Ducks Unlimited

Conserving

WATERFOWL AND WETLANDS AMID CLIMATE CHANGE

Submitted to:

The Wildlife Management Institute &
The Hewlett Foundation

By

Ducks Unlimited, Inc.

as part of the
Sportsman's Advisory Group on Climate Change

FOREWORD

The predicted and observed impacts of global climate change have received wide media attention in recent years. Scientists predict that climate change will affect almost every aspect of our environment, including North America's wetlands and waterfowl. Projections for the next 100 years indicate extensive warming in many areas, changing patterns of precipitation, accelerating sea level rise, changes in the timing and length of the seasons, declining snow packs and increasing frequency and intensity of severe weather events. Ducks Unlimited (DU) will need to plan for the effects of climate change if wetland and waterfowl management objectives are to be achieved.

DU has a long history of wetlands conservation in North America. Working with both private and public landowners, DU has protected, restored and/or managed over 12 million acres of important wildlife habitat. However, the potential consequences of climate change are significant, and DU is taking steps to keep informed and incorporate climate change science into conservation planning. The nation's duck hunters have a stake in the complex issue of climate change, and future hunting opportunities will rely on our collective ability to accurately assess, predict, and manage impacts on waterfowl and their habitats.

DU has prepared this white paper summarizing the impacts of climate change on waterfowl, wetlands, and the waterfowling community as part of the Sportsman's Advisory Group on Climate Change supported by the Hewlett Foundation. The paper synthesizes new conservation and research approaches to provide a series of science-based recommendations concerning the impacts of climate change and variability upon wetland ecosystems and waterfowl and acknowledges the important role that wetlands play in the carbon cycle. We describe how those impacts will affect existing programs and financial investments of both public and private agencies as well as those of DU and other conservation partners. We also describe ongoing research on this topic and recommend both on the ground and policy actions to respond to these global environmental and ecological changes.

While there are no practical, global solutions for protecting wetlands as a whole from increasing temperatures, changes in precipitation, or rapidly rising sea level – there are a variety of management measures that can be applied to increase the resiliency of specific wetlands or to reduce or partially compensate for impacts. Many of these measures could be justified based upon non-climate threats to wetlands alone. For example, increased protection for existing wetlands and removal of stresses (e.g., water pollution) may not only reduce the sensitivity of plants and animals to small changes in temperature or precipitation, but also achieve broader wetland protection and restoration goals. Further, wetlands play a vital role in the carbon cycle and wetland loss may have impacts that encourage global warming and climate change. DU is a pioneer in the newly developing science of carbon sequestration in wetlands, provides comment and guidance on proposed policy and programs that address terrestrial carbon sequestration, and works with major corporations to help ameliorate the effects of carbon dioxide in the atmosphere.

Additionally, waterfowl hunters in some parts of North America have experienced changes in duck and goose flight traditions for several years due to odd or unusual weather patterns. Those patterns have been erratic for rainfall with warm periods extending into winter. Consequently, waterfowl have not followed traditional migration patterns and hunters, who have often made major investments in land and club facilities, have experienced poor hunting. As climate change continues, we expect to see even more significant shifts in the patterns of the birds with direct impacts on hunting. The information presented in this paper can help educate the public about the changes affecting waterfowl populations and distribution as well as the importance of the early formulation of management strategies that recognize the gravity of the changes that could occur as a result of the alteration of the earth's climate.

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Ducks Unlimited Inc. is a private, non-profit organization dedicated to conserving wetland habitat for waterfowl and other wildlife and people.

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TABLE OF CONTENTS

1. INTRODUCTION

North America's migratory waterfowl and the habitats they require are highly valued by society. The benefits that waterfowl and their habitats provide are ecological, social, or economic in nature and include food, ecosystem stability, recreation, a source of income, and much more. Recognition of the importance of waterfowl and wetlands to North Americans has led to the establishment of many state and federal laws as well as international strategies to restore and protect waterfowl populations through habitat protection, restoration, and enhancement. Ongoing land use pressure as well as the effects and future predicted impacts of climate change challenge these efforts.

The impacts of global climate change have received wide media attention in recent years with the majority of the coverage focusing on bleak predictions – water shortages, drought, rising sea levels, species extinctions and extreme weather events. However, climate change will affect almost every aspect of our environment, including North America's wetlands and waterfowl. **The purpose of this paper is to help provide added understanding about climate change and its direct, indirect and long-range effects on wetlands and waterfowl.** We review the research that highlights known and probable effects on key North American migratory waterfowl habitats. We also address the impacts to waterfowl hunting and sportsmen as a result of land use change, waterfowl population and distribution changes, and impacts to public and private investments. Finally, we present recommendations for local, regional and policy related actions.

It is widely accepted by the scientific community that the earth, which has always experienced climate variation, is now undergoing a period of rapid climate change that is enhanced by anthropogenic atmospheric carbon enrichment during the past 100 years. These climatic changes are accelerating and projections for the next 100 years indicate extensive warming in many areas, changing patterns of precipitation and sea level rise. Other likely components of ongoing climate change include changes in season lengths, decreasing range of nighttime versus daytime temperatures, declining snow packs and increasing frequency and intensity of severe weather events. The many components of climate change, and especially the rapid rate of change, are just as important as increasing temperatures.

The effects of climate change now underway have extensive potential to affect waterfowl throughout North America, either directly or indirectly through responses to changing habitat conditions. When considered in combination with other pressures (e.g., pollution, urbanization) the potential effect is even greater. The effects of climate change on populations and range distributions of wildlife are expected to be species specific and highly variable, with some effects considered negative and others considered positive. Variations in this overall pattern will be dependent upon specific local conditions, changing precipitation patterns, and the response of different species to different components of climate change.

To ignore climate change would be to increase the risk of failure to reach wetland and waterfowl management objectives. Habitat managers need to become knowledgeable about climate change, ways to cope with it, and ways to take advantage of it. The ability to adapt, expect the unexpected and reduce non-climate stressors on wetlands is also necessary. Management options currently available include protecting coastal wetlands to mitigate sea level rise, adjusting yield and harvest models, accounting for known climatic variations in conservation planning, and taking climate change into consideration when selecting the location and other characteristics of conservation areas. Overall, wetland and waterfowl managers can minimize negative impacts and take advantage of positive aspects by planning ahead and employing adaptive management.

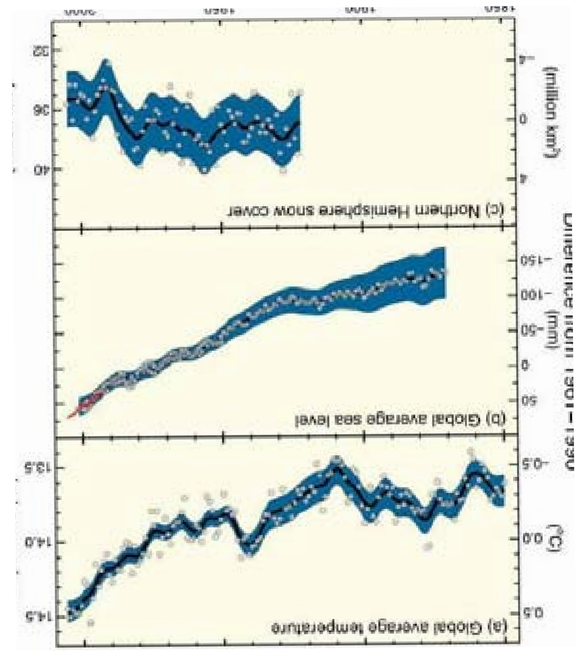
[1] Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs.

2. CLIMATES ARE CHANGING

The earth's temperature is normally regulated by naturally occurring greenhouse gases (GHGs) including carbon dioxide, methane, nitrous oxide and water vapour that trap the sun's heat and prevent it from being lost to space. This "greenhouse effect" is a natural phenomenon that maintains livable temperatures on the earth. Climate varies on all time scales, from one year to the next, as well as from one decade, century or millennium to the next. The complex nature of this variability is a major obstacle to the reliable identification of global changes brought about by the presence and activities of humans. Driven by complex interactions among the earth's solar orbit, atmospheric CO2 concentrations, continental ice sheets, ocean circulation, and other factors, climate variation is evident on many different scales and has many different patterns (Inkley et al. 2004).

Despite these complexities, significant changes in climate in the past 100 years have been documented (Fig. 1). The 20th century was the warmest period of the past 1000 years (Mann et al. 1998, 1999), and there have been fewer days of extreme low temperatures and more days of extreme high temperatures in the U.S. since the 1950s (Karl et al. 1996). Around the world, there is an increasing awareness of the importance of climate change as a factor in a range of environmental, economic and social issues. As a result, conservation and political action on climate change have taken many forms, most of which have the ultimate goal of limiting and/or reducing the concentration of GHG in the atmosphere or mitigating the impacts of climate change on the ground. In 1992, nearly all countries of the world signed the United Nations Framework Convention on Climate Change (UNFCCC), establishing a long-term goal to stabilize atmospheric concentrations of greenhouse gases. Each party to the Convention is committed to limiting greenhouse gas emissions and protecting and enhancing greenhouse gas "sinks and reservoirs." In December of 1997, as part of efforts to fulfill the Convention, international negotiators signed the Kyoto Protocol in Japan. The Protocol directs participating developed countries to reduce their emissions of carbon dioxide (CO2) and five other prominent greenhouse gases by at least 5 per cent below 1990 levels between 2008-2012.

FIGURE 1



Observed changes in (a) global average surface temperature: (b) global average sea level rise (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values and circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). (Source: IPCC Climate Change 2007).

While some people continue to view climate change as a part of natural variability in the earth's climate, the most recent report by the United Nations' Intergovernmental Panel on Climate Change (IPCC) concluded that human activities are partially responsible for recent increases in the average temperature of the Earth, primarily through the burning of fossil fuels and the related 35% increase in atmospheric carbon dioxide concentrations since pre-industrial times (IPCC 2007a). A second IPCC report concluded that many natural systems are already being impacted by regional climate change (IPCC 2007b).

2.1 Summary of Impacts

Several aspects of climate change will affect wetlands and the waterfowl that use them. An increase in carbon dioxide (CO2) will trap heat in the atmosphere causing a rise in air, water and soil temperatures—including wetlands, lakes, streams, rivers, estuaries, oceans and ground waters, which will present challenges to wetland plants and animals (Kusler 2006). Other factors include changes in precipitation, more intense climatological events, such as hurricanes, tornadoes, nor'easters and thunderstorms that affect wetland systems through intense rainfall and storm-caused erosion. Rising temperatures have reduced snow cover, mountain glaciers, and Arctic sea ice. Sea level rise resulting from thermal expansion of the ocean and freshwater input was 3.9–7.9 inches for the 20th century (IPCC 2001). Nighttime temperatures have increased more than daytime temperatures (thereby decreasing the diurnal range) (Karl et al. 1991), and land surface temperatures have warmed more than sea surface temperatures.

Sensitive wetland ecosystems may be significantly affected, both positively and negatively, by relatively minor climatic changes in hydrology. Changes may occur not only to precipitation levels, but also the timing of precipitation events – such as increases in the amount of precipitation per event yet drier periods in between events.

While it is certain that climate plays an important role in the health, functioning and distribution of wetlands, how variations will impact specific wetlands and waterfowl is difficult to assess given the multitude of interplaying variables. Further complicating the issue is the fact that wetlands are diverse entities and have varying degrees of vulnerability, for example, to changes in timing and amount of precipitation, and will therefore exhibit impacts differently. While existing global climate models differ in technical details, those differences are only part of the uncertainties in climate predictions.

The system being modeled (the atmosphere and its interaction with oceans and land masses) is enormously complex with feedback loops and other features that are still not well understood. Further, future greenhouse gas emissions scenarios are uncertain, and these forcing factors greatly influence the outcomes of the models. As a result, the best option for the present may be to compare predicted outcomes from several plausible emission scenarios while keeping in mind that complex systems might have unpredictable results. Finally, a specific challenge for waterfowl and wetland managers is that climate models were built to work at large geographic scales. Downscaling landscape model predictions to sub-regions, such as the prairie potholes, is very desirable for conservation planning but not well supported by current models and more research is required.

2.2 Climate and Waterfowl

Climate change likely will affect waterfowl in a number of different ways, including changes to species ranges and timing of migration. But most importantly, climate change is expected to alter the wetland habitats of waterfowl. Climate impacts are predicted for nearly every region important to waterfowl in North America to some degree. The mobility and adaptability of waterfowl may allow them to avoid areas that are most heavily impacted by climate change, but the sensitivity of shallow wetland habitats to changes in precipitation and soil moisture may make alternative habitats scarce. One certainty is that climate change has the potential to further threaten vital habitats and waterfowl that are already facing growing pressure from human development.

Climate change will affect wetlands through:

- **Sea level rise**
- **Changes in hydrology and hydroperiod**
- **Increased water temperature; possible trophic changes**
- **Favoring more invasive species**
- **Changes in precipitation patterns**
- **More intense weather events**
- **Increased temperature in taiga, tundra and polar areas**
- **Reduced snow cover, glaciers and permafrost**
- **Human land use changes**
- **Human water consumption patterns**

3. HABITAT CHANGES

3.1 Land Use Change

Land use and land cover are linked to climate and weather in complex ways. Key links include the exchange of greenhouse gases between the land surface and the atmosphere, the radiation balance of the land surface, the exchange of heat between the land surface and the atmosphere, and the roughness of the land surface and its uptake of momentum from the atmosphere (USCCSP 2003). Because of these strong links, changes in land use and land cover can be important contributors to climate change and variability. Changes in land use have historically been a source of anthropogenic emissions of carbon dioxide to the atmosphere, primarily through deforestation (Dixon et al. 1994; Houghton 1996). However, land use change through habitat restoration also presents opportunities to reduce net CO2 emissions to the atmosphere or to increase the net uptake of carbon from the atmosphere through biological carbon sequestration (IPCC 2007c).

Climate change has the potential to affect a range of human activities and land use patterns. Increased temperatures would expand the growing season across North America, most significantly at higher latitudes where growing-season length is an important limiting factor. The cumulative effects of increasing growing-season temperature, decreasing days below freezing, and increased atmospheric CO2 will likely have a positive effect on net primary productivity and the accumulation of carbon in many plant communities. Increased aboveground biomass increases the potential for wildfires, which can lead to rapid restructuring of ecosystems (VEMAP 1995, NAST 2000). Surprisingly, there is also the potential for these changes to have some positive implications for waterfowl. For example, the pressures of climate change on agriculture in the Prairie Pothole Region are expected to include increased periods of drought and rising energy costs, both of which may favor conversion of annual crops to rangeland, a change that may help to improve the nest success of upland nesting ducks in wet years. Milder winters may also enhance survival of fall-seeded crops such as winter wheat – which will provide a safe haven from spring tillage for nesting waterfowl. However, these potential improvements to upland habitat will be insufficient for waterfowl if the adjacent wetland habitats are dry.

3.2 Sea Level Rise

One of the most significant and costly potential impacts of climate change is sea level rise that will cause inundation of coastal areas, shoreline erosion, and destruction of important wetland and mangrove ecosystems. Average global sea level rose 3.9-9.8 in during the past 100 years, and a mid-range estimate projects an increase to 18.9 in by 2100 (IPCC 2001). While different methods were used to estimate sea-level rise in the IPCC Fourth Assessment Report released in 2007, the latest 7.1-23.2 in estimated range of sea-level rise does not include the full impacts of changes in ice sheet flow, which could add 7.9 in or even more. As global temperatures increase, sea level rise already underway is expected to accelerate due to a thermal expansion of upper layers of the ocean and melting of glaciers. Some climate models predict increased impacts on coastal landforms with increasing severity of tropical storms. However, even without increased severity, storm surge effects could be compounded as sea levels rise and natural coastal defenses deteriorate (Knutson et al. 1999, Timmerman et al. 1999). Increased storm surge and mean tide levels could also alter disturbance regimes in shallow coastal waters, thereby influencing the composition and productivity of sea grasses and other coastal vegetation important to waterfowl. Both average and peak salinity levels could increase in estuaries and adjacent habitats and sedimentation rates may vary, thereby altering the zonation and succession of vegetation (Inkley et al, 2004).

In past eras of sea level rise, wetlands could retreat naturally inland, but roads and coastal structures have closed off this option of natural retreat in much of the U.S. coastline. The result is that the total area of beaches and wetlands may diminish greatly in the U.S. over this century. Some waterfowl species could be displaced inland or disappear entirely if their low-lying coastal wetlands are rapidly inundated. Reduction of coastal marsh habitats is expected to be most severe along the U.S. Gulf and Atlantic coasts where effects of sea level rise are compounded by subsidence as well as freshwater and sediment diversions.

3.3 Snow, Permafrost, and Sea Ice Decline

According to the 2007 IPCC report on the physical basis of climate change, temperature increases in the arctic regions of the Northern Hemisphere are already adversely affecting snow coverage, permafrost and sea-ice. The extent of snow covered area in the northern hemisphere has declined rapidly since the 1970s, and is very likely to continue to decline as a greater percentage of precipitation will occur as rainfall, leading to rapid snowmelt. On the western coast of North America, the increase in rain-on-snow events has coincided with a greater frequency of severe flash floods (McBean 2005). Permafrost is also declining in area and with remaining sections undergoing degradation, altering the hydrology and plant composition of the landscape. By the end of the 21st century, the southern permafrost limit is expected to move northward several hundred miles, allowing the tree and shrub line to advance. These shifts in hydrological systems are already increasing the intensity of spring run-off, affecting the thermal structure and water quality of regional lakes and streams (IPCC 2007a). Arctic coastal environments are also under threat as sea-ice continues to decline in area and thickness. Sea ice acts as an important buffer of coastal shoreline from erosion. As greater amounts of sea ice melt and permafrost thaw, coastal erosion will likely be exacerbated.

There are many uncertainties on how the culmination of these effects will play out on waterfowl populations that rely on Arctic ecosystems for breeding or staging habitat, but some species will fare better than others. Earlier snow melts, thawing of waterways, and warmer spring temperatures may have positive effects on breeding season events. Arctic nesting geese are notable beneficiaries of these effects to the extent that favorable breeding season conditions have led to over population in recent years (see Case Study). Conversely, wetland dependent waterfowl species may face difficulties as wetlands change from permafrost thawing. In Central Alaska, wetlands are decreasing in size as permafrost melts (Riordan et al. 2006). In the Yukon Flats National Wildlife Refuge in northeast Alaska, the trophic composition of small wetlands has flipped from amphipods and other invertebrates to algae and other non-duck foods (Corcoran 2005). Waterfowl dependent on the protein rich invertebrate supply of these wetlands will be forced to migrate elsewhere to locate such wetlands or switch to new food sources.

3.4 Increased Invasive Species, Pests, and Pathogens

The stresses induced by invasive species, pests, and pathogens on native ecosystem structures and productivity are likely to increase as a consequence of climate change. Invasive species are plant, animal, or microbes non-native to an ecosystem. In the U.S. alone, an estimated $138 billion is spent annually controlling and repairing damages from invasives (Pimental et al. 2000). The lack of natural predators and parasites in their new environments frequently allows for the rapid reproduction and dispersal of invasives, often at the expense of native species.

An invasive species impacting waterfowl habitat in the coastal prairies and in much of the southern U.S. is Chinese tallow (Triadica sebifera [Sapium sebiferum]), a freeze-intolerant non-native tree species. The Chinese tallow has little to no habitat or food value for waterfowl and other migratory birds dependent upon the forested hardwoods of the gulf coast. Changes in land-management practices are largely responsible for the expansion of the plant. During a 14-year period in southeastern Texas (1981-1995), the tallow's range increased 30-fold (Harcombe et al. 1998). In Louisiana, a similar shift in forest composition is occurring from the effects of Hurricanes Katrina and Andrew in 2005. Bottomland hardwood tree mortality from the hurricanes provided an opening for the tallow to invade, dispersing migratory birds into upland forests and reducing forage opportunities (Faulkner et al. 2006). The Chinese tallow is expected to expand as freeze-free zones shift northward. Although it is difficult to manage against catastrophic forces of nature such as hurricanes, proper management of wetlands and other habitats will help prevent invasives such as the Chinese tallow from degrading important waterfowl areas.

Invasive species are currently a significant issue in other waterfowl regions, including the Great Plains. In the short-grass prairie, for instance, the slight warming of nighttime temperatures over the last 20 years has been linked to the decline of blue grama grass, the dominant grass of the short-grass prairie (Joyce et al. 2001). Invasive grassland plant species such as the leafy spurge (Euphorbia esula) and wetland species such as purple loosestrife are expanding in range, altering plant communities to the detriment of grassland nesting waterfowl (Blossey et al. 2001, Sheiman et al. 2003). The grassland ecosystems of the Great Plains are also vulnerable to invasions through riparian corridors adjacent to streams and rivers as invasives can easily advance through these regions, providing pathways into upland habitats. Historically, natural disturbances such as fire and grazing helped maintain plant composition of native grassland communities, as these plants had evolved to accommodate these events. Future alterations in the frequency, intensity, spatial distribution and scale of natural disturbances from climate change could alter this important dynamic and accelerate the replacement of native species with exotics.

Pathogens, disease-causing organisms, are also expected to respond to climate change. A warming climate will expand suitable habitats for pathogens and their vectors, and increase pathogen survival rates (Harvell et al. 2002). The increased availability of pathogens in both distribution and intensity could also coincide with vulnerable hosts, stressed by climatic or other anthropogenic factors. The potential for epidemics is also enhanced as pathogens inhabit new regions, infecting hosts with no or limited immunity. Due to their migratory nature, waterfowl face an increased exposure to these developments and may act as vectors between ecosystems.

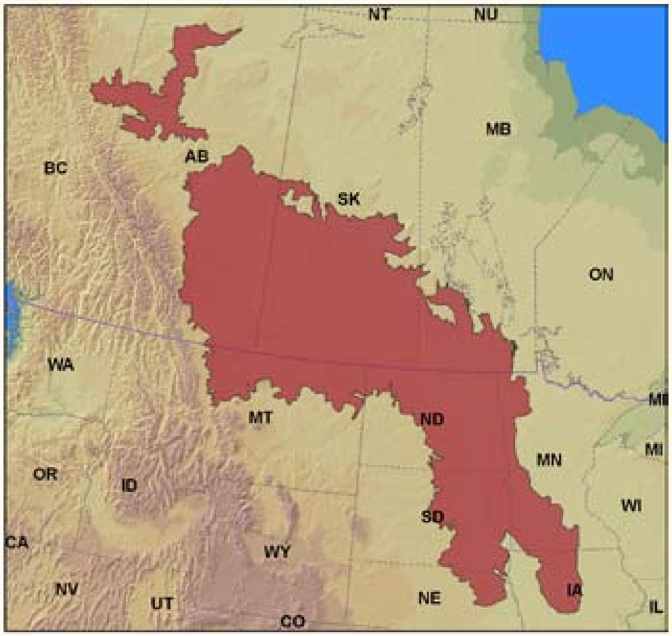
4. REGIONAL HABITAT IMPACTS

The following graphic depicts Ducks Unlimited's highest priority International Conservation Planning Regions that are based on the North American Bird Conservation Initiative regions for waterfowl. The following sections summarize some of the climate change impacts that are being realized or predicted in several of these key waterfowl areas.

4.1 Prairie Potholes

The Prairie Pothole Region (PPR) lies in the heart of North America and provides breeding habitat for 50% of North America's ducks. The PPR is the core of what was once the largest expanse of grassland in the world, the Great Plains of North America. When the glaciers from the last ice age receded, they left behind millions of shallow depressions that are now wetlands known as prairie potholes. The potholes are rich in plant and animal life, and support globally significant populations of breeding waterfowl and other migratory birds. Impacts from agricultural development have caused considerable wetland drainage in the area. Additionally, as the climate warms and evaporation and transpiration by plants increase, many of these shallow ponds may dry up or be wet for shorter periods, making them less suitable habitat for ducks (Glick 2005).

Average spring temperatures have increased in this region over the past 50 years and all global climate models predict further warming. Expected ecological changes include fewer wetlands on average; shorter flooding duration for wetlands; greater annual variability in surface water; changes in agriculture; and changes to water depth, salinity, temperature, plants and aquatic food webs. Models of future temperature and resulting drought conditions in the region on balance predict significant declines in Prairie Pothole wetlands, but vary from no change to a loss of up to 91 percent. Predictions about future changes in precipitation for this area are less certain and range from slight increases to slight decreases (Inkley et al. 2004). Wetland availability and emergent cover conditions are the primary factors that determine the number and diversity of breeding waterfowl



Prairie Pothole Region

that will settle in the PPR (Weller and Spatcher 1965; Johnson and Grier 1988). Drought can affect the breeding success of prairie ducks by decreasing the likelihood of breeding at all and by causing reduced clutch sizes, shorter nesting seasons, reduced likelihood of re-nesting, lower nesting success, and lower brood survival, collectively resulting in fewer ducks being produced (Sorenson et al. 1998; Inkley et al 2004). However, waterfowl are adapted to exploit periodic shifts in wetland conditions and are known to migrate past drought-stricken areas to settle in landscapes with an abundance of ponded wetlands. During times of widespread drought, waterfowl may only find favorable conditions near the wetter northern and eastern fringes of the PPR, or beyond in northern Canada (Johnson et al. 2005).

Continental waterfowl populations are characterized by boom and bust cycles that are largely dictated by regional wetland conditions. Under historic conditions, population declines were commonplace during drought, because recruitment was limited to a few remaining regions with suitable wetland conditions. Populations would then rebound when water returned to drier regions. Under a warmer and drier climate, however, it is estimated that populations would decline below historic levels, because wetlands in the central PPR that used to provide ample habitat would be too dry for most waterfowl in most years. Johnson et al. (2005) found that the PPR climate changed during the 20th century with nearly all weather stations examined in their study recording warmer temperatures, but western stations becoming drier and eastern stations wetter. They suggested that climate change may diminish the benefits of wetland conservation investments in the central and western PPR. Research is ongoing that may help determine whether the simulated favorable water and cover conditions in the eastern PPR can compensate for habitat losses in the western and central PPR.

Many climate related research efforts in this region have focused on trying to project future "average" conditions in a system where inter-annual variation is great. The interval patterns of wet and dry periods are going to be important to the future of waterfowl and other wildlife using these wetland systems. Additionally, changes in agriculture could have strong effects for wetlands and especially for upland-nesting birds. Reduction of tillage coupled with expansion of forage/hay crops could create more favorable conditions for nesting ducks. Conversely, climate-induced expansion of row crops, especially corn and soybeans, to the north would be highly detrimental – particularly given the drive toward corn-based ethanol production (Johnson 2007).

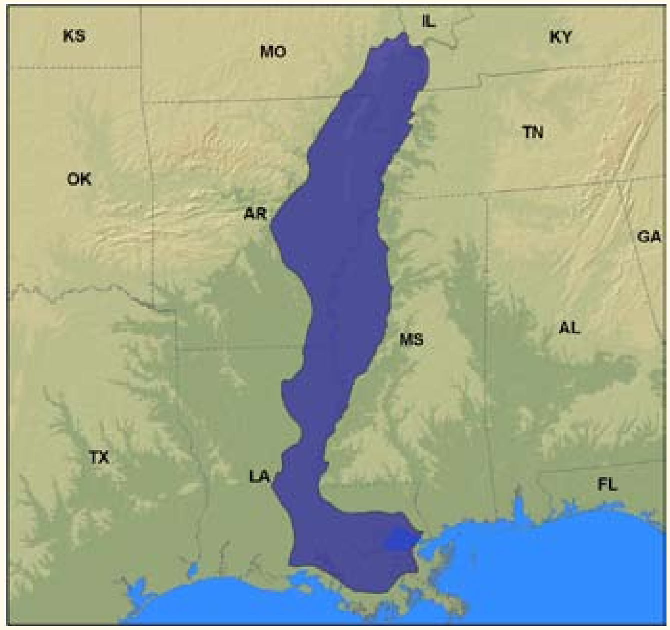
4.2 Western Boreal Forest

The vast Western Boreal Forest (WBF) of Alaska and northwestern Canada supports an estimated 12 to 15 million breeding waterfowl. Many more birds use these habitats for molting or staging when the prairies are dry. Boreal forest ecosystems could be among the most affected by global warming because of the greater temperature changes expected at high latitudes (Environment Canada 1995). Temperatures have risen faster here than in any other region of North America due to a number of factors including snow and ice melt. The reduction of snow and ice cover will reveal new land and ocean that absorb more solar energy. Ecological predictions include lengthening ice-free seasons on lakes and rivers; earlier runoff; melting permafrost; and northward range shifts by plants and animals (Inkley et al. 2004).

Substantial areas of western Canada's boreal forest were in drought conditions through much of the 1980s and early 1990s. Since the 1970s, the area of boreal forest in Alaska burned each year has more than doubled. It is not clear whether more frequent fires would degrade or improve habitat conditions for breeding waterfowl but continuing change is anticipated.

The biggest obstacle to anticipating impacts of climate change on waterfowl populations in this region is a lack of understanding of the basic ecology of boreal wetlands and breeding ducks. We know little about what limits waterfowl populations breeding in the region or the nature of wetland food webs on which ducks depend. This is a serious knowledge gap because while several duck species (scaup, scoters) in this region are declining, resource development (oil and gas, forestry, mining) is rapidly expanding, and climate change impacts on the habitats and ecosystem are expected to be significant. While we can say little with confidence yet about consequences of climate change for boreal forest waterfowl, it is clear that basic research and monitoring are urgently needed.

Western Boreal Forest - Canada



Mississippi Alluvial Valley

4.3 Mississippi Alluvial Valley

Uncertainty about future precipitation and runoff clouds predictions for the Mississippi River Basin, the third largest drainage system in the world. More than half of the land area of the basin is devoted to cropland, much of that being former bottomland hardwood forests. Wetlands in the upper basin provide important breeding and staging habitats for Mississippi, Central and Atlantic flyway waterfowl. The lower basin is the most important wintering area on the continent for mallards, and supports large numbers of other dabbling ducks and wood ducks (Bellrose 1980).

According to the EPA Climate and Policy Assessment Division, in a warmer climate, higher temperatures, increased evaporation, and changes in precipitation would heavily influence runoff in MAV states. Lower streamflows, lake levels, and groundwater levels in the summer could affect water availability and increase competition among domestic, industrial, and agricultural uses of water. Declining groundwater levels are a matter of concern throughout much of Arkansas and Mississippi. Increased rice irrigation and fish farming in the Delta region have reduced groundwater levels in the Mississippi alluvial aquifer. Increased municipal and industrial withdrawals in the metropolitan Jackson area, along the Gulf Coast, and in northeastern Mississippi also have lowered groundwater levels. Warmer and drier conditions, particularly if accompanied by sea level rise, could compound these types of problems due to higher demand and lower flows.

On the other hand, if precipitation increases it could help address water supply problems, but could also increase flooding, erosion and levels of pesticides and fertilizers in runoff from agricultural lands, a major cause of degraded water quality, including the Gulf of Mexico's hypoxic zone.

Trees and forests, including bottomland hardwood, are adapted to specific climate conditions. As the climate warms, forests could undergo changes in species composition, geographic range, and health and productivity.

The extent of winter flooding in the MAV affects body condition and winter survival of mallards. Presently, however, different climate models offer contrasting predictions about future river flows, leaving us with little ability to predict future flooding patterns in the Valley, and thus the future suitability of the region as waterfowl habitat.

4.4 Gulf Coast

Gulf Coast wetlands provide winter and migration habitat for up to 20-25% of North American waterfowl in some years, so prospects for climate change in this region are of great interest to Ducks Unlimited and partners working to conserve these habitats. The Gulf Coast marshes lie at the confluence, and for many species of waterfowl the terminus, of the Mississippi and Central Flyways. The wetlands along the Gulf Coast provide important winter habitat for migratory waterfowl that are produced in the Prairie Pothole Region and to a lesser degree, the Great Lakes states. Historically, these coastal marshes provided reliable, high quality habitat for millions of lesser scaup, pintails, gadwalls, American wigeon and green-winged and blue-winged teal. Also, the region provides year-round habitat for over 90% of the world's mottled ducks and winter habitat for approximately 75% of the world's redheads.

Herein, the focus of discussion will be the coastal wetlands of Louisiana. During the 1970's, coastal Louisiana wintered an average of about 9 million ducks annually. More recently, the Louisiana Department of Wildlife and Fisheries estimated 4.4 million waterfowl during winter surveys in 2007 (LDWF 2007). Some estimates suggest that over 50% of the waterfowl using the Mississippi Flyway winter in or migrate through coastal Louisiana. For example, a large proportion of blue-winged teal hatched in the Prairie Pothole Region use coastal Louisiana as fall and spring migration habitat en route to and from wintering areas in Latin America.

About 40 percent of the nation's freshwater and brackish coastal wetlands are found in Louisiana, but from 1956-1990, Louisiana coastal wetlands were lost at a rate of 25 to 40 square miles per year. In southeastern Louisiana, the Mississippi River deltaic processes have created six distinct deltas over the last 7000 years. However, during the last century dam construction on the upper Mississippi has reduced the river's sediment load by about 50 percent, while construction of flood control levees has greatly reduced seasonal flooding in the active deltaic region generally beginning around Baton Rouge. Today,

Gulf Coast

much of the freshwater and sediment that nourished and created southeastern Louisiana coastal wetlands is forced into deepwater of the Gulf of Mexico where it is lost off the edge of the continental shelf. Hence, there has been a fundamental disruption of the hydrological and geomorphologic processes that created these important wetlands such that natural rates of marsh creation today cannot keep pace with combined rates of sea level rise and subsidence, resulting in the loss of over 750,000 acres of coastal wetlands in southeastern Louisiana alone during the last 70-80 years.

Also, non-marsh freshwater habitats near the coast are somewhat limited and dependent upon intensive management. In recent decades, flooded rice fields have augmented natural marsh habitats in these regions and Gulf Coast Joint Venture plans call for them to provide food resources for about 25% of the birds that winter in the region. However, rice agriculture along the Gulf has declined significantly in recent decades in the face of competition from other rice-growing regions and high production costs. If loss of coastal habitats in Louisiana accelerates and if birds are provided few options for redistribution on nearby inland or non-marsh wetlands, over-winter survival rates could be reduced and possibly reflected in declines of overall continental waterfowl populations.

Case Study – Louisiana Coast

Prepared by Tom E. Moorman, PhD., Director of Conservation Programs, Ducks Unlimited, Inc.

Louisiana has the highest coastal wetlands loss rate of any state in the nation. The entire coastal area has already lost over 1 million acres of wetlands in the past century largely due to human activities that have disrupted natural wetland creation and maintenance processes. Further impacts and loss are predicted through complications of sea level rise.

Globally, average sea level has risen from four to eight inches over the past century, due mostly to thermal expansion of the warming oceans and melting of land ice. Climate models anticipate a further sea level rise of 18 to 20 inches by 2100 and more thereafter. The rate of sea level change along the coast of North America has varied from place to place because of differences in vertical movements of land, alluvial deposition, and land subsidence from extraction of water or petroleum. In historic times, relative sea level rise has been greatest in Louisiana, high in Texas and New Jersey, and intermediate along the mid-Atlantic coast.

The estimated 18 to 20 inch rise in sea level, without increased shoreline protection, would cause additional estimated land loss of 1,350 square miles in coastal Louisiana and 900 square miles in other states of the Gulf of Mexico. Such losses will exacerbate human impacts on coastal wetlands as coastal counties are predicted to increase 24% in population by 2025.

Coastal wetlands in Louisiana occur in two related but distinct groups based on their origin. In southeastern Louisiana from Vermilion Bay east, deltaic processes of the Mississippi River created coastal wetlands. From Vermilion Bay west, the coastal wetlands were formed by a complex interplay of Mississippi River sediment delivered to the region by westward flowing long shore currents and also by tropical storms. That source of sediment may have been supplemented somewhat by limited amounts from regional rivers. However, those rivers, including the Mermentau and Sabine, provided significant amounts of fresh water and nutrients during seasonal flooding. The result was development of a system of wetlands similar in some general ways to the Everglades. However, for coastal wetlands in both southeastern and southwestern Louisiana, a key feature that shaped their ecology was annual flooding.

In southeastern Louisiana, seasonal flooding of the Mississippi River shaped the wetland system through well-known deltaic processes. In southwestern Louisiana, seasonal flooding or sheet water flooding, interacted with sediment delivered to the region from the east by Gulf of Mexico currents and storms.

Regrettably, disruption of the natural hydrological and geomorphologic processes has caused significant losses of wetlands throughout coastal Louisiana. For example, over 750,000 acres of the Mississippi River deltaic marshes of southeastern Louisiana have converted to open water during the last 70-80 years. Historically, the Mississippi River flooded these marshes at least annually, depositing huge amounts of sediment and delivering a rich supply of nutrients that actually created marsh. Today, dams on the upper reaches of the Mississippi and its tributaries have caused an estimated 50% reduction in the sediment reaching coastal Louisiana. Additionally, a large flood protection levee system prevents most seasonal flooding, and hence, delivery of sediment to increase marsh substrate elevation. These coastal marshes have always undergone natural subsidence as the highly organic soils were compressed each time new sediment was added by a flood. Today, subsidence continues, but the replacement with new sediment is prevented or greatly reduced by the levee system.

Unfortunately, the levees now force the Mississippi's huge freshwater and sediment supply into deep water of the Gulf of Mexico, where it is essentially lost off the edge of the continental shelf. As a consequence, loss rates continue at high rates in southeastern Louisiana in particular.

These rates will be exacerbated by increases in climate change-induced sea level rise that will interact with the disruption of historical deltaic processes that originally created these highly productive wetlands so important to North America's waterfowl populations.

Similarly, Chenier Plain coastal marshes of southwestern Louisiana have also been impacted by alterations of hydrological processes. Historically, sediment from the Mississippi River was carried westward by near-shore currents. Some of that sediment was deposited by storms resulting in relatively thin layers that helped build or maintain marsh. Other portions of the sediment from offshore were deposited on beaches. As sea level fluctuated over the last several thousand years, some of these beaches, also referred to as Cheniers, were left behind and surrounded by marsh vegetation. The ridges apparently act like dams, holding or slowing sheet water that generally flowed from north to south, resulting in creation of deepwater marshes with ponds that contained large amounts of aquatic vegetation favored by wintering waterfowl.

Over the course of the last 75 years or so, thousands of miles of canals have been dredged in this marsh, mostly to permit access and extraction of fossil fuels. Additionally, several large north-south deepwater shipping channels also have been dredged and connected to the east-west Intracoastal Waterway. Collectively, these canals and shipping channels, and their associated dredge spoil banks, have dramatically changed the regional hydrology and caused loss of nearly 250,000 acres of important marsh and waterfowl habitat in southwestern Louisiana's Chenier Plain. The larger shipping canals and spoil banks cut off freshwater flowing from the north, and effectively drain it into to the Gulf of Mexico. Meanwhile, with freshwater supplies generally reduced or cut off, salt water from the Gulf enters marshes from the south via the numerous, smaller oil and gas exploration canals. Typically, marsh vegetation is not able to tolerate higher salinity, and in the absence of freshwater to mitigate the increased salinity, the vegetation dies, the marsh soils are eroded by wind and wave action, and the formerly productive marsh converts to large areas of open water of little value to waterfowl or other wildlife.

Currently, across coastal Louisiana, productive marsh is being converted to open water at a rate of about 25-35 square miles annually. Causes of coastal wetland loss in Louisiana are complex, but almost invariably related to human-induced changes that have disrupted natural processes that created and sustained this important wetland system. Losses have been severe, with nearly 40% of the original wetlands in coastal Louisiana having been lost. The effects of sea level rise and increased hurricane intensity, both associated with climate change, have been exacerbated by human-induced changes. If no action to restore coastal wetland processes is taken, sea level will accelerate rates of loss and could result in the collapse of this continentally significant area of waterfowl habitat.

Hence, it is clear that if we are to retain Louisiana coastal wetlands at a scale that is meaningful to continental populations of waterfowl and other wildlife, restoration of the processes must occur at a scale that either sustains or increases the present amount of coastal wetlands. This would be true without consideration of climate-change induced sea level rise. However, restoration of the processes that created these wetlands may be the only means of mitigating the potential effects sea level rise may have on this system. Consequently, Ducks Unlimited advocates strategic, large-scale use of Mississippi River energy, fresh water and sediment as the primary coastal management response to deteriorating coastal wetlands in southeast Louisiana. Two small-scale efforts are currently operational: Davis Pond and Caernarvon. However, to achieve meaningful restoration of coastal hydrological and geomorphologic processes that can sustain wetlands in the face of sea level rise, diversions will have to be implemented on a much larger systems scale. This is not to say that other restoration activities are unnecessary.

Gains can be made through strategic protection and restoration of barrier islands and beaches, by closing the Mississippi River Gulf Outlet or other infrequently used navigation canals, and by strategic use of dredge material. However, most of these activities treat local or regional restoration needs. It is difficult to envision restoration of a sustainable deltaic coastal wetland system without making large-scale, or systems-scale use of the mighty Mississippi River's energy, fresh water and sediments, particularly considering the likely effects of increased sea level over the next 100 years and beyond.

In southwest Louisiana, the management response has been use of perimeter protection and water control structures to intensively manage water and

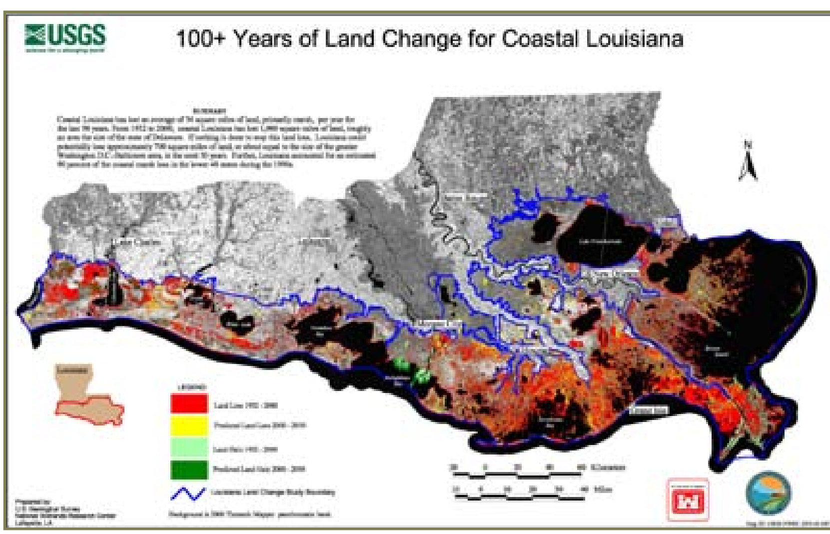


Figure 2. The red areas of this map show coastal marshes in Louisiana converted to open water between 1932 and 2000 resulting from disruption of natural wetland creation and maintenance processes.

Courtesy of USGS.

salinity levels via gravity/tidal flow. This technique has been widely applied not because of sea level rise, but to protect marshes from rapid, wide-ranging salinity variations associated with saltwater intrusion from the Gulf of Mexico. As mentioned previously, shipping channels have disrupted regional hydrology, particularly freshwater supply to many areas of marsh in the region. In the absence or reduction of freshwater inflows, saltwater from the Gulf moves north and into marshes where vegetation is not adapted to high salinity. The vegetation becomes stressed and dies, and the marsh soils then are subject to erosion and conversion to large areas of open water.

The management response of protecting salt-intolerant marshes from high salinity is logical in the short-term. However, there remains some uncertainty whether the technique facilitates increases in land elevation over the long-term. It is possible that disruption of regional freshwater flows has impaired the mechanisms that resulted in maintenance or increases in marsh soil creation, or marsh building. To counter this, Ducks Unlimited believes there is need to consider regional water management plans that use existing shipping channels, canals, and water control structures to deliver freshwater, and if feasible, sediment into this system in a way that resembles historical hydrological processes. In this manner, seasonal freshwater flows and perhaps some sediment could be delivered into the system. The intended result would be an intensively managed system where historic hydrological processes were not restored de facto, but where freshwater and some sediment were introduced to engender marsh creation or restoration through increases in marsh substrate elevation on a regional-scale versus the current local-scale basis. This should be a fertile area for additional planning, research and modeling to inform the process of restoration of these critically important wetlands. It is likely that much additional infrastructure will be required to enable moving water and sediment into the system, or to serve as barriers to salt water intrusion.

The other means by which marsh creation can occur in southwestern Louisiana is through vegetation growth and decomposition processes that can build soils and increase substrate elevation. Hence, protection of salt-intolerant vegetation from the effects of saltwater intrusion by perimeter protection, and managed introductions of freshwater supplies is necessary and likely has successfully prevented even higher losses of coastal wetlands in this region.

Strategic use of Mississippi River water and sediments at meaningful scales holds promise for mitigating effects of sea level rise in southeastern Louisiana. In theory, large-scale restoration of deltaic processes would appear to hold great promise to achieve equilibrium between rates of loss and rates of gain in southeastern coastal Louisiana wetlands. However, no such regular, somewhat predictable source of freshwater and sediment exists in the Chenier Plain. Hence the question becomes, "can vegetative decomposition and relatively low or irregular inputs of sediment raise Chenier Plain marsh elevations at rates that will offset rates of sea level rise?"

Most of the important coastal wetlands across Louisiana are about one foot above mean sea level (MSL). If the rate of sea level rise is greater than the ability of the Chenier Plain to build marsh in response, wholesale conversion to open water could result. Further, if levees and other barriers exist that prevent the "inland migration" of marsh in this region, the outcome will be accelerated rates of conversion of important waterfowl habitat to open water, with no offsetting increases in habitat in the region. Assuming most of the Chenier Plain is submerged or converts to open water, and only a narrow fringe of salt marsh exists, then it would be able to only winter approximately the same number of waterfowl as found in coastal Mississippi. Thus, whereas the Chenier Plain marshes of Louisiana can support upwards of 1.3 million waterfowl today, wholesale conversion to open water resulting from sea level rise could result in a system that could support perhaps 1% of those birds in the future. Such a prediction may seem overstated, but one need only look to the east to the Mississippi Sound where there are smaller rivers with relatively low sediments loads entering the system from coastal Mississippi. The resulting narrow fringes of marsh in the river estuaries combined with aquatic plant beds in the Sound, wintered approximately 25,000 ducks annually in the 1970s.

In summary, southeast Louisiana has potential solutions that provide the best opportunities to offset losses related to sea level rise in the form of strategic, large scale beneficial use of the Mississippi River's energy, fresh water and sediment. Restoration of deltaic processes is likely the best, and perhaps only, hope of mitigating potential effects of sea level rise in southeastern Louisiana. Uncertainties remain about the results of such restoration efforts, but no other management response appears to have the potential to produce results at the scale required to achieve at least equilibrium between rates of wetland loss and gain in southeastern Louisiana. Restoration actions there should advance based on clear statements of assumptions, and plans to evaluate restoration to reduce uncertainty following principles of adaptive management.

However, significant uncertainty also exists regarding the Chenier Plain marshes of southwest Louisiana. Additional planning, research and regional- or systems-scale hydrological modeling is needed to assess the practicality of introducing water and sediment, perhaps from the Atchafalaya River system to the east. Further, a better understanding of the processes by which these marshes formed is needed to enable the restoration community to respond in a timely fashion. The undesirable alternative to research and development of regional Chenier Plain management actions that restore or sustain coastal wetlands is retreat – essentially letting the Gulf of Mexico claim some of the most productive waterfowl winter habitat in North America. Waterfowl managers would then be faced with the prospect of seeking management opportunities to develop waterfowl habitat on agriculturally intensive lands immediately north of the coastal marsh. However, in that event, it appears unlikely that sufficient habitat could be secured to accommodate the populations currently supported by the Chenier Plain coastal marshes.

4.5 California Central Valley

Until the 19th century, the Central Valley of California contained one of the largest complexes of wetlands in the United States. Drainage for agriculture and human settlement eliminated some 95 percent of those wetlands, although many basins have been restored in the last 20 years, and flooded rice fields provide thousands of acres of supplemental habitat. The densities of waterfowl wintering in California are generally the highest in the United States, so any threat to the integrity of these wetlands is of concern.

Recent studies predict that warmer temperatures will cause more precipitation in the Sierra Nevada Mountains to fall as rain. More rapid runoff and earlier snowmelt would lead to higher winter flows and reduced summer flows in most California rivers and streams. Decreased summer stream flows would intensify competing demands for water. Moderate flooding in the Central Valley probably benefits wintering waterfowl by increasing the amount of feeding and refuge habitat available to the birds while simultaneously reducing crowding and the likelihood of disease transmission. So, if future winters are wetter than today, waterfowl may benefit. The value of this flooding, however, depends critically on underlying land use. If irrigation water becomes too costly in the valley and rice culture is reduced, then winter flooding of agricultural land of value to waterfowl would be reduced.

Central Valley /Coastal California

Along the California coast, sea levels are projected to rise by eight to 12 inches in the next century. Shallow tidal habitats could be reduced substantially because human development will limit inshore immigration of coastal wetlands. Increased winter stream flows following decreased summer flows to the Delta and San Francisco Bay are predicted to result in higher concentrations of contaminants in the estuary (Miller et al 2003). A resulting concern is that waterfowl dependent on the estuaries for food, like greater scaup, scoters, and canvasbacks, could potentially experience decreased food availability or increased contaminant loads. Diving duck habitats are generally more limited along the Pacific Coast than the Atlantic, so any deterioration of habitat quality would be cause for concern (Miller et al. 2003).

Case Study - The Sacramento–San Joaquin Delta and Suisun Marsh

Prepared by Rudy Rosen, Ph.D., Director of Operations, Ducks Unlimited, Inc.

Potential Impact of Climate Change

The Sacramento-San Joaquin Delta is a network of natural and man-made channels where freshwater from the southward flowing Sacramento River and from the northward flowing San Joaquin River converge with tidal flows from San Francisco Bay. Prior to the mid-1800s, the Delta was a vast wetland and part of a larger estuary that included the Suisun Marsh and San Francisco Bay. Development of the basin that began in the 1850s "reclaimed" nearly all the Delta's 400,000 acres of tidal wetlands for agriculture use by the early 1900s.

Connected to the Delta is the Suisun Marsh - the largest brackish water wetland remaining in California. Historically, the Suisun Marsh was a tidally influenced basin, but beginning in the 1850s, a 230-mile system of levees was constructed to block the marsh off from the Delta and restrict tidal flows. The marsh is now a complex of 158 privately owned managed and unmanaged wetlands, as well as upland habitat. There are 52,000 acres of non-tidal (managed) wetlands, 6,300 acres of tidal wetlands, 27,700 acres of upland grassland, and 30,000 acres of bays and sloughs. This is an important area for waterfowl and hunting, as most lands are managed either entirely or partially for waterfowl and other wildlife purposes.

There are two principal environmental alterations projected for California due to climate change that could adversely affect the wetlands and wildlife resources of the San Joaquin Delta and associated Suisun Marsh:

1) Changes are projected in the intensity, duration, timing and form of precipitation in California, which is expected to increase flooding and flood frequency and change the seasonal timing of peak flows in California rivers.

2) Sea level is expected to rise.

Warming has increased the fraction of precipitation that falls as rain versus snow during winter in California, and this trend is expected to continue and increase as warming continues. This will cause an increased intensity and number of flood events during winter and a decrease in water availability in late spring, summer and early fall. The potential effects of warming in California on wetlands and wildlife are expected to be particularly detrimental in the Delta and Suisun Marsh due to the highly altered nature of the ecosystem and fragility of the levees that now characterize and define the Delta and Suisun Marsh. Instead of the historic diverse system of tidal and freshwater marshes, normal islands, mudflats, uplands and a network of tidal water channels where water flows in a converging fashion, the Delta is now a homogenous place of closely-spaced sunken islands surrounded by an aging levee system.

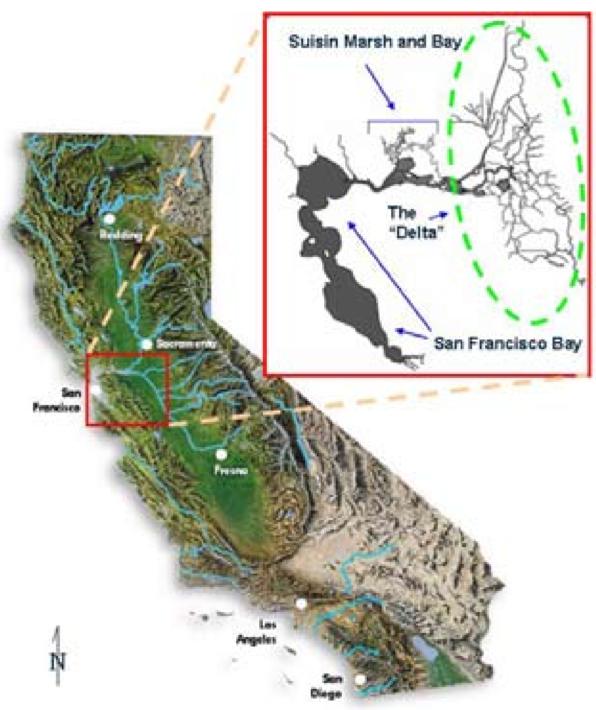


Figure 3. Location of the Suisun Marsh and San Joaquin Delta.

A 1,100-mile network of levees that in total protect over 700,000 acres from flooding now encloses sixty former wetland islands in the Delta encompassing over 300,000 acres. Islands are intensively farmed, although some are managed in part as duck hunting clubs with managed wetlands on the islands constituting important waterfowl habitat. Ducks Unlimited has completed 46 wetlands restoration and protection projects for a conservation investment of over $9.5 million in the Delta. These projects span about 20,000 acres.

Alteration combined with construction of upstream dams has caused a decrease in the deposition of sediments in the Delta and an increase in the rate of decomposition in the organic soils from farming. This has led to dramatic subsidence of most islands. Many "islands" now lie 20 or more feet below water level and are kept dry only by continual levee maintenance and pumping of water. Without maintenance, the levees would erode, settle, and ultimately fail. In time, the Delta would become an inland sea.

During the winter rainy season, rain normally falls at low elevations in the Central Valley. At higher elevations precipitation comes as snow which is "stored" as snow and ice in the mountains until spring. Spring snowmelt flows gradually into the rivers and down into the Delta. With increased warming, rain still falls in the Valley during winter, but instead of snow, rain also falls in the mountains, which enters rivers immediately along with rain in the Valley causing extraordinarily high flows of greater intensity and duration. Rain in the mountains during winter can also cause premature melting of any accumulated snow, which further increases winter runoff and river flows, but reduces spring runoff and river flows. Reductions in annual snowpack will reduce water available for storage for maintaining spring and summer flows and water supply for fish passage and wetlands.

This higher frequency and intensity of flooding in winter can cause damage to managed wetlands, interfere with hunting and potentially damage levees in the Delta, Suisun Marsh and elsewhere. In addition, winter and spring fish runs can be affected, because the normal timing and flow of rivers is disrupted and fish that return to spawn normally do so at a time when flow conditions favor upstream passage. Finally, reduced flow during spring and early summer may reduce the availability of water for late spring and early summer management of wetlands, in particular for breeding waterfowl. Sea level rise is also expected to have effects, including increasing the intensity of flood events in the Delta and saltwater intrusion there, which may affect species distribution and production, as well as impact overall primary and secondary productivity.

Levees are all that maintain the land base that allows for farming and the creation and management of freshwater wetlands. Tidal waters circulate in channels between the levees, but flows can sometimes be unpredictable as water doesn't so much flow as it does circulate throughout the jigsaw puzzle-like arrangement of islands, sometimes in unpredictable ways. This can exacerbate the erosive effects of flooding. The Suisun Marsh is essentially cut off from tidal influence and the rest of the Delta by a system of interrelated levees that allow for management of the Marsh's extensive wetlands. Levee failures that would lead to the flooding of islands and managed wetlands within the Delta and Suisun Marsh have the potential to directly affect wetlands, waterfowl and many species, included species at-risk. Flooding also causes increased water surface elevations, and combined with sea level rise, higher than normal tides, and storm surges, major flood events may result in water overtopping levees.

Climate change is expected to increase the potential for levee failure due to the projected increase in duration, number and intensity of floods, combined with sea level rise. Many levees were originally constructed as three to six foot-high dikes of peat over a century ago. No consistent standards were used in their construction and no levees have been constructed to standards sufficient to withstand catastrophic events. Over time, the weight of levees has compressed and displaced the soft organic soils underneath. At the same time, farming on the organic soils within the island interiors has resulted in oxidation and wind erosion of soils, resulting in significant subsidence. To counter these effects levees have been continually raised and broadened, causing further settlement and various flaws in the internal structure of many levees.

Delta levees are now typically over 20 feet high and surround farms and managed wetlands as much as 25 feet below sea level. Subsidence has continually increased the differential forces on levees. Levees are prone to failure during flood events, with 162 levee failures documented in the last century in the Delta. Seismic events common in the area, and the age and often deteriorated condition of levees have also created weakness that can lead to catastrophic levee failure when subjected to stress. In the future, any climate-caused increase in severity of flooding will further increase the erosive forces on levees.

Catastrophic failure of levees would result in significant inflow of high salinity water from the Bay into the Delta and Suisun Marsh, potentially damaging freshwater wetlands and impacting numerous fish and wildlife species. The Delta would become an inland sea about 20 feet in depth while the Suisun Marsh would become a tidally influenced, shallow brackish water bay. Long-term recovery could produce productive ecosystems more similar to the original habitat in the Delta, but the likelihood of natural recovery processes proceeding in this fashion is remote, due to the high value of the Delta to industry, agriculture and as the key to much of California's water supply.

Summary

Warming due to climate change may adversely affect Sacramento-San Joaquin Delta and Suisun Marsh wetlands and wildlife due to a number of interrelated factors, including increased intensity and duration of floods, sea level rise, and changes in the timing of peak river flows. Taken together or separately these climate related changes may increase the risk of levee failure and saltwater intrusion in the Delta and Suisun Marsh, and reduce water availability in late spring and summer for wetlands management throughout California.

Climate change impacts would affect wetlands and wetlands management, endangered species, migrating fish, and other fish and wildlife, as well as the overall productivity and stability of the Sacramento-San Joaquin Delta and Suisun Marsh ecosystem. When considered in light of the high likelihood of seismic events also affecting the stability of levees, climate change may create a "Perfect Storm" scenario for the wetlands and wildlife of the Delta.

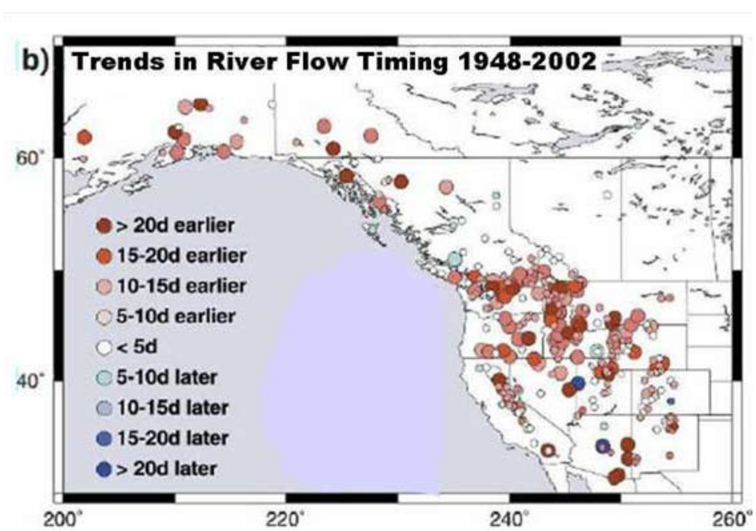


Figure 4. Trends in river flow timing from 1948 - 2002. Colors depict trends over a 50-year period and show the point when half the total annual flow has occurred. Thus, red dots point to rivers where flow is occurring earlier in the year. Earlier flows on snow-fed rivers are due to reduced snow (more precipitation falling as rain than snow) and earlier snow melt which may be the result of general warming trends (Stewart et al. 2004).

4.6 U.S. Great Lakes System

Climate change poses a significant threat to the remaining wetlands in the U.S. Great Lakes region. These ecosystems are critical to migratory bird populations, providing food, breeding grounds, and resting stops along major migration routes. With only an estimated one-third of the original wetlands remaining in the Great Lakes region (Fuller 1995), and much of these areas already stressed as a result of pollution and development, it is imperative that Great Lakes authorities take meaningful steps to protect wetlands ecosystems against the compounding effects of climate change.

According to the scenarios used in the First National Assessment of the Potential Consequences of Climate Variability and Change, scientists expect average temperatures in the Upper Great Lakes region to warm by 3.6 to 7.3 degrees F, while precipitation could increase by 25% by the end of the 21st century (Sousounis and Glick 2000). Despite this significant increase in precipitation, lake water levels are expected to fall by 1.5 to 8 feet by 2100 because of the higher temperatures, with the greatest impacts expected in Lake Erie, the shallowest of the Great Lakes.

Case Study – Wetlands of the Lower Great Lakes and Climate Change

Prepared by Roy Kroll, M.S., Executive Director, Winous Point Marsh Conservancy.

A long-tenured wetland manager with decades of experience and research on wetlands and moist-soil management around the Great Lakes prepared the following notes and observations. The comments were provided based on the awareness that anthropogenic activities have created or exacerbated problems with Great Lakes water levels and wetlands, and that substantial intervention is therefore required to solve them.

Contingencies for Great Lakes wetland managers during sustained low lake water levels.

Status and Goals: The Great Lakes watershed drains nearly 295,000 square miles, contains 95 percent of the fresh surface water in the United States, and is home to over 40 million people (www.epa.gov). More than two centuries of landscape-level changes including deforestation, agricultural drainage, wetland loss, and construction of impervious surfaces have drastically reduced the critically important water retention capacity of this massive watershed. The natural "sponge" of the Great Lakes system now has a big chunk missing, metaphorically speaking.

The natural hydrology of the Great Lakes system has been vastly altered, and water control structures on Lake Superior and diversion of over 5 billion gallons of water per day add to the long list of anthropogenic influences. Yet, lake levels are still determined primarily by precipitation events and generally follow multi-year precipitation trends. For many of the last 10 years, however, increasing air and water temperatures have increased evaporation rates and reduced ice cover, and lake levels appear even lower than expected from precipitation inputs (www.usace.army.mil/glhh).

The Great Lakes have recently experienced lake level declines very similar to those projected by climate change models, including a lake level drop of more than 3 feet in 4 years (Lake Michigan-Huron 1997-2001). In what could be a training exercise for climate change impacts, the search for solutions points squarely at the most basic and important terrestrial component of the Great Lakes ecosystem - water retention capacity in the watershed. Few controllable factors other than increased water retention, a common product of wetland restorations, can offset current trends of lower precipitation and higher evaporation.

Correspondingly, the goal for wetland managers during sustained low lake levels is to increase water retention capacity and storage in the Great Lakes watershed, and maintain or improve wetland biodiversity. The alternatives presented below suggest management actions proportional to the degree of impacts that may result from climate change. The options reflect the amount of intervention required for wetland management and restoration, including use of dikes and pumps to control water levels, establish wetland plants, and help control invasive species.

Minimal intervention: In this scenario, wetlands managers would continue programs as they currently exist in a "wait and see" approach with no extraordinary efforts to counter possible changes. This scheme would include continued restoration of wetlands, normal moist-soil and hemi-marsh management, and sustained efforts to integrate existing land conservation programs. Under a minimal intervention strategy, biotic responses to lower lake levels in coastal wetlands would be allowed to occur "naturally" (i.e., without further hydrologic modifications or other anthropogenic activities).

As a result, short-term (e.g., 2 year) successional responses by vegetation are likely to slightly increase abundance and diversity of aquatic flora and fauna as lake levels retreat, but long-term vegetation trends will decrease biodiversity due to invasive plant establishment. The current condition of coastal marshes in southwest Lake Erie provides a clear example of such processes. After nearly 30 years of above-average Great Lakes water levels, unprecedented declines in Lake Erie levels occurred from 2000-2004, exposing many new mudflats for plant colonization. Since then, the trends observed in native and invasive wetland plant reestablishment in southwest Lake Erie have been characterized by a change from first-year mixed stands of annual emergents to a Phragmites or Phalaris monoculture in just 3 or 4 years. Due to the nature of the invasive aquatic plant epidemic, these results are likely to accurately predict macrophyte trends during any additional low water periods for the foreseeable future. Invasive aquatic plants are colonizing and threaten to dominate wetland-upland fringe habitats, decreasing wetland biodiversity in the entire lower Great Lakes region.

However, establishment of invasive shoreline plant monocultures may not be detrimental to fishes and other biota with broad tolerances for use of aquatic emergent vegetation. Essentially, any emergent plant community providing unrestricted access of coastal habitats by fishes may be better than no emergent plants in water - the latter being the vastly predominant situation. Similarly, dense stands of invasive aquatic plant monocultures may improve water retention in the areas colonized, but net effects on ecology and biodiversity remain strongly detrimental.

A strategy of minimum intervention would require increased wetland restorations (as does current conservation efforts), and programs should be prioritized based on elevation in the watershed, with headwaters top-ranked. Restoration of headwaters wetlands is the first feasible step in the daunting challenge to reverse historic losses in water retention capacity resulting from landscape degradation. If existing successful wetland restoration programs (WRP, CRP, WHIP etc.), are combined with more strictly headwaters-based efforts, the prospect for restoring water retention in Great Lakes watersheds improves substantially. The effectiveness of WRP-type programs justifies exponentially increased implementation of additional water-quality based wetland restoration initiatives (e.g., for nitrate or phosphate reduction).

Sustained low lake levels will have many other negative impacts such as increased concentration of pollution, and increased disturbance of bottom sediments by commercial shipping and recreational boating, and have the potential to become major controlling factors in Great Lakes water policy.

Moderate intervention: In a scenario of moderate intervention increased capabilities would be required for capturing high-flow water events (e.g., storm runoff, floods, lake seiches, seasonal lake level changes) into diked wetlands. For example, an open pipe may be installed at a specific elevation to capture and hold water during high flow events between an agricultural drainage channel and a diked marsh, combined with a restricted-flow spillway to hold water and buffer the effects of flooding. Traditional spring drawdowns are increasingly favoring invasive species establishment, and areas of invasive monocultures have low prospects of regenerating a diverse wetland flora. Water control practices for managed wetlands should be implemented that delay moist soil drawdown dates until mid to late summer, and the frequency and severity of moist-soil drawdowns should be decreased.

The anthropogenic enhancement, restoration, and construction of Great Lakes coastal wetlands should be increased proportional to the scale of lake level decreases. This process should involve connecting the hydrology of existing wetlands to uplands when feasible. If water levels decline further, the increased need for intentionally modified hydrologies (e.g., water storage) and structural wetland management should be acknowledged and widely promoted. Improvements in water retention and storage in upper regions of the Great Lakes watershed are the most essential components needed to lessen impacts of declining lake levels (or historic landscape alterations).

Improvement in the design and function of fish access structures is needed to provide increased use of managed wetlands by fish, although available shoreline habitats (largely, Phragmites) have increased since 2000. Increased dredging of channels to the main lake may be required if connections with upstream hydrology provide water reserves inadequate to sustain aquatic macrophytes in coastal regions, but disposal of dredged materials must be environmentally sound.

At a minimum, an ecological corridor of wetlands with connectivity to the lake should be maintained. Many wetland wildlife species in the lower Great Lakes (king rails, black terns, Blanding's turtles) are at or near their minimum habitat threshold and will be severely affected if provisions to maintain their habitats are not undertaken.

The actions proposed for a moderate intervention response have the potential to decrease production of native annual seed resources serving as food sources for migratory waterfowl. Large declines in the amount of natural seeds in the diet of waterfowl can decrease physiological health and condition. However, late summer drawdowns foster crops of natural plant species that provide sufficient energy (Fredrickson and Taylor 1982, Hoffman and Bookhout 1995) to maintain high levels of duck use and duck health. Waterfowl will likely compensate for any reduced availability of native seeds by increased use of agricultural waste grain, and by foraging on submersed plants and aquatic invertebrates. Unfortunately, the energy budgets and net effects of such changes on waterfowl condition are not completely known, although the individual components of duck diets have been thoroughly researched (Havera 1999). To maintain adequate levels of duck use when moist soil crops are reduced, one proven method is to decrease hunter density – but not by limiting hunting. An alternative isto increase available wetland habitat, and the list of reasons to do so is ever-increasing. The prospect of increasing the amount of wetlands and providing good duck hunting is a well known theme to Ducks Unlimited members, and the current availability of joint ventures and no- or low-cost wetland restoration is a win-win situation for abating potential impacts of climate change, just as it has been for waterfowl conservation.

Aggressive Intervention: In the aggressive intervention scenario, wetland managers would engage in more intensive construction activities to artificially maintain a minimum wetland habitat base. In an approach that could be dubbed "chase the shoreline," wetlands managers would attempt to maintain wetlands at the edge of the lake as the shoreline progressively recedes. Managed wetlands, currently and for the foreseeable future, are likely the best hope for maintaining aquatic plant diversity in some of the largest wetland regions of the Great Lakes, including the clay-substrate marshes of southwestern Lake Erie, Saginaw Bay (Lake Huron) and Green Bay (Lake Michigan). If lake levels continue to decline, so will the prospects for native aquatic plant dominance in Great Lakes wetlands. Immense amounts (millions of acres) of headwaters and far-upstream native habitats need to be restored in order to relegate management of Great Lakes wetlands to natural hydrological functions and rationally expect maintenance or improvement of biodiversity.

Innovative engineering techniques would be used in aggressive intervention to provide adaptable systems that can serve as baffles to promote accretion during low-water periods or as barriers to erosion during high water periods. Such structures could be constructed as bands of linear or wing-dike segments located perpendicular to prevailing currents, or as contiguous perimeter dikes enclosing large areas prioritized for restoration.

Another construction intervention would involve building low-height levee systems designed to withstand frequent overflow by protecting the entire exposure of the dike with quarry-rock. If lake water levels remain low, water levels can be maintained inside the diked cell to promote establishment and growth of aquatic macrophytes. If water levels return and overflow the dikes, such rock-covered levees will extend the lifespan of marsh plants by reducing wave erosion and will provide substantial new fish habitats. Obviously, such structures would provide very serious hazards to navigation and would require identification and re-routing options of the highest order.

It will be important to anticipate the enormous demands and influence of industrial commerce, hydropower, potable water supply, and recreational navigation if lake levels decrease further. These vital economic activities will likely control government policy and funding for use of Great Lakes waters. In response to declining lake levels, these industries will have similar needs, and most will be related to increased dredging. Dredge disposal has come a long way since the era of unregulated open-water dumping, and if increased dredging is inevitable, construction methods that minimize impacts can be readily employed. Linear disposal sites to contain dredged spoils have been used for decades across the nation to create new wetlands, and provide a template for managers facing increased dredging in the Great Lakes. Innovative approaches and monitoring of stringent requirements for highly specific wetland plant associations will be essential components of any quest for maintaining biodiversity at such sites.

Summary

The Great Lakes watershed is a severely altered landscape in which the natural hydrology and functions of wetlands have been substantially changed, including large declines in water retention capacity. The Great Lakes are currently experiencing an atypical decline in water levels of nearly 3 feet since 1996-7, likely resulting from unusually warmer temperatures, increased evaporation, and decreased precipitation. The lake level drop is similar to the (additional) decrease predicted by most climate change models, and current trends in wetland plant establishment may mimic those caused by any near-future declines in water levels. Since 2000, many new areas of mudflats have been exposed and colonized by plants, and were initially comprised of diverse communities of annual emergent aquatics. However, within a few years, undesirable invasive plants, particularly Phragmites australis, establish dense monocultures and decrease biodiversity, including waterfowl use. These stands are highly resistant to successional or other natural biological changes, and prospects for control are currently limited to combining aquatic-approved herbicides with water level control. Water level control in these coastal areas usually requires the construction of systems of dikes and pumps, and some wetland scientists oppose the process.

If climate change causes further declines in water levels, wetland quality and biodiversity will continue to decrease. From a strategic view, the effectiveness of options to combat declining water levels will be directly related to the degree of anthropogenic intervention. In existing diked wetland systems, traditional water level drawdowns can be delayed or eliminated (without significantly affecting waterfowl condition and use). In order to increase wetland retention capacity, restoration of wetlands must increase, connect with upland hydrologies, and be prioritized by proximity to headwaters of the watershed. Diked wetlands can be engineered to provide a wide variety of wetland functions and values additional to increased water retention, and will become increasingly important if lake levels remain low. Future additional decreases in Great Lakes waters from current levels pose vital threats to the region, and the debate over the increased use of diked wetlands will diminish as the inability of other options to increase biodiversity becomes apparent.

4.7 Pacific Coast

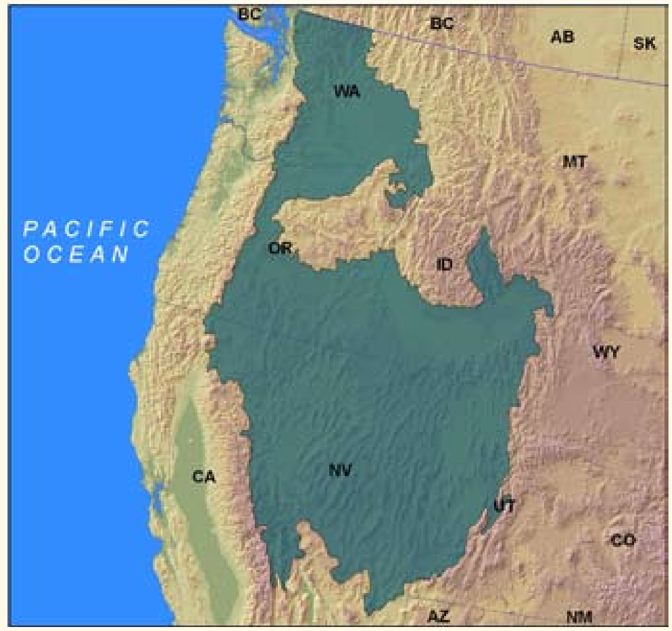
Despite its reputation for rain, the Pacific Northwest (PNW) experiences dry summers, and irrigated agriculture, urban users, and ecosystems rely on snowmelt for summer water. This fact is critical in understanding how the region responds to climate. During the past 100 years, the PNW has become warmer and wetter with the region's average temperature increasing 1.5 degrees F (Mote 2000). Snow pack has also decreased 11 percent and the dates of peak snow accumulation and snowmelt-derived stream flow have shifted by 10 to 30 days earlier during this time period. Some locations in the Cascades, for example, have already seen declines in snow water equivalent in excess of 70% (Mote et al. 2005). Climate change models predict the continuation of these trends.

Pacific Northwest

Areas at risk in this region include San Francisco Bay, San Diego Bay, the Puget Sound, and the Fraser River delta in Canada, which provide critical habitat for resident and migrating waterfowl in the Pacific Flyway. As a result of earlier spring runoff and lower water inflow in the summer months, salinity levels in these estuaries could be elevated since they are largely controlled by the fresh water fluctuations. Increased salinity levels could alter the distribution and availability of key food sources for resident and migrating waterfowl. In addition to habitat damages from salinity influxes, low-lying estuaries are also threatened by projections of sea level rise, affecting the quality and quantity of the region's coastal marshes and estuaries that are important for gadwalls, American wigeon, mallards, northern pintails, green-winged teal, snow geese, and brant (Buchanan 2006). Species expected to be particularly impacted are diving ducks, such as canvasbacks and ruddy ducks since their existing habitats in the region have already been severely affected by human development (Glick 2005).

4.8 Great Basin

The Great Basin region lies in the rain shadow of the Cascade and Sierra Nevada mountain ranges. The region contains a rich array of ecosystems, including playas and alkaline flats that are home to salt-tolerant plants, salt lakes, dunes, and marshes that are crucial habitat for migratory waterfowl. The region covers a vast area and contains scattered, but very productive wetlands that are currently threatened by various human activities. It is a major spring and fall migration stopover and an important Pacific Flyway waterfowl production area for cinnamon teal, redheads, gadwall, mallards and canvasback.



Great Basin

How the Great Basin biota will respond to climate change will depend importantly on how moisture patterns are affected. One possibility is that there could be a permanent northward shift of the subpolar storm track. Inasmuch as the region is a primarily winter-precipitation area, this would have a net drying effect with reduced snowpacks and stream run-off, and negative effects on wetlands. Another possibility is a northward extension of the monsoons, bringing more summer moisture at least to the southern half of the region. Whether or not this would result in a wetter summer environment would depend on whether the rainfall increases override the higher evapotranspiration resulting from higher temperatures.

Climate change that results in hydrological changes will have a major impact on riparian and wetland ecosystems in the Great Basin region. Further, increased winter precipitation with a decrease in summer would result in an increase in fuels from the growth of annual weeds and a priming for extensive and intensive fires during the summer. This may lead to changes in habitat, invasive species, and changes in ecosystem structure and function, which may feed back to permanent habitat changes.

Many vegetation communities in the Great Basin have evolved to take advantage of temporally and spatially limited soil-water supplies. This is particularly evident in the sagebrush steppe, dominated by sagebrush and perennial grasses. Much of the area still occupied by this vegetation type has been changed to one dominated by non-native cheatgrass that has entered as a result of disturbance (grazing), out-competes the perennial grasses for soil moisture, and responds aggressively after fire. It is anticipated that if winter precipitation increases and summer decreases, with rising temperatures, permanent habitat changes will occur that favor lower-productivity ecosystems (Wagner 1999).

5. WATERFOWL IMPACTS

Waterfowlers have historically been interested in weather patterns, as they can be the driving influence on the success and experiences of their sport. Although there are uncertainties in the science and future outcomes of climate change, it is clear that the tapestry of water and birds across the continent is likely to change in the years ahead. Coastal marshes are likely to lose birds as wetland losses mount; large inland waters may fare better in some places, but only if water quality can be protected and adequate food supplies can be maintained at the right times of the year. Climate variability also affects bird distribution and abundance indirectly through trophic level impacts on food availability (Butler 2005). Warmer winters will mean more birds, on average, wintering farther north, as long as they have water and adequate food supplies.

There will always be warm years and cold years, wet years and dry, cold fronts and nor'easters to make average years exceptional. The bigger question is whether waterfowl habitats in North America will be able to support historical numbers of breeding and wintering birds in the face of global climate change (Anderson and Sorenson 2005).

5.1 Population Changes

Long-term waterfowl population estimates are of limited use in assessing impacts because there remains a high degree of uncertainty in anticipating population responses to climate change. However, habitat impacts can be more readily predicted and important breeding habitats, such as seasonal prairie wetlands, have historically served as a proxy for breeding success and population growth fluctuations of North American waterfowl. For most species, breeding success is the most important factor limiting population growth. A study on mid continent mallards found that up to 81% of the variation in population growth rates was attributable to key breeding season events (Hoekman et al. 2002). Unfortunately, wetlands already face considerable human stressors, with global climate change providing an additional challenge. Alterations and destruction of surrounding habitats provide few opportunities for prairie wetland-dependent waterfowl to find new habitat, placing greater and greater significance on fewer and smaller areas.

5.2 Migration Changes

Climate change adds temporal and spatial uncertainty to the resources needed for breeding, migration, and wintering. The composition and geographic distribution of many ecosystems including wetlands is expected to shift as individual species respond to changes in climate. This will likely cause a reduction in biological diversity and in the subsequent goods and services that ecosystems provide society (IPCC 1996). Climate change is expected to affect the timing and distance traveled during waterfowl migration.

The primary expected response of waterfowl to climate change is redistribution as birds seek to maintain energy balance. When North America's waterfowl migrate south for the winter, the majority of them seek out freshwater lakes, riverine habitats, deltas, coastal marshes, and estuaries in the United States and Mexico as migration and wintering habitats of choice. Within the United States, many Atlantic Flyway birds travel through the eastern Great Lakes and New England to wintering areas along the Mid-Atlantic coast, including the Chesapeake Bay and Delaware Bay. Others move farther south into the Carolinas, Georgia, and Florida. Depending on water conditions, mid-continent species that use the Mississippi and Central flyways largely winter in the Platte River basin, the Mississippi Alluvial Valley, the lower Mississippi River delta, the Playa Lakes region, and in flooded agricultural land and coastal marshes along the Gulf of Mexico. In the Pacific Flyway, waterfowl that breed in Alaska and other northwestern regions of the continent opt for the wetlands associated with lakes, rivers, bays, and estuaries of Washington, Oregon, California, the western Rocky Mountain states, the Southwest, Mexico and beyond.

Warmer fall and winter temperatures in northern regions would make it unnecessary for waterfowl to fly as far south to find ice-free water and suitable food. For example, the unusually warm, late-arriving winter of 2001 increased hunting opportunities for waterfowl hunters in the Midwest and New England and reduced hunting opportunities in the Mid-Atlantic and South. Additionally, recent research by the USDA Forest Service projects that changes in seasonal temperatures and precipitation due to global warming will contribute to a significant northward shift in the breeding range of mallards and blue-winged teal in the eastern half of North America before the end of this century (Glick 2005).

In North America, most waterfowl species follow reasonably regular and predictable migration patterns. Biologists and hunters recognize that these patterns are affected tremendously by variations in weather for many species. If North American climate change causes weather patterns to be more erratic than at present, patterns of waterfowl habitat use will likely be more unpredictable as well. Such changes will have biological consequences and be a threat to hunting seasons and have significant impacts on the infrastructure and economies built upon hunting.

Case Study – Climate Change Effects on Arctic Nesting Geese

Prepared by Bruce Batt, Ph.D., Chief Biologist, Ducks Unlimited, Inc.

Most global climatic models predict the climate in the Arctic regions of North America will warm considerably more than most other regions of the continent. A longer and warmer ice-free season would result in many changes to the ecosystem and the organisms that occupy it. For Arctic nesting geese this would be expected to result in higher overall reproductive success. A key population control mechanism for these geese occurs during springs with persistent cold weather that shortens the interval during which the birds can complete all the steps required to successfully hatch and fledge young before the weather forces fall migration to occur. Adult birds survive well during these years but recruitment rates can be very low, sometimes approaching zero. If climate change results in fewer years with low reproductive success, we can expect average recruitment rates to be higher which would result in generally larger populations of most Arctic-nesting geese.

Most goose populations are effectively managed within targeted levels by harvest regulations that affect survival rates. This would presumably continue to be the pattern if recruitment rates increased because of climate change. Indeed, increased harvest opportunity would be a welcome outcome for hunters of some populations. However, in recent years, several populations of lesser snow geese have, for a collection of reasons, become so abundant that they are considered to be a threat to the long-term sustainability of the Arctic ecosystem where they nest (Batt 1998, Gauthier 1998). Besides being a threat to the future of the geese themselves, all organisms that depend on the ecosystem are at risk. Ross's geese and greater snow geese are also more abundant than they have ever been since data have been accumulated and are also considered to have the potential to expand in numbers beyond the level that can be supported by their Arctic habitats.

Populations of these geese are currently subject to special harvest regulations that aim to decrease survival of adults to a level that results in stabilization of the greater snow goose population and a decline by at least 50% in the numbers of lesser snow geese. These measures have been in place since 1998. The goal for greater snow geese has generally been achieved but the desired decrease in population size of the lesser snow goose has not. Indeed, it appears that, at best, the population may be somewhat stabilized but almost certainly not in decline.

Further increases in recruitment rates of these geese would be expected to result in even larger populations greatly exacerbating the problem of achieving harvest rates that result in stable or decreased populations. The problems with management of these geese has already resulted in an unprecedented challenge for population managers with no assurance that goals will be met under current climate conditions and associated recruitment rates. Further increases would compound the current challenges to a level that may be beyond our ability to address by any conceivable, practical and socially-viable methodologies.

5.3 North American Waterfowl Management Plan

The North American Waterfowl Management Plan (NAWMP) provides an institutional framework to address the effects of climate change on waterfowl populations and habitats. Geographically, the continental scope of the Plan and the regionally operating habitat Joint Ventures (JVs) are well suited to tackling a global phenomenon with heterogeneous impacts realized at the local to landscape level. At the landscape level, the adaptive nature of the Plan, the reliance on science, and the continued monitoring of Plan/JV activities and their effects, provides the necessary mechanisms for dealing with the dynamic effects of climate change. Among these mechanisms is a provision in the initial Plan requiring frequent review and revision of Plan objectives. The most recent review is the Continental Progress Assessment Report, which is significant for providing the first continental-wide assessment of the Plan.

The Report offers several recommendations on how the JVs and the Plan can incorporate climate change into overall management actions and objectives. As in the initial Plan in 1986, the Report reiterated the significance of the mid-continent prairies to breeding population dynamics. Towards this objective, a new and holistic policy approach is needed to leverage available conservation funds. The Plan committee recognized that wildlife-friendly policy will have to extend beyond direct conservation programs, and into the policy areas of energy, transportation, and climate change. Specific to the Joint Ventures, the Report recommended direct consideration of the impacts of global climate change in the design, emphasis, and regional targeting of JV programs. This recommendation is based on none of the 18 joint ventures having directly incorporated climate change into their conservation planning, although one had made an attempt and 4 others were developing strategies at the time of writing. The committee emphasized that impacts on coastal, arctic, boreal and prairie regions could likely be significant, and that conservation investments should be allocated accordingly to these risks. To facilitate the adoption of global climate change into Joint Venture activities, the Plan committee intends to sponsor a workshop on the topic in the future.

The Report also calls for greater scientific guidance and adaptive monitoring by the Joint Ventures. A survey of the JVs found many with a limited ability to evaluate JV success, and to track waterfowl numbers and distribution in response to JV activities. The JVs have so far been more successful in engaging the research community, prioritizing research needs, and developing mechanisms to provide feedback on JV actions. Successful incorporation of the Report's recommendations will better position the JVs, and the Plan, to monitor and address emerging climate change induced threats from disease, invasive species, and contaminants of water and food resources.

5.4 The National Wildlife Refuge System

The National Wildlife Refuge System (NWRS) is the largest system of protected areas in the world primarily designated to manage and protect wildlife (Czech 2005; Scott et al. 2004). The Refuge System includes 545 National Wildlife Refuges and over 30,000 waterfowl production areas that encompass an area of 93 million acres, distributed across the entire United States and its territories. National Wildlife Refuges contain a diverse array of species, including over 220 species of mammals, 250 species of amphibians and reptiles, and over 200 species of fish. However, birds remain the Refuge System's largest beneficiary. Over 800 species of birds have been recorded on National Wildlife Refuges.

One possible effect of climate change is total "regime shift," where entire ecological communities are transformed from their "historical" conditions. Where such regime shifts occur, even on smaller or partial scales, it may become impossible for certain NWRs to meet their original and specific purposes. For example, the habitats of a highly specialized refuge (such as one established for an endangered species) might shift away from the specialized habitat for which it was created. Less obvious, increasing competition for diminished water supplies in areas like California's Central Valley or southern New Mexico may restrict a refuge's access to that critical resource, thus making attainment of its purposes virtually impossible.

Climate change will likely introduce to the NWRS new threats or variations on existing ones, primarily by accelerating a convergence of issues (e.g., water scarcity, invasives, off-refuge agricultural change, and energy development), or creating such convergences where none existed before (NWRS Workshop Report 2007). Significant climatological change that permanently alters ecological communities makes it impossible to either preserve "historical" conditions or restore degraded habitats to such conditions. In effect, the "natural" condition of a given community becomes a historical description, and with ongoing change a manager can have no certainty what such a tract will support, nor for how long. Unfortunately, there is no policy guidance to direct the Fish and Wildlife Service in such situations. For example, if conditions change under pressures of climate change such that a refuge is no longer able to either fulfill its purpose or comply with the ecological integrity mandate, there is currently no direction available to drive decision-making (NWRS workshop Report 2007).

A workshop for the U.S. Climate Change Science Program (CCSP) focusing on the National Wildlife Refuge (NWR) System was held January 10-11, 2007. The workshop was a centerpiece of an effort by EPA's Global Change Research Program to coordinate scientific research on climate change across the federal government. The workshop produced a report that reviews management options for increasing the resilience and resistance of ecosystems to climate variability and change and be incorporated into the final Synthesis and Assessment Product 4.4: Preliminary Review of Adaptation Options for Climate Sensitive Ecosystems. Some adaptive management actions proposed to help manage refuge properties under climate driven changes included:

- Plant vegetation in riparian areas to lower water temperature.
- Translocation of species (plants, less-mobile species) to new locations.
- Protect migratory corridors so that species can move pole-ward and to higher elevations.
- Acquire land to secure needed habitat.
- Identify and monitor climate sensitive species and phenologies.
- Determine tradeoffs between existing habitats and potential habitats.
- Identify structures that are effective in adaptation.
- Recognize maladaptive practices, e.g., mowing wetland grasses, reduce peat content.
- Detection, containment and eradication of invasives.
- Triage: Should we abandon vulnerable populations or focus on them?
- Consider managing for open space or ecosystem services rather than for species.
- Develop an interagency council (interdepartmental) on climate change.

6. IMPACTS ON RECREATIONAL HUNTING

For nearly a century, waterfowl and wetland conservation has been a priority for North America's citizens, leading to the development of numerous policies and programs to restore and protect waterfowl species and their habitats. For decades, hunters and anglers have been at the forefront of a very successful conservation movement. Hunters support wetlands and waterfowl conservation more strongly than any other group of people by supporting agencies and organizations that directly conserve wetlands and other habitats. They also invest millions of dollars annually in proper management, acquisition and restoration of habitats important to waterfowl (Glick 2005).

Ducks, geese, and swans are important to waterfowl hunters, birders, and others. Waterfowl viewing is also popular among the more than 46 million birders in the United States (Glick 2005). According to the U.S. Department of Interior, hunting expenditures in Louisiana alone exceeded $446,000,000 in 2001 (USDOI 2001). Declines in duck numbers would likely have an impact on waterfowl hunting opportunities with a subsequent loss of revenue associated with waterfowl hunting and decrease in waterfowl and wetland conservation activities.

An economic analysis of waterfowl hunting impacts completed in 2001(Henderson 2005) estimated 1.8 million waterfowl hunters who spend nearly 30 million recreational days each year hunting waterfowl. They spend nearly $1 billion annually for waterfowl hunting on trips and equipment (not including boats, campers, vehicles, etc.). All of this economic activity generates total economic output of $2.3 billion, 21,415 jobs, and $725 million in employment income plus over $330 million in taxes. Waterfowl hunting is big business and any major changes in hunting opportunity will have significant impacts on that business.

Waterfowl hunters will directly feel the impact of climate change through their sport as species are displaced due to habitat loss, altering community structures, or increased competition, or simply temperature change. Wetland habitats will be significantly altered both in quantity and quality. That will make hunting seasons less predictable with impacts on agencies' abilities to properly manage seasons and take and likely reduce the numbers of people who hunt waterfowl and other migratory birds dependent on wetlands. As a result, there would be fewer managed hunting areas as individuals and groups sell their land-holdings or if they are less able to manage clubs and other lands for waterfowl.

Since the early 1990s when waterfowl populations and hunter numbers increased, there has been considerable investment in the infrastructure that supports hunting. Individuals and corporations have purchased land, built lodges and other accommodations, and expanded the industry associated with waterfowl hunting. While statistics are lacking, it is often said that some farmers and other landowners now make more money from leasing land to hunters, and especially waterfowl hunters in some areas, than they do from their regular agricultural practices. In addition, numerous companies specializing in equipment for waterfowl hunting have flourished in an era of relative long seasons with high bag limits. This entire infrastructure is at risk with resulting impacts on loss of revenues, degradation of managed hunting lands, and so forth if climate change results in less abundance of waterfowl or less predictable waterfowl migrations.

While a significant number of people care about and invest in both consumptive and non-consumptive waterfowl activities, it is difficult to estimate how changes in bird distributions might affect the economics of bird use. Shifts in regional spending are likely as some birding and hunting sites become less favorable and different sites become more favorable. Although many waterfowlers might simply adjust to the reduction in species richness in their areas, others may stop waterfowl hunting altogether.

In 2006, the National Wildlife Federation commissioned the first-ever nationwide non-partisan survey of hunters and anglers on the issue of global warming. Respondents were randomly selected, largely from the pool of people who have recently purchased hunting and fishing licenses. The results of the survey indicated that a vast majority of sportsmen are witnessing the effects of global warming and believe immediate action is necessary to address it. According to the survey, 85 percent of sportsmen believe we have a "moral responsibility to confront global warming to protect our children's future." Eighty percent of sportsmen believe the United States should be a world leader in addressing global warming. Seventy-five percent agree that Congress should "pass legislation that sets a clear national goal for reducing global warming pollution with mandatory timelines because industry has already had enough time to clean up voluntarily." According to the survey, more than three-quarters of America's hunters and anglers agree that global warming is occurring, and the same percentage said they have observed changes in climate conditions where they live, such as warmer, shorter winters, hotter summers, earlier spring and less snow. More than half (54 percent) said they believe these changes are related to global warming. Nearly three-quarters (73 percent) believe it either is currently impacting or will impact hunting or fishing conditions.

7. WETLANDS AND THE CARBON CYCLE

Healthy wetland ecosystems produce a myriad of ecological goods and services – one of which is carbon sequestration and storage. Wetlands (including peatlands) have considerable potential for long-term carbon storage as wetlands represent the largest component (14 per cent) of the global terrestrial biosphere carbon pool (Wylynko 1999). The drainage and subsequent alteration of wetlands release a significant proportion of stored carbon in these former wetland sites. In the course of human settlement, millions of wetlands have been drained for other uses, particularly agriculture. Many of these wetland areas could be restored, but unlike the forest and agriculture sectors, wetlands produced goods and services have tended to exist outside the market economy. In the past decade, however, wetland conservation has become an important component of the sustainable use and stewardship of agricultural and forested landscapes. On ecological, economic and conservation grounds, wetlands should be considered an equally important biome to target global warming mitigation activities as forests and agricultural soils.

The effect of wetland restoration and destruction are not homogenous as greenhouse gas fluctuations vary by wetland type (peatlands, freshwater mineral soil wetlands, and estuarine wetlands), wetland class, and regional climate (tropical, temperate and sub-arctic). The net effect of the alteration of a wetland can have both negative and positive impacts on global warming. Although wetlands can sequester and store significant amounts of carbon, they also have the potential to emit more potent nitrous oxide (N20) and methane (CH4) emissions. Individual wetland emissions have an absolute warming potential (radiative balance), however it is only when relative emission levels increase (radiative forcing) that the emissions have a contributing effect in global warming (Bridgham et al. 2006).

The largest impact that North American wetlands have had on global greenhouse gas fluxes has come from the destruction of wetlands associated with land-use change; oxidizing soil carbon, replacing plant biomass, and reducing available carbon sinks. Some research has shown the net GHG effect of this destruction across the continent has contributed to a net cooling effect, since the cooling effect from the decline in methane emissions exceeds the warming effect of the decline in sequestering abilities and loss of plant biomass (Bridgham et al. 2006). However, not all wetlands function equally. Targeted wetland restoration and preservation activities that maximize carbon sequestration and storage while minimizing N20 or CH4 emissions can still provide an effective terrestrial sequestration strategy while providing the numerous other benefits associated with functioning wetlands.

Unfortunately, the importance of conserving and restoring wetlands for mitigating the potential effects of climate change is still not widely acknowledged. The diversity of wetlands, concerns over non-carbon emission, and the lack of definitive science, has to date excluded wetlands from the Kyoto Protocol's Clean Development Mechanism. The Protocol's CDM allows developed nations to purchase credits for greenhouse gas emission reductions by other natural sinks such as forests. Further, the role of wetlands in mitigating the effects of climate change has only recently been explicitly recognized by the Intergovernmental Panel on Climate Change, recommending that the avoidance of wetland drainage and the conversion of drained wetlands back into wetlands as beneficial agricultural practices to manage organic soils (2007c). For wetlands to have a larger role under the Kyoto Protocol or any other future voluntary or regulatory emissions reduction program, scientists must be able to provide confident projections of carbon sequestration potential in wetlands, and an acceptable methodology for determining verifiable changes in carbon stocks. Areas of wetland research identified as key priorities in GHG estimation include the quantities and significance of sedimentation in fresh water mineral soil and estuarine wetlands, and methane (CH4) emissions in freshwater wetlands (Bridgham et al. 2006).

Case Study – Carbon Research in Prairie Wetlands and Grassland Systems

Prepared by Dawn M. Browne, Manager of Conservation Programs, Ducks Unlimited, Inc., Jim Ringelman, PhD., Director of Conservation Planning, Ducks Unlimited, Inc., and Randal Dell, Eco-assets Research Assistant, Ducks Unlimited, Inc.

Wetlands Prairie pothole wetlands play an important role in regional carbon sequestration and storage. Past research has found that restored semi-permanent wetlands in the Prairie Pothole Region have the ability to sequester 1.33 ST Soil Organic Carbon (SOC) ac-1 year-1, restoring the 4.45 ST SOC ac-1 that is emitted during a cropping regime (Euliss et al. 2006). The carbon sequestered is stored as plant biomass, soil organic carbon and sedimentation (distribution of material from upland to wetland). These wetlands are a promising terrestrial carbon sequestration method since they improve the quantity and quality of waterfowl habitat, enhance biodiversity, reduce soil erosion, minimize soil disturbance and filter agricultural pollutants. And, unlike most other wetland types, there has been an ongoing effort to monitor the carbon and other greenhouse gas fluxes of these wetlands, establishing prairie pothole wetlands as effective terrestrial sinks.

Research underway by Ducks Unlimited, Inc. (DU), Ducks Unlimited Canada (DUC) and partners on the greenhouse gas budgets of seasonal wetlands and native prairie grasslands may help with the preservation and protection of these vital habitats in a future regulatory environment for carbon emissions. During a workshop on wetlands and carbon sequestration held at the Oak Hammock Marsh in Manitoba, Canada sponsored by DUC, Wetlands International and the International Institute for Sustainable Development (1999), some ideas and suggestions for wetland carbon sequestration projects emerged and culminated in a summary, Prairie wetlands and carbon sequestration-- Assessing sinks under the Kyoto Protocol (edited by David Wylynko) that discusses the possible inclusion of wetlands as carbon sinks and policy advancements since Kyoto.

More recently, DUC is leading two large projects for the Agricultural Wetlands and Greenhouse Gas Initiative (AWGI) that are examining the functional linkages between prairie wetlands, riparian areas and their adjacent agricultural landscapes in terms of carbon sequestration and GHG fluxes. Preliminary results have indicated that N2O and CH4 emissions in the PPR, in terms of carbon equivalent, are relatively minor compared to the potential gains in SOC due to sequestration (P. Badiou, personal communication, April 10, 2007). Additionally, DUC and DU have been participating in the Plains Co2 Reduction Partnership (PCOR). PCOR is one of seven regional partnerships funded by the U.S. Department of Energy's National Energy Technology Laboratory Regional Carbon Sequestration Partnership Program, and is managed by the Energy & Environmental Research Center (EERC) at the University of North Dakota. The PCOR Partnership is a collaborative effort of more than 40 public and private stakeholders working toward a better understanding of the technical and economic feasibility of capturing and storing carbon dioxide emissions from the central interior of North America. Recent results of the study have shown that while wetlands comprise only 17 percent of the landscape, they may store as much as twice the carbon of the surrounding untilled agricultural soils.

Further supporting the potential of prairie wetlands as net sinks is a study conducted in a glaciated area of Germany similar to the PPR, that found N2O and CH4 emissions proportional to the quantities of fertilizer applied in the surrounding croplands (Merbach et al. 2002). Establishment of perennial grasses in the surrounding wetland catchment, as is common on retired Conservation Reserve Program (CRP) croplands, can reduce the likelihood of nutrient enrichment and subsequent N2O and CH4 emissions from restored wetlands (Euliss et al. 2006). Additionally, displacing cropping activities with perennial grasses will provide additional GHG reduction benefits.

Grasslands A spectrum of research has been conducted on the cycle and carbon sequestration abilities of prairie grassland complexes. Grasses have long been identified as an ideal source of carbon sequestration due to the rapid rate at which carbon can be sequestered and securely stored underground as root mass, protected from catastrophic events like fires. Some soil carbon originates from leaves, stems and other surface material that dies and is incorporated in the upper (0-4 in) region of the soil strata, but most carbon is derived from live, dead, and decayed root material that may occur a yard or more below the surface. The ability of perennial grasses to sequester and store vast amounts of carbon, make grassland restoration and preservation high quality terrestrial sequestration practices. Native prairie that has never been plowed contains substantial amounts of soil carbon that has, over the course of centuries, reached an equilibrium wherein the oxidation rate equals the rate of carbon deposition. When 10,000-year-old native prairie is plowed, vast amounts of organic carbon are oxidized in addition to destroying habitat for hundreds of wildlife species. Regrettably, the remaining native prairie in the Dakotas and northern Montana continues to be converted to cropland at an annual rate exceeding 1.5% per year. The current loss rate, compounded annually, means that 77% of the prairie grassland in existence today will be lost in the next 99 years.

If native prairie is plowed, most of the carbon is oxidized shortly after plowing, but CO2 emissions can continue for decades until much of the carbon has been depleted and a new equilibrium is reached. After 40-50 years of cultivation, grassland soils tend to lose 20-50% of their original SOC (Lal et al. 1998). A regional analysis in the U.S. Northern Great Plains (Montana and North Dakota) found that losses of SOC from conversion to cropland averaged 43% lower than undisturbed levels after 30-40 years of cultivation (Liebig et al. 2005).

After plowing up native prairie, farmers often find that the soils or topography are unsuitable for cropping, and the land would be better used as pasture or for hay production. The restoration of grass, whether for grazing, haying, wildlife benefit or as part of a government program (CRP), can sequester carbon anew. As with carbon release, the buildup of SOC is most rapid during the first decades following restoration, and gradually slows until reaching a new equilibrium point in approximately 55-75 years (McLauchlan et al. 2006). There is also a high degree of temporal and spatial variation in grassland sequestration rates, as can be seen by the grassland sequestration rates reported in Leibig's analysis, ranging from 0.04 to 0.80 ST C ac-1 yr-1. Sources of variation include site characteristics (i.e., soil type and slope) and annual variation in moisture and associated changes in primary productivity of plants and associated root development.

Carbon Mitigation Options A top waterfowl conservation priority is retaining existing native prairie. Fortunately, in exchange for a one-time payment, many landowners are willing to sell conservation easements that secure the grassland in perpetuity. These "grassland easements" forever prohibit plowing and also mandate that haying be delayed until after the primary nesting season of birds. However, grazing and other uses are allowed. Thus, land encumbered with a grassland easement continues to have significant value as grazing land, hay land, recreational land, and of course wildlife habitat. Avoiding the loss of soil carbon – in cases where destruction is almost certain to occur – is among the most cost-effective ways to address greenhouse gas balance in the atmosphere. Another approach is replanting cropland back to grass. In most cases, restored grassland in the PPR is a result of CRP, which was enacted to provide soil, water, and wildlife benefits. Under CRP, landowners normally entered into 10-year contracts in exchange for an annual rental payment. During that time, they agreed to leave the restored grassland "idle" (unused for haying or grazing) except for designated drought emergencies. As a result of CRP, soils whose carbon stores had been depleted when the land was cropped began regaining carbon after the grass was restored. This carbon accumulates at a predictable rate over a period of 30-40 years, at which time it begins to reach an equilibrium state. However, once a CRP contract expires, the landowner is free to plow up the grass again, thereby releasing the carbon that has been recently sequestered. In addition, along with the resumption of cropping comes the combustion of fossil fuel and the application of nitrogen fertilizer, both of which contribute additional greenhouse gases. A further approach to carbon sequestration is to engage farmers whose CRP contracts have expired and offer to provide them with grassland easement and carbon sequestration payments in order to permanently remove cropping. This secures the grassland (and carbon) in perpetuity but, as with native pasture, the grasslands are still available for economic uses such as pasture land, hay land, and/or recreation.

Finally, common management practices employed by waterfowl managers such as crop production, prescribed burns, and flooding have a GHG emission impact. Agricultural working lands provide the most room for improvement, and can be managed to maximize both waterfowl and greenhouse gas mitigation benefits. A significant adjustment is the adoption of conservation or reduced tillage practices, often referred to as 'no-till'. Conservation tillage minimizes soil disruption, reducing soil oxidization, and also decreases farm equipment operation time and fuel consumption. In many areas, conservation tillage is often economically superior to conventional tillage. In conjunction with a high intensity crop rotation, with no or minimal fallow periods, conservation tillage can shift agricultural land from a net emitter of GHG to a net sequesterer in the order of 1.1 STCO2e/acre/year.

For more than a century, sportsmen have stood at the forefront of the conservation movement in North America. Billions of dollars paid by hunters and anglers for license fees and excise taxes on sporting goods have conserved tens of millions of acres of wildlife habitat, and these revenues remain the primary funding source for state conservation agencies across the United States. Sportsmen also have been the driving force behind critical national and state conservation legislation; have founded and generously contribute to nonprofit conservation organizations; and directly own, lease, and manage land themselves for wildlife. In addition to these actions, waterfowl hunters have contributed directly to the conservation of wetlands by their annual purchase of the Federal Migratory Bird Hunting and Conservation Stamp. Their conservation leadership has not only helped to conserve habitat for waterfowl and other game, but has also benefited a host of other wildlife—including several threatened and endangered species—that share the same habitats.

Despite the progress, North America continues to lose ground every day as wetlands, native grasslands, and other waterfowl habitats are destroyed or degraded by development. Further losses in habitat area would mean greater challenges ahead for waterfowl as they face the added stressors from climate change. The uncertainties in projected impacts of climate change are due in part to the uncertainty as to what extent world-wide efforts will be undertaken to reduce the emissions of greenhouse gases, especially carbon dioxide. This underscores the importance of maintaining and enhancing conservation provisions under laws such as the Clean Water Act, the Endangered Species Act, and the Farm Bill conservation title, and similar laws and policies in Canada.

Recommendations

Following are recommendations for action to help mitigate the current and potential impacts of climate change on wetlands and waterfowl:

Inform public policy development Opportunity exists to scientifically inform and support public policy at the state, federal and international level that reduces emissions of carbon dioxide and other heat-trapping gases that contribute to global warming and climate change. These include policies that set specific limits on the nation's GHG emissions; protect and enhance the ability of forests, grasslands, wetlands, and other natural systems to absorb and store carbon; strengthen programs to promote energy efficiency; support the development of market based tools for conservation of environmental goods and services; accelerate deployment of clean renewable energy sources; and influence the design of a post-Kyoto agreement that recognizes the importance of wetlands in the global climate cycle (Glick 2005). As energy regulatory programs are developed and permit and credit systems are put in place with financial implications, a significant portion of new funds should be devoted to conservation of wetlands and associated habitats. Funding should be delivered via existing state, federal and private vehicles.

Additionally, federal programs focused on land management can increase carbon sequestration potential, including programs that retire farmland from crop production and convert it back into forests, grasslands, or wetlands. Major programs include the Conservation Reserve Program (CRP), the Wetlands Reserve Program (WRP), the Grasslands Reserve Program (GRP), and the Farmland Protection Program (FPP). The 2008 Farm Bill may include significant funding and incentives for alternative energy production, particularly ethanol production, as well as R&D and pilot programs for cellulosic ethanol. As the world searches for ways to meet energy demands, attention has been focused on the potential of the Northern Great Plains to produce energy from perennial plants like switchgrass. Shortly after scientists and policy makers began considering this opportunity attention quickly shifted to using existing grasslands – native prairie and CRP lands. An important part of this discussion must be the potential wildlife, conservation and environmental impacts of such a policy. Additionally, switchgrass and other perennial energy crops have already been identified as having carbon sequestration potential. As these become marketable commodities in "the new economy", wetland and waterfowl managers should work to inform discussion and encourage industry in a way that helps provide new energy sources that are complimentary to wildlife and the environment.

Recognize global climate change as a factor in waterfowl and wetland conservation Incorporating climate change science into conservation planning is critical for reaching wetland and waterfowl management objectives. While the most important strategy we can undertake to prevent broad-scale loss of wildlife and habitat due to climate change is to reduce greenhouse gas emissions, the nation must also begin to develop strategies to help species and ecosystems cope with some changes that are inevitable, as well as build in the flexibility to deal with those impacts that may be unforeseen. For waterfowl, taking the potential impacts and uncertainties associated with climate change into consideration in efforts such as the North American Waterfowl Management Plan and other relevant resource management activities will help ensure that our conservation successes will endure. This will involve cooperation and support for Joint Ventures, Flyways Councils, NGOs, and others in the recognition of climate change in management plans and waterfowl conservation strategies. Existing funding sources must be enhanced significantly for these purposes.

Work with agencies on public land issues relating to climate change Support efforts by the USFWS National Wildlife Refuge System, and other state and federal partners for applying adaptive management strategies to wetland conservation that take into consideration present and predicted climate change impacts to waterfowl habitat. In fulfillment of these actions, Federal climate change legislation must include adequate and dependable funding to state and federal natural resources agencies for land acquisition and adaptive management of wetlands and wetland-dependent species that may be affected by climate change.

Increase or sustain research, science and monitoring efforts Increased monitoring and research on known and potential impacts of climate change on species and habitats will help close the gap in knowledge. Future federal appropriations for climate change research should be significant and support land conservation offsets and adaptation projects and science. Local, regional and global research and science needs in support of wetlands and associated waterfowl habitats should be continually evaluated and prioritized.

Additional research is also required to determine how different wetland types capture and store greenhouse gases. Insufficient information exists on the sensitivity of wetland carbon stocks to land-use changes, such as drainage, conversion, flooding, nutrient inputs, or restoration. In addition, climate change scenarios predict warming and changes in precipitation patterns that could affect the carbon cycle in wetlands, warranting ongoing monitoring and research.

Overall, research on wetlands and waterfowl is underfunded and must be increased to help guide appropriate adaptive management. One immediate concern is the ability of management agencies to monitor and detect shifts in species population dynamics that could result from change to carrying capacity and affect levels of sustainable harvest. Agencies responsible for managing exploited populations must be able to test their assumptions and harvest models in the face of climatic conditions.

Additional socio-economic research should be done to determine the level of financial investment by clubs, corporations, agencies, individuals and others that will be at risk if hunting opportunities are lost because of climate change.

Manage water resource supply and demand Maintaining river flow characteristics, including low flows also represents an important approach to maintain wetland systems. In the Louisiana coast there is need to consider regional water management plans that use existing shipping channels, canals, and water control structures to deliver freshwater, and if feasible, sediment into this system in a way that resembles historical hydrological processes. In the Prairie Pothole Region, the likelihood of drier conditions should persuade resource managers, conservation organizations, and other stakeholders in the region to develop contingency plans such as promoting development of less water-intensive agriculture or securing long-term rights for water use to ensure its availability for wetlands when water resources are scarce, and to implement watershed-based land-use planning. In the Great Lakes, wetland restoration programs (WRP, CRP, WHIP etc.), could be combined with headwaters-based efforts, improving the prospect for restoring water retention in Great Lakes watersheds substantially. Additionally, the effectiveness of WRP-type programs justifies exponentially increased implementation of additional water-quality based wetland restoration initiatives (e.g., for nitrate or phosphate reduction).

Wetland restoration efforts should be increased in other ecosystems as well where multiple benefits of flood abatement, groundwater recharge, carbon sequestration and wildlife habitat can be realized simultaneously. Because temperature and precipitation patterns are expected to become even more variable in the future, the multiple "buffering" effects of wetlands may become even more valuable as well.

Develop new opportunities and partnerships Strategies to protect and enhance the ability of natural systems to absorb and store carbon can play a role in slowing the buildup of heat-trapping carbon dioxide in the atmosphere. Well-designed biological sequestration projects can provide significant additional benefits such as habitat for wildlife, economic opportunities for landowners, recreational outdoor opportunities for wildlife enthusiasts, and environmental stewardship opportunities for corporate climate response strategies. New partnerships on these and other opportunities should be pursued.

While federal lawmakers consider national policy to address global warming and climate change, states across the nation are already implementing programs to reduce carbon dioxide and other greenhouse gas emissions locally. Presently, this action has led to the development of several distinct registries, and an exchange that functions as a registry. Efforts are also under way to create a new registry, The Climate Registry, linking the registries of California and the Northeast. The U.S. registries vary in terms of objectives, regional and industrial coverage, allowance of offset projects, accounting procedures, and registration requirements. Opportunities exist to help develop the standards and protocols for biological sequestration carbon offsets to ensure high quality co-benefits for wildlife and society.

Focus on adaptive management techniques for ecosystem processes The recent advances in scientific understanding of the regional and localized consequences of global warming, as well as the vulnerability of species and ecosystems, will go far in helping resource managers and other relevant decision makers develop and promote appropriate solutions. Management of natural resources is characterized by the need to continuously adapt to changing circumstances. In this sense, adapting to a changing climate has many similarities with other aspects of natural resources management. Adaptation in the context of climate change can be defined as a deliberate management strategy to minimize the adverse effects of climate change, to enhance the resilience of vulnerable systems, and to reduce the risk of damage to human and ecological systems from changes in climate. Wetland rehabilitation can be a viable alternative to structural flood control and dredging/modification efforts designed to cope with larger and more frequent floods that may be associated with climate change in some areas. Adaptation strategies should not only involve physical alterations in the management system, but also technological and institutional changes that can deal with changing conditions.

Increase efforts to reduce stressors on ecosystems Examples of suggested strategies for minimizing impacts of climate change in the prairies includes targeting 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; and contingency planning for large managed wetlands (Anderson 2005). Reducing pollution, avoiding damage to native vegetation, and protecting wetland biological diversity and integrity are critical for maintaining and improving the resiliency of wetland ecosystems so that they continue to provide important services under changed climatic conditions (Kusler et al. 1999).

Protect coastal wetlands and mitigate sea level rise In the light of climate change, it is particularly important to protect coastal and estuarine wetlands and processes that could be further reduced or adversely affected by sea level rise. Everywhere that significant coastal wetlands are threatened by sea level rise, coastal zone regulations and development plans should be examined for opportunities to enable landward migration of wetland ecosystems. Southeast Louisiana has potential solutions in the form of strategic, large-scale beneficial use of the Mississippi River's fresh water and sediment for restoration of deltaic processes. Uncertainties remain about the feasibility of such restoration efforts, but no other management response appears to have the potential to produce results at the scale required to achieve at least equilibrium between rates of wetland loss and gain in southeastern Louisiana. Restoration actions there should advance based on clear statements of assumptions and plans to evaluate restoration to reduce uncertainty following principles of adaptive management.

9. CONCLUSIONS

Wetlands provide multiple and substantial ecological benefits to human society. Waterfowl, which depend on wetlands, are part of America's natural heritage, and they will no doubt continue to be a focus of conservation in the future. The success of those efforts will depend on how well we are able to manage all the growing pressures from human activities. Variations among models and other uncertainties make it difficult to assess and predict the precise impacts that climate change will have on wetlands and waterfowl in North America. Nevertheless, there is sufficient certainty for some areas and sufficient risk to waterfowl and wetlands as a result of climate change to justify taking some actions now. Ignoring climate change will only result in a continued increase in the atmospheric concentrations of GHGs, increasing the likelihood that worst-case scenario predictions could become reality and making the challenges of adaptation and mitigation even more difficult to successfully address.

The challenge is great—but there are solutions. Many of the strategies that help protect waterfowl today, such as protecting and restoring the quantity and quality of wetland habitat and regulating harvests, will also enable them to be more resilient to global warming. Taking climate change into consideration in long-term resource management plans will improve the outlook for waterfowl in the future. Ducks Unlimited and many other conservation partners have been working for decades to restore and protect North America's wetlands and surrounding upland habitat for the benefit of waterfowl, other wildlife and people and will continue to evaluate management responses to mitigate the impacts of climate change.

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