing the shoreline.

Strategy 3.1: Increase the climate change awareness and capacity of natural resource managers and enhance their professional capacity 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 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) 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.

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 the National Fish Habitat Action Plan (NFHAP), LCCs, JVs, and the Northeast Association of Fish and Wildlife Agencies regional application of State Wildlife Grant funds 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.

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 utility to address climate change impacts.

Actions:

- 3.3.1: Review existing legal, regulatory and policy frameworks that govern protection and restoration of habitats and ecosystem services and identify opportunities to improve, where appropriate, their utility 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, 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 utility to reduce risks and increase adaptation of natural resources and communities in a changing climate.
- 3.3.5: Review existing legal, regulatory and policy frameworks that govern floodplain mapping, flood insurance, and flood mitigation and identify opportunities to improve their utility to reduce risks and increase adaptation of natural resources and communities in a changing climate.
- 3.3.6: Continue the ongoing work of the Joint State Federal Task Force on Endangered Species Act (ESA) 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 utility 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 within the Conservation Title of the Farm Bill and other vehicles.
- 3.4.5: Review existing conservation related federal grants to tribal agencies and revise as necessary to provide apportioned 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;

- ☐ LCC Network engaged as primary venue for inter-jurisdictional collaboration;
- ☐ Criteria to include climate change adaptation in existing conservation grant programs developed;
- ☐ Laws, regulations, and policies regarding key conservation statues reviewed and as necessary, updated;
- ☐ Floodplain maps, insurance laws, and regulations updated;
- ☐ Dialogue initiated to improve implementation of the Coastal Zone Management Act, Clean Water Act, and state wetland protection programs to respond to climate impacts such as sea level rise;
- ☐ Criteria for including climate change adaptation needs in resource allocation developed;
- ☐ Funding and resource needs for climate adaptation identified.

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

As discussed previously, there is uncertainty regarding the specific impacts of climate change on natural resources. In addition, there is much to be learned about the effectiveness of management actions to mitigate these impacts. To continue to minimize uncertainty and 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. 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.

Coordinated inventory, monitoring, and observation systems should be developed 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. 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. Such systems allow managers and other decision makers to evaluate the efficacy of management actions.

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.

In addition, decision support tools that facilitate 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, build habitat resilience, and help ensure that changes to the built environment need not conflict with ecosystem needs.

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

Actions:

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

— 4.1.2: 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.

— 4.1.3: Conduct a gap analysis of existing observation networks, indicators, monitoring, and geospatial data to define priorities.

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

— 4.1.5: Expand and develop as necessary networks of places for integrated climate change inventory, monitoring, research, and education.

— 4.1.6: 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.

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

— 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, etc.) needed for regional-scale monitoring and land management.

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

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, and adaptive management evaluation systems) via dialogue with scientists, managers (of natural resources and other sectors), and stakeholders.

Actions:

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

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

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

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

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

— 4.2.6: Identify actions that can be implemented by a variety of sectors and are beneficial given a range of climate futures and desired future conditions (e.g., “no regrets” options).

- — 4.2.7: Ensure the availability of and provide guidance for decision support tools (e.g., NOAA's Digital Coast, 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, information, assessment, and decision support systems to monitor and determine the effectiveness of specific management actions to analyze the potential for maladaptation and adapt management approaches appropriately.

☑ GOAL 4 PROGRESS CHECK LIST:

- ☐ Public/private collaborative to build nationally integrated climate change inventory, monitoring, observation and information systems convened;
- ☐ Existing public and private inventory, monitoring, observation, and information systems assessed for use in detecting climate change;
- ☐ Existing public and private inventory, monitoring, observation, and information systems linked and interoperable;
- ☐ 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 linked to integrated observation and information systems;
- ☐ Regionally downscaled climate projections produced;
- ☐ Standardized climate change scenarios developed;
- ☐ Framework of tools for managing under uncertainty developed;
- ☐ Vulnerability and risk assessments conducted for priority species.

SENTINEL SITE MONITORING

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 50 years ago after an inlet was built to Moss Landing harbor, creating a permanent connection to the open ocean. Now, sea level rise is further threatening this valuable estuarine ecosystem. At the same time, the Reserve 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 and groundwater 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 combination of rising sea levels and the loss of marshes is increasing 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.

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

In addition to the need for data management, integration, and decision support tools, the design and delivery of fish, wildlife, and plant climate change adaptation programs has also been hampered by lack of detailed knowledge about specific impacts of climate change on fish, wildlife, plants, and habitats and their adaptive capacity to respond. Existing research collaborations such as the USGCRP can enable natural resource managers to focus and prioritize research. There are many critical areas where increased 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 and made available to managers, as well as into climate change adaptation planning, delivery, and evaluation.

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 changes in climate variables (e.g., temperature, humidity, atmospheric CO_2), 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.

Strategy 5.1: Identify knowledge gaps and define research priorities via a collaborative process among federal, state, and tribal resource managers and research scientists working with the National Science Foundation (NSF), USGCRP, NCA, USDA Extension, Cooperative Ecosystem Study Units (CESUs), CSCs, LCCs, JVs, and RISAs.

Actions:

— 5.1.1: Increase coordination and communication between resource managers and researchers through existing forums (e.g., NSF, USGCRP, NCA, USDA, CESUs, CSCs, LCCs, JVs, RISAs, and others) to ensure research is connected to management needs.

— 5.1.2: Bring managers and scientists together to prioritize research needs that address resource management objectives under climate change.

- 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 such as the NSF, NOAA, National Air and Space Administration, and the Department of Energy, and intergovernmental forums such as the 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 a national research agenda identifying key high level questions for which more fundamental research is needed to enable development of 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 and glaciated areas) or highly vulnerable species.

PLANTS AND THEIR POLLINATORS

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 shift when they bloom. That raises a high-stakes question: Will pollinators follow? If they cannot, then vital ecological relationships could be severed.

The FWS'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.

The initial results show that bees are the major pollinators at lower elevations, while flies are more important at higher elevations. The researchers also discovered a greater than expected diversity of bees. There are at least 85 species at the five plots, including five species found at all elevations. This is significant given the differences in vegetation of lower altitude deserts compared to higher altitude mixed conifer and aspen forests.

Strategy 5.2: Conduct research into ecological aspects of climate change, including likely impacts and the adaptive capacity of species, communities and ecosystems, 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/rewards of assisted migration; climate change synergy with existing stressors; etc.).
- 5.2.4: Accelerate research on establishing the value of ecosystem services and potential impacts from climate change such as loss of pollution abatement or flood attenuation, etc.
- 5.2.5: Conduct research on the propagation and production of native plant materials to identify species or genotypes that may be resilient 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.

☑ **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 metrics 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;
- ☐ Novel anticipatory strategies for adapting to climate change developed.

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 public and political support and if key groups and people are motivated to take action themselves. Limited 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. Helping stakeholders understand the concept of uncertainty, and managing/decision making in the context of uncertainty is also important and an integral part 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; zoning and transportation officials; etc. on ecosystem services, climate impacts to fish, wildlife, plants, and ecosystems, 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.
- 6.1.3: Identify and partner with key stakeholder groups (e.g., conservation and environmental organizations, hunting and angling groups, trade associations) 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.

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

Actions:

- 6.2.1: 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.
- 6.2.2: Develop specific programs and/or modify existing programs (e.g. bird and amphibian surveys) to 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.).
- 6.2.3: Make research and monitoring information regarding climate impacts to species and natural systems accessible to the public and other partners (e.g., commercial fisheries, etc.).
- 6.2.4: Develop educational materials and teacher trainings for K-12 classrooms on impacts and responses to climate change.
- 6.2.5: Develop collaborations with museums, aquariums, botanic gardens, arboreta, and other organizations to increase communication and awareness of impacts and responses to climate change.
- 6.2.6. Develop core messaging and recommended strategies to communicate the NFWPCAS within participating organizations and with the public.

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 like the LCCs, 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;
- ☐ Programs designed to engage citizens in monitoring impacts of climate change developed;
- ☐ Educational curricula developed;
- ☐ Collaborations with zoos, aquaria, museums, and botanic gardens initiated;
- ☐ Traffic to the *Strategy* web site and other electronic climate change adaptation resources increased;
- ☐ Workshops and communication programs increasing awareness of climate change related issues regarding fish, wildlife, and plants across agencies developed.

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 and fragmentation, degradation, invasive species, disease, pollution, over-harvesting, 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). Thus reducing these stressors can be some of the most effective – and doable – ways to increase resilience of fish, wildlife, and plants in a changing climate.

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 with land-use planners as well as major sectors such as agriculture, transportation, and water resource interests to identify common concerns and shared solutions should be actively pursued.

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 between 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. Also, decisions regarding increasing connectivity and repairing corridors will have to be weighed with the threat of invasives and the consequences of choosing one adaptation strategy over another.

Strategy 7.1: Slow and reverse habitat loss and fragmentation.

Actions:

- 7.1.1: Work with local land-use planners to identify shared interests and potential conflicts in reducing and reversing habitat fragmentation and loss through comprehensive planning and zoning.
- 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: 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.
- 7.1.4: 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.
- 7.1.5: 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.
- 7.1.6: Bridge the gap between ecosystem conservation and economics, and consider market-based incentives that encourage conservation and rehabilitation of ecosystems for the full range of ecosystem services including carbon storage.
- 7.1.7: Minimize impacts from alternative energy development by focusing siting options on already disturbed or degraded areas.
- 7.1.8: Identify options for redesign and removal of existing structures/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.
- 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: Reduce impacts of impervious surfaces and stormwater runoff in urban areas to improve water quality, groundwater recharge, and hydrologic function.
- 7.2.7: Promote water conservation, reduce water use, and promote increased water quality via proper waste disposal.
- 7.2.8: Develop and implement protocols for considering the carbon sequestration and storage services of forest, grassland, coastal, and other habitats in decisions affecting these areas.

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: 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) to address.

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

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

— 7.3.4: Implement existing strategies and where necessary, develop strategies for rapid response to contain, control, or eradicate invasive species.

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

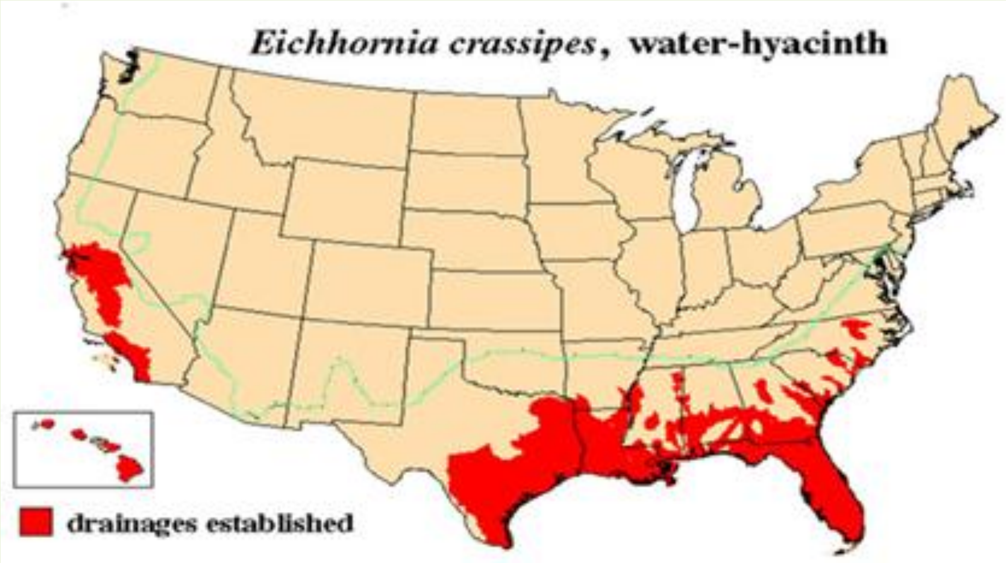
— 7.3.6: Monitor pathogens associated with fish, wildlife, and plant species for increased understanding of distributions and to minimize introduction into new areas.

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

FIGHTING THE SPREAD OF WATER HYACINTH

Introduced into the United State 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). 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.



The red areas indicate the range of water hyacinth as of 1999. The Green line is potential expansion if average winter temperature increase by 9 °F (USGS).

☑ GOAL7 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.

3.2 Opportunities For Multiple Sectors In Fish, Wildlife and Plant Climate Adaptation

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 and water resource use. The anticipated impacts to those sectors have been well documented (see box) and the threat of climate change has already prompted important adaptation efforts. 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 stormwater 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 15 states have completed a climate adaptation plan or are in progress. At the federal level, adaptation efforts are being coordinated by the ICCATF and are described in the October 2011 Progress Report to the President on climate change adaptation (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, for instance. Protecting coastal ecosystems also helps protect communities and industries 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).

Sample Reports Documenting Impacts to Other Sectors:

National Action Plan: Priorities for Managing Freshwater 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 2008c)

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 2008a)

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)

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 also to look for opportunities for coordinated adaptation strategies. These sectors also can take actions that 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.

COASTAL HABITAT CONSERVATION ON AGRICULTURAL LANDS

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 Farm Bill such as the Wildlife Habitat Incentives Program, Environmental Quality Incentives Program, and Wetlands Reserve Program 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 (development rights) from a willing farmer. 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.

It is outside the scope of this *Strategy* to describe in detail either the climate change impacts on other sectors or the sectors' adaptation needs. Instead, this chapter simply recommends actions for managers in these sectors to ensure that the needs of fish, wildlife, and plants are considered in their climate adaptation efforts.

There are eight overarching climate adaptation strategies that have been identified as common to all sectors:

1. **Improve the understanding of impacts to fish, wildlife, and plants from sectoral climate adaptation options and improve communication of those impacts**
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 incorporate fish, wildlife, and plants into 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. **Focus linear development (e.g., energy transmission, water pipelines, transportation) along corridors already developed for those purposes where doing so would minimize barriers to migration.**
8. **Expand compensatory mitigation requirements for projects that reduce ecosystem resilience.**

STORMWATER RUNOFF

A major nonpoint 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 and peak flow of stormwater runoff. 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.

NOAA'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.

Chapter 4: Integration and Implementation

4.1. How Federal Agencies, States, Tribes, and Other Partners Can Use this *Strategy*

As noted earlier, this *Strategy* is the first national-scale effort across all levels of government with authorities for fish, wildlife, and plants to jointly identify the major strategies and initial actions needed to help our valuable living resources and the communities that depend on them deal with 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, this is not a comprehensive action plan. Additional planning and action by federal, tribal, state, and local governments and many partners is essential to realize the goals laid out here.

4.1 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 plans and adapt to climate change, 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[2] and the NFHAP,[3] two 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 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 non-profit organization Climate Adaptation Knowledge Exchange (CAKE)[4] provides detailed information and access to information, tools, and case studies on adaptation to climate.

Many tribal governments and organizations are already experiencing the impacts of climate change on species, habitats, and ecosystems that are vital to their cultures and economies. They understand the need to adapt. 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.

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[2] http://www.fws.gov/birdhabitat/JointVentures/index.shtm

[3] http://fishhabitat.org/

[4] http://www.cakex.org

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 the 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[5] is responsible for publishing an 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. It will also 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 (SAPs) [6] 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 (SAP 4-1), ecosystem change (SAP 4-2), agriculture, biodiversity, land and water resources (SAP 4-3), adaptation options for climate-sensitive systems and resources (SAP 4-4), energy production (SAP 4-5), human health (SAP 4-6), and transportation (SAP 4-7).

Another important entity is the ICCATF,[7] 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 called for in the Task Force's 2010 Report 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 *National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate* (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 National Ocean Policy was released for comment in January 2012. A final Implementation Plan is expected in Spring 2012. This Implementation Plan has been developed in coordination with both the Freshwater Action Plan and the Ocean 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, the 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

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[5] http://www.globalchange.gov

[6] http://www.globalchange.gov/publications/reports

[7] http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation

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* can serve as a useful resource to all these efforts.

4.2 Strategy Implementation

This *Strategy* is a call to action and blueprint to meet the challenges of safeguarding the nation's fish, wildlife, and plants and the communities and economies that depend on them in a changing climate. To position the nation for action, this *Strategy* identifies seven major goals, then offers strategies and actions that government and conservation partners can implement or initiate over the next five to ten years.

Federal, state, and tribal governments and conservation partners are encouraged to read the document in its entirety to identify areas of overlap between the *Strategy* and their mission areas and activities. These entities are encouraged to identify existing and new efforts that help advance the goals and strategies in this document. Successful implementation of this *Strategy* will take commitment and resources by government and non-government entities, and must include steps to evaluate, learn, and adjust our course of action as needed to achieve our goals in a changing world. 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, CSCs, and 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.
    - State wildlife action plans should incorporate appropriate elements of this *Strategy*, AFWA's publication, *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.
2. Federal agencies with programs that affect fish, wildlife, and plants and the habitats they depend on should incorporate appropriate elements of the *Strategy* into the agency adaptation plans they are developing under Executive Order 13514.
    - Federal members of the Strategy Steering Committee will assign lead roles and implementation timelines for implementation of the *Strategy* across the federal sector. Once these activities are determined, they should be incorporated into each agency's climate adaptation plan.
3. An inter-jurisdictional coordinating body with representation and staff support from federal, state, and tribal governments will be established by June 30, 2012. This body will meet biannually to evaluate implementation of the *Strategy* and will report progress to Congress, CEQ, and federal, state, and tribal fish and wildlife agencies on an annual basis, with the first report due in June 2013.
    - 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 and CEQ, will 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 conservation partners, natural resource industries, and private landowners to assist with *Strategy* implementation and revision.

This *Strategy* is the beginning of a significant and collective effort to safeguard the nation's fish, wildlife, plants, and the communities and economies that depend on them in a changing climate. Lying ahead is an immense and challenging task, and much remains to be learned about the specific impacts of climate change and the responses of plants, wildlife, and ecosystems. 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 action to start the nation down the path to a meaningful adaptation response, and will help ensure that the nation's valuable fish, wildlife, plants, and ecosystems continue to provide important products and services to communities all across the country.

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Appendix A: Supporting Materials

Below are supporting materials for the National Fish, Wildlife and Plants Climate Adaptation Strategy (*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. 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/pdf/Marine_Ecosystems_Paper.pdf

Legislation

www.wildlifeadaptationstrategy.gov/pdf/2010_Legislative_Language_for_Adaptation_Strategy.pdf

Related Reports and Materials

Adaptive Management: The U.S. Department of Interior Technical Guide

http://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

http://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 Science Centers (CSCs)

http://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.

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.

National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate

http://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

A July 2010 Executive Order established a National Ocean Policy and tasked the interagency National Ocean Council with developing this strategic action plan.

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.

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.

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 the behavior, function, or structure of an organism physiological function or an anatomical structure of an organism that better suit it 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.

Carbon Sequestration – describes 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 greenhouse gases, which are 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 Modeling – 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.

Downscaling – refers to techniques that take output from the model and add information at scales smaller than the grid spacing. Downscaling methods are developed to obtain local-scale surface weather from regional-scale atmospheric variables.

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 Services – the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulation services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, 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, and 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 – a term used to describe 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 stomata in 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 – 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 current farm bill 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.

Green House 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 species 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 habitats and bioregions they invade economically, environmentally, and/or ecologically.

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, whilst 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, 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 water body 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 – the capacity of an ecosystem to return to the pre-condition state following a perturbation, including maintaining its essential characteristics taxonomic composition, structures, ecosystem functions, and process rates.

Resistance – the capacity of the ecosystem to absorb disturbances and remain largely unchanged.

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 and informing the development and implementation of resource management practices.

Appendix C: Acronyms

ACIA	Arctic Climate Impact Assessment
AFWA	Association of the Fish and Wildlife Agencies
AMSA	Arctic Marine Shipping Assessment
ASCE	American Society of Civil Engineers
AZ CCAG	Arizona Climate Change Advisory Group
C	Carbon
CADFG	California Department of Fish and Game
CAKE	Climate Adaptation Knowledge Exchange
CEC	Commission for Environmental Cooperation
CEICC	Committee on Ecological Impacts of Climate Change
CEQ	Council on Environmental Quality
CESU	Cooperative Ecosystem Study Unit
CO_2	Carbon Dioxide
CSCs	Climate Science Centers
CCSP	U.S. Climate Change Science Program
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 and GHGs	Green House Gas/Gasses

HABs	Harmful Algal Blooms
IPCC	Intergovernmental Panel on Climate Change
ICCATF	Interagency Climate Change Adaptation Task Force
JVs	Migratory Bird 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
PCSGA	Pacific Coast Shellfish Growers Association
REDD	Reducing Emissions from Deforestation and Forest Degradation
RISAs	Regional Integrated Science Assessments
RMRS	U.S. Forest Service: Rocky Mountain Research Station
SAP	Synthesis and Assessment Product
SNAP	Scenarios Network for Alaska Planning
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

Appendix D: Scientific Names

alpine chipmunk	*Neotamias alpinus*
American oystercatcher	*Haematopus palliatus*
American robin	*Turdus migratorius*
Arctic fox	*Alopex lagopus*
arctic fox	*Vulpes lagopus*
Asian carp	***Bighead carp** (Hypophthalmichthys nobilis)*
	***Black carp** (Mylopharyngodon piceus)*
	***Grass carp** (Ctenopharyngodon idella)*
	***Silver carp** (Hypophthalmichthys molitrix)*
Atlantic croaker	*Micropogonias undulatus*
blue crab	*Callinectes sapidus*
brook trout	*Salvelinus fontinalis*
brown treesnake	*Boiga irregularis*
buffelgrass	*Cenchrus ciliaris*
California vole	*Microtus californicus*
caribou	*Rangifer tarandus*
cheatgrass	*Bromus tectorum*
checkerspot butterfly	*Euphydryas editha*
Chinook salmon	*Onchorhynchus tshawytscha*
cisco	*Coregonus artedi*
coho salmon	*Oncorhynchus kisutch*
Cope’s gray treefrog	*Hyla chrysoscelis*
diamondback terrapin	*Malaclemys terrapin*
eastern tiger salamander	*Ambystoma tigrinum*
eelgrass	*Zostera marina*
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*
kudzu	*Pueraria montana*
	Pueraria lobata
	Pueraria edulis
	Pueraria phaseoloides
	Pueraria thomsoni
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*

	Phragmites
pinyon mouse	*Peromyscus truie*
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 tridentata*
Saguaro	*Carnegiea gigantea*
seabeach amaranth	*Amaranthus pumilus*
silver hake	*Merluccius bilinearis*
smallmouth bass	*Micropterus dolomieu*
southwestern willow flycatcher	*Empidonax traillii extimus*
spruce	*Picea*
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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