A person wearing a bright orange vest, a red cap, and camouflage pants stands in a snowy forest. They are holding a rifle. The trees are heavily covered in snow, and the ground is a thick blanket of white. The scene is bright and wintry.

Seasons' End

*Edited by the
Wildlife Management Institute
in cooperation with the following
sportsmen's organizations:*

- Ducks Unlimited
- Trout Unlimited
- BASS/ESPN
- Izaak Walton League of America
- Association of Fish and Wildlife Agencies
- Coastal Conservation Association
- American Sportfishing Association
- Pheasants Forever



Seasons' End

Global Warming's Threat to Hunting and Fishing

EDITED BY THE WILDLIFE MANAGEMENT INSTITUTE



BIPARTISAN POLICY CENTER

© 2008 by the Bipartisan Policy Center

All rights reserved. This book or portions thereof in any form whatsoever may not be reproduced without the expressed written approval of the Bipartisan Policy Center, Washington, DC.

Text and design by Koupal Communications, Pierre, South Dakota

*Additional information related to global warming's
threat to hunting and fishing can be found at*

www.seasonsend.org

A man with a beard and glasses, wearing a tan jacket and a cap, stands in a field of tall grass. He is holding a shotgun and a bird. In the background, there is a rustic building with a stone wall and a wooden roof. The sky is blue with some clouds.

CONTENTS

<i>Acknowledgments</i>	<i>vii</i>
<i>Foreword</i>	<i>ix</i>
<i>The Science of Global Warming</i>	<i>1</i>
<i>Waterfowl</i>	<i>7</i>
<i>Freshwater Fish</i>	<i>25</i>
<i>Big Game</i>	<i>45</i>
<i>Upland Birds</i>	<i>61</i>
<i>Saltwater Fish</i>	<i>79</i>
<i>Strategies for Hope</i>	<i>95</i>
<i>Appendix: Sportsmen's Letters to the U.S. Senate</i>	<i>108</i>
<i>Photography Credits</i>	<i>111</i>

Acknowledgments

The Wildlife Management Institute wishes to thank the following organizations and their affiliated authors and professional staffs. Their research papers, listed here, serve as the basis of this book. Without these contributors' dedication, persistence and expertise in writing technical reviews of global climate change and its effects on fish and wildlife, this book would not have been possible.

The Institute also wishes to recognize John Cooper, senior adviser to the Bipartisan Policy Center, for his tireless assistance and thorough review of the text; and Koupal Communications' Bill Koupal, Sharon Coogle, Tami Collins, Lisa Yessick and Diana Coogle, who wrote, edited and designed *Seasons' End*.

American Sportfishing Association (Fish America Foundation) and Coastal Conservation Association

Title: *Climate and Saltwater Fisheries: Prognosis for Change*

Authors: William Connelly, Lisa Kerr, Ed Martino, Adam Peer, Ryan Woodland and Dr. David Secor, all of the Chesapeake Bay Biological Laboratory, University of Maryland Center for Environmental Science

Association of Fish and Wildlife Agencies

Title: *Climate Change and Wildlife Health*

Author: Dr. John Fischer

Bass Angler Sportsmen Society/ESPN

Title: *Potential Impacts of Global Climate Change on Warmwater Fisheries of the USA*

Authors: Galen Kaufman and Dr. Mike S. Allen of the Department of Fisheries and Aquatic Science, University of Florida

Ducks Unlimited Inc.

Title: *Conserving Waterfowl and Wetlands Amid Climate Change*

Authors: Dr. Scott Yaich and Dr. Alan Wentz

Izaak Walton League of America

Title: *A Whole New Game: Climate Change Effects on Hunting, Fishing and Outdoor Recreation — a Five State Study*

Author: Nancy Lange

Pheasants Forever Inc.

Title: *Climate, Weather, Non-Migratory Upland Game Birds and Global Warming: Some Facts and Perspectives to Consider*

Authors: David E. Nomsen, Dr. Kenneth F. Higgins, Kent C. Jensen and Amy R. Lewis

Trout Unlimited

Title: *Prescriptions for Troubled Waters: Restoring Resistance and Resilience to Climate Change in Native Salmonid Populations*

Authors: Dr. Jack Williams and Steve Moyer

Western Association of Fish and Wildlife Agencies

Title: *Potential Impacts of Global Climate Change on Abundance and Distribution of Elk and Mule Deer in Western North America*

Authors: James C. deVos Jr. and Ted McKinney

Wildlife Management Institute

Title: *Adapting to Climate Change: Agency Science Needs to Adapt Game Management to a Changing Global Climate*

Authors: Dr. Steve Williams and WMI staff

Foreword

America's anglers and hunters enjoy a vast diversity and abundance of game species. Whether it is tarpon fishing in the Florida Keys, stalking elk in the Rocky Mountains, hunting waterfowl in the hardwood bottoms of Louisiana, fishing for eastern brook trout in the Appalachians or chasing pheasants in the Great Plains, we enjoy truly impressive opportunities for fishing and hunting. The diverse habitats of the United States and the conservation actions of the last century have delivered abundant and widely distributed populations of fish and game.

However, all is not well with the future of fishing and hunting. A controversial, yet real, global climate trend threatens to disrupt generations of plant and animal adaptations. Global warming threatens the health and well-being of both animals and their habitats. The varied impacts of climate change are potentially widespread. As the temperature gradually increases across the planet, we will experience

changes in the amount and patterns of precipitation, in the frequency and intensity of weather events, in the distribution and duration of drought, in levels of snowpack and the time of their melting, in timing of runoff and flooding, and in the timing of animal and plant life cycles. Each of these factors, alone and in combination, will undoubtedly affect plant growth, structure and distribution. They also may directly impact a species' ability to reproduce and survive.

There will be winners and losers. We should expect that the geographic ranges of fish, wildlife and habitats that we observe today will shift. Big game will have to adapt to changes in their forage base. They will likely alter their migration patterns. Changes in water quality and quantity will affect both saltwater and freshwater ecosystems and their fisheries. Wetland losses predicted for the prairie pothole region will severely reduce waterfowl productivity in North America's duck-breeding "factory." Invasive species, including

parasites and disease-causing organisms, may flourish in warmer temperatures, profoundly affecting habitat and challenging the survival of upland game birds.

Combine these natural-world changes with those caused directly by humans and the future looks even more challenging. Increases in human population and our growing demand for energy, development, transportation and natural resources will further strain our natural landscapes as they contend with climate change. These trends threaten to unravel relatively delicate, natural landscapes in an unprecedented manner.

In spite of incomplete knowledge about climate change and speculation about its impacts on our fish and wildlife resources, there is too much at risk not to take action now. As fish and wildlife abundance and distribution shift in response to climate change, those entrusted with managing these resources will have to adjust their activities to detect and adapt to the changes, whether real or perceived. Management agencies must take steps to monitor fish and wildlife resources and mitigate the effects of climate change by protecting critical wildlife habitat and adapting their management programs that protect

and conserve fish and wildlife populations. It will be critical that these agencies have the tools and financial resources to detect and adapt to change.

Hunters and anglers are likely to be among the first to experience the impacts of climate change due to their familiarity with game species and their habitats. Hunters and anglers can assist wildlife management agencies by becoming aware of climate change effects and by advocating sound, professional wildlife management and funding to achieve that goal.

Ultimately, hunters and anglers will see their hunting and fishing opportunities modified. What does this mean to the hunter or angler? In some of the fields, forests and waters where we have enjoyed past successes and great memories, there will be no opportunities to hunt or fish. The fishing and hunting traditions passed down from prior generations may deteriorate. We may have to travel to new areas to hunt some species. Some species may not exist in numbers that allow hunting, and seasons may be curtailed or dramatically changed in other ways. If fishing or hunting exists in the lifetime of our children and theirs, it may take on an entirely new face.

Humans have played a role in climate change and in conservation. Our conservation successes are borne out by the variety and abundance of species that make our nation so unique. Fish and wildlife beckon many of us as the seasons change, and we take the opportunity to pursue these wild and abundant resources. These opportunities should be passed on to future generations for their enjoyment. How we address the challenges of global climate change will dictate much of that future opportunity.

This book contains a compilation and synthesis of information generated by some of the leading conservation organizations in the nation. Its companion Web site, www.seasonsend.org, keeps readers up to date by posting ongoing studies of climate change, publishing

current observations from the field, offering subscriptions to action alerts and providing tools for sharing knowledge about global warming. Also available on the Web site are the sponsoring organizations' research papers in their entirety. Each organization recognizes that the implications of global climate change affect its members and the species and habitats they have successfully conserved and cherished for decades. All of us who are concerned about the future of fish, wildlife, their habitats and our outdoor heritage will benefit from their work and the information contained herein.

**Steve Williams, President
Wildlife Management Institute**





The Science of Global Warming

Nearly everyone who enjoys the out-of-doors has noticed signs of global warming — milder winters, drier summers, fewer snowfalls, fiercer storms — but debate has raged over the cause: Is global warming a natural cycle that in time will reverse itself, or is human activity responsible for changing the climate?

Now scientific evidence demonstrates with a high degree of certainty that a buildup of greenhouse gases is warming the earth and changing the climate. Ice core samples prove that carbon dioxide concentrations are the highest in 400,000 years, and they are increasing at an unprecedented rate — 30 times faster than 10,000 to 20,000 years ago. And the evidence imputes human consumption of fossil fuels as the primary culprit of this dramatic increase.

Warming the Earth

By trapping heat from the sun near the planet's surface, greenhouse gases, of which carbon dioxide (CO₂) is the most prevalent, warm the earth. Before the advent of the industrial age, plants on land and in the oceans absorbed roughly the same amount of CO₂ as was released from occurrences such as respiration, decomposition of plants and animals, volcanic eruptions and the burning of fossil fuels. Now, the escalating use of coal, gas and oil releases about 45 percent more CO₂ than can be absorbed. The excess accumulates in the atmosphere where it remains for at least a century, capturing solar heat and warming the globe.

The Climate Connection

As atmospheric concentrations of greenhouse gases increase, the temperature of air, land and water rises. Because temperature influences components of weather such as water evaporation, rainfall and wind, global warming affects climate.

Scientists are able to paint a broad-strokes forecast of changes likely to occur, a forecast that improves in detail and precision as data collection increases, as interactions among climatic factors are more thoroughly understood and as climate modeling improves. Presently the scientific community consistently predicts the following climate changes will take place during the next century:

- Overall temperatures will warm, with the most dramatic changes occurring in high latitudes. North America could experience increases of as much as 10 degrees Fahrenheit by 2099.
- Warmer temperatures will decrease snowfall, thus diminishing reflective ground cover and reducing seasonal storage of water as snowpack, and increase rainfall, thereby augmenting runoff and stream flows and boosting the threat of floods.
- Warmer temperatures will speed the melting of glaciers and sea ice, which will freshen ocean waters and accelerate the worldwide rise of sea levels.

- Warmer oceans will alter weather patterns. For example, the El Niño phenomenon seems to originate in the central Pacific Ocean, where water temperatures have risen in concert with global warming. El Niño influences rainfall and temperatures over land and can cause droughts, floods, wet winters and other extreme weather events. Global warming may result in El Niño-like conditions and trends becoming semipermanent.
- Precipitation patterns will shift. Hurricanes and thunderstorms will occur with greater frequency and intensity. In some regions precipitation could increase by as much as 24 percent. In other places long seasons of unusually hot, dry conditions could shrink surface water and introduce extended droughts.

Climate and the Natural Environment

There is a strong association between climate and the earth's living communities. Climate is a primary determinant of what lives where, what food is available and where suitable habitat conditions exist.





Global warming could cause the decline of some species that physiologically cannot adjust to warmer temperatures, such as moose and trout. Among other species, global warming could interrupt life history events that are triggered by temperature or precipitation, such as migration or reproduction. And global warming will affect other species by destroying or dramatically altering essential habitat. Following are projected effects of climate change on fish and wildlife habitat:

- Rising sea levels could inundate and destroy coastal wetlands, drown aquatic nurseries and increase estuarine salinity levels.
- Fierce storms can produce voluminous runoff that flushes silt and pollutants into rivers and streams.
- High levels of atmospheric carbon dioxide could favor fast-growing vegetation of low nutritional value and cause the distribution of trees to expand at the expense of shrubs and grasses.
- Drought could dry up wetlands, shrink surface waters and disrupt aquatic corridors.

- Mild winters can encourage the spread of invasive plants and disease-carrying insects.
- Dry conditions can increase the frequency and intensity of wildfires.
- Warmer temperatures could throw off synchrony between the birth of young and the emergence of food sources.

A species' ability to adapt to changing conditions will determine its long-term survival. If individuals cannot adapt and are unable to move, their species will not persist. Scientists predict that as many as one-third of all plant and animal species may become extinct if average global temperatures increase more than 3.6 degrees Fahrenheit.

The following chapters consider how waterfowl, freshwater fish, upland birds, big game and saltwater fish are likely to respond to global warming, how climate change could affect the sports of fishing and hunting, and actions that stakeholders in the future of the outdoors can take to address the challenges to the natural environment that lie ahead.





Waterfowl

For many waterfowl hunters, global warming is no longer a theory to be debated but a fact to be reckoned with. It's already affecting the way they hunt, the success of their hunts and the timing of their hunts.

While waterfowlers are accustomed to major variations in the number of ducks and geese in the flyways, historically the timing of migrations has been predictable enough for many hunters to plan their trips years in advance. "I've been hunting the Missouri River for 40 years, and I could always count on birds' being here by the first week in November," says Tony Dean, noted outdoorsman and conservation communicator from South Dakota. "But the migration has been getting later and later. Last year we saw more ducks in the closing days of the season than we'd seen at any other time in the

year. Global warming isn't some kind of nerdy abstraction; it's what I deal with every time I throw out my decoys."

Dean is not alone in his experience. Hunters from the Dakotas to Louisiana, from California to Virginia are reporting that migrations are occurring later in the season — and in some instances, not occurring at all. "Here in the central flyway, there are large numbers of Canada geese that are cutting short their southern migrations," says John Cooper, former U.S. Fish and Wildlife special agent and retired secretary of the South Dakota Department of Game, Fish and Parks. "Geese that used to winter along the Missouri River in Nebraska and South Dakota now seem to be ending their migrations as far north as Bismarck, North Dakota."

It might appear that late migrations and changes in routes are more frustrating than alarming. It would seem that seasons could simply be moved back and that a shift in migration patterns could be one hunter's loss but another's gain. Like a jump in the number of white cells, though, these changes are markers for what will become a cancer on the waterfowler's world. Scientists fear that in the years ahead the following changes will occur:

- The prairie pothole region could lose up to 90 percent of its wetlands, reducing the number of the continent's breeding ducks by as much as 69 percent.
- The Chenier Plain marshes of Louisiana, supporting over 1.3 million waterfowl today, could eventually support as little as one percent of that number.
- Water levels in the Upper Great Lakes region could drop as much as eight feet, parching wetlands and leading to a regional decline of up to 39 percent in the number of ducks.
- Sea-level rise along the Atlantic coast could destroy 45 percent of the habitat that supports canvasbacks, redheads and pintails.
- Sea-level rise will affect the entire coastal region stretching from California to Alaska and reduce habitat critical to breeding and migrating ducks and geese in the Pacific flyway.
- Climate-induced alterations in the vast Western Boreal Forest of Alaska and northwestern Canada will threaten the 12 to 15 million breeding waterfowl that the forest supports.

What Global Warming Means on the Water and in the Field

“Where are the ducks?” That question most likely leads to a discussion of the effects of global warming and changing weather patterns on waterfowl hunting. Waterfowl can fly wherever waterfowl habitat is available and can therefore adapt to some, but by no means all, of the effects of climate change. As birds adapt to new conditions, which probably will include decreased habitat, hunters will have to adapt their expectations and their practices if their sport is to survive over the coming decades.

Fewer birds, shorter seasons

Global warming will alter waterfowl habitats throughout the continent, contributing to a potentially dramatic decline in overall waterfowl numbers. The presence of fewer birds could cause hunting seasons to be shortened and bag limits to be reduced. Dedicated waterfowl hunters could experience fewer opportunities to enjoy their passion.



Following the birds

As warming continues, hunters can expect delays in the fall and early winter migrations of waterfowl from northern latitudes. Birds finding open water and food sources unrestricted by a cover of ice or snow will stay in northern climates for a longer time. For species such as mallards and Canada geese, only the harshest weather conditions will move them as far south as in the past.

So, for hunters in more northern latitudes, changes in traditional migration patterns will improve hunting in an extended season. Waterfowlers in more southern areas may have to travel to find birds as hunting declines close to home.

Protecting habitat in the fields and in the halls of government

For waterfowl hunting to continue in the coming decades, waterfowl hunters will have to assume responsibilities both in the realm of nature and in the arena of public policy.

In the field, hunters will need to help conserve, protect and restore habitats essential to the survival and resiliency of waterfowl populations. Hunters' support for managing water resources as a public trust will be critical to

- watershed planning
- maintaining river and stream flows
- securing long-term water rights for waterfowl habitat
- implementing wetland conservation programs

Improving the chances of sustaining waterfowl populations will depend on partnerships between the sporting community and management agencies. Hunters who understand the long-term needs of wildlife and participate in shaping policies and management responses to changing conditions will play a critical role. To conserve waterfowl and protect the heritage of hunting in the decades ahead, sportsmen and -women must continue their longstanding tradition of leadership on waterfowl and wildlife conservation issues.



With the mobility afforded by wings, waterfowl may have a better chance to adapt to climate changes than earth-bound species, but ducks and geese will not escape without consequences. Rising temperatures and altered precipitation patterns are predicted to reduce both the quantity and quality of North American waterfowl habitat. As a result, hunters are likely to see declining numbers as well as a major shift in the geographic distribution of migrating birds.

Global Warming and Waterfowl Life Histories

Bird health and reproduction

The number of waterfowl that the nation's hunters see each season depends largely on the birds' breeding success. Studies of mallards and other dabbling ducks suggest that events occurring during breeding season account for as much as 84 percent of the variability in population growth rates.

Rising temperatures will have complex effects on waterfowl breeding, and not necessarily entirely deleterious in every region. For some species in some places, warmer temperatures that melt snow and thaw waterways earlier in the spring may extend the nesting season and increase breeding success.

For example, several studies have found a correlation between increased productivity of lesser snow geese and other white geese and a trend toward earlier spring melt and warmer temperatures in the Hudson Bay region. As average temperatures in Alaska have risen since 1950, arctic geese there have demonstrated a consistent trend toward earlier nesting and hatching. However, a high rate of individual survival may not benefit the overall population in the long run if numbers overwhelm the ecosystem's supportive capacity.

Bird range and migration patterns

In the past 10 years, some hunters in all four North American flyways have noticed that their greatest success has tended to occur later in the season. As yet, there's no definitive proof that birds are migrating later, but hunters' experiences match scientists' predictions that waterfowl will postpone migration in response to climate change.

Seasonal changes in temperatures directly influence when and how far some waterfowl migrate; warmer fall and winter seasons mean waterfowl do not have to fly as far south to find food and ice-free water. As long as open water and plenty of food are available, many birds will remain in northern areas.

Ducks that traditionally winter in Maryland may not migrate that far if their usual stopover points around the Great Lakes stay warmer for the season. On Maryland's eastern shore and in the Chesapeake Bay area, the number of canvasbacks, scaups and mergansers arriving seasonally is already declining.

As a consequence of warming seasons, prime hunting locations could shift. The Midwest and New England may see improved hunting conditions. Spanning colder and warmer regions, states like New York, Illinois and Missouri might see a northerly shift of prime migratory waterfowl destinations within their borders.

Conversely, the quality of waterfowl hunting may decline in the Mid-Atlantic region and in the South. Hunters intent on enjoying the pleasures of the season and on passing sporting traditions down to younger generations could face added expense for travel to productive hunting locales.

No matter how distributions of waterfowl change in response to global warming, factors such as loss of breeding habitat could reduce their overall numbers and adversely affect hunting everywhere.

Global Warming and Changes in Waterfowl Habitat

Many waterfowl are well adapted to dynamic landscapes. However, it appears that climate change within this century could disrupt critical ecosystems across the continent at a pace more rapid than the birds' ability to adapt. Anticipated changes in conditions such as the availability of water, the composition of the food web and the presence of emergent cover will influence population numbers and the distribution of waterfowl. Although there might be both





winners and losers among species, in the struggle to find suitable habitat there will mostly be losers.

Wetlands, lakes and forests

Successful breeding in the prairie pothole region, North America's most important waterfowl nursery, greatly influences the size of waterfowl populations throughout the continent. Temperature and precipitation influence the region's wetland availability and emergent cover, conditions that contribute to determining the number and diversity of breeding birds.

Climate models predict that in the prairie pothole region, warmer temperatures will accelerate the evaporation of water bodies and reduce soil moisture, possibly by 25 percent before the end of this century. Up to 90 percent of the potholes could vanish, consequently reducing the numbers of the continent's breeding ducks by as much as 69 percent. Among the species that would be affected are the mallard, Northern pintail, blue-winged teal, canvasback, gadwall, Northern shoveler, redhead, lesser scaup and ruddy duck.

It is unknown whether waterfowl will be able to adapt by moving from their traditional breeding grounds, or how much suitable breeding habitat they will find elsewhere. Primary prairie pothole habitat could shift from the center (the Dakotas and southeastern Saskatchewan) to the region's wetter but less productive eastern and northern fringes. Already waterfowl habitat in these areas is constrained by wetland drainage and agriculture. Economic incentives for etha-

nol production have promoted the further conversion of grassland and prairie nesting cover into cropland, with consequent declines in habitat for waterfowl reproduction and population recruitment.

In the Upper Great Lakes region, scientists expect average temperatures to warm by 3.6 to 7.2 degrees Fahrenheit, while precipitation could increase by 25 percent by the end of the 21st century. Despite this significant increase in precipitation, higher temperatures are expected to increase evaporation and reduce lake water levels by 1.5 to 8 feet by 2100. Shoreline wetlands along the Great Lakes and the St. Lawrence River, habitat especially critical for diving and sea ducks, would dwindle. By 2030, changes in habitat could lead to a decline of 19 percent to 39 percent in the regional numbers of ducks.

Warming temperatures and changes in precipitation are expected to cause a northward shift in the breeding ranges of mallards and blue-winged teal in eastern North America. Geese have already ventured into the Maritimes of eastern Canada in response to three decades of milder winters and warmer springs. In Canada's Northwest Territories, the mallard, green-winged teal, American wigeon, surf scoter and common merganser are among nine bird species that have expanded their ranges northward as average temperatures have risen.

In regions where wetlands have formed on top of permafrost, thawing temperatures allow water to drain into previously frozen ground, reducing the size of present wetlands. In other areas, new wetlands may form where melting permafrost creates depressions. Scientists

believe the changes could be beneficial to some species of waterfowl that nest and breed in arctic lands, but unfavorable to others.

Many birds use boreal forests for breeding, molting or staging, particularly when the prairies are dry. Because temperature changes are expected to be greatest at the more northerly latitudes, this ecosystem could be among those most affected by climate change. Little is presently known about the relationship between the boreal forest ecosystem and ducks such as scaup and scoters that breed there, so it is difficult to yet anticipate how climate change will affect them.

Coastal habitat

As hunters know, coastal marshes everywhere provide habitat for large numbers of breeding, migrating and wintering waterfowl. Predicted as a consequence of global warming, rising sea levels threaten this critical habitat. Squeezed between rising oceans and coastal infrastructure such as roads and sea walls, coastal wetlands are expected to decline dramatically. Increased storm surges and higher mean tide levels will further endanger waterfowl habitat and survival by accelerating erosion, altering estuarine salinity and influencing the composition and productivity of coastal vegetation.

Coastal land loss and environmental decline are already affecting waterfowl habitat. For example, over the past century the salt marshes of Jamaica Bay, New York, have experienced dramatic loss of marshland due to sea-level change, increased land use and pollution.

Diving ducks such as canvasbacks and redheads overwinter in shallow wetlands along the Atlantic coast. As the climate warms over the next century, the rise in sea level could eliminate up to 45 percent of this vital habitat.

In the coastal region stretching from California to Alaska, human development has reduced the amount of waterfowl habitat. Projected sea-level rise threatens to diminish habitat further by inundating low-lying areas and degrading the quality of the coastal wetlands.

Historically Gulf Coast marshes lying at the southern confluence of the Mississippi and central flyways have provided winter and migration habitat for up to 25 percent of all North American waterfowl. Approximately 75 percent of the world's redheads winter in these wetlands, and more than 90 percent of the world's mottled ducks find year-round habitat there. Among the millions of migratory birds dependent on these marshes are lesser scaup, pintails, gadwalls, American wigeon, and green-winged and blue-winged teal.

Over the past century, navigation and flood control projects have interfered with natural marsh-building processes, resulting in hundreds of square miles of Gulf Coast wetlands converting to open water. With a mean elevation of about one foot above sea level, most of Louisiana's coastal wetlands are clearly vulnerable to the predicted sea-level rise of at least 18 inches over the next 100 years. Whereas the Chenier Plain marshes of Louisiana can support upwards of 1.3 million waterfowl today, conversion of land to open water caused





by sea-level rise could result in a future system able to support as little as one percent of those birds.

Global Warming and Changing Weather Patterns

Rain and snow

While climate change will affect ecosystems across the globe, it will not change the laws of nature: Moisture in the atmosphere will still condense and fall to earth. But climate change will alter where and how that moisture falls.

Although there will be great variability, precipitation is generally predicted to increase in the northern latitudes and decrease in the middle latitudes. But gains in rainfall could be offset by warmer temperatures' increasing the rate of evaporation from lakes and streams. Higher temperatures also increase plants' use of moisture, adding to the overall drying of the environment. As habitat conditions and food sources respond to changes in the availability of moisture, hunters will see waterfowl shift their traditional ranges.

Even where rainfall is projected to increase, changes in precipitation patterns could damage the environment. If, as expected, precipitation occurs in less frequent but more intense events, such as hurricanes, tornadoes and thunderstorms, waterfowl habitats could suffer increased flooding, erosion and pollution from runoff.



Another predicted change is winter precipitation falling more frequently as rain rather than snow. This has year-round implications because snowpack serves as a water storage system, reducing the volume of winter stream flow and releasing water as runoff in the warmer months of spring and summer.

Because climate is a complex interplay of global factors, precipitation patterns are difficult to predict. In the prairie pothole region, for instance, annual rates of rainfall may not change at all, or they may increase as much as 20 percent, with precipitation concentrated in extreme fall and spring events followed by drier summers. Because the ground absorbs rainwater more readily than it does snowmelt, winter precipitation producing more rain and a smaller snowpack could result in fewer and shallower prairie pothole wetlands that dry faster.

Climate change models indicate that current trends in the Pacific Northwest are likely to continue. Over the past 100 years the region has become warmer and wetter, with the average temperature increasing 1.5 degrees Fahrenheit. The volume of snowpack has decreased 11 percent, and the dates of peak snow accumulation and of stream flow derived from snowmelt have shifted 10 to 30 days earlier. As summer rains diminish, agricultural irrigation, urban users and natural ecosystems vie with waterfowl for dwindling water supplies.

Historically, the Great Basin region receives most of its precipitation in winter, so a northward shift of storm tracks would reduce snow-

packs and stream runoff. The result would be a net drying effect with negative implications for wetlands and waterfowl. Another scenario for this region is a northward extension of the monsoons, bringing more summer moisture at least to the southern half of the region. This would not necessarily result in a wetter summer environment, however, as higher temperatures could accelerate evaporation and nullify the gains of moisture from increased rainfall.

In the Sierra Nevada mountains, warmer temperatures are predicted to increase precipitation falling as rain rather than as snow. In most California rivers and streams, the more rapid runoff of rainfall and the earlier melting of snow would increase winter flows and reduce summer flows.

Waterfowl might realize some benefit from future wetter winters in California's Central Valley, as moderate flooding would increase the amount of feeding habitat available, reducing crowding and the likelihood of disease transmission. However, small-volume stream flows in summer could intensify competition for water, to the detriment of waterfowl habitat.

Increased winter precipitation, longer and drier warm seasons, less difference between daytime and nighttime temperatures and increased levels of CO₂ in the atmosphere combined are likely to produce vigorous plant growth. Increasing above-ground biomass could fuel intense, widespread wildfires that alter ecosystem structure and function and lead to permanent changes in waterfowl habitat.

Models vary in projecting climate changes for the South Central states, although the trend is expected to be toward greater extremes of weather, including flood and drought.

Drought

Prolonged drought is clearly detrimental to waterfowl, diminishing the availability of water and disrupting aquatic food webs. Drought can decrease the likelihood of breeding among prairie ducks. If breeding does occur, drought may still adversely affect nesting success, brood survival, clutch size and the likelihood of re-nesting.

Drier conditions will inevitably increase competition for water. Hunting clubs and wildlife refuges — and waterfowl themselves — will be among the throng of users competing for water resources. Without ensuring adequate water to maintain suitable conditions for waterfowl, clubs and refuges could experience silent seasons as birds seek habitat elsewhere.

Global Warming and Waterfowl Food Sources

No matter how high up the food chain a feeder is, weather ultimately controls its food resources. Factors such as the length of the growing season, the availability of water and the difference between daytime and nighttime temperatures — all factors that global warming will influence — affect the kinds and quantities of vegetation that grow,

which in turn affect the animals that eat the vegetation and the animals that feed on those vegetation eaters.

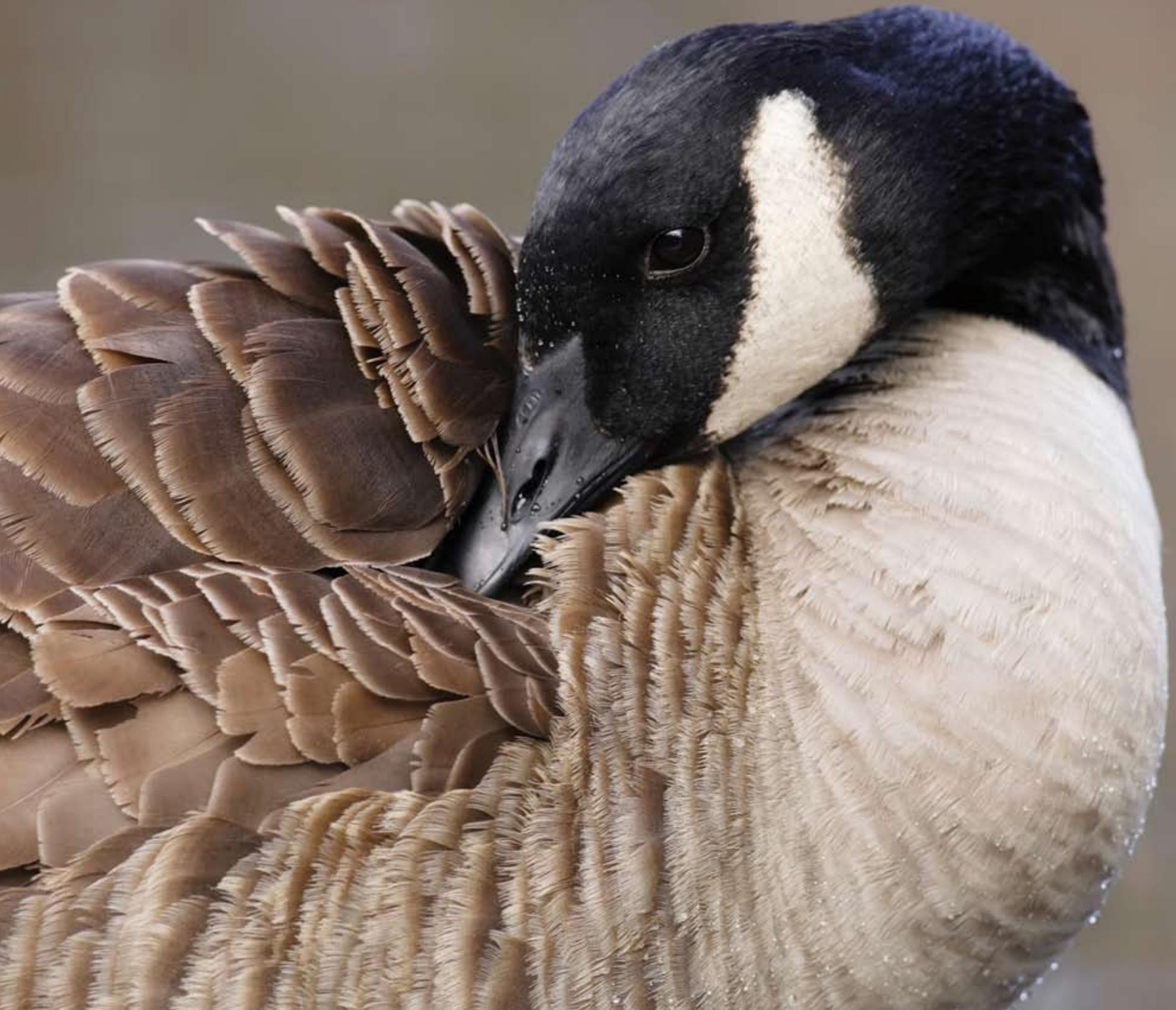
The effects of global warming on food resources will be pervasive. Already there are places where scientists have observed a correlation between rising sea-surface temperatures and a reduction in bird numbers. For example, in Alaska's Prince William Sound populations of white-winged scoters, surf scoters and other waterfowl have declined as warmer waters reduced the availability of the fish that they eat.

Persistently low lake levels could reduce the growth of the kinds of submerged vegetation most important to canvasbacks and redheads. In warming waters, algae and other non-duck foods could replace protein-rich foods such as arthropods. Feeding habitat for species dependent on an invertebrate diet could shrink.

In estuarine habitats, reductions in freshwater stream flows would increase salinity levels and change the availability of waterfowl foods. Everywhere, warmer lake water temperatures and decreased oxygenation could result in increased uptake and concentrations of contaminants throughout the food web.

Warmer temperatures and a longer growing season with fewer days below freezing will most likely favor the northward expansion of non-native, invasive plants, which typically are nutritionally inferior to native plants. Some such species' ranges have been held in check by climate-related factors such as cold and ice. Their advance could





cause shifts in the relative abundance and distribution of native species and significantly alter vegetative communities' structures in ways detrimental to waterfowl.

Summary

The effects of climate change are expected to be both beneficial and detrimental to waterfowl. On balance, however, waterfowl will face serious harm primarily from the dramatic loss of wetland habitat. The critical prairie pothole region of the upper Midwest, known to many waterfowlers as "the duck factory," will become increasingly imperiled, with the probable loss of as much as 90 percent of its wetlands. This in turn could reduce waterfowl populations by as much as 69 percent, an overwhelming impact on these birds and on the ability of hunters to practice their sport. Other areas are likely to be similarly affected. The Chenier Plain marshes of Louisiana will lose their ability to support 99 percent of the 1.3 million birds that currently rely on them for wintering habitat. Waterfowl production in the Upper Great Lakes region is anticipated to decline by as much as 39 percent. Sea-level rise will inundate the Atlantic coast, destroying 45 percent of current canvasback, redhead and pintail habitat. Warm-

ing will threaten as many as 15 million breeding waterfowl that depend on the Western Boreal Forest of Alaska and Canada. In short, climate change may lead to catastrophic losses of waterfowl habitat and species populations throughout North America.

Climate change most likely will have profound, negative effects on waterfowl hunting. The most obvious effect will be that hunters will have fewer birds to hunt and kill each season. This likely will result in lower bag limits and perhaps even compressed hunting seasons. In addition to the loss of habitat and associated waterfowl populations, shifting migration patterns will challenge the ability of hunters to plan hunting trips and successfully find birds at traditional hunting areas in the fall. Already, waterfowl hunters are experiencing noticeable changes in the migration patterns of ducks, geese and other species as the birds migrate south later and later each year. Migrating birds also are taking different routes, in some cases stopping as far north as North Dakota due to warmer weather, more open water and less snow covering their food sources. The changes associated with warming will challenge waterfowl hunters to design and implement creative conservation responses to maintain critical wetland and riparian habitat, including restoring previously drained wetlands and maintaining instream flows.





Freshwater Fish

A little rise in water temperature here, a small drop in water level there, a few more days of drought . . . does it really add up to all that much?

For trout, walleye, bass, pike and other freshwater fishes, it adds up to a lot. In fact, put it all together and you have a crisis that could take the magic out of those graphite wands.

While predictions of global warming are serious for all freshwater fish, they are dire for trout. “It doesn’t take a big jump in the temperature of a stream to wipe out a population of brookies,” says Steve Moyer, Trout Unlimited’s vice president for governmental affairs. “And it happens so fast — seems like they disappear while you’re switching your fly from a nymph to a dry.”

As snowpack decreases in volume and melts earlier in the season and as temperatures shoot up in midsummer, stream flows will plummet. “Trout in streams and rivers at upper elevations will be under a great deal of stress,” says Dr. Jack Williams, Trout Unlimited’s senior scientist. “At lower elevations they’re just not going to survive without a lot of help.”

While more able than trout to adapt to increased water temperatures, bass, bluegill and other warm-water species will face other threats from global warming. For example, changes in precipitation patterns — heavy, flood-producing rains interspersed with extended droughts — will cause major fluctuations in water levels. In lakes, rivers and reservoirs, these fluctuations could dramatically reduce the survival rate of eggs, larvae and fry. “Occasional extreme events have always been part of the weather cycle, but with global warming these exceptions could become the rule,” says John Lott, fisheries chief at the South Dakota Department of Game, Fish and Parks. “If so, recruitment into adult fish among all freshwater species would be seriously jeopardized.”

Current projections of the effect of global warming on freshwater fish include the following:

- Nationally, up to 42 percent of current trout and salmon habitat will be lost before the end of the century, with the South, Southwest and Northeast experiencing especially severe reductions.
- In regions most affected by global warming, trout and salmon populations will be slashed by 50 percent or more. Many trout species already listed as threatened or endangered will become increasingly vulnerable to extinction.
- In the Pacific Northwest, up to 40 percent of the salmon population will disappear.
- In localized, high-mountain areas of the West, bull trout will suffer reductions of up to 90 percent. In the lower elevations of the Appalachian Mountains, as much as 97 percent of the wild trout population will die.
- Sea-level rise will push salt water into rivers, over low-lying land and into freshwater lakes. This salinity will contract suitable habitat for warm-water fishes that require water with low or no salinity.

- Across the nation, increased water temperatures in rivers and lakes will promote the continued expansion of noxious, exotic plant species such as giant salvinia, hydrilla and Eurasian water-milfoil.
- Because fish recruitment in rivers and lakes is frequently tied to water levels, extreme droughts and floods will cause large fluctuations in the quality of recreational fisheries.

What Global Warming Means on the Water

Although predicting the exact timing and effects of global warming on fisheries is, at best, difficult, anglers should be prepared to see significant changes to their sport over time.

Familiar fishing holes just won't stay the same

As higher temperatures accelerate evaporation and contribute to drought, water levels will fall in many favorite fishing locales — small ponds, water-supply reservoirs, local creeks and streams, and public and private dams. This will stress fish populations and affect





angler access. Places popular for family recreation may cease to be places where kids can learn to fish.

Favorite fish will relocate

As fish respond to global warming by moving to new locations, anglers may have to travel farther to catch their favorite species. Or they might be forced to adapt by changing their target species from cool- and cold-water fishes such as walleye, trout or salmon to other, more resilient species that can flourish under warming conditions.

Anglers' support will be critical to preserve public water rights

Policies that protect recreational use of increasingly scarce water resources and reduce stress on fish will likely conflict with efforts to expand control over these same resources for private gain. Anglers' willingness to fight for water quality, water levels and water flows in their favorite lakes, streams and reservoirs will be essential to the success of management plans that safeguard public-trust rights to water.

Changing conditions will shape management practices and regulations

Actions to stabilize fisheries in light of the consequences of global warming may include

- using harvest regulations to protect adult fish
- promoting water use and water allocation measures to protect critical fish habitats
- enhancing habitat to improve fish recruitment during periods of low water

Anglers must educate themselves about adaptive management and how it influences regulations. They will need to stay informed about

actions management agencies undertake in response to changing conditions. Understanding management decisions will strengthen the increasingly important partnership between the fishing community and management agencies.

Protecting fish and habitat will increase the odds of fishes' adapting

Although the challenges that climate change poses to freshwater fish are great, much can be done to build resistance to global warming's effects. Protecting high quality habitats and currently healthy fish populations will, scientists believe, foster fishes' potential to adapt to warming water temperatures and other habitat changes.



Freshwater fishes will experience the effects of global climate change primarily through warming water temperatures and changes in rainfall and stream flow. Climate change will benefit some species as their range expands or as prey increases; other species will decline as their habitats contract and they are physiologically unable to adapt to warmer conditions. Greater volumes of stream flow could deliver more nutrients to fish, or raise mortality by increasing scouring and turbidity. Changes in species' presence and abundance will often refashion freshwater fish communities to the detriment of native species.

Global Warming and Freshwater Fish Habitat

The water in rivers, streams, lakes and ponds, in puddles, brooks and fishing holes is sensitive both to increased air temperatures and to altered weather patterns. Alterations in these two factors will cause far-reaching changes in fish habitats and, by extension, in fish populations.

Temperature and fish habitat

As air temperatures rise, water warms. Fish thrive within a temperature range that varies from species to species; temperatures exceeding the upper or lower limits affect fishes' survival. Fish seeking

cooler water might be able to find it at higher elevations, at more northerly latitudes or in deeper lakes. However, if passage to more suitable conditions is blocked, fish populations may become fragmented, decline and face local extinctions.

A nationwide analysis of the effects of warmer air temperature estimates that five percent to 17 percent of existing trout and salmon habitat could be lost by 2030, rising to 21 percent to 42 percent by 2090. Although substantial losses are expected throughout all regions of North America, losses in the South, Southwest and Northeast could be particularly severe. Most vulnerable are fish populations at the limits of their ranges, such as salmon in California and bull trout in the high-mountain areas of the West. Modeling an increase of 5.4 degrees Fahrenheit in July air temperature predicts losses of stream habitat ranging up to 24 percent for Bonneville cutthroat trout and 38 percent for westslope cutthroat trout. Scientists estimate that up to 90 percent of the wild brook trout in the Appalachians could be lost due to climate change.

Already the effect of rising temperatures has been documented in locations throughout the country. If stream temperatures in Maryland rise a few additional degrees, the eastern brook trout in the western part of the state and even the brown trout will lose the cold-water habitat necessary for survival. In Rapid Creek — a favorite destination among South Dakota anglers — brown trout numbers have fallen by more than 90 percent, due primarily to prolonged drought and associated low stream flow. In Minnesota, it is quite probable

that lake trout will not persist in lakes currently unable to provide an oxygen-rich environment in their deepest, coldest portions.

Lake trout are highly sensitive to increased temperatures. Though in certain cases lake habitats may provide important refuge, most lakes in the lower 48 United States are predicted to become less hospitable to cold-water fishes. Global warming is likely to produce early-season stratification — the phenomenon of warm, buoyant lake water lying atop cooler, denser water. Preventing wind-driven mixing of the thermal layers and delivery of oxygen to the lower depths, stratification causes toxic algae blooms, increases the release of contaminants from bottom sediments and exacerbates summer fish kill. Despite decreased winter mortality, fish losses are expected to increase overall due to summerkills in all but the deepest and coldest northern lakes.

Vegetation plays a number of critical roles in freshwater fish habitat: providing refuge; supplying nutrition to the food web; stabilizing aquatic areas; moderating water flow and temperature; and influencing water quality by affecting sedimentation, contributing dissolved oxygen, and cycling nutrients and other chemicals.

Rising temperatures may remove limitations imposed by frost kill, winter dormancy and abbreviated growing seasons on the range and growth of many aquatic plants. Fish could benefit from the resulting increase in plant diversity and expansion of vegetative cover. However, warmer temperatures accelerate phytoplankton growth, which

could decrease water transparency, stunting growth of submersed plants. And invasive plant species, with their fast growth rates and lack of natural competitors, are expected to benefit most from global warming; their effects on fish would vary and would not be consistently beneficial.

Shoreline vegetation contributes to quality fish habitat by moderating runoff and providing cooling shade. Management practices that maintain riparian flora could mitigate the floods and high temperatures expected to occur under global warming.

Sea-level rise and habitat

Sea-level rise, another consequence of global warming, will push saline water farther into rivers, low-lying lands and freshwater aquifers. As a result, habitat of saltwater-intolerant species will contract. Organisms in coastal areas offering no escape from high-salinity conditions — such as low-elevation wetlands and dammed coastal rivers — will be most vulnerable to the effects of saltwater intrusion.

Precipitation and habitat

Like rising temperatures, changes in weather patterns due to global warming could severely affect aquatic habitats. Extreme variations in rain and snowfall, in deluges and droughts, would disrupt fish and invertebrate community structures in a number of ways.





Deluges flush nutrients, acids, silt and pollutants into lakes, streams and rivers, resulting in the direct mortality of fish in all life stages. High levels of dissolved and suspended particles degrade all freshwater fish habitat; landslides resulting from deluges can cause catastrophic loss in local populations. Because they cannot survive without cold, highly oxygenated, flowing water, trout will be among those most affected by the rapid runoff following extreme storms and heavy rains.

Floods damage aquatic vegetation, especially during winter, by destabilizing the shoreline, uprooting established plants and disrupting rooting zones and seedbeds. Sediment-laden floodwaters restrict the growth of submersed plants by limiting depths at which light is available.

Other effects of global warming could benefit aquatic plants, however. As warmer temperatures cause ice covers on northern lakes to thin and be of shorter duration, plants could receive more light, experience a longer growing season, and colonize and overwinter more successfully.

But overall changes in ice cover may prove detrimental to fish habitat. Lake Superior has already warmed twice as much as air temperatures, which may be due to a lack of ice cover. As a result, Lake Superior's water levels are the lowest in recorded history.

Drought

The variable weather patterns predicted to accompany global warming will cause regional droughts as well as floods. In some places, persistent drought, combined with high water temperatures, has already diminished water reservoirs so severely as to endanger fish. For example, in Georgia's Lake Lanier, prolonged drought has forced bait fish to concentrate in receding waters, a short-term boon to the lake's bass but a long-term threat to the fishery's stability.

Long periods of drought will cause regional declines in the abundance of aquatic plants and lead to changes in the composition of vegetative communities.

Although native fishes are well adapted to natural fire regimes, the increased frequency and intensity of wildfires caused by global warming will be detrimental because of loss of riparian vegetation and increased sediment delivery.

Global Warming and Fish Health

Temperature and fish physiology

Because a fish's body temperature fluctuates with that of its surroundings, fish health, metabolism and activity levels are directly linked to water temperature. Typically, metabolism operates best near the upper limit of a fish's thermal niche. When ideal metabolic function is achieved, growth, fitness and reproductive capability are maximized. Fish thrive.

Temperatures exceeding those to which a fish is adapted can be taxing. Low dissolved oxygen, commonly associated with warmer temperatures, is an additional stress. These two factors are powerful determinants of what species inhabit an area.

Warmer temperatures would improve conditions in high elevations and northern latitudes historically too cold to sustain fish populations. However, species that dwell in lower elevations or more southerly latitudes could suffer increased temperature-related mortality. Starvation could also result from heat as fish expend more energy on maintaining metabolic functions and less energy on feeding and growth.

Many lower-latitude trout habitats may already sustain temperatures that cause summerkills and starvation. Rainbows usually die when waters reach about 70 degrees Fahrenheit over an extended time. Brown trout are able to survive slightly warmer waters, but not for more than a couple of weeks. Global warming would push both of these species up to cooler places — to higher elevations or more northerly streams.

By producing unhealthy conditions, global warming will increase fishes' susceptibility to disease and parasitic infections. Pathogens causing whirling disease, proliferative kidney disease and other maladies are expected to expand in distribution and increase in virulence.



ALWELD

376

LA 7811 EZ

Toxins flushed into aquatic systems by rainstorms and floods pose another threat to fish health. The danger increases if dry periods follow extreme high-water events and concentrate the toxins in diminished volumes of water.

Global Warming and the Food Web

Warming temperatures can boost the productivity of an aquatic system and reorder the intricate fish food web. While food sources for some stages of fish development could become more plentiful, warm temperatures could reduce availability of prey dependent on cold water.

For instance, in the upper three Missouri River reservoirs in Montana and the Dakotas, healthy populations of species like walleye, northern pike, smallmouth bass and land-locked Chinook salmon exist because cold-water habitat is available. These species experience optimal growth at temperatures found in the cold-water layer near the bottom of the reservoirs during summer stratification. Food for these predators — rainbow smelt and ciscoes — also inhabits this cold-water layer. As extended drought has caused decreased water levels and overall warming temperatures, fisheries managers have become increasingly concerned about the disappearance of cold-water habitat and baitfish reproduction and recruitment. Global warming and continued drought, coupled with demands for

Missouri River water to be released for authorized purposes downstream, will continue to stress these populations of baitfish.

Other Midwestern states face similar problems. In Minnesota there are currently about 650 lakes with the conditions of temperature and water quality needed to maintain a population of ciscoes. According to fisheries managers, within 50 years only 50 to 100 lakes will remain healthy enough to support ciscoes.

Fish that feed on insects will also find adjustment difficult. For example, with reduced snowpack and earlier runoff, mayflies and other aquatic insects are likely to emerge earlier. Though the results for fish and the broader aquatic community are uncertain, they are most likely to be detrimental.

Biologists posit that consistently low stream flows contribute to the explosive growth of didymo, an invasive algae that covers stream beds and destroys the plant and insect growth necessary for healthy brown trout. If so, global warming could worsen the problem.

The expected increase in erosion and sedimentation from storms, floods and wildfire will affect every tier of the fish food web. Loss of riparian vegetation and warmer stream temperatures would cause declines among invertebrates, a chief source of nutrition for many stages of fish life.

Global Warming and Life Histories

Temperature and migrations

The life histories of freshwater game fish include migration, maturation, reproduction and recruitment. Predicted climate changes will, to a greater or lesser degree, influence all of these phases. Warming waters will likely have particularly dramatic impacts on the life cycles of cold-water fish, including trout, char and salmon.

For instance, for most species migration and smolting — the movement of young salmonids from fresh water to the sea — coincide with narrow temperature ranges. As increased temperatures and the abbreviated spring freshets that they cause instigate smoltification earlier in the season, the proportion of smolts mature enough to migrate may shrink. In some species migratory behavior may be lost altogether. In steelhead, for instance, smolts' migration occurs only when spring water temperatures are below 54 degrees Fahrenheit. Earlier out-migrations for all species may cause a mismatch between feeding needs and food-producing conditions in estuaries and oceans.

Temperature and reproduction

Both temperature and weather influence fish reproduction and recruitment. Warmer temperatures increase the growth rate of many warm-water sport fish and decrease the length of time to maturation

and reproductive age. Although many factors contribute, proper temperature initiates a fish's successful reproductive cycle.

An earlier onset of spring will advance the date at which waters are suitably warm for spawning. In general, spawning temperatures for warm-water fish range from minimums of 54.5 to 71.6 degrees Fahrenheit to maximums of 60.8 to 84.2 degrees Fahrenheit — temperature limits that will likely be exceeded in many regions as a result of global warming.

In both rainbow and brook trout, an increase in temperature has been shown to increase egg production. Faster egg development results in better survival and, therefore, an increase in trout population. However, other effects of global warming such as intense storms and increased stream flow that lead to scouring and redd mortality could offset this advantage.

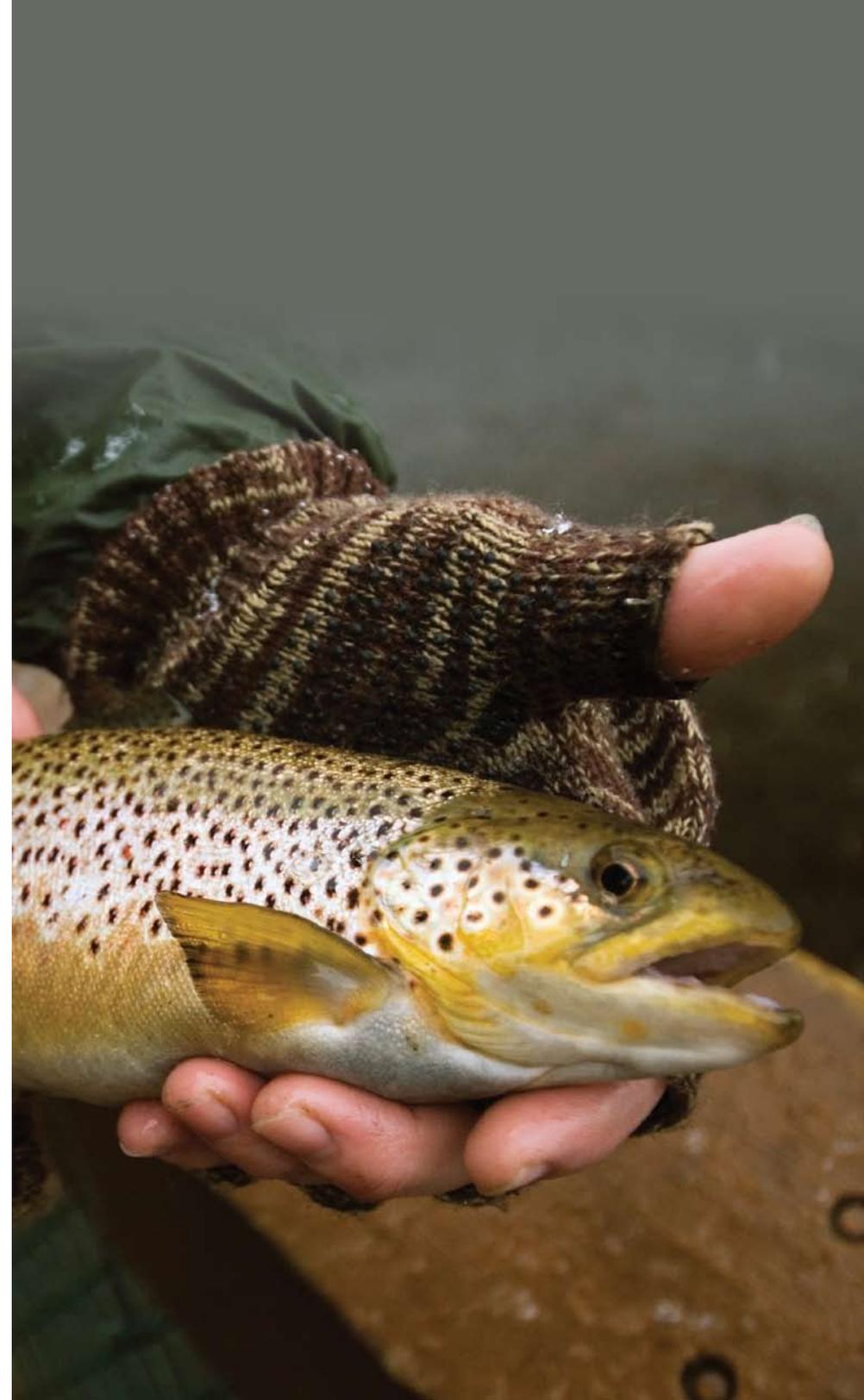
Rising temperatures will reduce ice cover and snowpack, affecting life cycles of species dependent on these sources of cold. For example, lack of ice cover in Lake Superior jeopardizes whitefish, which reproduce in shallow bays and rely on ice cover to protect their eggs from storm disturbance. In warming waters temperature-sensitive lake trout will require more food. It is likely that many lakes will be unable to supply enough summer nutrition to sustain healthy lake trout and fuel fall spawning.

Precipitation, stream flow, sea-level rise and reproduction

Made more variable by warming temperatures, changing precipitation patterns will affect river flow, lake stages and other aspects of aquatic habitat, with both beneficial and detrimental effects on fish reproduction and recruitment.

As an example, when scientists simulated a combination of altered flow and increased temperature, they found that the growth rates of upstream rainbow trout increased so much that the fish matured a year early. As a result, species abundance increased dramatically. In contrast, the fall-spawning brown trout suffered high incidences of redd scouring from increased winter flows and greater egg mortality from dewatering when redds built at high flows became exposed as flows decreased.

Although all fish would suffer under conditions of frequent and prolonged drought, the quality of recreational fishing for cool-water fish such as channel catfish, walleye, tiger muskie and striped bass as well as some warm-water fish like sunfish, black bass and crappie would fluctuate with variable water levels. Using harvest regulations to protect adult fish and fish habitat and allocating water resources to stabilize fisheries are among the management practices that can mitigate the effects of global warming on freshwater fish.





Global Warming and Population Distribution

As global warming alters ecosystems across the country, some species' ranges will expand while others will contract. Most reductions in the ranges of freshwater fish will occur from south to north and somewhat less from east to west. Lost freshwater fish habitat could extend from 22 percent in some areas to 92 percent in other areas. Populations at the southern rim of their native distributions, which may already be near their thermal limits, are likely to suffer more than populations near the center or northern portions of their ranges. Problems could be particularly acute for species in the shallow rivers of the Southwest.

Fishes that prefer cool waters, such as smallmouth bass, striped bass and walleye, will be particularly sensitive to rising temperatures and will push into the northern reaches of their ranges. Where fish have become adapted to cooler, more oxygen-rich waters, the combination of poor oxygenation and high temperatures will be especially problematic as stratified water bodies squeeze fish between warm and cold layers of low-oxygen water.

Global warming could be disastrous for trout populations in low-elevation southern streams. Losses of 53 percent to 97 percent of wild trout in the Appalachian Mountains are predicted; remaining populations will likely be highly fragmented and restricted to isolated drainages, increasing their vulnerability and making natural recolonization improbable.

The northern limits of most species are determined by the ability of the young to grow during warmer months and to survive low temperatures in the colder months. Extended periods of cold lead to starvation, and intense cold below a fish's physiological threshold can be lethal.

As the thermal boundary of their ranges shifts upward and poleward, cool- and cold-water fish may populate some waters that historically have been inhospitably cold. Warmer stream temperatures could benefit species such as greenback cutthroat trout, which has been limited by poor recruitment in cold headwaters at high elevations. The earlier spawning and faster growth rates predicted with warmer stream temperatures will likely increase summer growth and the overwinter survival of these species.

However, gains could be erased by waters' warming farther upstream and contracting headwater habitat, by increased landscape disturbances from storms and wildfires, and by high temperatures evaporating water supplies. The range of some trout species is predicted to decrease by as much as 80 percent. Such contraction will likely be accompanied by increased fragmentation of fish populations, further compounding the effects of shrinking habitat.

Species facing habitat fragmentation have literally no place to go. Changing environmental conditions may provide fish no options, or habitat may not allow egress to more favorable sites. Smaller stream flows can limit movement, as can the presence of steep gradients,

dams or non-native predators. Where conditions exceed the adaptive capability of the fish, local extinctions of species eventually occur.

Among fishes able to move to more favorable environs, global warming will cause shifts in distribution. Some species will avoid physiologically stressful conditions by abandoning traditional localities, either seasonally or permanently.

While global warming could restrict the movement of fish by reducing stream flow, it may also create new stream networks by melting glaciers and thawing permafrost. These networks could potentially increase connectivity among habitats and enhance colonization, promoting expansion for some species.

Global Warming and Community Structure

Global warming will alter freshwater conditions, disrupt interactions among fishes and shift patterns in the food web. Fishes suited to warm waters — such as bluegills, bass and perch — will move into waters vacated by cool- and cold-water species like walleye and trout.

Warming trends could also kill off predators. No longer controlled by predation, species like smallmouth bass or brown trout could expand their ranges northward and compete for food and habitat with native salmonid populations.

Any invasion by a species — flora or fauna — not historically present in an ecosystem will cause some disruption, although a system's exact response is impossible to predict. New species could be incorporated into the environment with relatively little disturbance and no long-term detriment. Or disruption could be widespread and result in the suppression or even local extinction of native species.

Global warming is likely to support an increase in the numbers and an expansion of the ranges of exotic invasive species such as the New Zealand mudsnail, tropical blue tilapia and butterfly peacock bass. Limited by minimum temperatures or dependent on thermal refuge during winter, such species will benefit as temperatures open new areas of suitable habitat. Invasive species are particularly threatening in Florida, California and Texas, where favorable climates are likely to foster exotic flora and fauna.

Management strategies to protect native fish populations could include erecting barriers to prevent invasion of an ecosystem. But because such practices could potentially isolate populations, managers must weigh the threat posed by invaders against the value of preserving corridors connecting native fish to habitats up- and downstream.

Hatchery fish potentially pose another threat to wild populations. Not dependent on spawning and rearing habitat, hatchery fish may possess physiological, survival and competitive advantages over wild populations. Mixing genes of hatchery and native fish may

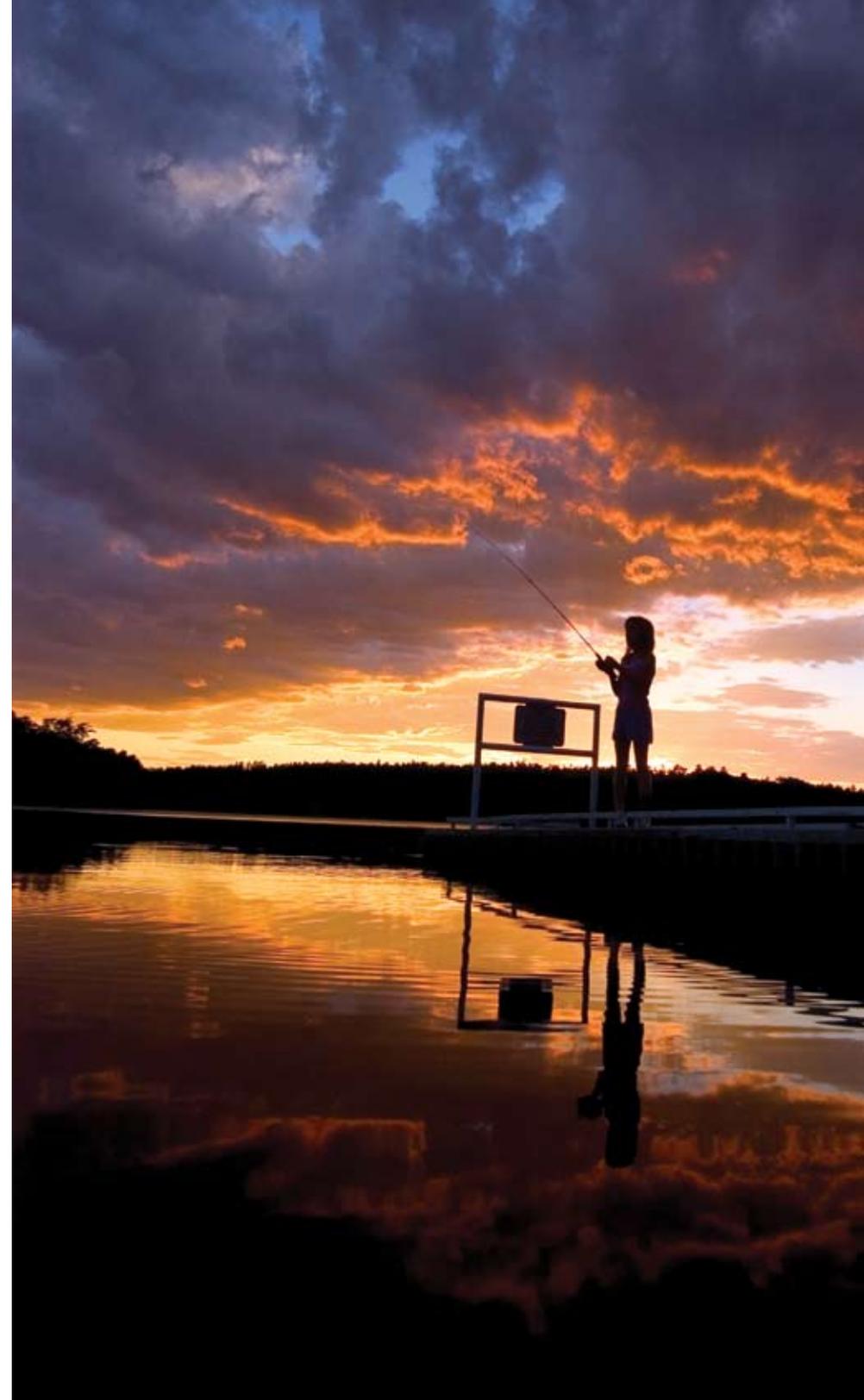
dampen wild populations' instincts to adjust their migration and spawning patterns to changes in temperature and hydrology. The effects of climate change on the interactions between hatchery and wild fish populations loom as an increasing concern in fisheries management.

Summary

Freshwater fish species, particular those that rely on cold-water habitat, will be dramatically affected by climate change. Reduced summer flows due to lack of snowmelt will combine with generally higher temperatures to pose real risks to the survival of cold-water species like trout and salmon. It is predicted that up to 42 percent of trout and salmon habitat will be lost within the next hundred years. In some regions, this will result in a 50 percent decline in population of those species. At lower elevations, entire populations of cold-water species may disappear, while even populations living at higher elevations will feel stress. Bass, bluegill and other warm-water species also will face stress from droughts, lower summer river flows and increasingly severe fluctuations in river and lake levels. This can affect the survival of eggs and jeopardize the recruitment of adult fish. Throughout the country, warmer water temperatures will lead to the expansion of noxious, exotic plants like hydrilla and Eurasian watermilfoil. Sea-level rise will push saline water farther upstream, in some cases reducing suitable freshwater habitat. At the

same time, the ranges of certain warm-water species may increase with water temperatures rising in northern climes.

Scientists don't know how climate change will affect every aspect of the fishing experience, but they do know that anglers should count on change. In many lakes and rivers, water levels will suffer from higher evaporation rates, lower spring and early summer snow-melt and prolonged drought, making boat access more challenging. Trout and salmon will disappear from many streams and rivers that today hold viable populations, severely diminishing opportunities to catch those species. Moreover, fishery managers likely will be forced to reduce daily bag limits to better protect adult fish. As more frequent droughts heighten competition for water resources among all users, both fisheries managers and fishermen may need to get more involved in efforts to protect instream flows. Depending on where anglers live and practice their sport, they may need to change their target fish from cold-water species to more resilient warm-water species or be prepared to travel longer distances to pursue their cold-water favorites.







Big Game

Maybe it's a virulent disease ripping through a Texas herd of whitetail. Or maybe it's a deep and prolonged drought in the Midwest. The threats to big game are real, persistent . . . and about to become much worse. "You'd think that a warmer climate would take some stress off the big game populations," says Mark Van Deusen, an avid deer hunter from Prescott Valley, Arizona. "But it appears to me just the opposite is going to happen."

Scientists agree. Their projections show that global warming will expand the range of disease-carrying insects, accelerate the impact of crippling parasites and reduce the big game forage base.

"Cold temperatures are a barrier that limits the spread of potentially devastating outbreaks of disease in our northern big game herds,"

says Jim deVos, retired chief of research for the Arizona Game and Fish Department. "If that barrier comes down, big game will die from those diseases at a steadily increasing rate."

Of equal concern is the effect of global warming on the big game food web as elevated levels of carbon dioxide reduce the nutritional value of forage. "The leafy portions of plants will become more fibrous and tough and will contain concentrations of substances that diminish the ability to digest food," says Dr. Ted McKinney, a research biologist for the Arizona Game and Fish Department. "As a consequence, big game will weaken and eventually die from malnutrition."

In addition, high carbon dioxide levels will allow trees to out-compete other kinds of vegetation and reduce critical forage such as shrubs and forbs. This domination by woody species could diminish big game numbers by reducing critical habitat.

Scientists have concluded that global warming will stress big game populations in several ways:

- Big game health will decline and mortality will rise as infestations of parasites, pests and disease-carrying insects, no longer held in check by cold, increase in severity and geographic range.

- Across the continent, deer, elk and other big game populations will shrink as high levels of greenhouse gases make the plants they eat less nourishing and tougher to digest.
- Desert shrub zones, pinyon-juniper woodlands and numerous other big game ecosystems will be increasingly at risk from wild-fires, which will burn with greater intensity and frequency as invasive species replace less fire-prone native plants.
- Pronghorn, elk and mule deer will lose vital habitat in many regions of the American West as rising temperatures allow trees and shrubs to overwhelm sagebrush ecosystems.
- Rising temperatures will allow forests to climb to higher elevations, severely limiting the alpine habitats that support bighorn and other mountain sheep.
- As temperatures rise, moose, uniquely suited to cold weather, will continue to experience declining pregnancy rates and suffer poor individual health, due largely to increased winter tick infestations. Populations will shrink and drift northward, eventually disappearing from the upper Midwest.

- As fragmentation and loss of winter ranges continue, mule deer and elk will dwindle in number in the Rocky Mountain states, the Intermountain West and the Northern Boreal Forest. In some locations, over time both species will disappear entirely.

What Global Warming Means in the Field

How climate change will affect the participation of an estimated 10.7 million big game hunters and the geography of hunting in North America is hard to predict. As wildlife habitat, abundance and distribution shift in response to global warming, patterns of recreational activities will shift as well. Fixed borders of protected areas as they exist today may not be relevant to the ecological communities of tomorrow. Because of their heightened vulnerability to climate change, the Southwest and the western Mountain states are most likely to see dramatic changes in hunting activity.



Decisions concerning wildlife management, including regulation by state agencies of hunting limits and seasons, will increasingly need to consider factors such as

- changes in vegetation and their effects on forage availability and nutritional value
- changes in habitats and food sources and their influence on a region's carrying capacity
- species' expansion and distribution as a result of more snow-free areas
- increased fragmentation of ranges and extirpation of small and isolated populations of wild animals
- changes in predation, herbivory, parasitism and inter-species competition as species' distribution patterns respond to global warming





Climate changes resulting from global warming include rising temperatures, increased frequency of extreme weather events, and alterations in patterns of rain and snowfall. Results will not be uniform across North America, and interaction among the many climate variables hampers accurate predictions of local and specific outcomes. However, some broad conclusions are possible.

While some big game, most notably moose, are physiologically incapable of adapting to increased temperatures, most species will experience the effects of global warming through radical changes in their habitat. Generally, those species able to move long distances, eat a variety of foods and colonize new habitats rapidly will be the most resilient to global warming. Unfortunately, the opportunity for wildlife to adjust to climate change by migrating is limited because human development has already significantly altered and fragmented wildlife habitats.

As a result of the numerous, profound, ecological changes that global warming will produce, some species may thrive in the short term but face long-term decline. Some animal communities will increase their geographic ranges; other populations will become isolated and face local extirpation. Many wildlife experts expect climate change to lead to more crowding at water supplies, declines in nutritional quality of food resources, and more opportunities for the expansion of certain diseases.

Big game will most keenly experience the effects of global warming through two major influences on their habitat: temperature and precipitation. Further, game species will have to adjust to diminished nutritional quality in forage, increased invasion by non-native species, and an increased presence and severity of drought and fire. Global warming will also cause changes in the health of individual animals and in danger from predators.

Global Warming and Big Game Habitat

The major influences on habitat: temperature and precipitation

Rising temperatures and varied precipitation, including altered rainfall patterns and decreased amounts and duration of snow, will affect vegetation closely linked to wildlife habitat. Across the continent climate change will modify the composition and structure of plant communities on which animal species depend. Disruption of historic plant distributions could cause animals to die from lack of adequate food and shelter, or to move in search of hospitable locales. In some instances, wildlife species may vanish from locations where conditions become inhospitable or where a human presence eliminates movement corridors.

Temperature

Rising temperatures will change the composition and structure of forests, including the understory plants essential to big game as food and cover. Competing for water in a hotter, drier climate and for sunlight under tree canopies grown dense during longer, warmer seasons, understory plants could lose vigor and decline. Elk and deer will be among the animals dramatically affected by the loss of this source of nutrition.

As climate warms in the North, frost lines climb to higher elevations and belts of vegetation on mountain slopes move upward. Since 1950, plant species have retreated up mountains about 20 feet per decade and have generally migrated toward the poles at the rate of about four miles per decade. In the future, boreal habitat zones are expected to ascend 1,640 feet for every 5.4-degree-Fahrenheit rise in average temperature. Such a geographic shift could increase stresses on deer and elk populations, which feed on increasingly remote and fragmented pockets of vegetation.

In the Southwest, a 2,000-foot scarp separates sagebrush ecosystems from desert ecosystems and demarcates a frost line that prevents expansion of cold-sensitive, broadleaf evergreen trees and shrubs. As rising temperatures remove this frost barrier, trees and shrubs are expected to expand across sagebrush habitat. Scientists calculate that for every rise of 1.8 degrees Fahrenheit, approximately 33,350 square miles of sagebrush — 12 percent of present coverage — will be lost.





Such a reduction could severely diminish the region's populations of mule deer and elk, two species that depend on sagebrush habitat.

In western mountains rising temperatures mean that forests will likely overtake and eliminate almost all alpine ecosystems. In the Northwest, mountainous territories occupied by wet, coniferous forests will probably shrink. Diminution of this habitat would reduce meadows where elk graze in summer.

In the Northeast, a warming climate will cause maple, beech and birch forests to retreat northward; aspen and birch may all but disappear from the region. In the Mississippi Valley, grasslands and pasture could replace the current range of forests. These changes would cause the displacement of animals that depend on forests for food and shelter. Survival of these populations will vary according to their mobility and their adaptability to changing conditions.

Warming temperatures that reduce the length and severity of winter could encourage survival among some wildlife populations. The depth of snowpack affects the winter range, health and mortality of large herbivores. In regions where species such as mule deer and elk die during periods of extreme snowfall, decreases in snowfall could benefit short-term abundance and distribution. Elk populations could grow in the Rocky Mountains as warmer winters cause enhanced rates of survival, faster reproduction and improvements in body conditions. If warmer winters are coupled with wetter summers, elk populations could double. However, drier summers that

reduce forage and expand health threats from drought, parasites and wildfire would slow or cancel the rate of increase.

As winter conditions change, interactions with other species might shift. New patterns of competition for food could emerge and impact the overall health of big game species. Relations with predators will also change. For instance, in areas with wolf populations, incidents of predation on hoofed animal populations correlate with winter severity and the depth of snow. Milder winters could reduce mortality but the surviving population could strain the carrying capacity of seasonal habitats.

Precipitation

Like ranges of temperature, patterns of precipitation will be severely affected by global warming. A warmer planet generates more evaporation, rain and wind, which in turn influence plant growth, vegetative cover and food availability.

For each degree Fahrenheit of global warming, average precipitation is expected to increase by one percent. But an increase in total precipitation does not necessarily mean that more water would be available in the landscape: Higher temperatures also cause higher rates of evaporation from lakes, streams, snowpacks, plants and soil, resulting in drier conditions within an ecosystem. Decline of habitat will probably be the most notable and serious effect of drought, although long droughts could lead directly to elk and deer mortality.

Warmer temperatures will increase the amount of precipitation and cause it to fall more frequently as rain rather than snow. Snowpacks will form later in the winter, accumulate in smaller quantities and melt earlier in the spring. Because snow stores water for release during thaws, changes in the snowpack profoundly affect the seasonal availability of water. Water determines the presence of vegetation, which in turn influences the quality and availability of cover and forage. The changing climate will affect animals dependent on seasonal cycles of vegetation or prey by altering the timing that food sources become available.

Regions such as the Midwest and Northwest that depend on snowpacks for warm weather stream flows and for water during dry summers will be most acutely affected by changes in precipitation patterns.

The Results of Habitat Changes

Declines in plants' nutritional value

Most species are dependent on nutritious forage at key points in their life cycles, such as during fawning. Climate changes that disrupt seasonal patterns of warmth and moisture could impair critical relationships between the timing of vegetative growth and animal life cycles, to the detriment of wildlife populations. The maturation of vegetation earlier in the growing season would lower the food quality for all herbivores, especially during summer.



As a landscape modifies in response to climate change, the composition and nutritional capabilities of its vegetation change too. For example, increased levels of atmospheric carbon dioxide could give trees a competitive advantage over shrubs and would benefit grasses least of all. Woody species are likely to encroach most quickly in regions such as the West where rising temperatures and increased levels of atmospheric carbon dioxide correspond with wetter winters and springs and drier summers.

Although herbivores eat fast-growing plants, future levels of greenhouse gases will likely make these foods less nutritious. Experiments reported in scientific journals have shown that enriching plants' intake of carbon dioxide reduces nutritional value, toughens leaves and builds concentrations of phenolics and tannins that potentially interfere with digestion. Low nutritional quality of forages is already a limiting factor for wildlife such as deer in much of their western North American range. Declining levels of nutrition in available food could affect an area's carrying capacity, cause fluctuations in big game populations and, consequently, reduce hunting opportunities.

Invasive plants

Invasive plants seem to respond more successfully to rises in temperature and changes in precipitation patterns than do native species. As climate changes, native plant communities could be increasingly exposed to invasive weeds that expand relatively quickly and threaten to diminish biodiversity.

The menace that invasive plants can pose to wildlife is exemplified by cheatgrass in the American West. Cheatgrass has invaded desert shrub communities, sagebrush zones, pinyon-juniper woodlands, and some ponderosa pine and Douglas fir zones, destroying native shrub habitats important to elk and mule deer for food and cover.

Risk of wildfire

The encroachment of cheatgrass, which greens up early in spring and dries quickly, increases the risk of fire. The dried herbage carries wildfire much more efficiently than do native shrubs, thereby increasing fire frequency and intensity. Because many native shrub species are not fire resistant, an increase of fires could remove them from the ecosystem.

Other effects of global climate change also contribute to frequent and severe wildfires. Temperature controls the timing of snowmelt; earlier thaws result in an earlier drying of the landscape, which extends the fire season. Warmer temperatures may also extend the growing season, producing increased biomass available to fuel wildfires.

As with many consequences of global warming, fire is destructive to some species but beneficial to others. Warming trends and increased wildfires in western North America potentially benefit aspen production and distribution and the animals that depend on aspen for habitat. However, increased vegetative mass from invasive weeds coupled with expansion of woody species results in fires of unprecedented intensity. As a consequence, habitats burn in such a fashion

as to transform woodlands into shrublands, resulting in diminished aspen habitat for deer and elk.

Global Warming and Health of Big Game Animals

In addition to diminishing the quality and distribution of habitat, climate change will likely affect the health of big game populations directly.

Warmer and wetter environments should result in greater densities and distributions of disease-carrying insects. As temperatures rise and extreme cold no longer limits the survival and expansion of pests, parasites and disease, health risks will increase for many wildlife species.

Examples include the giant liver fluke, the life cycle and abundance of which are controlled by cold weather, and the muscleworm. The northern distribution of this parasite has been limited by temperatures too cold for larval development, but warming may soon eliminate this constraint. Expansion of the worm's range could significantly affect populations of mule deer and other native hoofed animals. A warming climate could extend the seasonal window for transmission of parasites and diseases, increasing outbreaks of these pathogens in host populations.

Global Warming and Big Game Populations

Mule deer and elk

Predictions of the future abundance and distribution of elk and mule deer are confounded by the limited ability to forecast specific local and regional changes in climate and the response of vegetation communities to those changes. The more moist ecosystems are expected to be the least affected by changes in climate and vegetation. The more arid regions such as the sagebrush steppes and pinyon-juniper woodlands of the Southwest are likely to experience the most adverse effects.

If vegetation changes include growth in woody and herbaceous plants, if precipitation patterns support the flourishing of forage, and if the nutritional quality of forage does not become deficient, in the short term mule deer populations in the West and Southwest could remain stable or even expand slightly. In regions where drought conditions become frequent or intense, abundance of mule deer will remain low or decline.

It is likely that mule deer, which require highly nutritious, highly digestible, concentrated foods, will in the long term fare more poorly than elk, which are more adaptable to marginal habitats. Elk digest foods high in cellulose such as grasses and older-growth parts of plants. Able to meet their metabolic demands through a wide array of low- to moderate-quality forage, elk could increase in abundance

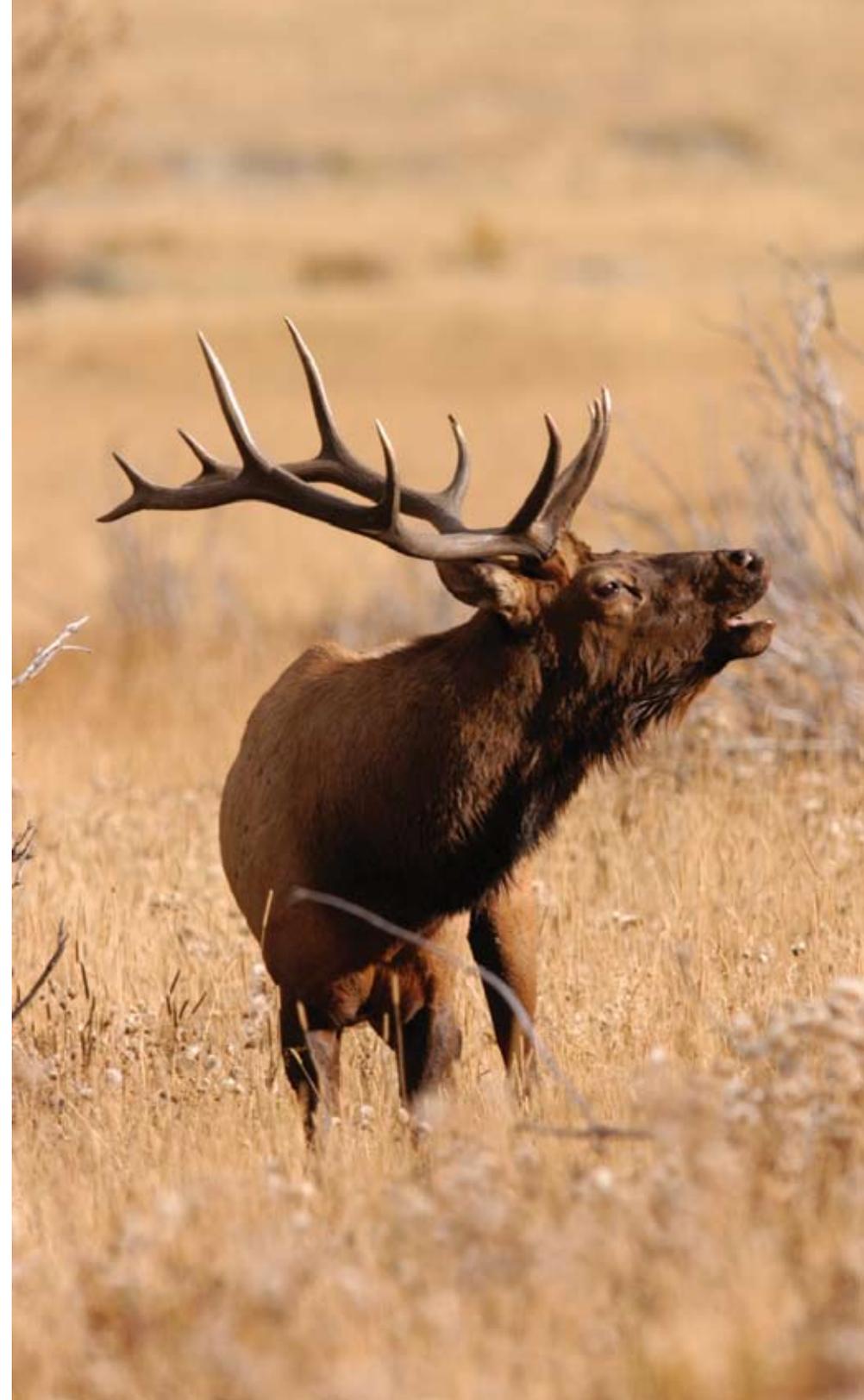
in some areas of western North America during the 21st century. Changes in elk distribution are more likely to be caused by changes in vegetation than directly by changes in temperature.

Climate changes that alter seasonal habitat will modify migration and distribution patterns for both mule deer and elk populations. Warmer temperatures, a retreating tree line and reduced snowpacks could encourage northward expansion of the species in the West, especially during the spring and fall.

Reduced distribution, nutrition or productivity of grasslands and of traditional winter ranges such as sagebrush and shrublands would adversely affect mule deer and elk populations. Winter range is a concern particularly within the Colorado Plateau, the Northern Boreal Forest and the Intermountain West regions. Population numbers in these areas will likely correlate to habitat quality during winter months.

Moose

A warming climate is predicted to put at risk the continued presence of moose in the Northeast and North Central temperate forests. Unlike many wildlife species, moose are directly affected by rising temperatures: Evolved to withstand cold, moose experience heat stress when ambient temperatures exceed 57 degrees Fahrenheit. Studies indicate that in moose populations heat stress is manifested as a decline in body condition and a reduction in rates of pregnancy. Distribution of moose is expected to shift northward as temperatures warm.





Moose may also face chronic malnutrition and parasitism as indirect consequences of climate change. Models predict that browse upon which moose depend will vanish as aspen-birch and spruce-fir forests disappear from their current range. If white-tailed deer expand into moose habitats, moose will face increased competition for food and intensified threats from parasites and diseases that white-tailed deer carry. Without winters sufficiently cold to kill ticks, infestations could result in increased moose mortality.

White-tailed deer

Because white-tailed deer live off body fat reserves through winter, demands on their energy determine winter mortality. To reduce expending energy, white-tailed deer in the northern regions of the eastern temperate forests migrate to winter ranges that provide shelter from deep snow and cold temperatures. Less severe winters resulting from a warming climate could reduce mortality in northern deer populations. Deer populations will respond by growing rapidly and reaching the point at which density rather than winter mortality regulates their numbers.

In the Northeast and North Central regions, changes in vegetation could continue to support high white-tailed deer populations. As oak-dominated forests replace maple, beech and birch forests, hard mast will become a more available food source.

With ranges in the drier, southern portion of the region, white-tailed deer populations in the Midwest are not expected to change dramati-

cally in response to global warming. Shifts in the extent and distribution of trees and shrubs will probably be the most noticeable influence on deer habitat. Outbreaks of parasite-caused disease, however, could increase in frequency and become more threatening to deer populations.

Black bear

Black bear populations could benefit if, as predicted, global warming causes oak-dominated forests to replace northern hardwood forests in the Northeast and North Central United States. Supplies of oak mast allow black bears to forage and fatten in the fall one to two months longer than they would otherwise, significantly enhancing their rates of survival and reproduction. Expanded oak forests would support greater distribution and abundance of black bears. However, in the drier regions of the Southwest, preferred habitat will likely deteriorate and black bear populations will likely decline or be extirpated.

Summary

Big game species like mule deer, pronghorn antelope, elk and moose will be significantly affected by climate change. The range of disease-carrying insects will expand, leading to increased mortality among northern big game herds. Higher carbon dioxide concentrations will reduce the nutritional value of traditional forage, leading some

animals to suffer and even die from malnutrition. Tree species are expected to out-compete important forage like shrubs and grasses, reducing their availability and thus creating additional nutrition challenges for some species of big game. Some species, particularly pronghorn antelope, elk and mule deer, will lose important habitat in the Southwest and the Intermountain West as trees and invasive species like cheatgrass out-compete sagebrush ecosystems. Moose populations will decline, and they will migrate northward, largely abandoning the upper Midwest. Habitat suitable for bighorn sheep and mountain sheep will constrict as a warmer climate allows trees to colonize higher elevations. Fragmentation and loss of winter range in the Rocky Mountains will cause populations of mule deer and elk to dwindle in those states. Conversely, less snowpack in mountains may reduce the vulnerability of species like elk and mule deer to predation.

Over time, hunters in general will find fewer big game species throughout their traditional ranges as warming reduces the availability of suitable habitat and nutritional forage. Wildlife managers likely will be forced to respond by adjusting seasons and management units, setting lower seasonal take limits and making fewer permits available to sports enthusiasts each year. A warming climate may lead species like elk and mule deer to stay in higher elevations during the traditional fall hunting season, making it more difficult for hunters to reach them and retrieve game.





Upland Birds

If they've been at it long enough to break in their boots, you won't find many upland bird hunters who don't marvel at the survival instincts of pheasants, grouse, woodcock and quail. But as remarkable as those instincts are, they may fall short when the new predator in the field is global warming.

"Birds are resilient and highly adaptable," says Dave Nomsen, vice president of Pheasants Forever, "but when the food base is unstable and the protective vegetative covers are inadequate or unavailable, when there's no moisture during the brood-rearing period, you've got trouble. When those conditions become the norm, you've got a disaster."

If temperatures rise as much as experts forecast, up to 10 degrees Fahrenheit by 2099, and suitable habitat becomes scarce, upland bird

populations are expected to collapse. “We’ve already seen northern bobwhite quail populations decline precipitously over the last half-century,” says Kim N. Price, editor of *Covey Rise* and a member of the board of directors of Pheasants Forever. “Loss of successional habitat is severe. Compound this with the various factors related to climate change — additional losses of water, ground cover and food — and a serious situation becomes critical. We face a future where population losses of unseen proportions could make some upland bird species extinct.”

Recent analyses of American birds show that their breeding ranges are shifting northward, coincidental with a period of rising global temperatures. This change is occurring even though, worldwide, temperatures have increased on average only about one degree Fahrenheit during the past century.

While a 30 percent loss in the number of bird species is the worst case scenario, even conservative projections say that climate change is likely to alter the makeup of entire ecosystems, forcing wildlife to adapt or perish. Scientists’ concerns include the following:

- Across central North America, including the prairie pothole region, global warming will cause droughts that could devastate food sources for upland birds. Prairie chickens, sharp-tailed grouse and pheasants will be among the species most diminished in number by these changes.
- In the popular upland bird-hunting areas of the Great Plains and throughout the Midwest, the threat of long-term drier conditions and much warmer summer temperatures will decrease the nesting successes and recruitment rates of pheasants, grouse and prairie chickens.
- Higher temperatures will foster conditions favorable to invasive species such as the fire ant. Already in Texas and Oklahoma the problem of fire ants is increasing and puts hatchling quail at particular risk.
- In the Deep South, summertime drought and high temperatures will shrink bobwhite quail populations by disrupting the birds’ breeding cycles and reducing availability of the insects that hens and chicks eat. Hot, dry conditions will also stunt the growth of vegetative cover, leaving broods vulnerable to predators.

- In the desert Southwest and the high desert valleys of California and Nevada, drier and hotter conditions throughout late fall and early spring will imperil the overall health, reproduction and recruitment of quail and chukar.

What Global Warming Means in the Field

Game birds' adaptability will be pressed to keep up with the predicted speed of global warming. It remains to be seen if the birds will evolve to withstand significantly hotter and drier conditions. Even if bird adaptation proves highly successful, the upland game hunter is likely to experience effects of global warming such as the following:

Fewer birds in the field and in the bag

The forecast for declining numbers of game birds means that hunters will find fewer birds in the field. And to protect the long-term stability of upland birds, wildlife management agencies will monitor populations and set bag limits that reflect the health and density of those populations.





Birds concentrated in reduced and fragmented cover

Changes in the age and composition of forests, in agricultural practices and in the health of native flora will reduce cover quality and availability, making birds more vulnerable to all forms of predation. Although it may seem that concentrating birds in smaller areas of quality cover would make them easier to pursue, many veteran upland bird hunters say that is not the case. Hunting the same areas over and over scatters and stresses the birds, to the long-term detriment of both the hunter and the hunted.

Habitat quality increasingly dependent on human assistance

In many locations, habitat will continue to support upland game only with human assistance. Hunters will need to maximize the

quality of that habitat through activities such as building water containment structures, restoring wetlands, improving riparian zone habitat, using moist-soil management practices to attract beneficial insects, removing non-native invasive plants and replanting native vegetation.

Game bird policies formulated with hunters' participation

As competition for natural resources, most notably water, becomes fierce under conditions of global warming, hunters will be indispensable in voicing the requirements for the survival of upland birds. With hunters' support of wildlife management agencies and programs such as the Conservation Reserve Program and the Wetlands Reserve Program, game birds will more likely be winners in the game of resource allocation.



Because of the extremely variable and rapidly changing climate of the 21st century, scientists expect the ranges and demographics of many mammal and bird species to be highly unstable, with populations increasing in cool, mountainous areas but decreasing in much of the southern United States. In the short term, most changes are expected to adversely affect species' abundance and distribution. The results of climate change will be local and specific, most likely causing shifts and declines in present game bird populations. Global warming will affect game birds' life histories — their health, reproduction and range — and conditions within their habitat.

Global Warming and Upland Bird Life Histories

Bird health and reproduction

Stresses caused by global warming will result in fluctuations in annual game bird numbers and in disruptions in their patterns of reproduction, survival and recruitment — the ability to add new members to the breeding population. High temperatures and drought are conditions particularly detrimental to the health and reproductive capacity of upland birds.

Studies show that heat in excess of 102 degrees Fahrenheit for an extended time can cause the death of game bird adults, chicks and even embryos in eggs. Heat also interrupts game bird reproduction in a number of ways: by causing premature incubation and staggered

hatching, reducing the length of the laying season, inhibiting re-nesting and multiple-brooding, and causing reproductive incapacity in males and females. Populations of pheasants and quail are especially vulnerable to heat-related declines.

Bird range

As habitat conditions change under global warming, upland birds will shift their ranges. Especially in the Northeast and Midwest, shorter and milder winters will push the boundaries of cold and snow northward, causing some bird species — and some of their predators — to expand their ranges.

As birds' territories shift in a warming climate, hunting opportunities could fall out of sync with game presence and birds' life cycles. New patterns of recruitment, survival and natural mortality among upland birds would affect hunting locales and harvest rates.

Global Warming and Changes in Upland Bird Habitat

In addition to stressing the health and reproductive capability of upland birds, global warming will affect the birds' habitats.

As global warming alters the location of hospitable conditions, habitat for upland game will shift in place and abundance. Shrublands and grasslands will both expand and contract. Forests will change in type and composition. Woody shrubs will generally advance in northerly and westerly directions and die away in southwestern

deserts. In addition to these natural changes, upland bird habitat will continue to face fragmentation and destruction as a result of human development.

Vegetation provides upland birds with food and with cover for breeding, brood-rearing and thermal regulation. As global warming reconfigures patterns of heat and rainfall, effects on habitat could be either beneficial or detrimental to game birds. Precipitation influences when and how vigorously plants grow as well as their nutritional quality, reproductive capacity and survival within the habitat. Good game bird habitat needs the right amount of rainfall at the right time during the spring. With too much rain the undergrowth thickens and prevents movement and foraging. With too little, the cover is thin, unable to provide protection or to support the insect populations young chicks depend on for food. Higher concentrations of atmospheric carbon dioxide coupled with rising temperatures will spur overall plant productivity, probably increasing the difficulty of controlling exotic invasive plant species.

Snowfall-dependent ecosystems

Many ecosystems from New England to the mountainous West depend on winter snowfall for summer moisture, both in the soils and in seasonal stream flows. The reduced depth and frequency of snowfalls, brought on by warmer winters, may extend seasonal forage and benefit resident game bird populations. But less snow could also increase a landscape's aridity, especially in areas that historically

have depended on melting snow to supply summer water. Vegetative changes due to late and diminished stream flows would profoundly affect upland birds by changing cover conditions, such as by restricting forage or removing barriers to predation, and altering the food web by changing the availability and nutritional quality of food sources.

In the Southwest, for instance, sagebrush depends on water deep in the soil for summer moisture. This water is replenished by winter precipitation. As the soil becomes increasingly dry, sagebrush becomes scarcer and less nutritious. Game bird species such as prairie grouse that depend on sagebrush for food and cover will suffer accordingly.

Rain-dependent ecosystems

The predicted rise in cumulative levels of precipitation does not imply an increase in wetness overall. Higher temperatures increase the rate of evaporation, leaving a net result of less water in the landscape. Precipitation is also expected to occur in events more extreme than is presently customary, such as fierce storms that cause swift runoff yet fail to deeply saturate the ground. Timing of precipitation is likely to change as well, with seasons of excessive rainfall followed by seasons of drought even in areas that currently enjoy a more nearly uniform distribution of precipitation throughout the year.

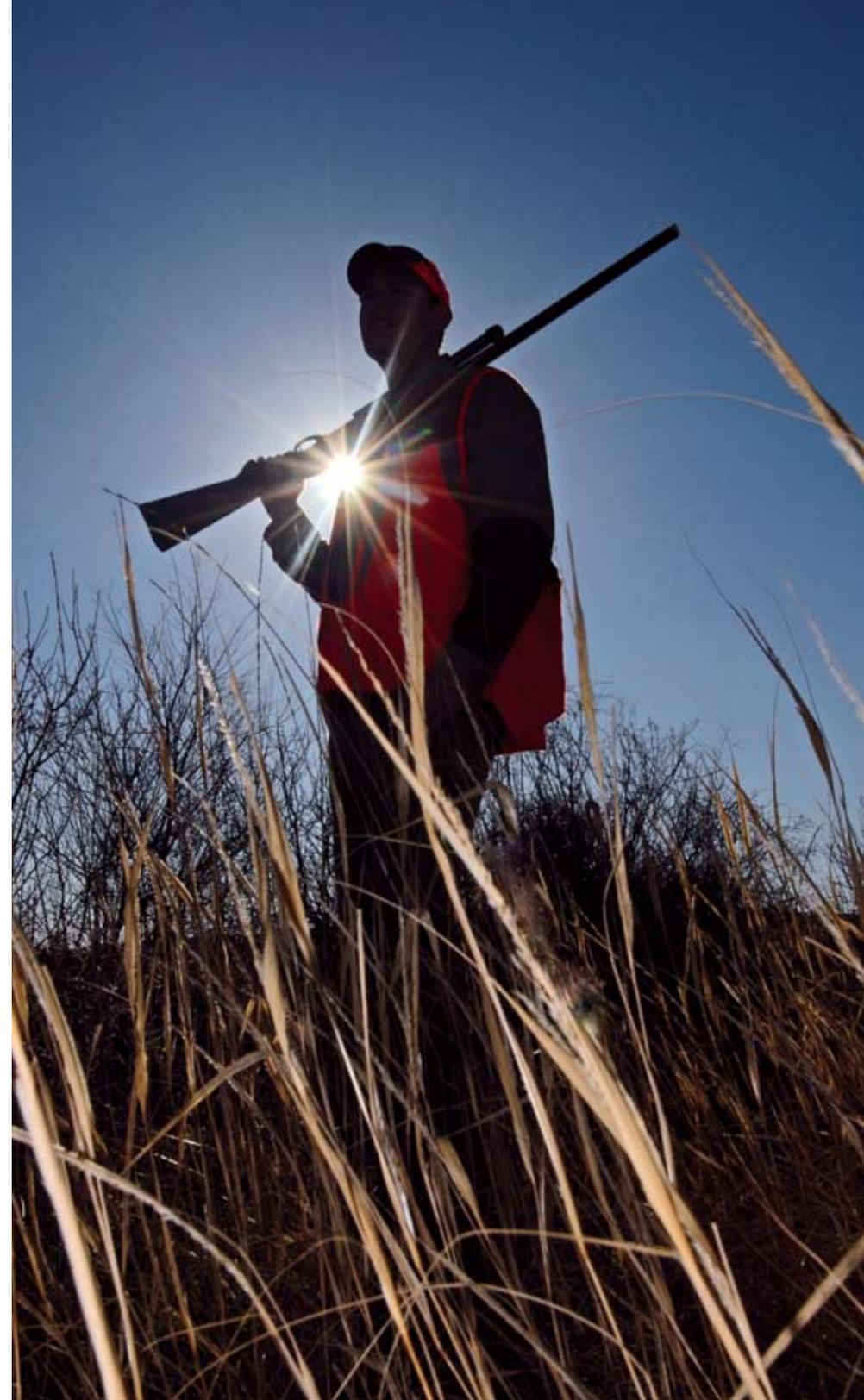
These rain-dependent habitats generally provide upland birds with sufficient moisture from rainfall, dew and succulent food. Nonethe-

less, changes in precipitation would affect these birds by shifting habitat conditions: Increased drought and decreased seasonal stream flows will reduce the overall level of soil moisture and alter the communities of organisms that the soil supports.

California quail, whose productivity correlates directly to soil moisture in late April; woodcock, which feed on earthworms in forest environments; and pheasants, which find food and habitat in the grasses and forbs, illustrate correlations among the population of game birds, the amount and timing of precipitation, and the amount and quality of vegetation in any particular ecosystem. Warmer and drier soils in California could depress quail populations. Droughts in the Southeast could diminish the pine-hardwood stands, hardwood drainages and bottomlands that provide habitat for the earthworms that woodcock eat. And seasonal shifts in leafing and fruiting of the grasses and forbs that provide food and habitat for pheasants in the Midwest could disrupt the synchronicity between the pheasants' needs and the availability of their food.

Forest ecosystems

Various forest ecosystems, whether snow-dependent, rain-dependent or dry, are important for many species of game birds. Climate modeling typically predicts four broad-stroke scenarios for North American forests: deciduous trees replacing forests of spruce, fir and pine; oak replacing maple, beech and birch; maple, beech and birch replacing aspen-birch forest; and elm, ash and cottonwood trees expanding their range in the Midwest.





Of these changes, the most profound effect on game birds might result from the disappearance of aspens in Northeastern and North Central forests. The ruffed grouse, which inhabits dense, woodland habitats as varied as boreal forests, Pacific coast rainforests and relatively dry deciduous forests, always occurs with some deciduous trees and especially with aspen. Except in parts of western North America, the range of ruffed grouse closely matches that of quaking and bigtooth aspen, which typically inhabit boreal and montane forests regenerating after fire, logging and other disturbances. As former aspen-birch forests become habitat for maples, beeches and birches, ruffed grouse populations will decrease.

Northern bobwhite quail, which prefer habitats of early successional growth, especially in mixtures of croplands, woodlands, brush and grass, and the American woodcock, which occupies Southeastern and Gulf Coast forests that support earthworms, are other arboreal species likely to be highly affected by global warming.

Agricultural ecosystems

Global warming may change agricultural practices and the kinds of crops grown, consequently affecting the abundance and range of habitat for many game birds. Quail and pheasants are among the birds that find food and cover in cultivated land, especially where it is interspersed with grass ditches, hedges, marshes, woodland borders and brushy groves. Loss of farmland could mean loss of habitat for these birds.

Global Warming and Invasive Species in Upland Bird Habitat

By creating conditions that modify an ecosystem's community of organisms, climate change increases the potential for invasive species to flourish. As they replace native flora and fauna, invasive plants, animals and insects upset the ecological balance by interrupting the customary food web and degrading habitat for species that historically populated a region.

In Southern forests, gains made by oak species could be offset by damage from expanding populations of red oak borers and gypsy moths. In the West, pine forests are succumbing to the mountain pine beetle where cold no longer controls the insects' advance.

In addition to replacing native plants that provide cover and nutrition for game birds, invasive species can alter the environment by increasing the risk of fire. In parts of the West, for instance, sagebrush is losing ground to cheatgrass, an invasive annual. When cheatgrass dies off each summer, it leaves behind a mass of dried vegetation, which fuels intense fires that, in turn, further damage the native sagebrush.

Depending on the timing and the habitat involved, upland game can benefit from disturbances in the landscape such as fire or logging. Fire can restore grasslands invaded by woody species or encourage

growth of early successional shrubs and forbs. Landscape disturbances are particularly advantageous to grouse and quail habitats.

Global Warming's Effects on Game Bird Species

Grouse

Ruffed grouse occur in dense woodland habitats across North America. Their ability to thrive on a wide range of foods including buds, leaves, berries, seeds and insects has promoted their adaptation to varied habitat across the continent. In recent decades, however, habitat loss has resulted in a decline in their numbers. Because they prefer early successional stages of woody vegetation, future maturation of deciduous forests could further reduce ruffed grouse habitat. Ensuring that stands of closely interspersed younger and older trees are available in forest ecosystems could offset those losses. Landscape disturbances caused by increased incidence of fire, as predicted by models of global warming, also could expand habitat. If urban development and summer home construction continue to diminish and fragment habitat, corridors connecting ruffed grouse populations will become increasingly important.

Ruffed grouse are closely associated with the presence of aspens; aspen leaves and twigs supply grouse with winter food. Forecasts

for the Northeast and North Central United States predict that as the climate changes, aspen and birch forests will disappear throughout the region, except perhaps in northeastern Minnesota. Consequently, ruffed grouse populations would also decline throughout the region.

Drier weather in the Southwest causing decline in sagebrush would deleteriously affect prairie chickens and sage grouse. Under global warming the vulnerability of the sage grouse, dependent on a single type of vegetation, would increase in all regions. Sage grouse could further suffer from susceptibility to diseases proliferating under global warming, such as West Nile virus.

In the Northwest black cottonwood is similar to the Southwest's sagebrush in providing grouse with food and shelter. Smaller snowpacks and faster stream runoff in that region could cause black cottonwoods to shrink and wither, especially in late summer, with detrimental consequences for species that rely on them, including ruffed and sharp-tailed grouse.

The North Central states would see the largest decline in ruffed grouse population — as much as 33 percent — because of widespread loss of aspen-birch forests. New England would also witness a decrease as populations shrink by 20 percent. Populations in other regions might largely stay the same, except in the Appalachian Mountains, where ruffed grouse populations are predicted to increase by eight percent. In the West and Northwest, where the birds rely upon

habitat in riparian corridors, global warming is expected to increase severe flooding that would threaten spring season nests and reduce grouse populations.

Ring-necked pheasants

In the Midwest pheasants find habitat in cultivated areas, interspersed with grass ditches, hedges, marshes, woodland borders and brushy groves. Their diet consists of seeds, cultivated grains, grasses, leaves, roots, wild fruits, nuts and insects. Although global warming is not expected to alter agriculture in the Midwest significantly, pheasant numbers are forecast to decline as a result of increased droughts and high temperatures during nesting and brood-rearing periods. Subtle changes in the micro-climates of nest sites may affect site selection and nesting success. As birds adjust timing of nesting to adapt to changing conditions, availability of insects critical to young chicks may become out of sync with peak hatching periods.

Other extreme weather events, such as severe storms and floods, could contribute to declines in pheasant populations as well. However, warming winter temperatures and a decreased snowpack on the Great Plains would enhance adult birds' survival to the next breeding season. Warming winters could also cause a northward expansion of the pheasant's primary Midwestern range, although climate change-induced reductions in spring and early summer recruitment could limit such expansion.





Quail

Bobwhite quail, known also as the northern bobwhite or Virginia quail, are found throughout the North, Southeast, Midwest and Pacific Northwest. Primarily a southern species, bobwhites are limited in their distribution by snow and winter weather. As a changing climate makes winters in the Northeast and Midwest shorter and milder, bobwhite populations may expand northward.

Like other species of quail, bobwhites prefer habitats that offer a mixture of croplands, woodlands, brush and grass. Early successional growth dominated by pine and hardwood and including woody and herbaceous growth provides the best conditions for bobwhite. If hotter, drier weather slows the rate that plant succession progresses toward forests, quality bobwhite habitat could increase, offsetting population losses attributed to heat-induced mortality and depressed reproduction.

The frequency and intensity of fire due to global warming conditions would also promote early successional habitat, to the benefit of bobwhite. Climate change will alter the kind and abundance of species comprising forests. Forest management that allows soil and vegetation disturbance, permits interspersed stands of older and younger trees and encourages species favored by quail could further bolster quail habitat.

Heat and drought affect reproduction of bobwhite quail. Typically the breeding season begins in mid-April and can continue through

mid-October, with birds laying, incubating and hatching up to three clutches. In the Southeast, as many as 40 percent of bobwhite chicks are hatched in August and September. But hot, dry summers curtail breeding and prompt quail to abandon nests. High temperatures cause embryo mortality and the premature incubation of eggs, contributing to declines in bobwhite productivity. Annual bobwhite numbers could fall due to increased summer heat and drought brought about by global warming.

Quail species of the West and Southwest prefer open habitat, such as farmland or desert, dotted with low bushes or tall grass for cover. Predicted effects of climate change potentially beneficial to quail habitats include an increased incidence of fire, which, depending on timing and the habitat involved, could aid quail by maintaining early successional shrubs and forbs and limiting woody species that threaten to overtake grasslands. Potentially detrimental effects include changes in the kind and distribution of trees and shrubs, replacement of native plants by nutritionally inferior invasive species, dwindling oak cover, drying of meadow and riparian habitats, and expansion of shrubland steppes.

Changing patterns of precipitation also will likely affect western quail populations. As with so many desert species, quail are dependent upon timing and amount of precipitation. California quail productivity seems to correlate to rainfall from September through April and to soil moisture in late April. Precipitation influences the

survival of young mountain quail in southern California. Abundance of Gambel's quail is directly linked to winter precipitation; development of this species' reproductive organs is stimulated by reserves of vitamin A, obtained from green vegetation. Drier and hotter seasons that limit vegetative growth would thus depress quail reproduction.

Woodcock

Woodcock are night-feeding birds that eat invertebrates, especially earthworms. They prefer open forests with shrubby areas. The predicted increase of oak-pine forests replacing predominately pine forests should increase suitable winter habitat for woodcock, offsetting the contraction of their habitat caused by shrubby areas' reverting to forests.

But because soil moisture levels influence woodcock selection of habitat, more frequent droughts or droughts of longer duration could reduce woodcock feeding areas, leading to a decline in woodcock populations.

A hotter, drier climate with more extreme weather events, such as droughts and floods of less frequency but greater intensity, will affect the tree species that comprise Southeastern hardwood bottomlands. Suitable woodcock habitat in that region will increase if oak-pine mixtures replace pine-dominated forests, while it may decrease in the East where shrubby areas are reverting to forests.

Summary

Depending on the pace of warming and its related effects such as drought, the loss of protective cover and the reduction of traditional food bases, climate change could dramatically reduce populations of upland game birds. At minimum, breeding ranges are expected to shift northward. More frequent, prolonged and severe droughts are expected to sharply reduce food sources, greatly affecting the survival of pheasants, prairie chickens and sharp-tailed grouse across the southern part of their current range. Nesting success also is expected to be reduced by drier and warmer summer temperatures. Newly hatched quail in southern states like Texas and Oklahoma will face greater risks from invasive species like fire ants. Bobwhite quail populations in the South are expected to shrink as warming disrupts their breeding cycle and reduces availability of insects traditionally consumed by hens and chicks. Quail and chukar populations in the desert Southwest and parts of California will decline as warmer

and drier conditions imperil their overall health, reproduction and recruitment. Remaining populations of all these species of upland birds also are expected to shift their ranges to more habitable areas.

The bottom line is that climate change will reduce the number of upland birds in the field, shift their ranges and generally pose new challenges for hunters. Reduced cover will make upland birds more susceptible to predation, while making the birds themselves spookier and harder to hunt. Moreover, if populations decline enough, wildlife managers will be forced to reduce daily bag limits and possibly even shorten seasons. Sportsmen and -women, hunting organizations and state and federal agencies will need to redouble efforts to maintain quality upland bird habitat on the ground and, in some instances, provide supplies of water. The successful implementation of initiatives such as the Conservation Reserve Program may become indispensable to the long-term survival of species like pheasant and prairie grouse throughout much of their existing ranges.







Saltwater Fish

If you're chasing redfish in Florida's Pensacola Bay, you're probably not thinking about glaciers melting in Greenland or about Atlantic coastal waters engulfing thousands of acres of tidal flats and salt marshes.

But that's going to change. In the years ahead, those who care about fishing for spotted sea trout, grouper, snapper, tarpon, bonefish and all other saltwater species are going to think a lot about Greenland, rising sea levels, increasing ocean temperatures and expanding zones of hypoxia.

"No doubt, global warming will affect saltwater fish populations, although it's uncertain how quickly changes will occur," says Dr. Luiz Barbieri, director of the Marine Fisheries Research Section of the Florida Fish and Wildlife Conservation Commission. "Rising sea levels and higher salinity gradients will alter estuarine ecology,

resulting in a decline or loss of critical nursery and feeding areas. Over time, rising sea levels will push salt marshes upland except in those coastal areas where substantial development has occurred.”

The loss of such critical foraging and nursery habitat will mean a dramatic reduction in algae, zooplankton and macro-invertebrates, the primary food sources for juvenile and small forage fishes. “The loss of habitat essential to fish in the early stages of their life history will impact the structure of marine communities,” says Barbieri. “The consequences of loss or degradation of nursery areas will eventually show up in the size and numbers of fishes most popular among sportsmen.”

Increased seawater temperatures will directly affect a wide range of factors critical to fishes’ survival — the availability of food, the timing and success of reproduction and migrations, and the prevalence of disease. “As yet, we don’t know how saltwater fish will adapt to a change in water temperature,” says Kenneth Haddad, the executive director of the Florida Fish and Wildlife Conservation Commission. “We do know, however, that temperature influences fish in every

phase of their life cycle. The survival of a species will depend on its ability to adapt to warmer conditions.”

Based on current data regarding saltwater fish and global warming, scientific projections include the following:

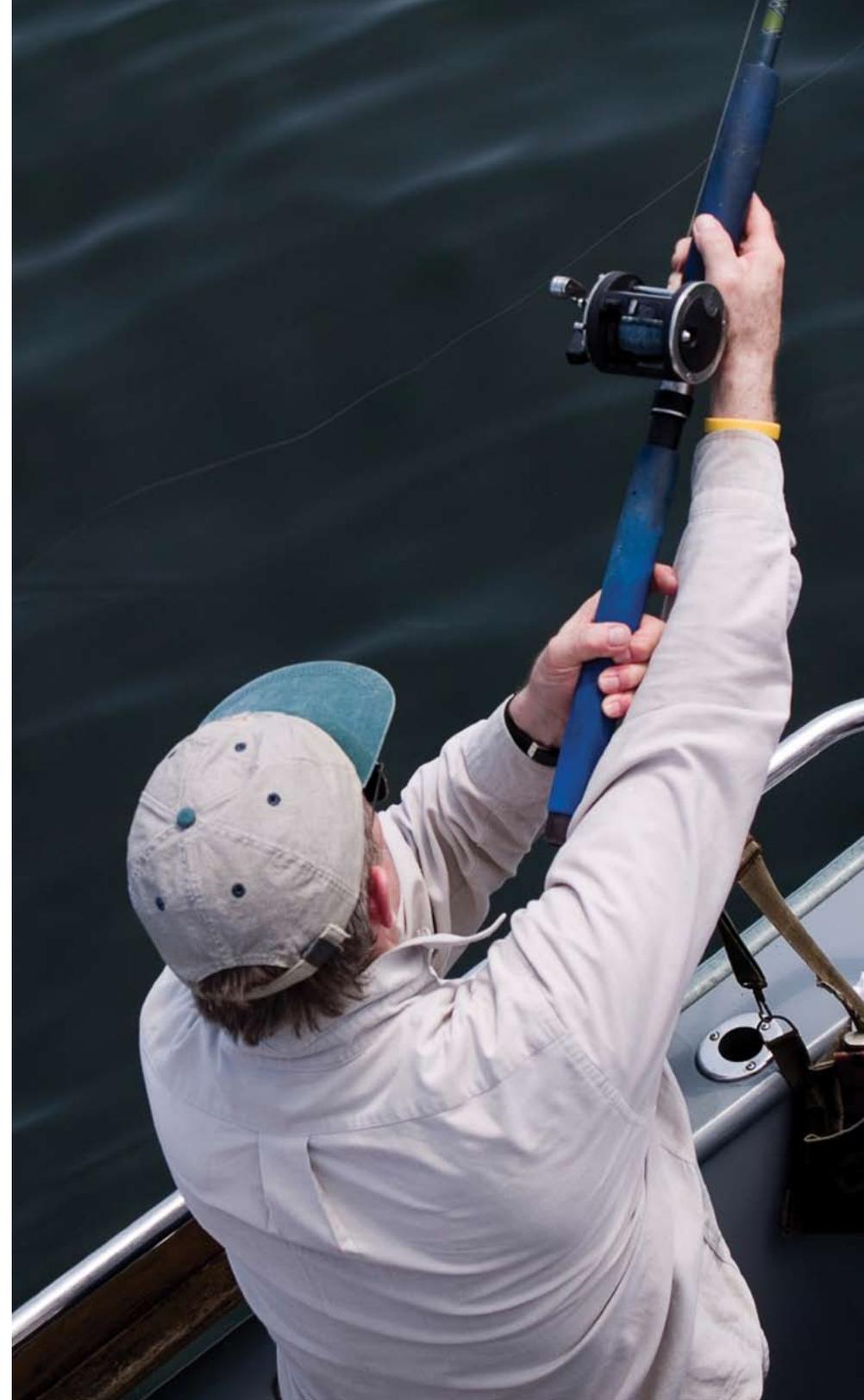
- Subsequent to only a moderate increase in water temperature, changes in distribution, growth rates and recruitment success will benefit some species. Among others, large population declines and possible local extinctions may occur.
- Sea-level rise will destroy thousands of acres of coastal salt marshes and sea grass beds that are home to egg, larval and juvenile stages of game fish.
- The prevalence of disease caused by marine bacteria, fungi and parasites may increase with rising water temperatures.
- Cold-water fish will retreat from the southern boundaries of their ranges, while warm-water fish populations will expand into more northerly waters.

- Warming waters may encourage the prevalence of invasive species that compete for the prey and habitat of native saltwater game fish.
- Increasingly frequent and severe storms could disrupt feeding and nursery conditions for the eggs and larvae of game fish like snook and croaker, causing declines in recruitment. Marine species spawning offshore, such as Atlantic menhaden and blue crab, could benefit from winds that push their offspring landward.

What Global Warming Means on the Water

Favorite species may move from home waters

Shifts in the populations and distributions of prey fish will have a direct effect on the locations of favored game fish species. Changes in the suitability of habitat and competition for habitat with non-native fish species will move or displace the traditional game fish that anglers are accustomed to finding in their home waters. Warming is





expected to cause declines in fishing for cool- and cold-water species, especially in more northerly waters, but to increase success of fishing for warm-water species colonizing new areas.

Storms will affect recreational fishing

Anglers will have to contend with intensified coastal storms, which could reduce the number of days of good weather for fishing and produce wind and wave conditions that hamper fishing success. Increased wind, tidal surge and shoreline loss threaten to damage launching and docking facilities and will put marinas and boating facilities at risk.

Regulations will change as conditions change

Climate change will increase the challenges that state and federal management agencies face. Continued research and monitoring of fish populations and habitats will provide the basis for regulations to protect the stability of fisheries. Rules governing fishing limits, seasons and locations will guide anglers in adapting to the effects of climate change on saltwater fish.

Global warming will affect fish either directly through higher temperatures, increased precipitation, rising sea levels and more variable weather; or indirectly through changes in factors such as the quality of water, availability of prey and suitability of habitat. Because of the complex nature of marine ecosystems, specific changes in current fish stocks are difficult to predict. Fish will respond to the effects of global warming depending on their geographic location, tolerance to environmental changes, individual health, species life history, migratory behaviors and interaction with other species in the food web. Thus, global warming has implications for individual saltwater fish, for saltwater fish populations and for the marine communities to which they belong.

Global Warming and Saltwater Fish Habitat

The viability of a fish species — its ability to survive, grow and reproduce — depends on suitable environmental conditions: favorable water temperatures, adequate concentrations of dissolved oxygen, and appropriate levels of salinity and water acidity. Most climate-change scenarios predict long-term disruptions of these conditions, which could prove detrimental to some fish species, especially in near-shore areas.

How species will respond to rising temperatures depends on their tolerance for, adaptability to, and ability to move from warmer waters. Rising temperatures, accompanied by decreases in dissolved oxygen and increases in salinity in deeper water, can diminish suitable habitat. Populations at the southern end of a species' range are likely to be most affected. Additionally, sedentary species and fishes associated with reefs, such as black sea bass, are less able to move in concert with changing environmental conditions. They may face population declines and possible local extinctions following even a moderate increase in temperature. Already some Atlantic salmon populations may have vanished from portions of their native range; local extinctions have been reported in the Connecticut and Merrimack rivers, and most populations in Maine are endangered.

Temperature and fish habitat

Even small changes in temperature can alter fish habitat. A model simulating summertime habitat of juvenile Atlantic sturgeon in Chesapeake Bay exemplifies this, showing that an increase of less than two degrees Fahrenheit can lead to major reductions in suitable conditions.

Loss of habitat could reduce the numbers of fish an area supports, resulting in fewer fish to catch. Alternatively, habitat loss could increase the density of fish living within a smaller zone. While greater density could improve chances of catching fish, it can also limit fish growth and increase the incidence of disease among fish, to the peril of both fish and fishermen.

Sea-level rise and fish habitat

Supplying forage for fish and offering juveniles refuge from predation, shallow-water habitats such as salt marsh and sea grass are important to many commercial and recreational fisheries. Rising sea levels will reduce the extent and quality of these habitats, and the situation will be exacerbated where excess nutrients and other stressors have already damaged estuarine ecosystems.

Many fish and shellfish species have higher survival and growth rates in submerged aquatic vegetation (SAV) habitats than in open water. As sea levels rise, SAV beds will become more deeply submerged, receive less sunlight and diminish in size. A change in the composition of SAV beds or a decline in their overall coverage would reverberate throughout the food system, affecting numerous fish species including spotted sea trout, red drum and striped bass.

The extent of marsh and SAV loss caused by rising sea levels will depend on the local geography and the kind and degree of development on adjacent land. Erosion control projects such as bulkheads that harden shorelines will restrict vegetation from colonizing intertidal areas newly created by the rising sea levels. Controlling erosion by constructing shallow-sloped shorelines and permitting marshes to migrate would mitigate some effects of sea-level rise. The degree

and type of shoreline development will ultimately determine whether new shallow habitats will form.

Loss of valuable near-shore habitats will affect popular sport fish such as grouper, pompano, tarpon and sea trout. Fishing enthusiasts may confront reduction in these species' numbers as populations dwindle or as the fishes relocate to more suitable habitat. Rising seas confined by erosion control structures will limit surf fishing and increase sportsmen's dependence on boats. Additionally, sea-level rise and coastal flooding could affect the recreational fishing industry adversely by damaging or forcing the relocation of facilities such as docks, marinas, bait shops and charter boat operations.

Stream flow and fish habitat

Increased precipitation and accelerated melting of ice and snow forecast under global warming will alter saline conditions at the interface of rivers and seas. Although freshened water can be advantageous to fish at some points in their life cycles, a greater volume of fresh river water can impair the vertical mixing of fresh water with the saltier waters of estuaries and oceans. The resulting stratification will isolate the bottom layers of the water column from the oxygen-rich surface and facilitate the formation of oxygen-depleted areas unable to support fish habitat.

Global Warming and Saltwater Fish Health

Temperature and fish physiology

With few exceptions, the internal temperature of fish is determined by the ambient water temperature. Consequently, fish metabolism is sensitive to changes in water temperature. Warming waters could speed growth of fish near the northern limits of their thermal zone, but temperatures rising above or falling below an ideal range force fish to devote more energy to maintaining metabolic functions and less to moving, feeding, growing and reproducing. This shift in activities can cause a decline in health, exacerbate vulnerability to disease, increase susceptibility to predators and reduce reproductive success. Mobile species may respond to rising temperatures by shifting their distribution, with accessibility and catchability of fish increasing in some regions and decreasing in others.

Rising water temperatures likely influence the prevalence of some marine diseases. Growth rates and reproduction of potential pathogens such as marine bacteria, fungi and parasites generally increase with temperature. Therefore, the severity of infections or infestations among fish is expected to increase with temperature. However, declining fish numbers could slow transmission of disease and moderate this trend.

Global warming can also increase the incidence of invasive species, such as the zebra mussel, that adversely affect the health of native





species. Zebra mussels, which quickly colonize warm-water habitats, can have large-scale impacts on ecosystems, affecting important recreational and forage fish. In the Hudson River, zebra mussel colonization has slowed the growth of striped bass, American shad and blueback herring and reduced the abundance of juvenile American shad, alewife and blueback herring.

Global Warming and the Food Web

As the kind, quality and abundance of plankton within an environment respond to a changing climate, the suite of predators, competitors and prey that the environment supports changes too.

For example, an abundant prey community including bay anchovy, Atlantic silversides, mysid shrimp and zooplankton thrives in the coastal and estuarine waters of the Mid-Atlantic. These species feed directly on algae or are only one or two links in the food chain distant from them. Declines in the quality and quantity of plants in the region will damage the growth and survival rates of these species, which are in turn a major food for juvenile and adult fishes including striped bass, weakfish, bluefish, Atlantic croaker, spot and white perch.

Stream flow and the food web

Nutrients are carried into estuaries and oceans by rivers and streams. During the peak of the spring stream flow, nutrients fuel the produc-

tion and growth of phytoplankton; the amount of nutrients available in fish habitat strongly correlates to the volume and timing of stream flow. Changes in stream flow could favor fish growth by increasing the amount of nutrients available, but could also deprive fish of needed food during drier seasons.

Sea-level rise and the food web

Marsh habitat is characterized by high rates of production of algae, zooplankton and macro-invertebrates, which support foraging habitat for juveniles and small bait fish. As rising sea levels swamp coastal marshes, these sources of nutrition will decline.

Alterations in the food web at any level can be either beneficial or detrimental to fish growth, recruitment and mortality. Resulting changes in the composition and distribution of fish populations would necessitate adjustments of fishing regulations, specifically the designation of target species and the magnitude of harvests.

Global Warming and Saltwater Fish Life Histories

Temperature and migrations

Fish migrate to seasonal habitats that favor their reproduction, growth and survival. Among the recreationally important species that migrate long distances are salmonids, tuna, striped bass, bluefish and shad.



A shift in the timing of natural cues that initiate fish migration and reproduction could result in a loss of correspondence between key life history events and appropriate habitat conditions. Consequences would range from interference in an individual fish's feeding success to the disruption of an entire population's annual spawning.

Timed to provide the best chance for growth and survival of offspring, the spawning migrations of many species are initiated by seasonal differences in temperature. Temperature has been documented to stimulate spawning in certain species, such as members of the porgy family (e.g., sheepshead, scup). American shad spawn within a specific temperature range (from about 57 to 73 degrees Fahrenheit) in freshwater portions of rivers and estuaries along the Atlantic coast. But climate change could cause mismatches between timing of food production and fish cycles of migration, spawning and egg ripening. Fish commence spawning migrations so that offspring arrive in their nursery habitat when prey is at the peak of its availability. Under normal circumstances, young fish entering favorable habitats early in life grow quickly and become increasingly less vulnerable to predators. But if the onset of feeding by fish larvae fails to coincide with peak abundance of food, poor early growth and low rates of survival could result. Bluefish, Atlantic croaker, spot and red drum are among the many recreationally important species vulnerable to this lack of synchrony.

Successful saltwater fishing depends on synchrony between fish life cycles and fishing seasons. Climate change could alter the timing of

the presence of fish in a region, affecting local recreational fisheries. To adapt harvest regulations to changes in the seasonal and geographic presence of fish, fishery managers may need to coordinate seasons with temperature ranges rather than with calendar dates.

Temperature and reproduction

The timing of reproductive cycles varies among species and locations and has evolved to ensure that species are reproducing at the times and places best suited for their success. That some aspects of reproduction are regulated by temperature is quite evident in many fishes. Recent experiments on striped bass show that the onset and progression of maturation are regulated by water temperature. Temperature also appears to trigger egg ripening in striped mullet. Additionally, as observed in Atlantic salmon, high temperatures at inopportune times can reduce fertility and impair the survival of eggs.

Survival of fish during their first few weeks of life often determines the overall success of a year's fish production. Larvae are very sensitive to changes in environmental conditions such as temperature, salinity, acidity and oxygen concentrations. If nursery habitat undergoes a dramatic change — for instance, a sudden surge in temperature — the eggs or larvae of some species may not be able to survive. For example, volatile spring temperatures produced by climate change could reduce the early survival of striped bass, the young of which are notably sensitive to rapid changes in temperature.

Precipitation, stream flow, sea-level rise and reproduction

Because water density varies with salinity, saline levels affect the movement of water. Some consequences of global warming — increased precipitation, greater volume in stream flows and accelerated glacial melting — will reduce the salinity of seawater. Already the ocean along the coasts of Labrador and Greenland has become less saline. Freshening oceans could modify the flow of worldwide currents, including the Gulf Stream, and alter fish spawning grounds, influence reproductive success and interrupt larval transport.

The volume of a stream's flow also affects the reproductive success of many recreationally important fish, especially anadromous species that leave the ocean and swim upriver to spawn. The effects of stream flow conditions can be either beneficial or deleterious, depending on the species, the ecosystem and the volume and timing of episodic seasonal flows. Higher stream flows tend to support the reproductive success of striped bass. In contrast, American shad in the Connecticut River respond negatively to increased stream flow.

If changes in climate cause an early peak in stream flow, the environmental conditions necessary for a species to thrive, such as appropriate temperatures and nutritious food, may not be present. Already, the onset of peak stream flow in the Northeast occurs one to two weeks earlier than it did in 1850 and is projected to occur 10 to 14 days earlier still by the end of the century.

The more frequent and intense storms predicted under conditions of global warming could directly affect the survival of fish in their early life stages. For example, a sudden drop in temperature during or after a storm can cause direct mortality of striped bass eggs and larvae. In addition, many species rely on prevailing wind and ocean currents to move or retain eggs and larvae within the safe harbor and life-enhancing environment of nursery habitats. When the prevailing patterns of these currents change, eggs and larvae may be put at risk.

In some circumstances, however, severe storms can benefit fish populations. For example, hurricanes with strong northeasterly winds and westward currents favor the dispersal of croaker larvae from offshore areas into Chesapeake Bay.

Severe storms are unlikely to benefit recreational fishing or the industries that support it. Storm damage threatens boats and marinas and other shoreline facilities, and inclement weather reduces the number of days anglers can get out on the water to fish.

Global Warming, Population Distribution and Community Structure

Consequences of global warming — the loss or degradation of preferred habitat, changes in the abundance or composition of forage, altered interactions among species and pressure from non-native

species — could stimulate changes in fish communities. Some species may flourish while others decline or are completely replaced by species better equipped to thrive under the new conditions.

Marine food webs will record environmental responses to global warming as shifts in plant productivity and fish community structures. Additionally, changed conditions could force key predators to move from a region, causing a cascade of top-down effects similar to those resulting from overfishing. As competing species move in to fill vacated ecological niches, the structure of the marine community changes. Local habitat conditions, influenced by factors such as seasonal winds, ocean currents and rainfall, will determine how extensively climate change affects any particular fish community and the recreational fisheries it supports.

While warming water temperatures are likely to prove detrimental to temperate and boreal fishes, tropical and subtropical species that already inhabit waters with elevated thermal ranges may eventually benefit from the warming of waters in higher latitudes. Species such as red drum, mullet and spotted sea trout could disturb the current ecological balance in temperate ocean regions by extending their ranges, increasing competition for resources and restructuring marine communities.

Such a situation was observed at “210 rock,” a reef popular among North Carolinian recreational and headboat fishermen that witnessed a substantial turnover in community composition between





1975 and 1990. The shift from a temperate-subtropical community to one dominated by tropical species occurred in conjunction with an increase in average winter bottom water temperatures of about six to 10 degrees Fahrenheit.

Fishermen may respond to changes in the distribution of fish populations and in the composition of marine communities by targeting new species or traveling longer distances to reach old favorites. While loss of a species from a portion of its historic range will reduce catch within that region, colonization of newly suitable habitat could open opportunities for recreational fishing elsewhere. Overall, fishing for warm-water species such as snapper and grouper is expected to improve as these fishes expand their ranges under conditions of global warming. Fishing for cool-water species, including striped bass, cod and swordfish, will likely decline as their habitat shrinks and they suffer physiological stress from the consequences of climate change.

Summary

While there is much that is not known about how climate change will affect saltwater fish, it is anticipated that climate change will lead to large population declines and possibly to local extinctions of

some sport fish. Rising sea levels will harm coastal habitat such as salt marshes and sea grass beds used by juvenile fish, thus ultimately leading to reduced numbers and sizes of sport fish. Frequent and severe storms likely will destroy physical habitat such as mangroves. Destruction of thousands of acres of critical forage and nursery habitat and aquatic vegetation, and increased salinity of many estuaries, will reduce the availability of algae, zooplankton and other primary food of juvenile fish. At the same time, higher water temperatures and ocean acidification will challenge the survival of fish eggs, fish larvae and coral reefs. The prevalence and severity of disease spread by bacteria, fungi and parasites is expected to increase among saltwater fish. All of these effects of climate change will alter population distributions and the structure of marine communities.

For sportsmen, there will be fewer fish to catch. The ranges of sport fish are expected to shift, with effects likely to be most pronounced for cool- and cold-water species in northern waters. Ultimately, regulators may need to reduce catch limits and the lengths of seasons to cope with reduced sport fish populations and shifts in ranges. Finally, intense and frequent coastal storms not only could reduce the number of days fishing is possible, they also may harm basic boating infrastructure, such as launching and docking facilities and marinas.

Two Visions of the Future

A landscape-scale model to help at-risk species adapt to human influences and a changing climate

The following graphic shows two visions of the future.

On the left-hand side, we see what a typical large-river system is likely to look like in the next 30 years if we do nothing to intervene. Development in the headwaters will degrade the last remaining intact habitat, eliminating the best refuge for native fish, which face a host of threats downstream, from migration barriers to pollution. This grim picture reflects only the current threats — it doesn't begin to show the potential impacts of global warming. On the right, we see a landscape knit back together through a conservation approach. Protect high quality habitats in the headwaters. Reconnect large river systems by removing obstructions. Restore degraded habitats. And the final step, not pictured here: create a new generation of cold-water stewards to see that this work continues well into the future.



Protect:

Backcountry land intact, improving water quality downstream and providing a stronghold for native fish and other species.

Reconnect:

Obsolete dams and diversions removed. Fish ladders and fish passages installed. Sufficient water left in stream, allowing fish to migrate through the river.

Restore:

Tree-shaded river reconnected to its floodplain. Grazing and development practices protect water quality. Industrial and agricultural pollution reduced.

Sustain:

Our conservation legacy will endure by engaging young people and mobilizing community members to protect, reconnect and restore lands and waters.

Strategies for Hope

While it's disquieting to realize that human activity contributes to global warming, that reality is also a wellspring of hope. If mankind is a cause of the problem, then mankind is also part of the cure. That cure begins when individuals accept responsibility for contributing to global warming, but it doesn't end there. The magnitude of the threat also requires

- federal legislation that puts a mandatory cap on greenhouse gas emissions
- funding for research, programs and projects that will reduce the effects of global warming on wildlife and fish
- an aggressive plan for implementing those projects

None of these critical objectives will be accomplished without the forceful support of sportsmen at the grassroots level as well as of local and state chapters of wildlife organizations. This combination of

individual and organizational effort is the foundation for optimism. Building on it, however, requires sportsmen who are willing to educate themselves and vigorously support state and federal wildlife agencies as they undertake critical tasks of research, monitoring and development of projects to put on the ground.

National wildlife organizations have created a list of actions that sportsmen must take if the work of government agencies is to shift the balance in favor of fish and wildlife. The organizations' broad recommendations encourage the support of programs and projects that

- ensure the health and resilience of existing ecosystems by eliminating stresses that increase susceptibility to global warming
- restore habitats such as streams and wetlands in areas where they can withstand and adapt to global warming
- connect federal and state lands, including parks, national wildlife refuges, national forests and game production areas, to enable migration
- reflect flexible decision making by state and federal wildlife agencies, especially when based on principles of adaptive management

In particular, the wildlife organizations urge sportsmen to

- Support existing conservation programs: It is more important than ever for sportsmen to support federal programs that focus

on habitat conservation, including those that retire marginal farmland from crop production and convert it back into forests, grasslands or wetlands. Major national programs that should be expanded include the Conservation Reserve Program (CRP), the Wetlands Reserve Program (WRP), the Grasslands Reserve Program (GRP), the Farm and Ranchland Protection Program (FRPP), the National Fish Habitat Plan and the North American Wetlands Conservation Act.

- Understand and support new public policy development: Opportunity exists to inform and support state, federal and international policies that reduce emissions of carbon dioxide and other heat-trapping, global-warming gases. These include policies setting specific limits on the nation's greenhouse gas (GHG) emissions; protecting and enhancing the ability of forests, grasslands, wetlands and other natural systems to absorb and store carbon; strengthening programs to promote energy efficiency; accelerating deployment of clean, renewable energy sources; and influencing the design of national and international climate change agreements. As new legislation to limit GHG emissions is debated, sportsmen must demand that the effects of climate change on wildlife are addressed and that a significant portion of new funds is dedicated to the conservation of fish, wildlife and their habitats.
- Support efforts that recognize global climate change as a factor in habitat conservation planning: Ignoring climate change is likely to result in a failure to reach habitat conservation objec-

tives. The strategies most important to implement will reduce greenhouse gas emissions and prevent broad-scale loss of wildlife and habitat as a consequence of global warming. The nation must also develop strategies that both actively help species and ecosystems cope with inevitable changes and build in flexibility to deal with unforeseen consequences. For example, with respect to waterfowl, the North American Waterfowl Management Plan, the North American Wetlands Conservation Act and relevant resource management activities must take global warming into consideration.

- Engage with agencies on natural resource issues relating to climate change: As fish and wildlife contend with consequences of climate change, it is increasingly crucial for sportsmen to stay involved in their sport and maintain their dedication to protecting and ensuring the resiliency of regional and national habitats. This means supporting the U.S. Fish and Wildlife Service, the U.S. Geological Survey, state game and fish agencies, conservation organizations and other groups in their efforts to apply adaptive management strategies that consider the effects of climate change on fish and wildlife habitat. Individuals and sportsmen's clubs must become involved with conservation districts, county commissions, local projects and partnerships as they restore wetlands; conserve instream flows in streams, rivers and lakes; and meet the needs of small, local habitat and water projects. At the national level, the ongoing work of major organizations involved in conservation will largely determine how effectively





we prepare for the consequences of global warming. Such organizations include the Coastal Conservation Association, Ducks Unlimited, Pheasants Forever, Trout Unlimited, the Bass Angler Sportsmen Society, the Wildlife Management Institute, the National Wildlife Federation, Delta Waterfowl, the American Sport-fishing Association and the Isaak Walton League of America.

- Encourage increasing research, but insist on action: Additional research, representing a significant cost to sportsmen, will be needed to close the knowledge gap. While new knowledge is essential for effective long-term decision making, absolute certainty about every possible alternative should not be required before projects to address global warming are put in place. Make the effort to be informed about the issues confronting state management agencies as they seek the resources they need for research and monitoring.
- Promote water management plans that include the needs of fish and wildlife: As global warming progresses, the competition for water will intensify. Maintaining river and stream flow characteristics, including periods of low flows, is essential to the survival of fish and wildlife. In coastal Louisiana it is important that water management plans deliver fresh water and sediment into wetlands in ways that resemble historical hydrological processes. In the prairie pothole region resource managers, conservation organizations and other stakeholders must be persuaded to

develop contingency plans for dry spells, such as adopting less water-intensive agricultural methods; securing long-term rights for water for wetlands, rivers and streams; and implementing watershed-based land use planning. In the Great Lakes, wetland restoration programs (such as WRP, CRP and WHIP) should be combined with headwaters-based efforts to improve the prospect for restoring water retention in Great Lakes watersheds.

- Prepare for change: Sportsmen and -women must be ready to adjust to changes in the behavioral patterns of their favorite species and to modify their recreational expectations. As fish and wildlife respond to global warming, their recruitment, productivity and sustainability may increase or decrease on a regional basis. Wildlife managers will adapt yield and harvest regulations based on research and monitoring. Sportsmen's adjustments may include traveling longer distances to hunt and fish and accepting reduced limits and shortened or closed seasons.

Strategies to Address the Effects of Global Warming: Cold-water Fish, Waterfowl, Big Game

Debate has begun among wildlife professionals regarding strategies to respond to global warming, but the discussion is in its initial stages. The following recommendations, restricted to cold-water fish, waterfowl and big game, are not meant to be a prescription or

the final word. Their purpose is limited: to nudge the conversation forward.

Cold-water Fish

There are a number of strategies that can build resistance and resilience to the effects of climate change in freshwater aquatic ecosystems. Taken individually, the strategies are not novel and include commonly accepted principles of conservation biology and restoration ecology. Simply stated, steps must be taken now to preserve the best remaining habitats and populations, protect genetic diversity of native species, restore life history diversity in vulnerable populations, reconnect watersheds and restore river systems. To deal with the uncertainty that is inherent in a changing future, monitoring and adaptive management will be necessary to reveal the resource needs and the appropriate management responses.

Protect remaining central habitat areas

It is vital that rivers and streams containing salmon and trout are protected. Headwater streams and lakes that offer high quality, cold-water flows will be integral to maintaining suitable downstream conditions during periods of warming. Watersheds without roads or those that are otherwise minimally disturbed typically provide the most reliable sources of cold water.

- Protect healthy, connected habitat. Fish need high quality habitat, which means that rivers and streams must be surrounded by

healthy, natural vegetation and their watersheds must have the proper cycles of rising and falling water levels.

- Maintain genetic diversity of native fish populations. Higher levels of genetic diversity enable populations to better adapt to future environmental change. The predominance of certain characteristics in a population may boost the likelihood of that population's surviving and successfully reproducing through periods of extreme change.

Reconnect high quality habitats

- Identify and reconnect important stream systems that have been physically disconnected by dams and culverts or that seasonally run dry from water diversions and other dewatering processes. Trout and salmon need access to a wide variety of habitats, from small headwater streams to deep river pools. Waterways are most valuable when they are connected to one another. Barriers that restrict fish from moving up and down the watershed can reduce overall fish populations and compromise genetic integrity.
- Remove or modify physical barriers. Obsolete or unnecessary dams, culverts and other blockages to fish movement should be removed to facilitate the recovery of migratory fish within a population and to increase the likelihood of fish finding suitable habitat conditions.

- Return water flows to streams. Many streams periodically run dry because of inefficient irrigation and water withdrawals. Creating incentives to leave water in streams will help to recover more natural river flows and enable fish to find cold water and high quality habitats.

Restore entire watersheds, not just individual streams and rivers

Taking a broad geographical approach to identifying areas to improve water quality, streamside vegetation and instream habitat is critical to restoring the overall health of lower-elevation valley bottom streams and rivers. Restoring streams and floodplains to a healthy, more natural state gives fish a greater opportunity to withstand the effects of floods, fire and droughts.

- Restore habitat. Re-creating diverse habitat to benefit and support a range of ages will increase populations' resilience to climate change. If native populations exist in headwater and lower-elevation habitats and across large geographic areas, they will be more resistant to local extinction.
- Restore native fish populations. Small, fragmented trout and salmon populations are at great risk of extinction, while larger populations are better able to survive. Non-native species and hatchery fish may limit native fish populations and increase their vulnerability to climate change. Non-native fish not only compete for food and habitat, but they may also thrive in warmer





and more polluted waters. Hatchery fish interbreeding with native populations can weaken the gene pool that could ultimately provide fish with the ability to adapt and survive.

Waterfowl

As wetlands and native grasslands are destroyed or degraded, North America continues to lose ground in maintaining waterfowl habitat. Further losses will magnify the challenge for waterfowl as they confront the stresses of global warming. The following strategies could mitigate the effect of those stresses.

- Employ adaptive management techniques for ecosystem processes: Management of natural resources is characterized by the need to adapt to continuously changing circumstances. Adaptation in the context of climate change can be defined as a deliberate management strategy to
 - enhance the resilience of vulnerable systems
 - minimize the adverse effects of climate change, reducing the risk of damage to human and ecological systems
- Rebuild wetlands as a natural form of flood control: Wetland rehabilitation can be a viable alternative to structural flood control and dredging for coping with large, frequent floods associated with climate change.
- Reduce stresses on ecosystems: For example, possibilities for minimizing the effect of climate change in the prairies include

- directing long-term waterfowl conservation actions to less vulnerable sub-regions of the prairies
- protecting native parkland habitats at the northern fringe of the pothole region, where longer growing seasons will favor agricultural expansion
- reducing existing human-caused stresses on wetlands (e.g., drainage, filling, road impacts) and associated uplands (e.g., overgrazing, intensive tillage)
- restoring or protecting complexes of wetlands of varying permanence in order to hedge against more variable moisture conditions
- developing contingency plans for large, managed wetlands
- Protect coastal wetlands and mitigate sea level rise: The implementation of integrated, watershed-level solutions to protect coastal and estuarine wetlands will be essential to the future success of waterfowl. For example, in southeast Louisiana large-scale diversions of fresh water and sediment from the Mississippi River into wetlands have the potential to bring equilibrium to rates of wetland loss and gain.

Big Game

A landscape degraded and fragmented by oil and gas drilling, human development and other factors increases the difficulty for big game to adapt to global warming. There are a number of steps to

undertake immediately to prepare for global warming's effects on big game populations:

- Ensure that the issue of global climate change is incorporated into all land use planning documents and that planning efforts incorporate steps to minimize the effects of global warming on biotic communities.
- Plan and implement programs to maintain or enhance early successional stages of vegetation and to ensure connectivity between summer and winter ranges.
- Initiate monitoring programs to collect and evaluate data on biotic community responses to global warming.
- In areas where winter or summer range is a crucial component of mule deer and elk habitat
 - limit disturbances on winter ranges
 - protect existing mule deer winter range; acquire and secure additional winter range that provides food and thermal protection and maintains connectivity with summer ranges
 - aggressively pursue land use planning in areas of rapid urbanization to minimize the loss of key winter and summer habitats
 - develop management actions that minimize encroachment of invasive weeds or tree species on seasonal mule deer and elk ranges



- guarantee that key browse species are maintained as a component of the vegetative community on winter ranges

Making the Protection of Fish and Wildlife a Part of the National Response to Climate Change

Currently there are no penalties in the United States for emitting the greenhouse gases that cause global warming. Moreover, with the exception of a few new state programs, there has been no effort to require industries to pay the real cost of discharging greenhouse gases into the atmosphere. These circumstances will change, however, when Congress adopts a mandatory, nationwide program to reduce emissions of these pollutants.

There are a number of approaches that Congress could adopt, including

- setting limits for every significant emitter, as is done to achieve water quality objectives through the Clean Water Act
- establishing a national tax on carbon, as is advocated by many economists
- enforcing a cap-and-trade system that allows a fixed amount of greenhouse gas emissions each year based on permits to regulated industries

Cap-and-Trade Approach

As of now, the cap-and-trade approach appears the alternative most likely to be adopted. Under this approach, caps, or annual limits on emissions of greenhouse gases, would be established for sectors that release pollutants, such as oil companies or fossil-fuel-burning electric utilities. These sectors would purchase from the federal government annual permits, or allowances, allowing emissions up to the capped levels.

In a newly created carbon credit market, regulated industries could buy, sell or trade credits among themselves or purchase additional credits to offset their excess carbon emissions. Credits would be purchased from sources that reduce polluting emissions — like farmers who sequester carbon in the soil. The marketplace would establish the price or value of the credits (e.g., \$15 per ton of carbon dioxide emitted).

All of the major greenhouse gas control programs in place to date have adopted the cap-and-trade approach. The international Kyoto Protocol is a cap-and-trade system, as is the European Union (EU) emissions trading scheme (ETS).

In the United States, the Regional Greenhouse Gas Initiative (RGGI) was developed by several New England and Mid-Atlantic states to cap and trade CO₂ emissions from power plants. RGGI now involves 10 states. California also is developing a cap-and-trade system to

limit emissions of greenhouse gases. It appears increasingly likely that Congress will adopt such an approach for the entire country.

Typically, a cap-and-trade system seeks to capture the efficiencies of market-based systems by capping those sectors or emitters capable of reducing a large percentage of pollutants. A cap-and-trade system regulating large, easily monitored entities like oil companies and electric utilities could prove less costly and more efficient than attempting to monitor and reduce emissions from numerous small “downstream” sources such as individuals and small businesses. As a result, Congress is likely to choose to regulate a few large “upstream” sources rather than many diffuse downstream sources.

Money for Conservation

When Congress adopts a cap-and-trade system, auctions of greenhouse gas emission permits to major upstream industries will generate billions of dollars annually. This money will be available to use for purposes related to climate change, including fish and wildlife conservation and research into low-carbon-emitting energy sources. Therefore numerous national conservation organizations have been working with U.S. senators and members of the House of Representatives to ensure that climate change legislation gives conservation a fair share of funds. These organizations believe that, from the money raised each year, billions of dollars should be dedicated to fund efforts by state game and fish agencies and federal environmental and

land management agencies to help fish and wildlife adapt to climate change.

In particular, two bills have already been introduced that are very promising for sportsmen. Both the Low Carbon Economy Act, introduced by Senators Jeff Bingaman (D-NM) and Arlen Specter (R-PA), and the Lieberman-Warner Climate Security Act of 2007, introduced by Senators John Warner (R-VA) and Joe Lieberman (D-CT), would require state and federal conservation agencies to develop detailed plans to help species adapt to climate change and would fund those plans annually with billions of dollars through a range of existing conservation programs including state game and fish agency programs, the North American Wetlands Conservation Act, the National Fish Habitat Action Plan, the Land and Water Conservation Fund, national forests and grasslands, Bureau of Land Management lands, national wildlife refuges, national parks, Fish and Wildlife Service easements, and federal and state freshwater, coastal and estuarine conservation programs.

While differing on the merits of competing national climate change bills, the nation’s leading hunting and fishing organizations broadly support the conservation provisions of the Bingaman-Specter bill and the Lieberman-Warner bill (see appendix A). These organizations are working to secure conservation funding in climate change legislation so that future generations will enjoy the hunting and fishing experiences central to the American legacy.



Appendix

Sportsmen's Letters to the U.S. Senate on Climate Change Legislation

AMERICAN FLY FISHING TACKLE ASSOCIATION * AMERICAN SPORTFISHING ASSOCIATION *
ASSOCIATION OF FISH AND WILDLIFE AGENCIES * BERKLEY CONSERVATION INSTITUTE
* BOONE AND CROCKETT CLUB * BEAR TRUST INTERNATIONAL
* CONGRESSIONAL SPORTSMEN'S FOUNDATION * DUCKS UNLIMITED, INC.
* FEDERATION OF FLYFISHERS * INTERNATIONAL HUNTER EDUCATION ASSOCIATION
* MULE DEER FOUNDATION * NATIONAL ASSEMBLY OF SPORTSMEN'S CAUCUSES
* NATIONAL WILD TURKEY FEDERATION * NORTH AMERICAN GROUSE PARTNERS
* PHEASANTS FOREVER * QUALITY DEER MANAGEMENT ASSOCIATION
* TEXAS WILDLIFE ASSOCIATION * THEODORE ROOSEVELT CONSERVATION PARTNERSHIP
* TROUT UNLIMITED * WHITETAILS UNLIMITED * WILDLIFE FOREVER
* WILDLIFE MANAGEMENT INSTITUTE

July 9, 2007

Honorable Jeff Bingaman, Chairman
Senate Energy and Natural Resources Committee
304 Senate Dirksen Office Building
Washington, DC 20510

Honorable Arlen Specter
United States Senate
711 Senate Hart Office Building
Washington, DC 20510

Dear Chairman Bingaman and Senator Specter:

The organizations on the letterhead, representing millions of hunters, anglers and other conservationists, very sincerely appreciate your willingness to add the attached wildlife conservation funding proposal to your climate change legislation. As you know, this carefully crafted and balanced proposal authorizes new resources to address the impacts of climate change on fish and wildlife, including dedicated funds for state fish and wildlife agencies and federal land and natural resources agencies' efforts to sustain fish, wildlife and their habitats in the face of anticipated pervasive and ongoing effects of climate change.

State fish and wildlife agencies and the federal natural resources agencies will be instrumental in implementing conservation strategies to mitigate the impacts of climate change on fish and wildlife resources. Funding for these efforts should be delivered through existing programs with track records of success in on-the-ground conservation, as called for under our proposal. At the state level, the long-standing and successful Pittman-Robertson Wildlife Restoration program and Dingell-Johnson/Wallop Breaux Sportfish Restoration and Boating program provide the most appropriate means of delivering many of the needed conservation benefits. More recently, the State Wildlife Comprehensive Conservation Strategies (State Wildlife Action Plans) have demonstrated the states' capacity to comprehensively address fish and wildlife species which status is in most urgent need of conservation assistance, and thus likewise are appropriate programs to receive funds.

To address the upcoming challenge of assisting fish and wildlife to respond to climate change, at least \$1.2 billion per year should be made available to be spent through these three programs: the Wildlife Conservation and Restoration account under the Pittman-Robertson Fund; Pittman-Robertson Wildlife Restoration; and Dingell-Johnson/Wallop Breaux Sportfish Restoration. The new funds should be expended only on activities that facilitate the resiliency and sustainability of fish and wildlife and their habitats in response to climate change impacts.

Our proposal also authorizes a new program to require the development of a coordinated strategy among federal agencies, with input from state fish and wildlife management agencies. At least \$1.2 billion per year should be provided for the federal response to this issue, and implementation of the coordinated strategy should be done through well-regarded federal programs, such as the North American Wetlands Conservation Act, and others with demonstrated track records of success.

Thank you again for working with us to help enact this important new fish and wildlife conservation proposal. We look forward to working with you and your staff on this very crucial and complex issue.

cc: Honorable Pete Domenici, Ranking Member, Senate Energy and Natural Resources Committee

State Fish and Wildlife Directors

AMERICAN FLY FISHING TACKLE ASSOCIATION * AMERICAN SPORTFISHING ASSOCIATION
* ASSOCIATION OF FISH AND WILDLIFE AGENCIES * BERKLEY CONSERVATION INSTITUTE
* BOONE AND CROCKETT CLUB * BEAR TRUST INTERNATIONAL
* CONGRESSIONAL SPORTSMEN'S FOUNDATION * DUCKS UNLIMITED, INC.
* FEDERATION OF FLYFISHERS * INTERNATIONAL HUNTER EDUCATION ASSOCIATION
* MULE DEER FOUNDATION * NATIONAL ASSEMBLY OF SPORTSMEN'S CAUCUSES
* NATIONAL WILD TURKEY FEDERATION * NORTH AMERICAN GROUSE PARTNERS
* PHEASANTS FOREVER * QUALITY DEER MANAGEMENT ASSOCIATION
* TEXAS WILDLIFE ASSOCIATION * THEODORE ROOSEVELT CONSERVATION PARTNERSHIP
* TROUT UNLIMITED * WHITETAILS UNLIMITED * WILDLIFE FOREVER
* WILDLIFE MANAGEMENT INSTITUTE

October 18, 2007

Honorable John Warner
United States Senate
Senate Russell Office Building
Washington, DC 20510

Honorable Joe Lieberman
United States Senate
Senate Hart Office Building
Washington, DC 20510

Dear Senators Warner and Lieberman:

The organizations on the letterhead, representing millions of hunters, anglers and other conservationists, very sincerely appreciate your willingness to add a balanced and thoughtful fish and wildlife conservation funding proposal to your climate change legislation. Your carefully crafted proposal will help ensure the long-term survival of fish and wildlife by providing important new resources through direct spending to address the impacts of climate change.

State fish and wildlife agencies and the federal natural resources agencies will be instrumental in implementing conservation strategies to mitigate the impacts of climate change on fish and wildlife resources and their habitats. Funding for these efforts should be delivered through

existing programs with track records of success in on-the-ground conservation, as called for under your proposal. At the state level, the long-standing and successful fish and wildlife restoration programs provide the most appropriate means of delivering many of the needed conservation benefits.

We particularly appreciate the fact that you intend to provide 40 percent under direct spending of the natural resource conservation funding available under your legislation to be spent through the Wildlife Conservation and Restoration Account established under the Pittman-Robertson Wildlife Restoration Act for comprehensive programs to remediate impacts from climate change to all fish and wildlife species. The state cost share requirement of 10 percent will help ensure that states can utilize these funds immediately to implement conservation actions and put needed habitat on the ground. By funding state fish and wildlife agencies in this manner, your legislation will effectively and efficiently support critical activities that enhance the resiliency and sustainability of fish and wildlife and their habitats to climate change.

Federal agencies also will play an important role in assisting fish and wildlife to adapt to the impacts of climate change and we applaud your efforts to provide direct spending resources for a wide range of important federal programs, including implementing cooperative grant programs that benefit fish and wildlife.

In conclusion, our organizations, representing millions of American sportsmen and sportswomen, thank you again for working with us to help address the challenge of climate change by both reducing emissions of greenhouse gases and providing important new resources to assist fish and wildlife to survive in the face of this unprecedented challenge. We look forward to working with you and your staff on this very crucial and complex issue as your legislation moves forward.

Photography Credits

The Wildlife Management Institute wishes to thank the following for their generous assistance in providing photographs and graphics for the book *Seasons' End*:

Covey Rise

pages 64, 104

Andy Crawford

page 99

Idaho Travel Council

pages 1, 101

Louisiana Office of Tourism

page 36

Natural Resources Conservation Service

Tim McCabe, photographer, page 14

Gary Kramer, photographer, page 77

South Dakota Tourism

pages i, v, 24-25, 33, 43, 48-49, 54, 57, 60-61, 66, 69, 70

Trout Unlimited

pages 94-95

