National Fish, Wildlife and Plants Climate Adaptation Strategy

Inland Water Ecosystems

Photo: AFWA

Disclaimer

The information in this Inland Water Ecosystems Background Paper was developed by the Inland Water Technical Team of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*), and was used as source material for the full *Strategy* document. It was informally reviewed by a group of experts selected by the Team. While not an official report, this Inland Water Ecosystems Background Paper is available as an additional resource that provides more detailed information regarding climate change impacts, adaptation strategies, and actions for U.S. inland water ecosystems and the species they support. 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.

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Introduction

Over the past decade, there have been increasing calls for action by government and non-governmental entities to better understand 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 the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*).

In 2009, Congress asked the Council on Environmental Quality (CEQ) and the Department of the Interior (DOI) to develop a national, government-wide climate adaptation strategy for fish, wildlife, plants, and related ecological processes. This request was included in the Fiscal Year 2010 Department of the Interior, Environment and Related Agencies Appropriations Act Conference Report. 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*.

A Steering Committee was established to lead this effort and it 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 tribal commissions. The Steering Committee charged a small Management Team including representatives of the FWS, NOAA, Association of Fish and Wildlife Agencies (representing the states) and Great Lakes Indian Fish and Wildlife Commission to oversee the day-to-day development of the *Strategy*.

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 five Technical Teams centered around a major ecosystem type. These teams, which were co-chaired by federal, state, and I most instances, 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 five ecosystem technical teams are: Inland Waters, Coastal, Marine, Forests, and a fifth team comprising four ecosystems: Grasslands, Shrublands, Deserts, and Arctic Tundra.

This Background Paper focuses on inland water systems, including information about these systems, existing stressors, impacts from climate change, and several case studies highlighting particular impacts or adaptation efforts. Information from this Background Paper informed discussion of inland water impacts and adaptation measures in the full *Strategy*, and was used to develop the Goals, Strategies, and Actions presented in that document and repeated here. This Background Paper is intended to provide additional background information and technical details relevant to inland water systems, and to summarize those approaches most relevant to managers of these areas and the species they support. Some of the material presented herein overlaps with that for other ecosystem types, particularly regarding cross-cutting issues.

The ultimate goal of the *Strategy* is to inspire and enable natural resource professionals, legislators, and other decision makers to take action to adapt to a changing climate. Those actions are vital to preserving the nation's ecosystems and natural resources—as well as the human uses and values that the natural world provides. The *Strategy* explains the challenges ahead and offers a guide to sensible actions that can be taken now, in spite of uncertainties over the precise impacts of climate change on living resources. It further provides guidance on longer-term actions most likely to promote natural resource adaptation to climate change. The *Strategy* also describes mechanisms to foster collaboration among all levels of government, conservation organizations, and private landowners.

Federal, state, and tribal governments and conservation partners are encouraged to look for areas of overlap between this Background Paper, the *Strategy* itself, and other planning and implementation efforts. These groups are also encouraged to identify new efforts that are being planned by their respective agencies or organizations and to work collaboratively to reduce the impacts of climate change on inland water fish, wildlife, and plants.

Inland Water Ecosystem Description

Inland Water Systems encompass a wide range of surface and underground physical, hydrological, and biological systems and include ponds and lakes, springs, streams, rivers, and wetlands. To distinguish these waters from coastal systems, inland waters end at head of tide. Inland water systems may be natural, as well as human-altered or engineered waterbodies, such as ponds, reservoirs, canals, and ditches (Cole 1994). These waters range from small or ephemeral (e.g., seasonal pools and intermittent streams) to large regional and national features such as the Great Lakes, Mississippi River, and Everglades.

Ecological characteristics of inland water systems are strongly influenced by elevation, topography, vegetation, soils and bedrock geology, precipitation, chemical constituents (Heinz Center 2008), and human alterations-both direct and indirect. Direct alterations of inland water ecosystems can include channelization, water withdrawals, and introduction of invasive species, whereas indirect changes may consist of land use effects on sediment supply from the watershed, impacts on groundwater discharge or recharge, or removal of vegetation adjacent to the waterbody which may alter water temperature and food webs. Frequency and duration of extreme events (i.e., flooding and drought) also influence both physical and biological features of inland waters. These diverse ecosystems host a broad range of aquatic life from microscopic plants and animals to large trees and major predators, and can include rare, endemic species.

Ponds and lakes:

Ponds and lakes are diverse in form and function and are typically distinguished by size and depth with ponds typically smaller than lakes (Summerfelt 1993, U.S. EPA 2010). Both systems lack notable flow and may be found at any elevation. The origin of ponds and lakes may be natural or human-made. Physical-chemical features of a pond or lake are dependent upon depth, water source, location within a drainage (e.g., a reservoir formed by a dam in a river), latitude, land-use, and vegetation within and near the waterbody (Hansen et al. 2010, Willis et al. 2010). Saline conditions of inland waters are found primarily where geological features allow salts to be directed into the waterbody (e.g., Great Salt Lake). Composition of the plant and animal communities found in these habitats is strongly influenced by these physical-chemical conditions.

Springs, streams, and rivers:

Springs, streams and rivers are found at all latitudes in the United States. Stream size, network density, and geomorphic pattern are greatly influenced by the soils, bedrock geology, topography, and precipitation (Gresswell and Vondracek 2010). Flowing waters are also affected by land uses in the drainage basin, as well as near-stream habitat such as floodplain wetlands and shoreline vegetation. Stream and river habitats are typically classified as pools (slack water), runs (moderate flow), and cascades (fast, near-vertical flow). Stream plants and animals are strongly influenced by both stream bottom composition and flow regime, often changing from the headwaters to river mouths. Human influences on flowing water systems include dams, channelization, and artificial withdrawals and discharges, all of which strongly influence the biological and physical characteristics of the modified system.

Wetlands:

Often considered among the most biologically diverse of all ecosystems, wetlands are found at all latitudes and may range in size from small seasonal pools of a few dozen square feet to expansive habitats encompassing several hundred square miles such as the Everglades. The three basic characteristics of wetlands are wet soils, aquatic vegetation, and water regime (Environmental Laboratory 1987).

Vegetation may include floating and attached forms of algae, submergent and emergent non-woody vascular plants, and seasonally or permanently flooded forests. Although typically of freshwater composition, inland wetlands may also be saline. Wetlands are often inhabited by a broad range of aquatic and terrestrial wildlife including, insects, mussels, fishes, amphibians, reptiles, mammals, and birds.

Impacts of Climate Change on Inland Water Ecosystems

Increasing global air temperatures and changing precipitation patterns are contributing to rise of water temperatures and shifting stream flow regimes to the inland waters of the United States, in some areas. These changes vary regionally with higher precipitation and runoff in the winter and spring in the Northeast and Midwest, and decreasing precipitation and runoff in the arid West in spring and summer (USGCRP 2009). In areas of high snowpack, runoff is beginning earlier in the spring and flows are lower in the late summer. In addition to these climate effects, more than a century of land use practices have degraded inland water ecosystems and the goods and services they provide to society. Likely impacts are summarized in Table 1.

Table 1: Expected Climate Change Impacts on Inland Water Systems (USGCRP 2009 and IPCC AR4 2007)*

Major Changes Associated With Increasing Levels of Green House Gases (GHGs)	Major Impact on Inland Waters
Increased temperatures:	Increase of warm-water species, depleted oxygen levels, stress on cold-water fish, creation of habitat for invasive species
Melting ice/snow:	Affects water temperatures which affect coldwater fish, such as bull trout and salmon
Rising sea levels:	Inundation of freshwater areas, groundwater contamination
Changing precipitation patterns:	Decreased lake levels, changes in salinity, flow
Drying conditions/drought:	Loss of wetlands and intermittent streams, lower summer base flows
More extreme rain/weather events:	Increased flooding, widening floodplains, altered habitat, spread of invasive species

**Refer to the Appendix A (Table 2: Inland Waters Climate-related Impacts and Challenges) for a more detailed list of climate-related impacts and challenges for inland water systems, including the significance and severity of these assessed qualitatively by members of the Inland Waters Technical Team.*

Changes in Hydrology:

Ecologists describe freshwater flow regimes as the primary factor in determining freshwater ecosystem function. Lower flows can impact flow-dependent species and estuarine systems, reduce habitat area and connectivity, and increase water temperature and pollution levels. For example, decreased flow in Hawaiian streams has resulted in significantly smaller caddisflies (McIntosh et al. 2003) and atyid shrimp (MacKenzie et al. 2011). Atyid shrimp also exhibited lower body condition with decreasing stream flow (MacKenzie et al. 2011). Higher flows and frequent storm flows can create wider floodplains and other habitat, alter habitat, increase connectivity, displace riparian and bottom-dwelling species, or further distribute invasive species. Changing flood and freshwater runoff patterns can impact critical life stages that are attuned to the timing of stream flows, such as the spawning and migration of salmon. Increased evaporation of seasonal wetlands and intermittent streams can destabilize permanent water bodies, causing a loss of habitat or a shift in species composition.

Thermal Stress, Range Shifts, and Food Web Disruption:

Water temperature controls the physiology, behavior, distribution, and survival of freshwater organisms, and even slight temperature changes can affect these functions (Elliot 1994). Global climate models predict a 2 to 11.5 °F increase in air temperature by 2100 (IPCC AR4 2007), leading to higher water temperatures in lakes, wetlands, streams, and rivers. 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 0.36 °F per decade based on greenhouse gas emissions scenarios (IPCC AR4 2007). Temperature increases also affect freshwater ecosystem processes, such as development, productivity, and decomposition rates, and disrupt integral food web relationships.

Freshwater organisms are often classified by temperature guilds, grouping species according to temperature tolerances for growth, survival, and reproduction (Magnuson et al. 1997). As the climate warms, the geographic area suitable for warm-water species is predicted to expand as water temperatures increase (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 predicted to increase by 31 percent across the United States (Mohseni et al. 2003). For example, the recent establishment of two species of tropical dragonflies in Florida represents a natural invasion from Cuba and the Bahamas that might be related to climate change (Paulson 2001). In contrast, Muhlfeld et al. (2011) showed that the distribution of *Lednia tumana*, a stream invertebrate that resides in small streams directly below glaciers in the Waterton-Glacier International Peace Park in Canada and the United States, is anticipated to contract because the park is expected to lose most of its glaciers by 2030 (Hall and Fagre 2003).

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 *(Salvelinus fontinalis)*. 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.

One long-term study of coho salmon (*Oncorhynchus kisutch*) showed that a 1.26 °F increase in stream temperature impacted their life history and survival. This temperature increase caused coho salmon to emerge from the gravel six weeks earlier and go to the ocean two weeks earlier, resulting in lower survival rates than coho emigrating later (Holtby 1988). Scientists believe the lower survival rate was due to a mismatch between the timing of coho emigration and peak prey abundance in the ocean (Holtby 1988).

Mild warming may eliminate wetland plant and animal species in alpine regions due to limited dispersal opportunities among these isolated habitats (Burkett and Kusler 2000). Major shifts in species composition, diversity, and ecological function are more likely to occur for species with narrow thermal tolerances in smaller, fragmented, or isolated habitats than for those with broader thermal requirements and larger, more inter-connected habitats.

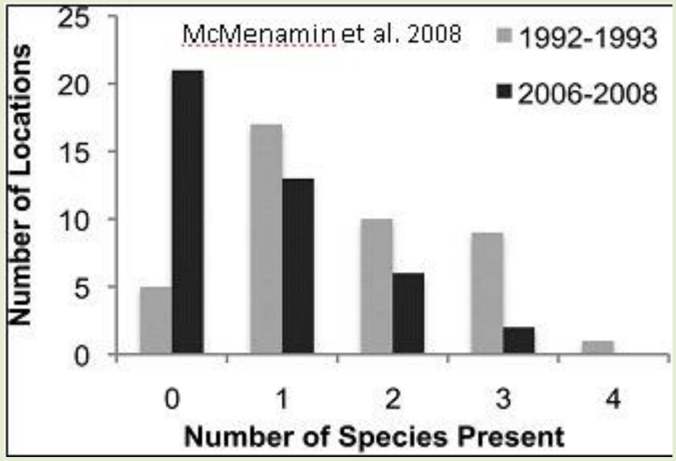
AMPHIBIANS: PROTECTION IS NOT ENOUGH

A study conducted in the northern Yellowstone National Park has documented that recent climatic warming and resultant wetland drying have caused severe declines in three once-common amphibian species native to the area (McMenamin et al. 2008). Yellowstone National Park has been under protection since 1872 and is free from direct human impacts to the ponds and wetland systems. Many of the ponds are seasonal, recharged by groundwater and local surface runoff during the spring.

Photo: USGS

The researchers reviewed climate data from the past six decades and conducted repeated surveys of almost 50 ponds.

Four species of amphibians are found in the northern Yellowstone region. Three species are commonly found, including: the blotched tiger salamander (*Ambystoma mavortium*), the boreal chorus frog (*Pseudacris maculata*), and the Columbia spotted frog (*Rana luteiventris*) (Koch and Peterson 1995). The researchers observed severe reductions in the number and diversity of amphibian populations in this area over the past 16 years. The number of blotched salamander populations has fallen by nearly half. Both populations of frogs have declined in number with the spotted frog populations declining by 68 percent and the chorus frog populations by 75 percent.



McMenamin et al. 2008

The researchers documented that the decline in amphibian populations is linked to regional changes in the hydrologic landscape and overall groundwater condition. The results of this study indicate that decreasing annual precipitation and increasing temperatures have significantly changed the landscape and the associated fish and wildlife communities.

Much emphasis is being placed on the potential impacts of climate change on existing vulnerable fish and wildlife species and ecosystems. These results showcase that species and ecosystems within one of the best-protected areas in the nation are currently being impacted by climatic warming and that current assessments of species' vulnerability do not adequately consider such impacts (McMenamin et al. 2008).

Increase in Blue-green Algae (cyanobacteria) and Noxious Algae Blooms:

Cyanobacteria, commonly called blue-green algae, live in all freshwater habitats. Given ample nutrients, many species form thick, noxious mats or surface scums that are called blooms. Global temperature increases may lead to an increased abundance of harmful algal blooms (Pearl and Huisman 2008). Although cyanobacteria are not pathogens, they can produce potent toxins that are harmful to wildlife and humans, if consumed (Carmichael 1997).

CLIMATE CHANGE PROMOTES HARMFUL ALGAL BLOOMS

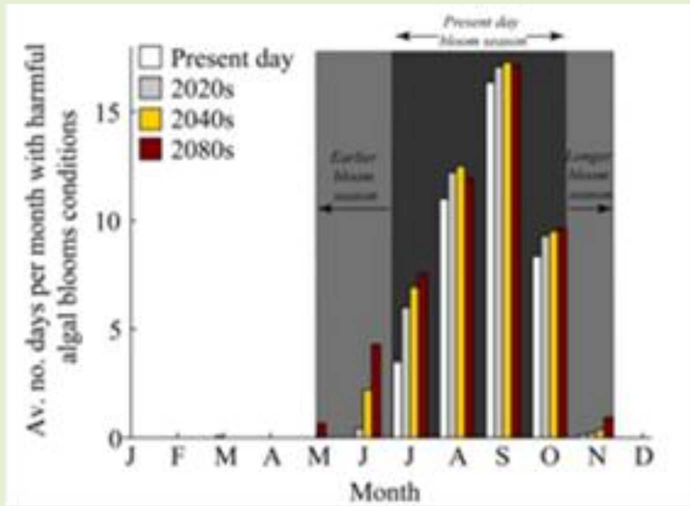
In the past three decades, harmful algal blooms (HABs) have become more frequent, more intense, and more widespread in freshwater, estuarine, and marine systems (Sellner et al. 2003). These blooms are taking a serious ecological and economic toll. Algal blooms may become harmful in multiple ways. For 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,

Cyanobacterial bloom of the toxin producer, Microcystis.

Photo: Nara Souza.

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.

Warmer temperatures are contributing to 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 would 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 may increase the range of the microalga—and the threat of poisoning.



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

The key strategy to addressing HABs 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.

Increased Susceptibility to Contaminants, Diseases, and Parasites with Warming Temperatures:

Diseases, parasites, and chemical toxicity in water bodies are also influenced by rising temperatures. The toxicity of some substances, such as lead, copper, and ammonia, becomes more potent at higher temperatures (Piper et al 1982, Heugens et al. 2003, Lovett 2010). Warming temperatures also increase the susceptibility of organisms to disease because the host animal or plant is already stressed making it less able to fight the disease. Diseases may also spread for longer periods and reproduce faster, threatening larger populations. For example, low flows and warmer waters in the Klamath River (California) in September 2002 were contributing factors to a massive fish kill due to a parasite infestation among spawning Chinook salmon (*Oncorhynchus tshawytscha*) (CADFG 2008).

Disease and parasite dynamics in amphibian assemblages are also changing with increased climate variability (Kiesecker and Blaustein 1995, Garcia et al. 2006, Alford et al. 2007). The emergent amphibian disease chytridiomycosis has reduced populations worldwide and the impacts of this disease may be compounded by climate change (Pounds et al. 2006, Alford et al. 2007, Bosch et al. 2007). Yellow-Legged Frogs (*Rana boylii*) in Northern California suffered high rates of infection from a parasitic copepod during two years when daily mean summer temperatures exceeded 68 °F (Kupferberg et al. 2009). Similarly, Kiesecker and Blaustein (1995) found decreased wet periods and warmer water temperatures facilitated *Saprolegnia* fungal infections of frogs in the Oregon Cascades.

Reduction in Ice Cover, Evapotranspiration, and Lake Stratification:

Ice cover on freshwater systems is sensitive to climate changes (Magnuson 2002) and is an indicator of climate warming (Gitay et al. 2001). Higher air and water temperatures will shorten lake ice cover seasons and increase evapotranspiration and thermal stratification. A long-term record of water levels in a northern Wisconsin seepage lake (Anvil Lake) demonstrates the problem of maintaining aquatic habitat during periods of recurring droughts in lakes, ponds, and wetlands that are located relatively high in the surrounding landscape.

During winter the productivity of lake systems is likely to increase without ice cover. This might also result in the reduction of "winter-kill" due to depleted oxygen levels in shallow lakes, favoring predator fish such as northern pike over a diverse community of small winter-kill-adapted fish species (WICCI 2011).

In summer, deeper, less productive, stratified lakes in the northern United States could face lower oxygen levels at greater depths. Prolonged warm weather would lengthen thermal stratification periods and deplete oxygen levels in stratified cooler waters at greater depths. Coldwater fish, such as lake trout (*Salvelinus namaycush*) and cisco (*Coregonus artedi*), may no longer find oxygenated waters in their required temperature ranges.

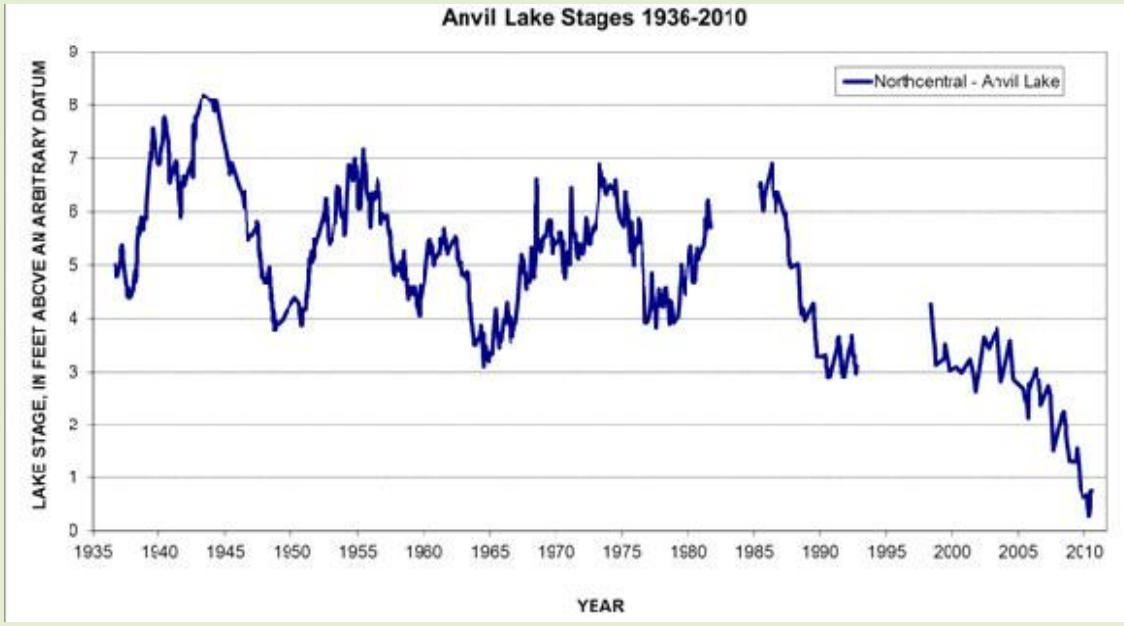
WATER LOSSES UNDER CLIMATE CHANGE

Between 2000 and 2010, the worst drought ever recorded since Euro-American settlement hit the Colorado River Basin (Southwestern United States). Water levels in Lake Mead dropped to record lows. The drought not only threatened the supply of water to cities like Las Vegas (Nevada), 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 fish, wildlife, plants, 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)

Sea Level Rise:

The ocean's thermal expansion coupled with glacier melt is projected to increase sea level by 40 to 200 cm by 2090 (IPCC AR4 2007, Rahmstorf 2010). Scientists believe this may 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). These impacts are apparent in freshwater swamps along the coastlines of Australia, the French West Indies, 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 10-50 percent of the freshwater sawgrass prairie are likely to be transformed to salt marsh or mangroves by 2100 (Kimball 2007).

Groundwater supplies are anticipated to shrink as sea water inundates the bottom portion of freshwater layers or groundwater recharge from tidal/storm surges increases salinities (Fletcher and Richmond 2009). These lenses are critical in island ecosystems such as in the U.S. affiliated Federated States of Micronesia or Republic of the Marshall Islands, where small, isolated freshwater wetlands are often the only source of water for plants, wildlife, and people. Furthermore, many such islands are low-lying atolls so their water resources are vulnerable to seawater flooding and/or tidal and storm surges (IPCC AR4 2007).

Increase in Extreme Weather Events:

Temperature and precipitation changes impact the timing, duration, frequency, and magnitude of extreme weather events, such as flooding and drought. As the climate warms and precipitation patterns change, extreme weather events are likely to intensify and occur more frequently. For example, altered precipitation patterns may manifest as heavy storms that punctuate extended periods of hot, dry weather, yielding floods. More severe droughts may dry streambeds and wetlands. For example, the prairie pothole region in the Midwest United States and Canada contains millions of glacially formed wetlands that provide habitat for 50 percent to 80 percent of the continent's waterfowl. Drought impacts could contribute to the reduction in waterfowl populations unless wetlands are protected and degraded wetlands restored (Johnson et al. 2005).

Increased tidal/storm surges are expected to affect freshwater ecosystems, especially with increases in hurricane/typhoon intensities (IPCC AR4 2007). Tidal and storm surges can cause oxygen depletion, changes in salinity, mud suffocation, and turbulence (Tabb and Jones 1962). Storm surge can cause salt-kill in coastal freshwater swamp forests if storms do not carry heavy rain to wash salt from soil.

Changes to Ecosystem Services:

Intact, natural ecosystems offer four types of goods and services: provisional services (e.g., food, timber, medicines, water, and fuels), regulating services (e.g., water purification and carbon sequestration), supporting services (e.g., climate regulation and nutrient cycling), and cultural services (e.g., aesthetic values and sense of place) (Millennium Ecosystem Assessment 2005). They generate value when people enjoy them directly (e.g., eating fish) or indirectly when they support other things people enjoy (e.g., instream flows providing habitat for fish, wildlife, and plants).

Some benefits provided by well-functioning ecosystems will change or be lost due to climate change impacts 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 traditional ceremonial and cultural practices for indigenous peoples.

The water needs of humans for such uses as hydropower, navigation, municipal, industrial, agricultural, and recreational purposes must be balanced with the aquatic ecosystem needs and adaptively managed based on an uncertain changing climate and integrated with all natural resource management strategies.

CLIMATE CHANGE IMPACTS ON TRIBAL RESOURCES

The Columbia River Treaty was signed by the United States and Canada in 1961 and implemented in 1964 with two purposes: optimizing power generation and coordinating flood control on the Columbia River. The original Treaty was ratified before the environmental movement gained momentum and before the United States moved to protect Native American rights. The Treaty doubled water storage capacity on the Columbia River system with construction of large storage projects in Canada and in the United States. But it did this without accounting for the effect on overall function of the ecosystem and resources of

Traditional tribal fishing on the Columbia River.
Photo: Columbia River Inter-Tribal Fish Commission

Columbia Basin tribes and the region.

Although the Treaty has no expiration date, beginning in 2024 and thereafter, either country has the option to terminate with 10 years' notice. The Treaty is now under review by the U.S. government, Canadian government, and interested tribal governments.

The 15 Columbia Basin tribes urge that ecosystem function (including climate change impacts), are included when the Columbia River Treaty is renegotiated. The tribes suggest the following goals are integrated into an Ecological Assessment of alternative operations under a modified Treaty post-2024:

- Develop mitigation and adaptation responses to address climate change impacts;
- Determine flows and reservoir operations for future alternatives, using regional hydro regulation, flood risk management, and downsizing of global climate models to create and compare data sets for alternatives;
- Examine water quality regimes under different future operational alternatives for aquatic resources, including temperature, turbidity, salinity, dissolved gas, and contaminants;
- Determine annual juvenile salmon and steelhead survival through the mainstem hydrosystem and adult returns under different modeled flow regimes and alternatives;
- Determine fish and wildlife resource impacts in affected reservoirs and tributaries; and
- Develop habitat assessments of the mainstem, estuary, and river plume functions.

The future of Columbia Basin aquatic resources, including 13 Endangered Species Act listed species of salmon, Pacific lamprey, sturgeon, and smelt, depend on future flow regimes driven by climate change, and balancing flood risk management, power, and ecosystem function.

Climate Adaptation Strategies and Actions for Inland Water Systems

The *Strategy* identifies seven primary 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. Each Goal identifies a set of initial Strategies and Actions that should be taken or initiated over the next five to ten years.

Actions listed here were derived from those Technical Team submissions determined to be most applicable to inland water systems. Numbers that correspond to the full *Strategy* document are designated by *Strategy* (S) and the Action number (e.g., 1.1.1). Strategies that are specific only to inland waters are designated with (IW) before the strategy number.

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

Habitat connectivity and space are two key elements of functioning ecological systems. Adopting strategies to achieve increased habitat connectivity and space will increase the likelihood of sustaining abundant and diverse populations and ecosystem functions in a changing climate. Identifying, conserving, and restoring natural areas will deliver ecological benefits such as refugia for cold-water species that may be vulnerable to high temperatures (Torgersen et al. 1999). Protecting and restoring floodplains and riparian forests will increase nursery habitats for a variety of organisms (Jeffres et al. 2008). Additionally, improved riparian area and vegetative conditions will help provide and maintain cool water temperatures (Kiffney et al. 2003) and deliver organic matter inputs that serve as important nutrients and components for freshwater ecosystems (Kiffney et al. 2009). Ensuring connectivity between and among habitats by assessing and where appropriate, altering or removing anthropogenic barriers that block movement is especially important for key life stage events (e.g., reproduction) or avoiding stressful conditions (e.g., high water temperature). Connectivity is also important for movement of materials such as sediment and wood that are essential for well-functioning ecosystems. Although ensuring habitat connectivity is important for limiting climate change impacts, preventing the spread of invasive species must be considered when implementing this strategy (Fausch et al. 2006, Fausch et al. 2009). A barrier may control the expansion of invasive species, thereby limiting additional ecological stressors on native populations. Protecting, maintaining, and restoring surface and underground flows, as well as important features and components of a watershed's hydrologic regime, will improve or maintain habitat area, connectivity, and complexity in aquatic ecosystems. Conserving and restoring surface and underground flows, as well as natural hydrologic components, are important because of the strong link between natural flow regimes and habitat diversity (Poff et al. 1997). Actions that increase the number and distribution of critical habitat areas, remove anthropogenic barriers to movement, and protect or restore surface and underground flows (e.g., implementing water conservation actions, protecting springs and seeps) will increase the likelihood of achieving robust populations, increasing biodiversity, and improving ecosystem function and resiliency in a changing climate.

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:

— A: Identify and map high priority inland water areas (i.e., refugia) 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). (**S 1.1.1**)

— B: 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. (**S 1.1.4**)

— C: Identify and prioritize groundwater sources, recharge and discharge sites, and areas that provide sediment resources necessary for ecosystem processes.

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:

— A: 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. (**S 1.2.1**)

— B: 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 inland water landscapes under climate change. (**S 1.2.4**)

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

Actions:

— A: Develop and implement restoration protocols and techniques such as instream flows and water management plans that promote inland water ecosystem resilience and facilitate adaptation under a range of possible future conditions. (**S 1.3.1**)

— B: Restore degraded habitats as appropriate to support diversity of inland water species assemblages and ecosystem structure and function. (**S 1.3.2**)

— C: Restore or enhance inland water areas that will provide essential habitat, hydrologic function, and ecosystem services during climate change ecosystem transitions. (**S 1.3.3**)

— D: Secure instream flows through various efforts such as removal or modification of dams and other barriers.

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:

— A: Assess and prioritize critical connectivity gaps and needs across current inland water conservation areas, including areas likely to serve as refugia in a changing climate. (**S 1.4.2**)

— B: Conserve corridors and transitional habitats between ecosystem types (riparian areas, mangrove forests) through both traditional and non-traditional (e.g., land exchanges, rolling easements) approaches. (**S 1.4.3**)

— C: Assess and take steps to reduce risks of facilitating movement of undesirable non-native species, pests, and pathogens. (**S 1.4.4**)

— D: Assess existing barriers or structures such as dams that impede movement and dispersal within and among aquatic habitats to increase natural ecosystem resilience to climate change, and where necessary, consider the redesign or mitigation of these structures. (**S 1.4.5**)

— E: Identify, prioritize, and improve, remediate or remove thermal, physical, or chemical barriers to connectivity in aquatic habitats where appropriate such as:
    - Retrofit and construct new infrastructure to accommodate species movement and life stage needs as well as anticipated climate changes (e.g., extreme events and increased flows).
    - Reconnect floodplains, including channel migration zones for streams and rivers.
    - Improve operational and structural components of artificial channels (e.g., ditches and canals).
    - Address and develop provisions for aquatic species migration needs in dam licensing and relicensing decisions.

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.

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

Humans depend upon and derive multiple benefits from fish, wildlife, and plants associated with inland water resources, and a changing climate is expected to exacerbate current stressors (e.g., water quality, invasive species). "Climate-smart" management activities and projects are those that "will maximize the effectiveness of restoration investments under both current and expected future climate conditions" (Glick et al. 2011). Strategies and actions identified to meet this goal are expected to reduce effects of these stressors and contribute to diverse assemblages of fish, wildlife, and plant populations that provide sustainable resources for various human uses and are more resilient to climate change impacts.

Addressing the anticipated climate change impacts is especially important due to the diverse, regional, and cultural uses of fish, wildlife, and plants by humans. These uses include ceremonial, spiritual, and subsistence practices by indigenous peoples; recreational activities such as plant identification, sport fishing, waterfowl hunting, birding, and nature photography; and commercial fisheries for local economies. Typically, the livelihood, cultural-identity, and tradition of American communities are based upon these uses. Consequently, the strategies and actions are diverse and encompass a broad range of practices. Strategies and actions address native species and non-native, yet desirable species. Additionally, strategies and actions prevent and eradicate invasive species, and also provide for artificial propagation or transport of at-risk populations in extreme situations. The strategies and actions rely upon increased interagency and intergovernmental coordination at multiple levels to provide adequate supplies of clean water for inland water species and secure inland water resources for human uses (e.g., integrated water resources management plans and sediment management plans). Many of these types of actions, by virtue of the geographic scope, are crosscutting with the other ecosystems (i.e., coastal, marine, forest, grassland, and shrubland).

The following strategies and actions are identified for fish, wildlife, and plants associated with inland waters to meet Goal 2:

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:

— A: Incorporate climate change considerations into existing and new inland water management plans and practices using the best available science regarding projected climate changes and trends, vulnerability and risk assessments, and scenario planning. (**S 2.1.1**)

— B: Identify species and habitats particularly vulnerable to transition under climate change (e.g., cool-water to warm-water fisheries) and develop management strategies and approaches for adaptation. (**S 2.1.3**)

— C: Develop basin-specific integrated water management plans that address in-stream flows, inter-basin water transfers, and surface and groundwater withdrawals while promoting water conservation and ecosystem function.

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

Actions:

— A: Use vulnerability and risk assessments to design and implement inland water management actions at species to ecosystem scales. (**S 2.2.1**)

— B: Develop criteria and guidelines for the use of translocation, assisted migration, and captive breeding as climate adaptation strategies. (**S 2.2.2**)

— C: 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. (**S 2.2.3**)

Strategy IW 2.3: Develop guidelines and incentives to reduce development in floodplains and riparian areas.

— A: Ensure co-management between tribal governments and local, state, and federal agencies during natural resource management decision-making.

— B: Use best available science and risked-based assessments to guide federal, state, and tribal agencies in developing or enhancing ceremonial, subsistence, commercial, and recreational fisheries while minimizing risk to native species.

Strategy IW 2.4: Manage water resources for culturally-, recreationally-, and commercially-important fish, wildlife, and plants.

— A: Implement structural and operational improvements in flow regulated systems to ensure quality, quantity, timing, and distribution of flows and other habitat forming elements for species life stage needs.

— B: Improve integrated water resource management, including coordination of surface and groundwater withdrawal, to meet the needs of fish, wildlife, and plants and consumptive human uses.

— C: Develop and implement regional sediment management plans to improve water quality and habitat conditions.

— D: Develop plans and implement measures that address non-point pollution sources (e.g., nutrient, thermal, chemical).

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

To address the many challenges of climate change, agencies will want to consider many options for implementing actions. It is generally recognized that addressing climate change impacts on inland waters will require coordination and collaboration among partners. This collaboration may include reaching beyond the typical scope of current programs and partnerships, communication with tribal governments, and providing diverse formats and easy access to much-needed informational resources. Improved coordination can lead to increased efficiencies and enhanced outputs especially when financial resources are leveraged from diverse sources and contribute to increased technical assistance. This technical assistance is considered important for building capacity to implement on-the-ground practices and foster communication.

The following strategies and actions are identified for fish, wildlife, and plants associated with inland waters to meet Goal 3:

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:

— A: 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. (**S 3.1.2**)

— B: 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). (**S 3.1.3**)

— C: 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. (**S 3.1.5**)

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:

— A: 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. (**S 3.2.2**)

— B: 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), Landscape Conservation Cooperatives (LCCs), Migratory Bird Joint Ventures (JVs), and the Northeast Association of Fish and Wildlife Agencies regional application of State Wildlife Grant funds to foster collaboration. (**S 3.2.3**)

— C: Collaborate with tribal governments and native peoples to integrate traditional ecological knowledge and principles into climate adaptation plans and decision-making. (**S 3.2.4**)

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:

— A: 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. (**S 3.3.1**)

— B: 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. (**S 3.3.4**)

— C: 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. (**S 3.3.6**)

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

Actions:

— A: Prioritize funding for land and water protection programs that incorporate climate change considerations. (**S 3.4.1**)

— B: 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. (**S 3.4.2**)

— C: 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. (**S 3.4.3**)

— D: Coordinate and leverage private and public sources of funding that address climate change impacts on natural resources at local, regional, national, and international scales.

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

There is an increasing need for coordinated data collection, analysis, and distribution of findings such as through the USGS Climate Science Centers, to provide for efficient and effective use by agencies and conservation partners. An expanding body of literature and collaborative initiatives are reflective of an increasing need for information management (USGS 2007, Glick et al. 2011, U.S. ACE 2011). Consistent data collection methods can help support better decision-making tools through development and refinement of hydrologic models and decision support systems that incorporate climate change factors. A notable feature of this goal is the implementation of an information clearinghouse to enhance user access to the information. A multi-disciplinary approach, to link data currently developed by separate agencies or groups would be expected to increase use of the information by resource managers, planners and decision-makers. Regional initiatives, such as the Department of Interior's Landscape Conservation Cooperatives-LCC's, can support this inventory and monitoring effort by assessing needs of agencies and non-governmental conservation partners. This information can then be applied to implement management actions, such as advanced notification systems for invasive species, which address the climate change impacts to vulnerable species and habitats. It can also be used, through an adaptive management approach, to identify the most efficient and effective applications of these data.

The following strategies and actions are identified for fish, wildlife, and plants associated with inland waters to meet Goal 4:

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:

— A: 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. (**S 4.1.2**)

— B: Work through existing distributed efforts (e.g., National Climate Assessment (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. (**S 4.1.4**)

— C: Monitor and assess functionality of created wetlands and restored wetlands, streams, and lakes.

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:

— A: Conduct risk assessments to identify key climate change hazards and assess potential consequences for fish, wildlife, and plants in inland water systems.

— B: 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. (**S 4.2.2**)

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

— D: Ensure the availability of and provide guidance for decision support tools that assist federal, state, local, and tribal resource managers and planners in effectively managing inland water fish, wildlife, and plants in a changing climate. (**S 4.2.7**)
— E: Develop and adopt standardized assessment methods for quantifying service benefits to humans originating from ecosystem functions (e.g., carbon sequestration, flooding and erosion, fish and wildlife-based recreation and commodities, nutrient provision, and water improvement services).

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

Numerous studies have been completed, are ongoing, or are being planned to assess and understand the effects of climate change within and across all ecosystems. Increasing our knowledge of these effects and of fish, wildlife, and plant responses will advance future research by improving data; verifying—and when necessary, correcting assumptions; discovering additional strategies; and responding appropriately to changes.

Particularly important to this endeavor for inland waters is the role lakes, streams, and wetlands play to support life. The value of increasing our knowledge and information for these systems relates to the role they play for plants and animals, including humans, which are drawn to and depend upon inland water systems. Human activities, such as development, mining, agriculture, and recreation have contributed to vulnerabilities and decline of fish, wildlife, and plants. Through this goal, human activities—our ingenuity and persistence in understanding the natural world—also provide us a means of stabilizing and ensuring the health of these fragile, beautiful, and essential resources.

The following strategies and actions are identified for fish, wildlife, and plants associated with inland waters to meet Goal 5:

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), Climate Science Centers (CSCs), LCCs, JVs, and Regional Integrated Sciences and Assessments (RISAs).

Actions:

— A: 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. (**S 5.1.1**)
— B: Bring managers and scientists together to prioritize research needs that address resource management objectives under climate change. (**S 5.1.2**)
— C: Prioritize research on questions relevant to managers of near-term risk environments (e.g., low-lying islands and glaciated areas) or highly vulnerable species. (**S 5.1.6**)

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:

— A: 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. (**S 5.2.4**)

— B: Conduct research to determine temperature increases and glacial melt impacts on water temperature, evapotranspiration rates, flow characteristics, stream channel processes, and aquatic species.

— C: Conduct research to determine flows required to support sustainable populations of vulnerable species, such as during prolonged drought.

— D: Evaluate responses of aquatic indicator species to changing habitat conditions.

— E: Conduct controlled laboratory and field studies to better understand future vulnerabilities (e.g., physical, biological responses) of fish, wildlife, and plants.

— F: Promote and enhance clearinghouse resources highlighting climate adaptation strategies and case studies .

— G: Conduct research to understand the relationship between climate impacts such as predicted increases in air temperature and water temperature, including groundwater influences and non-climate stressors such as land use changes.

— H: Increase data collection of evapotranspiration rates of lakes, wetlands, and reservoirs to allow development of better hydrologic models.

— I: Identify and inventory vulnerable fish, wildlife, and plant species and conduct assessments.

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

Actions:

— A: 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. (**S 5.3.1**)

— B: Update hydrologic statistics and stream channel characteristics needed to delineate areas prone to flooding and channel migration as a result of climate impacts.

— C: Model climate change impacts on the spatial extent, distribution, and probability of persistence of vulnerable aquatic species and projected habitat changes.

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.

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

Ensuring the general public, agencies, and the scientific community are well-informed is the focus of this goal and associated strategies and actions. Concise, timely, relevant, and accurate information must be available for users to understand their options when making decisions relevant to climate change. Various climate change impacts can have economic, health, and safety implications. To effectively inform users and allow them to make appropriate decisions for their personal and civic interests and guide actions that will minimize harm to inland water systems. Materials for public awareness campaigns must be provided through a variety of media in formats convenient to the users. Outreach efforts to enhance public awareness of issues associated with climate change would be expected to inspire and encourage engagement in public forums.

The following strategies and actions are identified for fish, wildlife, and plants associated with inland waters to meet Goal 6:

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.

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

Strategy 6.3: Coordinate climate change communication efforts across jurisdictions.

Strategy IW 6.4: Promote and encourage conservation of water.

Strategy IW 6.5: Improve outreach to facilitate implementation of strategies.

- A: Develop consistent messaging, outreach, and educational tools to address public need for information on climate change impacts to society, and actions people can implement.
- B: Promote and encourage civic engagement in local watershed councils, associations, and voluntary organizations to engage citizens and youth in activities such as riparian plantings, invasive species management, and similar activities.
- C: Encourage reduction of residential use of chemicals, fertilizers, and pesticides by offering more ecologically-friendly alternatives.
- D: Increase public awareness about the importance of healthy intact wetlands, floodplains, and riparian areas in providing ecosystem services such as protecting property by attenuating flooding and reducing associated damages.
- E: Increase public awareness of the negative impacts of invasive species through prevention and eradication campaigns.

Strategy IW 6.6: Promote public safety awareness on changing inland water conditions.

- A: Increase campaigns to inform anglers about ice safety in a changing climate.
- B: Improve monitoring and public notification systems for harmful algal blooms and other resource-related concerns that can impact public health.

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

Humans preferentially settle near freshwater and concentrate their activities in areas with ample freshwater supplies. Thus, many aquatic ecosystems have been affected for centuries by non-climate related human stressors that include chemical pollution, agricultural and forestry practices, and overfishing. As a result, freshwater and riparian-associated species are the most imperiled biota in the United States (Master et al. 2000). Non-climate stressors interact with one another to reduce ecosystem resilience and many interact with climate-related stressors to further exacerbate the effects of climate change on aquatic systems. Strategies such as improving infrastructure to address the needs of aquatic biota, reducing environmental consequences of alternative energy sources (i.e., wind, hydroelectric, and solar), and encouraging best management practices are important to reduce non-climate stresses on fish, wildlife, and plants.

The following strategies and actions are identified for fish, wildlife, and plants associated with inland waters to meet Goal 7:

Strategy 7.1: Slow and reverse habitat loss and fragmentation.

Actions:

— A: 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. (**S 7.1.2**)

— B: 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. (**S 7.1.3**)

— C: 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. (**S 7.1.4**)

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:

— A: Work with private land owners and water resource managers to identify, upgrade, or remove outdated legacy water resources infrastructure (i.e., outdated sewers, stormwater infrastructures) to improve aquatic organism passage and reduce water contamination. (**S 7.2.4**)

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

— C: Reduce impacts of impervious surfaces and stormwater runoff in urban areas to improve water quality, groundwater recharge, and hydrologic function. (**S 7.2.6**)

— D: Promote water conservation, reduce water use, and promote increased water quality via proper waste disposal. (**S 7.2.7**)

— E: Increase research, development, promotion, and implementation of sustainable land use practices (i.e., agriculture, forestry, urban development).

— F: Implement watershed best management practices to provide stable water sources for fish, wildlife, plant, and competing human uses.

— G: Increase technical and financial support for the development and implementation of best management practices for instream, wetland, lake, and riparian management.

— H: Incentivize best management practices that protect existing and newly identified ecosystem services (e.g., improved water quality) across multiple sectors.

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

Actions:

— A: 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. (**S 7.3.1**)

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

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

— **Strategy IW 7.4: Develop and improve alternative energy sources and technologies to reduce stresses on aquatic habitats.**

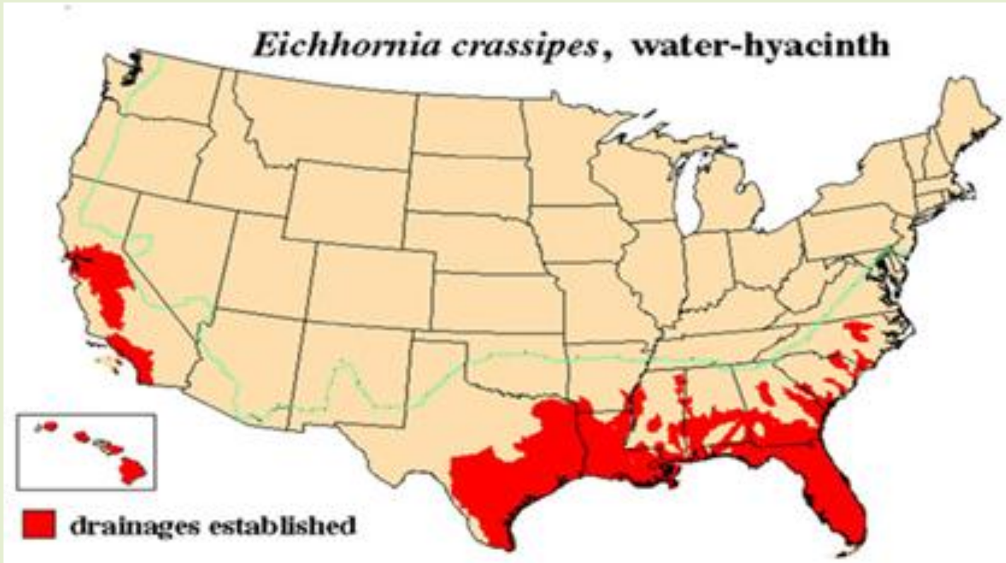
— A: Increase funding for re,search on alternative energy technologies compatible with inland water habitats.

FIGHTING THE SPREAD OF WATER HYACINTH

Water Hyacinth rapidly covers water bodies. Photo: Willey Durden USDA Agricultural Research Service

Water hyacinth (*Eichhornia crassipes*) is already a major pest. Introduced into the United States in the late 1890's from South America, this floating plant has spread rapidly across the southeastern United States. It produces vast, thick mats that clog waterways, crowding out the native plants and making boating, fishing, and swimming almost impossible.

Climate change would be expected to make the problem worse by allowing this pest to invade new areas. That's because water hyacinth is limited to states where winter temperatures rarely go below freezing. So, if temperatures rise, as predicted, the plant can be expected spread north. Fortunately, at the onset of an invasion, there are effective measures for fighting water hyacinth. These steps must be taken before the plant gets established, emphasizing the vital importance of planning for invasions predicted in a changing climate, and the need to constantly monitor 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).

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Appendix A: Inland Water Systems Climate-related Impacts and Challenges

Table 2: Inland Water Systems Climate-related Impacts and Challenges. Table 2 displays the results of a qualitative assessment by Inland Water Team members evaluating various climate stressors and related climate change responses, impacts, and challenges on inland water systems and associated biota. The significance and severity for each climate change response, impact, or challenge is given as the modal response amongst Inland Water Team member ratings according to the following rating scale. [Rating Scale: ++++ Nationally Significant/Severe Impact; +++ Regionally Significant/Severe Impact; ++ Moderate Impact at Any Scale; + Minor Impact or Very Localized Impact (<5 %) where Lakes = lakes (freshwater and saline), ponds, reservoirs, and associated groundwater; Streams = streams, rivers, canals, ditches, and associated groundwater; and Wetlands = all wetland types above current head of tide and associated groundwater.]

Climate Stressor	Response/Impact /Challenge	Lakes	Streams	Wetlands
Increased Air/Water Temperature				
	Thermal tolerance exceeded for certain aquatic organisms resulting in:			
	loss of sensitive taxa via increased mortality, stress, and/or reduced growth and fitness	++++	+++	++++
	increases in populations of non-native species allowing (native and invasive species) adapted to warmer water to become dominant or gain a foothold via more successful species invasions/introductions	++++	++++	++++
	loss of thermally suitable habitat	+++	+++	++++
	shift in distribution or range of species upslope and northward, or inability of species to shift upstream or northward due to habitat restriction or physical, thermal or chemical barriers	+++	+++	++++
	Reduction in or exacerbation of existing low dissolved oxygen levels			

	resulting in:			
	lower DO levels generally, episodically or seasonally (e.g., in highly degraded systems in summer)	+++	+	+++
	synergistic stress (with higher temperatures) to aquatic organisms, leading to reduced growth, fitness or survival	+	+++	+
	Increased blue-green algae (cyanobacteria) and noxious algae blooms resulting in:			
	toxins affecting human health, domestic animals, and wildlife	++	+	+
	increased noxious algae blooms impairing water quality and altering food webs	+++	+	+
	Thermally tolerant species increase, such as:			
	non-native fish spp.	++++	++++	++++
	noxious and exotic species	++++	++++	++++
	Less ice coverage resulting in:			
	changes in lake dynamics (i.e., productivity and food web structure) and increased evaporation during winter affecting water budgets and levels	++	**n/a**	+++
	Increased duration of lake stratification resulting in:			
	decline in cold water fish needing oxygenated hypolimnetic refugia in late summer important to coldwater fish and other aquatic organisms	++	**n/a**	**n/a**
	Disruption of aquatic and terrestrial food webs through phenological changes causing:			

	mismatching of primary and secondary production, associated all life stages, and susceptibility to diseases	++	++	++++
	Increased susceptibility to contaminants, diseases and parasites contributing to:			
	higher levels of stress, reduced fitness, or mortality of aquatic biota	++++	+++	++++
	increase in frequency and/or severity of disease or parasite outbreaks	++	++	++++
	Temperature-dependent sex determination: skewing of sex ratios	++	+	++
	Increased evapotranspiration rates resulting in:			
	impact on hydrologic budgets - decreased soil moisture, groundwater levels, water levels in lakes and wetlands, and streamflows	++++	+++	+++
Decreased Water Quality				
	Increased precipitation / runoff leading to:			
	increased water turbidity affecting fitness and survival of aquatic organisms	++	++	++
	increased nutrient loading causing eutrophication and shifts in aquatic communities	++	++	++
	increase contaminant loading causing the impairment and loss of sensitive species	+	++	+
	increase in abundance and distribution of pollution-tolerant, non-native and invasive species	++	++	++
	Decreased precipitation / runoff resulting in:			

	increased salinity and the inland movement of salt wedge causing habitat losses and changes in species distribution and composition	+	+	+++
Changes in Water Quantity, Timing or Availability				
	Increase or decrease in the amount and/or type of precipitation resulting in:			
	changes in seasonality and run-off timing of flow that shift floral and faunal assemblages	++	+++	++
	disruption of egg incubation, emergence, and reduced survival of early life stages of fish, amphibians, riparian plants, and disruption of aquatic foodwebs	++	+++	+
	Changes in snowpack and permafrost melt affecting:			
	quantity of runoff and timing of streamflows	+++	+++	+++
	upslope or northward habitat/species shift or loss	++	+++	+++
	Decrease in the amount and type of precipitation resulting in:			
	reduced water for streams, lakes and wetlands and/or modification or loss of habitat and habitat connectivity	+++	+++	+++
	Increase in the amount and type of precipitation resulting in:			
	additional run-off that causes the spread of invasive species due to greater interconnection of water bodies	+	++	+
Increase in extreme events, e.g. storms, wildfires, flooding, drought				
	Extreme events causing:			

	extinction of endangered and rare species or local extirpations of populations	+++	+	+++
	large-scale sediment and nutrient loading	+++	++	+++
	bank erosion and channel instability	+	++	+
	loss of vegetation and/or soil	+	++	+
Sea level rise and tidal/storm surge				
	Loss of freshwater habitats in coastal areas	+	+++	+++
	Increased salinity in coastal freshwater wetlands affecting associated biota	++	++	+++
Changes to ecosystem services				
	Loss of commercial, recreational, traditional and subsistence uses of aquatic fish, other aquatic organisms, wildlife, and plants	+++	+++	+++
	Locally diminished supplies of water for agricultural, industry, and municipal uses and increasing demand from human population growth, causing pressure on water resources for aquatic ecosystems	++++	++++	++++
	Loss of natural storm buffering, flood mitigating, and water purifying capacities due to loss of wetlands and floodplains	+++	+++	+++
	Changes in nonconsumptive recreational uses	++	++	++
	Changes in or loss of ceremonial, subsistence and/or cultural practices	+++	+++	+++

Appendix B: Team Members and Acknowledgments

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Acknowledgments

The Inland Water Technical Team and Strategy Management Team would like to sincerely acknowledge and thank the experts, academics, and professionals who completed an informal review of this document.