SWIMMING UPSTREAM

FRESHWATER FISH IN A WARMING WORLD

NATIONAL WILDLIFE FEDERATION®

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Frank Weissbarth

EXECUTIVE SUMMARY

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Whether fly fishing for wild trout in the legendary waters of Yellowstone National Park or ice fishing on Michigan's famed Black Lake, fishing traditions hold a special place for Americans of all ages. Generations have enjoyed our nation's clean waters in pursuit of the fish that give life to rivers, streams, and lakes across the country. Today, angling is big business, generating $26 billion annually in expenditures by some 27 million adults.

Changing climate poses new risks for our treasured freshwater fish resources. Warming waters mean lost habitat for cold-water species, the likely encroachment of species typically found in warmer areas, and exacerbation of existing stressors such as habitat loss, pollution, invasive species, and disease. More extreme weather events—especially longer and more intense droughts, heat waves, wildfires, and floods—mean increased likelihood of fish mortality. Shorter winters with less snow and ice cover mean shifts in stream flow and water availability through the spring and summer months, as well as lost opportunities for ice fishing.

We need to act swiftly to protect our fishing heritage. We must cut the carbon pollution that currently is on track to cause significant warming by mid-century. At the same time, we must take steps to safeguard fish and their habitats from the climate changes that we can no longer avoid. This requires redoubling our efforts to restore and expand critical habitat, while carefully considering climate impacts in all our conservation activities. Finally, we must manage our water resources in a way that ensures that both people and fish have the clean, cool, and abundant water they need to survive.

A NEW THREAT FOR FISH

Fishing is a great family activity enjoyed by anglers across the nation. But, scientists and anglers alike are noting changes in fish species and the rivers, streams, and lakes they call home. It is clear that climate change is creating new stresses on fish, whether brook trout in Appalachia, walleye in the Midwest, Apache trout in the arid Southwest, or salmon in the Pacific Northwest. Many of these species already face numerous environmental threats—including invasive species, habitat loss, disease, and pollution—leading to the federal listing of 147 freshwater fish species and populations as threatened or endangered.[1] Indeed, an estimated 37 percent of freshwater animals—from fish to crayfish to mussels—are considered at risk, a rate much higher than their terrestrial counterparts.[2] An estimated 55 percent of the nation's river and stream miles do not support healthy populations of aquatic life largely due to nutrient pollution, sedimentation, and habitat degradation.[3]

A wealth of scientific evidence shows that human activities are causing the climate to change. Average air temperatures in the United States have increased approximately 1.5 degrees Fahrenheit since 1895.[4] This warming is mostly due to the addition of carbon dioxide and other heat-trapping gases to the atmosphere. This carbon pollution is primarily from the burning of coal, oil, and gas, with a secondary contribution from deforestation and other changes in land use. The resulting atmospheric warming has ripple effects throughout the climate and Earth system more broadly.[5]

Climate change has direct implications for freshwater fish in the United States. Rivers, streams, and lakes are warming and subject to more severe and prolonged droughts, leaving shallower waters prone to even more warming. Snowpack on western mountains is melting 1 to 4 weeks earlier than it did 50 years ago, shifting the timing of flow regimes that are connected to fish life cycles.[6] More severe wildfires followed by heavier rainfall events are allowing massive amounts of ash and silt to be washed into rivers. Heavier rainfall events also propel pulses of excess sediment, phosphorus, and nitrogen pollution downstream, degrading fish habitat.

The loss of recreational fishing opportunities could have real economic impacts across the nation, particularly in rural areas that depend on angling-related expenditures. In 2011 more than 27 million adults sought out their favorite fishing holes. On average, each angler went fishing some 17 days and spent an average of $934. A significant boost to the economy and jobs, freshwater fishing expenditures totaled more than $25.7 billion in 2011 alone.[7]

By the end of this century, habitat that meets the climate requirements of cold-water species is projected to decline by 50 percent across the United States.[8] For example, native cutthroat trout are expected to lose an additional 58 percent of their current habitat.[9] As a result, the number of days anglers participate in cold-water fishing is projected to decline by more than 1 million days by 2030 and by more than 6 million days by the end of the century. Associated with the decline in fishing days for cold-water fish is a projected annual national economic loss of as much as $6.4 billion annually by the end of the century, if carbon pollution is not curbed.[10]

Freshwater Fishing Recreation in 2011

State	Freshwater Anglers	Freshwater Fishing Expenditures
Alabama	598,000	$368,812,000
Alaska	302,000	$348,229,000
Arizona	637,000	$691,744,000
Arkansas	555,000	$481,107,000
California	1,352,000	$1,301,129,000
Colorado	767,000	$612,692,000
Connecticut	243,000	$152,178,000
Delaware	55,000	$7,591,000
Florida	1,214,000	$709,725,000
Georgia	763,000	$740,358,000
Hawaii*	22,000	$3,658,000
Idaho	447,000	$361,629,000
Illinois	937,000	$729,581,000
Indiana	716,000	$573,057,000
Iowa	473,000	$258,551,000
Kansas	400,000	$164,788,000
Kentucky	554,000	$722,017,000
Louisiana	720,000	$504,802,000
Maine	283,000	$252,968,000
Maryland	227,000	$395,878,000
Massachusetts	294,000	$105,863,000
Michigan	1,361,000	$1,896,784,000
Minnesota	1,413,000	$2,305,289,000
Mississippi	609,000	$260,188,000
Missouri	1,071,000	$618,381,000

State	Freshwater Anglers	Freshwater Fishing Expenditures
Montana	267,000	$243,927,000
Nebraska	207,000	$165,266,000
Nevada	147,000	$129,515,000
New Hampshire	209,000	$110,581,000
New Jersey	258,000	$100,358,000
New Mexico	278,000	$401,758,000
New York	1,212,000	$895,763,000
North Carolina	1,054,000	$574,377,000
North Dakota*	106,000	$87,701,000
Ohio	1,161,000	$1,015,294,000
Oklahoma	729,000	$396,015,000
Oregon	516,000	$445,594,000
Pennsylvania	874,000	$347,592,000
Rhode Island	42,000	$16,913,000
South Carolina	537,000	$494,158,000
South Dakota	268,000	$197,485,000
Tennessee	826,000	$1,084,278,000
Texas	1,758,000	$608,287,000
Utah	414,000	$431,329,000
Vermont	207,000	$115,543,000
Virginia	551,000	$455,818,000
Washington	743,000	$691,510,000
West Virginia	305,000	$422,650,000
Wisconsin	1,107,000	$1,078,412,000
Wyoming	303,000	$438,872,000

* Hawaii and North Dakota use the most recent applicable data from 2006.
Source: U.S. Fish and Wildlife National Survey of Fishing, Hunting, & Wildlife-Associated Recreation (FHWAR), 2011.
http://www.census.gov/prod/www/fishing.html

TOO HOT TO HANDLE

Water temperatures in rivers, streams, and lakes are increasing, with significant impacts for fish health and distributions. In a study of 40 major rivers and streams in the United States, half experienced significant warming trends over the past 50 to 100 years.[11] Another analysis found that 70 percent of the watersheds in Arizona, New Mexico, Colorado, and Utah experienced warming during the past 55 years.[12]

Fish are especially sensitive to water temperatures, as indicated by their generalized grouping into cold-water, cool-water and warm-water species. As water temperatures move away from a species' optimal temperature range, growth and survival rates decline, reproductive success declines and the fish become more susceptible to pollution, parasites, and disease.[13] Via these mechanisms affecting fish health and populations, water temperatures play a fundamental role in determining the distribution of the various fish species.

Increasing water temperatures, in combination with other climate change factors, are expected to make more northerly areas less suitable for cold-water species and more suitable for warm-water species. For example, the Great Lakes could become more suitable for warm-water fish such as smallmouth bass and bluegill, but less suitable for cool-water and cold-water species such as northern pike and whitefish.[14] Suitable thermal habitat for walleye, a cool-water species,[15] is projected to shift northward as the climate warms.[16]

Whether warm-water species actually benefit as waters warm depends on a number of factors. Growth rates may increase in warmer waters, but so too would stress from excessively high temperatures. Northerly lakes may become more suitable for warm-water species, but fish may have no means to move into these areas unassisted. Warming may also affect prey species or the broader ecosystem.

Warmer air could also lead to earlier stratification of lakes and ponds in the spring, causing increases in summer fish kills due to oxygen-depleted waters. Seasonal temperature stratification is a normal process for temperate zone lakes wherein the steep temperature gradient between shallow warm water and cold deep water during the summer prevents mixing of the water layers.[17] This inhibits delivery of oxygen-rich water from the surface to the lower depths, leading to fish kills in deep waters.[18,19] In states like Minnesota where early stratification is becoming an issue, lakes may someday be unable to support lake trout and other species that live in the deepest, coldest zones.[20]

Rising temperatures threaten to compromise the success of restoration efforts underway in many freshwater systems. For example, the restoration of a diverse fish community to Ohio's lower Black River is at risk due to rising stream temperatures projected with climate change.[21] The maximum temperature thresholds[22] for 12 of 22 of the river's fish species assessed would be exceeded by mid-century based on projected increases in water temperature. Especially vulnerable are the river's cool-water species, such as the white sucker, as well as popular sport fish such as pumpkinseed, yellow perch, rock bass, and smallmouth bass.

Brook Trout: Warmer Temperatures Threaten an Already Stressed Species

The cold-water brook trout, sporting a blush underbelly and lightly speckled with dots across its body, enjoys a special honor in Virginia. As the official state fish, the brook trout is an essential part of the state's thriving fishing and wildlife industries. It inhabits only the coolest, clearest, and cleanest flowing streams and rivers in most of the eastern United States and throughout the mountains of Appalachia.

About half of the brook trout's historic range has been lost due to a number of factors, including poor grazing practices, deforestation, and competition from introduced brown and rainbow trout.[23] As air temperature increases due to climate change, brook trout are expected to lose additional habitat as the cool water they depend upon warms and oxygen levels decline. More frequent droughts can further harm brook trout by reducing stream flow and killing vegetation, which provides shade that helps keep streams cool.

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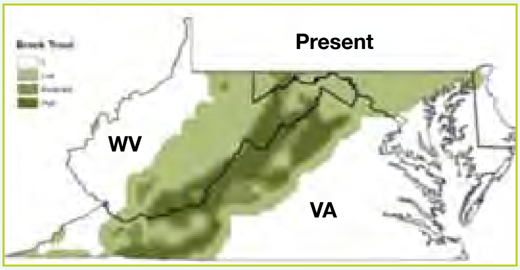
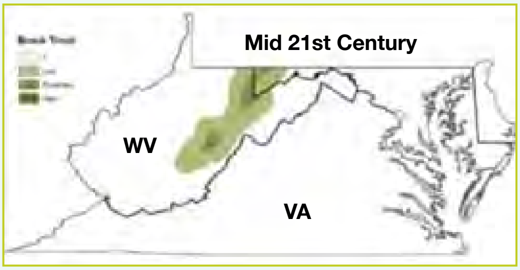
Brook trout have already been extirpated from more than 35 percent of their habitat in Virginia. A recent climate modeling study projects that brook trout could be extirpated from Virginia by mid-century.[24] "Warmer and drier won't be good for trout, period," says Graham Simmerman, chair of the Virginia Council of Trout Unlimited. "Brook trout have proven to be very adaptive and resilient to habitat disruptions, but warm, oxygen-depleted stream conditions are not easily avoided."

Despite these bleak projections, Simmerman and his organization are looking for more ways to help preserve brook trout populations. "We are identifying places that might be resilient to climate change, bringing money and resources to try to secure those places for the long term, and putting in projects to enhance those habitat areas." Without such protections in place, it seems that Virginia's beloved state fish may entirely disappear.





Brook trout distribution at present (left) and projected for the mid 21st century (right) for a business-as-usual emission scenario.[25, 26]

MORE EXTREME WEATHER CREATES NEW CHALLENGES

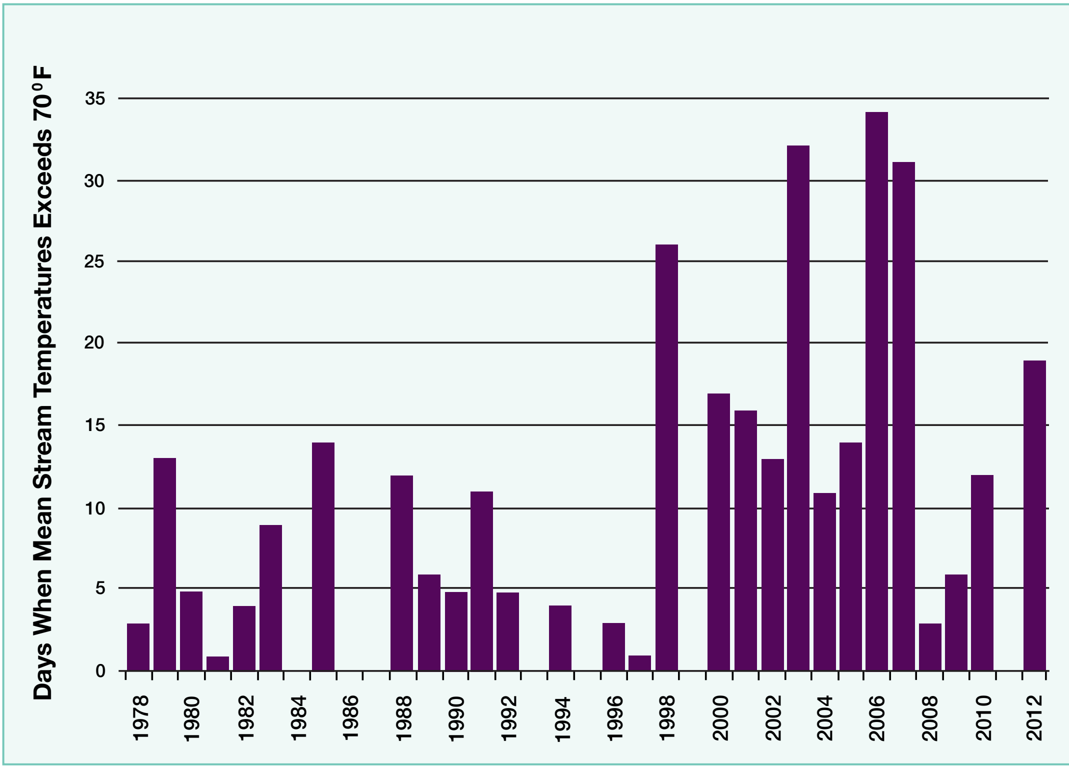
The summer of 2012 was a window into the sorts of weather and climate extremes that climate change is bringing. Average temperatures for June through August were the third warmest on record, with July the hottest month ever recorded for the nation. Nearly two-thirds of the contiguous United States experienced drought conditions. Wildfires spanned more than 3.6 million acres across the western and central United States during August, a record for the month.[27] Just one year later, many states in the Ohio Valley and on the East Coast contended with much more rainfall than normal, often accompanied by major flooding.[28] These climate extremes are creating new challenges for fish across the nation.

U.S. Forest Service

During heat waves, water temperatures can become warm enough to cause massive fish kills, either through direct thermal stress or by creating conditions conducive to dangerously low levels of dissolved oxygen. During the summer of 2012, fish kills attributed to high water temperature were reported in many states, including Iowa, Michigan, Minnesota, Pennsylvania, Wisconsin, Ohio, Indiana, and Illinois.[29] For example, nearly 58,000 fish, including 37,000 sturgeon with a market value of nearly $10 million, died along 42 miles of the Des Moines River.[30]

Extreme heat is a concern for fish requiring cold waters, such as trout and salmon, but even warm-water species are susceptible when water temperatures exceed their temperature thresholds. For example, more than 1,700 walleye in Kansas's Cheney Reservoir were killed a year earlier when water temperatures exceeded 80 degrees Fahrenheit in late August 2011.[31]

In many cases, it is the combination of drought and high temperature that proves fatal for fish. As water levels decrease during drought, the remaining water can more easily warm, leaving fewer cool- or cold-water refuges for fish. Furthermore, receding water can shrink and fragment available habitat, leaving fish stranded. The potential for more frequent and severe droughts, especially in the Southwest, is particularly worrisome when combined with the increasing demand for water by the rapidly expanding population in the region.



Daily mean stream temperatures exceeded 70 degrees Fahrenheit and were thermally stressful for trout in the Madison River, near McAllister, Montana. Data Source: USGS.

Climate change is also leading to an increase in the frequency and severity of wildfire in the West.[32,33,34] While fish can typically survive the fires themselves, they are at much greater risk in the aftermath. The lack of trees and groundcover means less shading to keep rivers cool and a greater likelihood of extensive erosion. Heavy rainfall events coming on the heels of a wildfire can wash large quantities of silt and ash into local streams.

The combined effects of drought and wildfire have been particularly severe for trout in the Southwest. Native Apache, Gila, and Rio Grande cutthroat trout have been the focus of multi-decade conservation efforts. The biggest threat to these species is non-native trout that compete with, prey upon, and hybridize with the native trout. To address this threat, managers commonly isolate native trout using in-stream barriers. Unfortunately, when drought and wildfires strike, native trout cannot relocate from their isolated stream segments and many can perish. This scenario has played out several times in recent years. For example, trout populations declined 70 percent in the South Platte River following the 2002 Hayman Fire in Colorado.[35] The 2011 Wallow Fire took place in the Apache-Sitgreaves National Forest,

Heat and Drought Mean Lost Opportunities to Fish in Prized Streams of the Greater Yellowstone Ecosystem

"The rivers and streams that flow through Yellowstone support some of the world's most renowned fisheries and the fantastic angling opportunities that go with them," says Land Tawney, Executive Director of Backcountry Hunters & Anglers. Native cutthroat trout are the crown jewel of Yellowstone's fisheries. Biologists estimate that up to 42 species—including otters, osprey, and grizzly bears—rely on these native icons, making them a critical link in the food chain.

Drought and summer heat waves are combining with other threats—such as invasive lake trout, whirling disease, and hybridization with rainbow trout[40]—to put Yellowstone cutthroat trout at increasing risk. Several tributaries are now running dry in late summer, interrupting trout migration and making them more vulnerable to predation. During recent hot summers, the National Park Service issued widespread fishery closures. For example, stretches of the Madison, Gibbons, and Firehole Rivers were closed in August 2012 due to high air temperatures, low precipitation, and runoff of warm geothermal waters.[41]

"Guides, outfitters, fly shops, and rural communities depend on these waters to feed their families and pay the bills," says Tawney. Closures of destination fishing locations can have major economic implications. Indeed, the fishing opportunities in Yellowstone National Park alone are valued at between $67.5 and $385 million annually.[42]

Unfortunately, streams across the Rocky Mountain region have been warming up. For example, the average number of days each year that are thermally stressful for trout has approximately tripled in Montana's Madison River since the 1980s (see Figure on page 7).[43] This warming, combined with the other factors affecting trout habitat, do not bode well for anglers like Tawney.

"For me, fishing the aqueous veins of Yellowstone goes beyond the pursuit of high alpine backcountry adventures and the lure of leviathan trout in its big rivers," says Tawney. "These waters are truly a unique place that have shaped traditions and the heritage that my family treasures. I feel obligated to protect the health and vitality of these waters cherished by those who came before us and as a legacy to my children."

Flickr / USFWS

important habitat for Apache trout in Arizona.[36] And, Gila trout in New Mexico's Gila National Forest had to be manually relocated following the 2012 Whitewater-Baldy Complex Fire, the largest wildfire ever recorded in New Mexico.[37]

In much of New England the problem is not lack of water, but too much, especially in large doses. Rainfall and storm intensities are increasing across much of the region with more than 90 percent of U.S. weather stations reporting increases in storms dropping more than one inch of precipitation.[38] Parts of New England have had "100-year" storm events in 2005, 2006, and 2007. This has resulted in major flooding and, in some places, misplaced efforts to channelize streams to speed runoff. Unfortunately, these attempts at flood control degrade fish habitat by removing trees and boulders, and eliminate the connections between rivers and floodplains. When floodplains are restored, their trees provide shade and cool streams while the floodplains themselves store floodwaters and reduce damage.

A dramatic hypoxia event in Maine's Lake Auburn during the summer of 2012 exemplifies how the combination of multiple extreme events can cause surprising impacts for fish. Unusually warm spring weather caused lakes throughout Maine to be free of ice anywhere from 4 to 6 weeks earlier than their historical average. By early June, lake surface temperatures in central and southern Maine reached 80 degrees Fahrenheit. Then, the Lake Auburn watershed received 6 inches of rainfall in a 24-hour period, resulting in severe soil erosion from the watershed and nutrient loading to the lake. Preliminary studies indicate that the warm water and heavy nutrient loading were major factors leading to excessive algal blooms. Dissolved oxygen levels in the deeper areas of the lake were the lowest on record, leading to significant die-off of the lake trout population.[39]

CHANGING COMPLEXION OF WINTER

Climate change isn't just making summers hotter; it is also changing the nature of winter. Winters are becoming warmer and shorter on average. For ice anglers across the Midwest and Northeast, this means fewer days cold enough to sustain sufficiently thick ice cover. Meanwhile, fish species that rely on the runoff from melting mountain snowpack are facing earlier peak stream flow as melting occurs earlier in the season. They then must contend with insufficient flow by late summer and fall, when the snowpack melt has been exhausted.

Ice fishing: A tradition melting away?

Ice fishing is a beloved pastime throughout the Midwest and Northeast. The cold winters in Wisconsin, Minnesota, Michigan, New Hampshire, Maine, Ohio, and Iowa have long sustained a culture of ice anglers who can't wait for the ice to be thick enough to get out and spend hours catching yellow perch, bluegills, and other panfish.

This sport has spanned generations, but is now at risk of disappearing as warming winters are literally taking this pastime out from under anglers' feet. Ice anglers know the ice fishing season, which is entirely dependent on the ice being thick enough to walk on, is short and can end abruptly as soon as the weather warms. Unfortunately, as carbon emissions continue increasing, these fishermen and women can expect warmer winters and even shorter seasons—a change that already is starting to happen.[44]

Winter temperatures across the Midwest and Northeast are increasing at about twice the national average, with many states having warmed 3 to 4 degrees Fahrenheit since 1970.[45] As a result, the Midwest is seeing fewer days that ice is covering lakes in the region.[46] Since 1855, researchers at the University of Wisconsin-Madison have recorded the dates when the surrounding lakes have frozen ("ice in") and melted ("ice out"). The data show a clear overall

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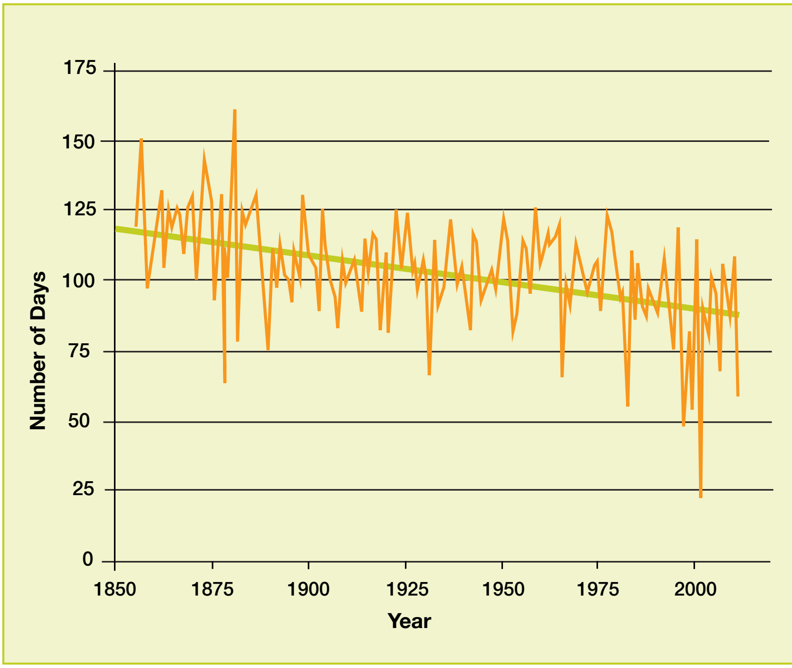
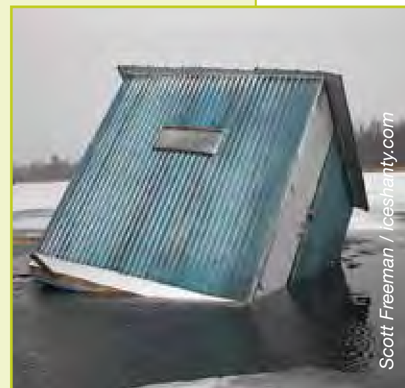




Long-term change in ice-cover duration for Lake Mendota, Wisconsin. Source: National Climate Assessment.

trend of ice-in dates coming later and ice-out dates coming earlier, resulting in an ice season that is almost 18 days shorter than it was 150 years ago.[47]

Midwesterners and Northeasterners are also concerned about the economic impacts to local businesses that rely on winter tourism. Many communities host ice festivals, dog sled races, snowmobile races, and ice fishing tournaments to bring commerce to their area in the winter. In recent years, ice fishing competitions, derbies, and demonstrations were cancelled in the Midwest and Northeast because of the lack of safe and secure thick ice, and worse still, authorities reported numerous cases of cars and people falling through the ice in states like Minnesota and Maine. These cancellations have greatly impacted the communities that financially rely on cold winters.[48]

Declines in ice cover can also affect some coldwater species, such as the lake whitefish. Because the survival of their eggs is highly dependent on winter ice cover that protects against wave damage, the abundance of lake whitefish populations in the Great Lakes region has been directly linked to the timing and amount of ice cover. The continued decline in ice cover projected to occur with climate change will likely have a strong impact on future reproductive success for this species.[49]

Opportunities Lost on the Ice

"Our long-standing ice fishing heritage is something that is deeply entrenched in our culture," says Brenda Archambo, president of Sturgeon for Tomorrow in Michigan and a 4th-generation ice angler. "I have so many fond memories of spending days out on the frozen lakes here in northern Michigan, sitting in a warm, comfortable shanty with my father, grandfather, uncles, and brother—and now, with my family, grandchildren, nieces, and nephews."

Abby Batchelder

Archambo has witnessed the impacts a warming climate has had on ice fishing and understands all too well what these changes mean for this tradition. "I used to log about 100 ice-hours per season. But winters aren't normal anymore, and the past few years I only have logged about 25 hours of ice time. The conditions just have not been the same the last few winters, making it unsafe to go out onto the ice in many areas."

New Hampshire native Jason McKenzie has also witnessed the effects of a changing winter firsthand. McKenzie's family has run the Suds N' Soda convenience store and sport shop for more than half a century, but the warming winters are hurting business.

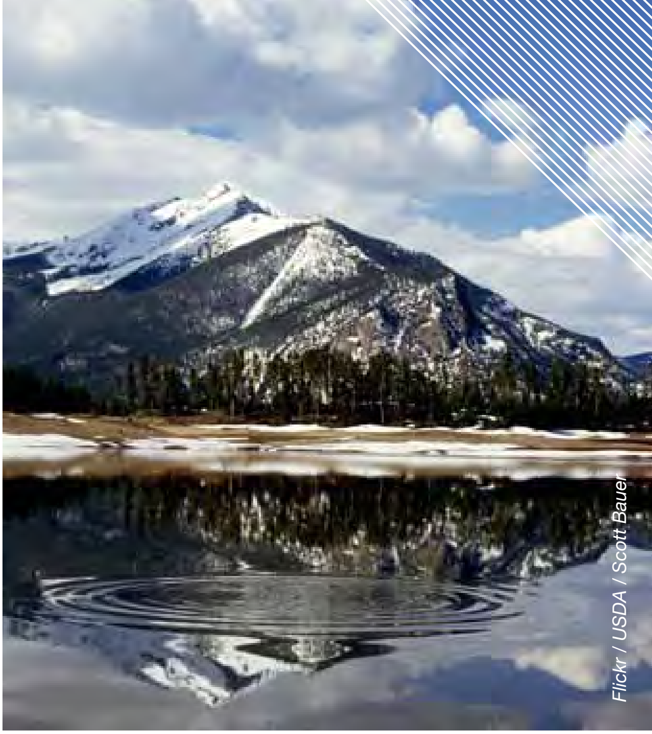
"We've had to adjust our inventory since winter and ice-fishing went away five years ago," McKenzie says. "We just can't count on a New Hampshire winter to provide us with ice fishing business like we used to."

The recent mild winters have prevented historically safe ice-fishing areas from freezing and kept anglers away. As a result, two-thirds of McKenzie's inventory was left unsold in 2010. The next year, wary ice fishermen and women were reluctant to buy any equipment, worrying the trend of unseasonable warmth would continue.

For anglers, the loss of ice fishing is not just about the economics. Says Archambo, "I'm concerned these changes will affect our ice fishing heritage and future generations of ice anglers. It's incumbent on us to instill a stewardship ethic in the next generation, and the best way to do that is to get them outdoors to experience and appreciate nature. Without memorable outdoor experiences, there's not going to be anyone here to defend our sport in the future."

Shifting Snowpack Has Downstream Impacts

Many fish species are especially dependent on melting mountain snowpack for stream and river flow. Increased temperatures over the past several decades have already begun to alter the amount of average snowpack and the timing of springtime snowmelt, leading to changes in the timing of runoff and peak stream flows. For example, in western North America, snowpack is melting 1 to 4 weeks earlier than it did just over half a century ago.[50] Even the mildest climate projections estimate snowmelt will occur an additional 2 to 4 weeks earlier within the next century.[51] Earlier snowmelt and reduced average snowpack means that peak flow occurs earlier in the season and summer flows are lower.


Flickr / USDA / Scott Bauer

Such changes in stream flow will have numerous effects on fish. They will disrupt the migratory behavior and timing of several fish species, for example, by impeding their ability to orient themselves for effective navigation.[52] Reproductive success will be affected for those species that time reproduction to coincide with pulses in stream flow. Earlier peak flow can scour streams and destroy the gravel beds that some trout, steelhead, and salmon use for nesting sites.[52,54] For example, the increasing frequency of high flows in winter, associated in part with more rain-on-snow events, is projected to especially affect fall-spawning brown trout and brook trout in the Pacific Northwest.[55] Even the stream insects that fish depend on for food are disrupted as adults emerge earlier and at smaller sizes than would normally occur.[56]

With increasing demand for water resources throughout the western United States, more stress will be put on water storage systems and freshwater fish populations. Yet such systems are highly threatened by the reduced amount of snowpack and the timing of its melting, as 75 percent of the water resources in many western states are tied exclusively to snowmelt.[57] Much of the water in snowmelt-dependent waterways is allocated for various human uses, including energy production, agriculture, and municipal supply. Water shortages in many regions will present potential harm for fish species, as tradeoffs arise between maintaining fish populations and continuing intensive irrigation and hydropower.[58] New storage solutions will have to be considered to ensure that water is distributed effectively, efficiently, and fairly, and that essential populations of salmon, trout, and other fish are not harmed in the process.

Pacific Salmon and Tribal Traditions in the Pacific Northwest

Salmon fishing is deeply important to the culture and economy of tribal communities in the Pacific Northwest. Pacific salmon spawn and rear their young in the cold, clean waters of the Columbia, Nooksack, Skagit, Klamath, and other famed rivers spanning northern California to Alaska. Salmon populations have already declined significantly from historic levels, owing to a number of obstacles including dams and pollution. Now, climate change poses yet another threat to the future of Pacific salmon.

Flickr / goingslo

For Indian tribes, salmon declines pose immediate risk to their way of life. Because tribal fishing rights are constrained to specific locations, the reduction of salmon populations in these areas can affect tribes acutely. The cultural, economic, and religious resources of these tribal communities are being threatened, and they may be lost if protections are not put in place for salmon.[59]

In California's lower Klamath River, the Yurok and Hoopa Valley Tribes have traditionally depended on abundant salmon resources. Increasingly warm water in the river during summer and fall has heightened the importance of restoring and protecting cold-water tributaries that provide refuge for migrating salmon and steelhead and enables them to reach their spawning grounds. Blue Creek is the primary cold-water refuge in the lower river where nearly all migrating fish stop off and cool down during warm months.[60] Protecting these high quality cold-water inflows, such as from the Blue Creek watershed, becomes more critical as climate change proceeds.

For Billy Frank, Jr., chairman of the Northwest Indian Fisheries Commission, safeguarding Pacific salmon is a high priority for current and future generations. "We're running out of time," said Frank in a recent interview.[61] "We've got to make a change."

CLIMATE CHANGE ADDS INSULT TO INJURY FOR FISH

Our freshwater ecosystems have borne the devastating effects of multiple assaults. Intensified land clearing and development have destroyed or degraded shorelines, floodplains, and wetlands. Pollution enters our waters from factories, farms, cities, roads and suburbs. Coal plant emissions are doubly harmful: they pump carbon into the air and toxic waste into the nation's waters. Sediment, pesticides, herbicides, and fertilizer enter our waterways from agricultural lands. Excessive water use dries out some streams. Dikes, dams, and stream channelization all change the basic ecology of aquatic ecosystems. The introduction of non-native species and diseases creates additional stress. Climate change will interact with these various stressors, in many cases creating even more challenging conditions for fish.

Invasive Species

Invasive species are a leading factor in freshwater fish extinctions and endangerments, damage our natural ecosystems, and are costly to manage.[62] In the Great Lakes region alone, aquatic invasive species cost local people, businesses, utilities, and communities at least $200 million a year.[63] Invasive species have high growth and reproduction rates, allowing them to spread efficiently and aggressively. Invasive species threaten native fish by preying on these species, out-competing them for food or other resources, causing or spreading disease, and negatively impacting their reproduction.[64]

Higher average temperatures and changes in precipitation patterns caused by climate change are expected to enable the expansion of many invasive species into new ecosystems.[65,66] As many invasive species can tolerate a wide range of environmental conditions, a changing climate may allow these species to further impact and out-compete native species that are not adapted to the new conditions.

The likelihood of more droughts and more heavy rainfall events also will affect dispersal of invasive species. Low water flow can reduce dispersal opportunities and might slow the spread of invasive aquatic species, while the opposite is true for high water flow conditions. The interaction of climate and invasive fish are important factors driving the structure of trout communities.[67,68]

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Wikimedia commons / USGS

Sea Lamprey Invasion: Impacts Increase in the Great Lakes as Climate Warms

In the Great Lakes region, the invasive predaceous sea lamprey is well-known for harming native fish species such as lake trout, whitefish, chubs, burbot, walleye, catfish, and sturgeon.[70] This aquatic vertebrate, native to Atlantic coast watersheds, is thought to have made its way to Lake Ontario in the early 1800s through shipping canals, and from there, spread to the other Great Lakes by 1939.[71,72] Sea lamprey spend part of their life cycle attached to fish and feeding parasitically on their blood, often scarring and killing the host fish. Under certain conditions, only one out of seven host fish will survive.[73]

Its aggressive feeding behavior and the lack of any predators already give sea lamprey a distinct advantage against native Great Lakes fish species. By the 1940s and 1950s, sea lamprey combined with overfishing led to the collapse of lake trout, whitefish, and chub populations,[74,75] with a substantial impact on the local economy.

Now, climate change is expected to give sea lamprey an even bigger advantage. In Lake Superior, summer surface temperatures have increased 4.5 degrees Fahrenheit since 1980.[76] Scientist Tim Cline has studied the shifting species distributions and interactions in Lake Superior associated with this warming. "One species that has clearly benefited from warmer waters and longer growing seasons is the invasive sea lamprey that, lake wide, have increased in size by 12 percent," Cline says.

Cline notes that bigger lampreys create bigger problems for native fish. "Larger lampreys consume more blood, kill more host fishes, and lay more eggs," which further benefits them and puts native fish species at greater risk. The growth of lampreys in size and population will make it that much harder to control and manage this destructive invasive species.

Climate change will pose further challenges for management and control strategies by altering the way invasive species interact and spread.[69] Preventing new invasions is the most effective and economical method for protecting the nation from the threats posed by invasive species. Management of established populations of invaders must consider how climate change will affect the success of control strategies.

Water Withdrawals

We rely on freshwater for irrigation, drinking water, agriculture and other purposes. These withdrawals reduce water levels, making our lakes, streams and rivers more prone to warming and evaporation, leading to even further decline in water levels. The combination of low flows and warm waters can reduce oxygen levels and exceed temperature thresholds for fish, which may harm or kill them. In a warming world with more periods of intense drought, water resources will be less readily available and will have to be stretched further for irrigation and energy purposes, especially in the summer. By 2060, U.S. freshwater withdrawals are projected to increase by 12 to 41 percent due to energy demands and human population growth.[77]

Much of these future withdrawals will occur in the southwestern United States, an area already experiencing water scarcity, extreme droughts, and harsh heat waves that may be more frequent in the future.[78] Fish populations in this area tend to have smaller habitat ranges and therefore fewer options for relocation as conditions change.[79] The combination of increased water demand and climate change may cause river flow to decline as much as 48 percent, further limiting available fish habitat.[80] With water rights already an issue of contention among states in the region, lower flows in the coming years will only cause more strife and peril for people and freshwater fish.

Disease

Climate change may increase the vulnerability of fish to disease. Rising temperatures can stress fish, making them more susceptible to infection, as well as lengthen the period during which diseases may be transmitted, leading to increased infection and impact.[81] Warmer waters can facilitiate shorter regenerative cycles for diseases, increasing disease prevalence.[82] Increasing temperature may also increase the virulence of some diseases.[83]

Several links between climate change and fish disease are already raising concerns in fisheries across the country. For example, concerns have been raised about the potential for large fish kills from Columnaris (see box on page 18). Fueled by hot weather during the summer of 1998, a Columnaris outbreak killed an estimated 70,000 to 80,000 white bass in Kansas's Cheney Reservoir.[84] Higher temperatures can also lead to higher prevalence and severity of proliferative kidney disease in salmon, with an associated increase in mortality. Although the overall geographic range of the disease may decline, outbreaks are projected in more northerly areas as temperatures rise.[85] Another disease—Ichthyophonus—develops more quickly and has greater prevalence and higher mortality in rainbow trout in warmer waters than those in cooler waters. The invasive pathogen that causes the potentially fatal whirling disease is likely to increase as the climate warms. The neurological damage and skeletal deformation caused

Columnaris Disease: A Growing Concern in Warming Waters

Columnaris is a deadly bacterial disease in fish. Naturally present in freshwater ecosystems, it usually does not cause serious problems for otherwise healthy fish populations. However, it is well known that outbreaks of the disease can cause large fish kills when water temperatures increase. Temperatures between 68 and 86 degrees Fahrenheit are conducive for outbreaks while temperatures below 59 degrees Fahrenheit rarely cause mortality.[87]


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"In 2005, I first saw a large die-off of smallmouth bass in the Susquehanna River, which has subsequently become the new normal in hot years with low water flow," says Ed Perry, formerly with the U.S. Fish and Wildlife Service "Columnaris was identified as the primary source of mortality, and now we are seeing the same type of disease outbreaks occurring in the Delaware, Allegheny, and other rivers. Rising water temperatures that trigger the disease and cause the die-offs of smallmouth bass are a major concern. At times Susquehanna River temperatures exceed 90 degrees Fahrenheit." Investigations continue on contributing factors to the smallmouth bass die-offs caused by Columnaris.[88]

On the other side of the country, Senior Scientist Jack Williams of Trout Unlimited has similar concerns. "Right here in Oregon's Rogue River, fall and spring Chinook are susceptible to Columnaris," says Williams. "The disease is not a problem at higher water flows and in cool water but becomes really nasty at lower flows and higher stream temperatures. Exactly how much of this is caused by climate change is, of course, hard to tease out, but we are likely to see an increasing frequency of those conditions that contribute to outbreaks of the disease as our summers warm."

by this disease can severely and negatively affect salmonid ability to swim, feed, and avoid predation, and increases in virulence in warmer streams.[86]

Water Pollution

Our nation's waterways still face major challenges from pollution. Climate change may complicate efforts to address these challenges by altering how pollution makes its way into our water bodies and the extent to which fish are sensitive to pollutants.[89]

More frequent heavy rainfall events in certain parts of the Midwest, such as Ohio, along with increased drainage,[90,91] have washed excessive quantities of phosphorus and nitrogen into streams, lakes, and ponds, leading to algal blooms and subsequent oxygen-depleted hypoxic zones. Algal blooms can be further stimulated by warmer water temperatures.[92] Some algal species such as blue-green algae (cyanobacteria) can be toxic, causing illness and death for fish and wildlife.[93,94] Escalation of harmful algal blooms and hypoxia will have serious economic and ecological implications, particularly in places like Lake Erie that support economically important fishing industries.

Climate change is also expected to worsen the effects of pollution from heavy metals, especially mercury, in many freshwater systems.[95] When coal is burned in power plants mercury is emitted to the atmosphere, deposited into soils, and then washed into streams, lakes, and rivers. As coal burning continues and heavy rainfall events become more frequent, more mercury will contaminate aquatic environments. Increasing frequency of severe wildfires is also expected to increase mercury pollution because wildfire can char the soil, releasing mercury that can wash into waterways.[96,97]


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Once in the water, warmer conditions would hasten the conversion of mercury into toxic methylmercury, because the organisms that convert mercury to methylmercury thrive in warmer bodies of water.[98] Fish populations are especially sensitive to methylmercury, and can accumulate it through the food chain. Methylmercury can limit reproductive success by nearly 40 percent, increase mortality rates in fish embryos,[99] reduce liver size and function, and lower growth and development rates.[100,101]

CLIMATE-RELATED SHIFTS IN THE BROADER ENVIRONMENT

Our favorite fish species are also vulnerable to ways that climate change, in combination with other environmental stressors, are expected to affect the entire aquatic food web. Aquatic invertebrates are an important food source for fish. Mayflies, which fly fishers try to mimic when tying flies, may spend many months under water as nymphs but only one day out of water as an adult.[102] Mosquitoes and midges, which we love to hate, are important fish food in their aquatic nymphal life stages. Then, there are dragonflies and damselflies, voracious underwater predators as nymphs, but which we regard so reverently due to their brilliant colors as they dart through the air when adults. Even some moths,[103] beetles, wasps,[104] and flies[105] spend part of their life cycle in freshwater ecosystems.

The incredibly rich diversity of aquatic invertebrates is highly sensitive to water conditions.[106] Changes in aquatic invertebrate communities can be useful indicators of how climate change is affecting water conditions. For example, aquatic invertebrates, such as caddisfly, mayfly, stonefly, and mosquito larvae have a range of temperatures to which they are best adapted.[107] It follows that warming summer water temperatures and other climate change factors will affect the abundance and composition of aquatic invertebrate communities. A study of mosquito and midge larvae in Vermont found a strong dependence on water levels, with mosquitoes having more reproductive success when water levels were lower and midges preferring water levels that consistently stayed high.[108] The emergence of the adult life stage of many aquatic insects is keyed into peak stream flows and water temperatures. As adult females emerge earlier because of earlier snowmelt, their smaller bodies produce fewer eggs, which impacts future generations.[109]

Mussels are an important component of many healthy aquatic habitats and are even more susceptible to changes in stream flow regimes than fish.[110] The United States has the greatest diversity of freshwater mussels in the world, with more than 290 species, many of which are concentrated in the Southeast.[111] Many mussels have life cycles that are inextricably linked with freshwater fishes, relying on particular fishes to transport their larvae to new locations.[112] It follows that changes in fish communities also affect mussels. The alteration of natural flow regimes in rivers has been the major cause of mussel decline in the United States,[113] suggesting that they will be sensitive to further changes in flow regimes driven by climate change.

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The Southeastern United States: An Aquatic Biodiversity Hot Spot

Although freshwaters cover only 1 percent of Earth, they are home to 10 percent of the world's animal species, including 40 percent of all fish species.[114] The southeastern United States is a global hot spot for this aquatic biodiversity. For example, more fish species are found in Tennessee's Duck River than in all of Europe.[115] Only 290 miles long, the Duck River is home to 150 fish species, 55 freshwater mussel species, and 22 aquatic snail species.[116] The southeastern United States also has the largest number of imperiled fish and mussels in the country.[117] Now this rich aquatic diversity is at further risk due to climate change.

"I can already see the effect of climate change on North Carolina's rivers," says Fred Harris, past president of the American Fisheries Society and current Resource Specialist with the North Carolina Wildlife Federation. "Floods are bigger, droughts are more severe, and the ecosystem seems less stable. It is critically important that we protect the Southeast's incredibly rich community of aquatic life for healthy rivers for our children's future."

One of the rarest fish in North America is the diamond darter, found only in a 22-mile stretch of West Virginia's Elk River. It has been severely impacted by extensive loss and degradation of its habitat. When first proposed for listing under the Endangered Species Act, the increasing likelihood of droughts and floods in the region due to climate change was identified as a concern.[118] Given its already limited range and genetic diversity, the diamond darter is especially vulnerable to these sorts of extreme events.

"Climate change only serves to exacerbate the continued threats to the diamond darter from sources like insufficient wastewater treatment and natural resource extraction and development, which have already degraded water quality," says Kathleen Tyner, conservation and advocacy program manager for the West Virginia Rivers Coalition. "At long last, the diamond darter was listed as an endangered species this year and will receive the strongest protections available."

GIVING FRESHWATER FISH A FIGHTING CHANCE

We can no longer wait to take action to address the increasing threats to America's freshwater fish. Climate change is already having significant impacts on important rivers, streams, lakes, and ponds, as well as the fishing opportunities they provide. The past century's conservation achievements are now at risk from the pervasive effects of climate change. Anglers, boaters, shoreline property owners, fisheries managers, and many others all have a vested interest and role to play in safeguarding fish and their aquatic habitats in the face of climate change.

Get at the Root of the Problem and Tackle Carbon Pollution

The threats to the nation's fish will only increase if carbon pollution continues on the business-as-usual path. Urgent action is needed to change the course we are on: We must move away from the current reliance on fossil fuels and invest in clean energy solutions that do not pollute. Fortunately, we have the tools and know-how to start making this transition today. While the climate crisis is ultimately a global problem, America can be a leader in driving forward policies here at home. Addressing carbon pollution requires the following priority actions:

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- **Use and protect the proven, existing laws to tackle carbon pollution.** The Clean Air Act was put in place to protect people and wildlife from pollution. Under this law, the U.S. Environmental Protection Agency (EPA) has the authority and obligation to limit carbon pollution, most notably from large sources like coal-fired power plants. The President has set a clear path for the EPA to issue and finalize the first-ever limits on carbon pollution from new and existing power plants by 2016. This rulemaking is a key component of a national plan to reduce the carbon that drives climate change.

- **Prioritize clean energy and reduce fossil fuel use.** A serious effort to reduce carbon pollution must include smart energy choices that reduce dependence on fossil fuels and move us quickly towards a future powered by clean energy. Investing in clean energy options such as wind, solar, geothermal, and sustainable bioenergy will reduce our consumption of carbon-polluting fuels like coal, oil, tar sands, and natural gas, which are driving climate change. It is essential that clean energy sources be developed in an environmentally responsible way to minimize potential effects on fish and wildlife.

Dirty Power Plants and Water Use

The electricity generated in the United States today overwhelmingly comes from thermoelectric power plants that use water as part of the process to produce energy from coal, oil, and natural gas. Each day, these plants withdraw hundreds of billions of gallons of water.[119] Older 'once-through' systems discharge water back into the lakes, streams, or rivers where it originated, but typically at a higher temperature. Newer re-circulating systems withdraw much less water, but end up consuming more, such that less is discharged back into waterways.[120]

Billions of fish and other aquatic life are killed annually by power plants. In the state of New York alone, more than 17 billion fish, their larvae, and their eggs are mutilated or destroyed each year.[121] Many fish are sucked into the power plants with the water or are trapped on intake screens. Others are unable to tolerate the higher temperatures of discharged water, which may approach or exceed thermal thresholds or lead to algal blooms that deplete oxygen and suffocate fish.

By 2030, increased demand for electricity is expected to increase freshwater consumption by thermoelectric plants by nearly 30 percent.[122] Meanwhile, nearly a quarter of current electricity generation is projected to encounter extreme water sustainability issues, in part related to climatic shifts.[123] These conflicting projections for the future—one showing we will need more water for electricity and the other noting less water will be available—show firsthand the problems presented by thermoelectric power generation moving forward.

The "National Fish, Wildlife, and Plants Climate Adaptation Strategy," released in March 2013, is available at http://www.wildlifeadaptationstrategy.gov/.

- **Protect and restore natural carbon sinks.** In addition to transitioning to clean energy, we must also enhance nature's ability to balance the system. Restoring the ability of farms, forests, wetlands, and other natural lands to absorb and store carbon not only provides critical habitat and increased benefits for wildlife, but also helps mitigate climate change.

Safeguard Freshwater Fish and Their Aquatic Habitats from Climate Change

Climatic shifts are amplifying the effects of a host of existing threats to our species and ecosystems, and undermining the ability of natural systems to provide for both people and fish. To sustain our rich legacy of conservation achievements and ensure the survival of cherished fish species, policies and practices will have to embrace climate-smart approaches to conservation. Preparing for and managing these changes—climate adaptation—increasingly will need to serve as the basis for fish conservation and water resource management. We can prepare for and cope with the new conservation challenge of climate change by taking the following actions:

- **Design, fund, and carry out climate-smart conservation strategies** that can help fish adapt to climate change. Priority steps are to adopt forward-looking conservation goals and design conservation actions that reduce climate vulnerabilities and enhance ecosystem resilience. The National Fish, Wildlife and Plants Climate Adaptation Strategy represents a shared federal, state, and tribal vision for 21st century conservation, and should be aggressively implemented. Federal and state programs critical to advancing climate science and adaptation will require adequate funding to be successful. These include several relatively new efforts intended to meet these new needs, such as the U.S. Department of the Interior's Climate Science Centers and Landscape Conservation Cooperatives, as well as existing programs that are being refocused or expanded to address climate adaptation, such as U.S. Fish and Wildlife Service's State Wildlife Grants program, state wildlife action plans,[124] and the National Fish Habitat Action Plan.[125]

- **Minimize other stressors on aquatic ecosystems**, such as habitat degradation, invasive species, pollution, sedimentation from roads, and development in floodplains and along shores. In many cases, reducing the cumulative impacts of these other factors can directly protect fish from harm and increase the resilience of fish populations, making it possible for them to survive some climate-related stresses. For example, protecting and restoring wetlands and forested riparian buffers along tributary streams will help shelter, buffer, and cleanse streams, mitigating higher water temperatures, sedimentation, and pollution stressors and increasing resilience of stream ecosystems. Ensuring stringent limits are placed on mercury emissions and toxic discharges from coal power plants will help safeguard fish populations and fish habitat. Clean Water Act permitting standards and Farm Bill conservation incentives are important tools for minimizing habitat and water quality degradation and encouraging climate-smart restoration.

- **Prioritize and promote the use of non-structural, nature-based approaches**—such as wetlands and riparian buffer restoration, and floodplain protection—in lieu of levees and reservoirs. These approaches minimize impacts on fisheries while also providing benefits to communities such as clean drinking water, flood protection, filtering out of pollutants and excess nutrients, and maintaining water quality. Where new development or infrastructure is necessary, direct it away from sensitive aquatic habitats and climate-vulnerable areas by using water permitting and land-use planning tools such as zoning, comprehensive plans, and incentivizing development in less vulnerable areas. Urban landscapes should be made sustainable through smarter planning and design choices that use green infrastructure—including landscape features (open space, parks, wetlands) and low-impact development—to minimize storm surges and reduce polluted runoff.

Successful climate adaptation benefits from a watershed-scale approach. The left face shows degraded habitats where the cumulative impacts from climate change will be more severe. The right face shows strategies of protecting best remaining habitats in the headwaters, restoring lower elevation valleys, and reconnecting stream networks between the two. Source: Trout Unlimited.

Improve Water Infrastructure and Management

As population increases in the coming decades, so too will the demand for freshwater to support agriculture, municipalities, and energy production. Coupled with higher temperatures and the increasing likelihood of severe and prolonged droughts, water shortages are expected to increase. It is essential that we consider the implications for fish and other aquatic species as federal, state, and local agencies wrestle with how to address these challenges. Important steps that can be taken now include:

- **Upgrade water infrastructure.** Demand for water will continue to rise as the population grows. As more freshwater is removed from the natural system, less is left for fish and habitat. As infrastructure ages, it loses its ability to efficiently transport water, resulting in waste. Experts estimate that drinking water systems lose 6 to 25 percent of water, depending on their condition, adding up to an estimated 25.3 billion gallons of water wasted from leaky pipes each day across the nation.[126] Investing in federal Drinking Water and Clean Water State Revolving Funds can reduce waste, increase efficiency, and reduce the demand on natural freshwater sources. When upgrades are made, they should be based on projected future climatic conditions.

- **Optimize existing water infrastructure and management to enhance aquatic ecosystems.** The reproductive success and survival of freshwater and anadromous fish are dependent upon the volume, quality, and timing of freshwater flow. Federal and state permitting policies should require compliance with practices that optimize aquatic habitat, water quality, and fish spawning needs for changing climate conditions.

- **Use natural water storage.** Intact wetlands and functioning floodplains, in lieu of dikes and dams, are cost-effective ways to store water and minimize flooding, while also maintaining flows beneficial to fish and other aquatic life. Construction of dams and reservoirs should be avoided. They are costly to build and maintain and completely change the natural ecology of streams and lakes.

- **Establish broader in-stream flow requirements that account for future climate conditions.** Many riverine systems are managed without a complete assessment of competing uses. Water-use permits are issued with incomplete consideration given to in-stream needs. This is akin to purchasing real estate without first comparing monthly mortgage payments with monthly income. Accordingly, water managers should assess the in-stream and downstream requirements to maintain a healthy riverine ecosystem, as well as how climate change may affect water availability, and then manage water supply to maintain that required flow.

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