# Climate Change:
# Preliminary Assessment for the Section of Wildlife of the Minnesota Department of Natural Resources

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May 14, 2008

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## EXECUTIVE SUMMARY

The Intergovernmental Panel on Climate Change (IPCC), in their latest assessment report, concluded that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures…" (IPCC 2007:30), and "Most of the observed increase in global average temperatures since the mid-20th century is very likely [>90% probability] due to the observed increase in anthropogenic GHG [greenhouse gas] concentrations" (IPCC 2007:39). Some of the impacts of recent warming on the Earth's biota have been documented (Parmesan and Galbraith 2004), and projected climate change will have implications for wildlife in particular (Inkley et al. 2004). In recognition of the importance and urgency of developing approaches to deal with climate change, senior managers in the Minnesota Department of Natural Resources' Division of Fish and Wildlife convened a working group within the Section of Wildlife during August 2007. The purpose of the Wildlife Climate Change Working Group was to guide the Division of Fish and Wildlife in describing (1) climate change in Minnesota, (2) its effects on wildlife species and habitat, and (3) the development of wildlife management and monitoring actions needed to respond to this unprecedented wildlife management challenge. The goal was to produce this summary document by spring of 2008.

During the next 100 years average temperatures in Minnesota are projected to increase by 6–10 $^{o}$F (3–5.5$^{o}$C) in winter and 7–16 $^{o}$F (4–9$^{o}$C) in summer (Kling et al. 2003, IPCC 2007). Precipitation is projected to decline by 0–15% during summer but increase by 5–30% overall (Kling et al. 2003, IPCC 2007). The frequency of extreme precipitation events is projected to increase by 50–100% (Kling et al. 2003), which will result in greater surface runoff and less percolation into the soil. Increasing temperatures and declining soil moisture during summer will have dramatic effects on plant communities. The boundary between grassland and deciduous forest biomes will shift. Tree species composition in forests will change. Specific effects of climate change, however, are difficult to predict because of uncertainty in future precipitation patterns and because climate change will interact in complex ways with changes in other disturbances like human land use and invasive species. Climate change may affect forest disturbances by changing the frequency, duration, and severity of fires, tornadoes, outbreaks of insects and pathogens, thunderstorms, and drought (Dale et al. 2001). Due to differences among species in sensitivity to temperature and precipitation, rates of dispersal, and vulnerability to various disturbances and threats, biological communities with which we are familiar may not

remain intact. New biological communities may be dominated by plant and animal species best able to disperse, including many of the invasive species we are currently managing.

Climate change will be beneficial for some species, but it is likely to be detrimental for many species. In response to climate change, plants and animals can adapt, migrate (i.e., shift their range), or become extirpated or extinct (Noss 2001). In Minnesota, it is likely that ranges of some species will shift generally from south to north with increasing temperatures and perhaps from west to east if summers become drier. It is predicted that ranges of many wildlife species may become smaller (Parmesan and Galbraith 2004). As the spatial distributions of species change, some species will become extirpated from Minnesota and others will move into Minnesota (Price and Glick 2002). Several wildlife species have expanded into northern Minnesota from the south during recent decades, presumably due to warmer temperatures and mild winters. Examples include mourning doves, northern cardinals, and opossums. Wildlife associated with near-boreal forests in northern Minnesota may be under the greatest threat of extirpation from the state due to climate change.

Rising interest in and development of renewable sources of energy, partially due to desires to mitigate for climate change, are influencing land-use decisions that affect wildlife. For example, in western Minnesota commercial wind turbine projects and planting feedstocks for ethanol fuel and biomass (e.g., corn, switchgrass) are becoming more common. Opportunities exist, however, to produce biofuels, sequester carbon from the atmosphere, and provide other ecosystem services using high-diversity plantings of native grassland perennials (Tilman et al. 2006).

We in the Wildlife Climate Change Working Group believe that communicating and establishing a clear, shared vision within the Section of Wildlife (or higher level within MNDNR) about climate change is important. A critical aspect of the vision should include being proactive in identifying and implementing responsible, science-based strategies for mitigating climate change and adapting to unavoidable climate changes. We also believe that the significance of climate change to the management and conservation of wildlife warrants making it an explicit priority of the Section, Division, and Department to develop and implement a proactive response to climate change.

In general, we in the Section of Wildlife should (1) focus on objectives that help the Section accomplish its mission and mandates; (2) acknowledge uncertainty when making decisions and confront it in a logical, productive manner; and (3) strive to work effectively with colleagues and stakeholders to achieve wildlife management goals. Furthermore, the Section of Wildlife as a whole should address climate change using mitigation and adaptation strategies. The following lists highlight some of our recommendations for how to approach climate change:[1]

**Mitigate climate change:**

- Accomplish gubernatorial mandates to reduce energy consumption and increase efficiency of energy use by staff (Pawlenty 2004*a*,*b*; 2005; 2006).
- Develop recommendations for personal choices that result in mitigation.
- Seek carbon sequestration opportunities that do not conflict with or diminish wildlife conservation.

**Adapt to unavoidable consequences of climate change:**

- Develop, utilize, and communicate transparent decision processes.
- Identify important decisions and decision thresholds, so management and monitoring objectives can be specified.
- Establish interdisciplinary teams to collaborate on climate change issues.
- Provide specific guidance to staff about whether or how to address climate change in management actions and planning efforts (USGAO 2007).
- Dedicate 1 new FTE position at the Program level in the Section of Wildlife or the Division of Fish and Wildlife to lead and coordinate climate change efforts.
- Link monitoring programs to specific management decisions or scientific hypotheses.
- Continue to acquire and manage land for wildlife purposes.
- Maintain ecological structures and functions (e.g., biodiversity, water quality).
- Reduce nonclimate stressors that we can influence now (e.g., habitat loss; Inkley et al. 2004:18).
- Proactively choose where and when to resist climate-induced changes, encourage resilience of systems to change, or enable climate-induced changes (Millar et al. 2007).

[1] The suggestions and recommendations in this report are intended primarily for the Division Management Team and, therefore, do not represent a statement of policy by the Section of Wildlife, Division of Fish and Wildlife, or any other unit within the Minnesota Department of Natural Resources.

## 1. INTRODUCTION

The most comprehensive research on climate change is summarized by the Intergovernmental Panel on Climate Change (IPCC). The IPCC, comprised of many scientists from around the world, was created by the World Meteorological Organization and the United Nations Environment Programme to provide an objective source of climate change information for policymakers. In their latest assessment report, the IPCC made the following conclusions: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC 2007:30); "Most of the observed increase in global average temperatures since the mid-20th century is very likely [>90% probability] due to the observed increase in anthropogenic GHG [greenhouse gas] concentrations" (IPCC 2007:39); and "It is likely [>66% probability] that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)" (IPCC 2007:39).

Some of the impacts of recent warming on the Earth's biota have been documented (Parmesan and Galbraith 2004), and projected climate change will have implications for wildlife in particular (Inkley et al. 2004). In recognition of the importance and urgency of developing approaches to deal with climate change, senior managers in the Division of Fish and Wildlife of the Minnesota Department of Natural Resources (MNDNR) started 2 initiatives. First, a group in Fisheries Research redesigned its long-term lake survey program to detect early climate change impacts. The new program is called Sustaining Lakes in a Changing Environment (SLICE, Valley 2008). The second initiative was to form a short-term working group within the MNDNR Section of Wildlife. Three Advisors, who provided direction and oversight, convened the Wildlife Climate Change Working Group during August 2007. The purpose of the working group was to guide the MNDNR Division of Fish and Wildlife in describing (1) climate change in Minnesota, (2) its effects on wildlife species and habitat, and (3) the development of wildlife management and monitoring actions needed to respond to this unprecedented wildlife management challenge. The goal was to produce this summary document by spring of 2008.

The organization of this report follows directly from our 3-point statement of purpose. Knowledge of climate change as it relates to Minnesota is summarized in Section 2. Observed and potential effects of climate change on wildlife and habitats are described in Section 3. Our suggestions for how to approach the challenges posed by climate change and ideas for next steps are presented in Section 4.

This report is intended primarily for the Division Management Team of the MNDNR Division of Fish and Wildlife and the Advisors of the working group. The efforts and products of the working group, including this report, are simply the Section of Wildlife's first step in considering how to approach the issue of climate change. The suggestions and recommendations in this report do not represent a statement of policy by the Section of Wildlife, Division of Fish and Wildlife, or any other unit within the MNDNR. Furthermore, there is no expectation for implementation of any of our recommendations unless or until they are requested by the Director of the Division of Fish and Wildlife or the Commissioner of the MNDNR and specified in a separate document.

## 2. CLIMATE CHANGE IN MINNESOTA

### 2.1. Climate predictions

#### *2.1.1. How are climate change predictions made?*

First, it is important to distinguish between weather and climate. Weather is the state of the atmosphere (e.g., temperature, wind speed, pressure, water vapor content) over a relatively short period of time (e.g., minutes to months). Climate is the average weather over a longer period of time (e.g., seasons to many years). Importantly, average conditions are often easier to predict than specific temporal and spatial patterns. For example, gross changes in climate (averaged across space) can be predicted by considering overall changes in solar and terrestrially emitted radiation resulting from increases in the concentration of greenhouse gases, decreases in surface reflectivity (or albedo) following snow and ice melt, variation due to the Earth's orbit, etc. (Thorpe 2005). More detailed predictions, however, are usually made with global circulation models (GCMs).

Similar to weather prediction models, GCMs forecast changes in atmospheric conditions using classic laws of physics (Thorpe 2005). This process requires modeling complex interactions between the atmosphere, oceans, land, and sea ice. Importantly, changes in climate may result from changes in external forces (e.g., solar radiation, volcanic activity), human actions (e.g., emission of greenhouse gases), and complicated feedback loops involving the climate system itself (NRC 2003), such as:

- melting sea ice reduces the Earth's albedo, which in turn increases average temperatures;
- warming air and sea temperatures influence ocean circulation patterns, which in turn influence heat and carbon uptake by the world's oceans;
- higher temperatures lead to more water vapor in the air, which in turn traps more energy radiated from the Earth's surface; and
- increased greenhouse gas concentrations may lead to changes in the amount and distribution of cloud cover, which in turn changes the reflective properties of the atmosphere.

Vegetation can also have a strong influence on climate (e.g., due to carbon uptake, evapotranspiration, and albedo effects) and vice versa. Plants typically assimilate more carbon with warmer temperatures, but changes in precipitation patterns and soil moisture levels may lead to large changes in the amount and distribution of vegetation. Wide-spread changes in land use that alter the amount of vegetation and the reflective properties of the Earth's surface are also expected in the future (see Section 2.2.2 below).

*2.1.2. Model uncertainty*

Weather and climate projections both require the solution to partial differential equations, which describe continuous changes in measurements through time and space. These solutions are approximated at a set of grid points using numerical methods. In the case of climate models, this grid is fairly coarse. As a result, effects on scales smaller than the grid cannot be accounted for directly in the models and must be predicted by linking historic regional data with GCMs of the Earth's climate system. Sub-grid predictions are typically more uncertain, particularly for climatic variables that vary substantially across space and that are difficult for GCMs to predict with a coarse grid (e.g., rainfall). Although predictions should improve over time with advances in computing power, considerable uncertainties result from limited understanding of the complex physical processes that influence climatic variables (e.g., the feedback loops discussed in Section 2.1.1) and inadequate parameterization of model sub-components. Forecasts must also consider a range of future greenhouse gas emissions that reflect uncertainty in future development trends, energy systems, and societies' responses to climate change. As with weather predictions, the range of possible outcomes is captured by making multiple projections starting at different initial conditions and using slightly different parameter values in the models. The end result is an ensemble of forecasts that can be used to describe predictive uncertainty.

*2.1.3. Model validation*

Climate models have been subjected to an extensive series of validation tests (IPCC 2007:Chapter 8), and have largely been able to reproduce accurate descriptions of the following:

- spatial distribution of observed climatic conditions on global and regional scales,
- explosive volcanic events leading to short-term perturbations in global climate,
- 150-year mean annual global temperature record,
- 50-year record of oceanic heat gain or loss,
- 1,000-year northern hemispheric surface temperature record, and
- 10,000-year reconstructed record of northern hemispheric surface temperatures.

However, these models cannot account for recent temperature increases without including emissions of greenhouse gases by humans (Stott et al. 2000, IPCC 2007). In its fourth assessment report, the IPCC concluded, “most of the observed increase in global average temperatures since the mid-20th century is very likely [>90% certainty] due to the observed increase in anthropogenic GHG [greenhouse gas] concentrations” (IPCC 2007:39).

*2.1.4. Summary of current predictions*

The following are projections for the next 100 years, generated by linking GCM predictions from IPCC (2000) emission scenarios to past historic data from Minnesota (Kling et al. 2003):

- Average temperatures in Minnesota are projected to increase by 6–10 $^{o}$F (3–5.5$^{o}$C) in winter and 7–16 $^{o}$F (4–9$^{o}$C) in summer. The number of days with extreme temperatures (e.g., >95$^{o}$F) is expected to increase.
- Average annual precipitation for the Great Lakes region may increase, decrease, or stay about the same, but precipitation levels are expected to increase in the winter (15–40%) and decrease in the summer (up to 15%).
- Frequency of extreme precipitation events is expected to increase. Projections suggest 24-hour and multi-day heavy rainstorms will increase in frequency (50–100% higher than current values).

- With precipitation concentrated in fewer storm events of shorter duration, longer intervening periods of more intense drought and increased risk of wildfires may be expected.
- Duration of seasonal ice cover on the Great Lakes and inland lakes is expected to continue to decline (see also Austin and Colman 2007).

Projections from the latest set of climate models (IPCC 2007, Table 1) differ slightly from those above. Although the projections in Table 1 do not attempt to link coarse scale GCM results to historic data, they are based on more recent climate models.

Table 1. Differences in mean values of climate parameters for Minnesota during the 100 years between the periods 1980–1999 and 2080–2099 (IPCC 2007).

| Climate parameter | Dominant change | Exception | Location of exception |
|---|---|---|---|
| Surface temperature (°C) | | | |
| Annual | +4 | +3.5 | Extreme south |
| Summer | +3.5 | +4 | Southwest |
| Winter | +4 | +4.5 | Extreme north |
| Precipitation (%) | | | |
| Annual | +5 to +10 | | |
| Summer | 0 to -5 | 0 to +5 | Extreme north |

*2.1.5. Summary of the potential impact of climate change in Minnesota*

- Possibly reduced summer water levels will result in loss of wetlands and lower lake levels unless precipitation offsets losses.
- Pollution in the water supply is expected to increase (e.g., due to increased runoff associated with a greater frequency of larger storm events).
- Agriculture will see a longer growing season but may be constrained by a decline in soil moisture and an increase in soil acidity.
- Increased frequency of severe weather events (e.g., storms, floods) will place heavier burden on emergency management, with increased costs in clean-up and rebuilding.

- Native aquatic plant and animal species will be affected by warming waters, oxygen depletion, possibly lower water levels, and increases in invasive species.
- Boreal forests will shrink, causing some terrestrial wildlife species' ranges to move northward.
- Recreation and tourism will be affected by loss of habitat, possible changes from pines to hardwoods, shifts in migratory bird populations, and reduced winter sporting opportunities.
- Warmer minimum winter temperatures will result in range expansions for some plant and animal species.
- Warmer nighttime summer temperatures will stress both humans and wildlife.
- The costs of suppressing wildfires are increasing rapidly and will likely account for an even greater portion of future natural resource budgets if anticipated changes in climate occur.

## 2.2. Other trends to consider with climate change

Addressing climate change in Minnesota will require consideration of large time scales, and the context in which we practice wildlife conservation is likely to change over time. It will be important, therefore, to consider potential impacts of trends in other major influences on wildlife, particularly those associated with human activities (Vitousek et al. 1997).

### *2.2.1. Human demographics*

The following list of projections of future population demographics are from the Minnesota State Demographic Center < www.demography.state.mn.us >:

- Minnesota's population will increase by 2.7 million by 2060 (to 7.1 million total). Population gains are achieved by both natural increase (more births than deaths) and by immigration (internationally and from other states).
- Substantial growth in the Twin Cities suburbs and the Rochester and St. Cloud regions. The lakes area of northcentral Minnesota is also projected to have a considerable increase. Western Minnesota and the urban neighborhoods of the Twin Cities are projected to experience a slow growth or decline.
- "Baby boomers," born between 1946 and 1964, will produce a doubling of the number of people ages 55–69 by 2035 (623,200 in 2005 to 1,400,000). The population under age 65 will grow only 10%. The number of very old in Minnesota will surge after 2025 as baby

boomers begin to pass their 85th birthdays. Increasing longevity contributes to the predicted gains for this age group.

- Households in Minnesota will change. As the population grows older, more people will be living in small, one- or two-person households instead of in larger families (a projected decrease of more than 22% in the number of households with a married couple and children by 2035).
- Minnesota is one of the least diverse states in the nation (in 2000, minorities in Minnesota were 14% of the population vs. 33% for the U.S. average). However, Minnesota's non-white and Latino populations are projected to grow substantially faster than the white population. By the period 2025–2030, the non-white population will account for more than half of the total population gain. The Latino population is projected to almost triple over 30 years, due to a combination of international immigration, immigration from other states, and a high birth rate. Non-white and Latino populations are younger than the white population, and this will continue in the future.
- Levels of education have risen sharply in Minnesota. In the last 40 years, the number of people >25 years old having completed high school (high school graduation or GED) increased by 52% while the number having completed college rose by 75%. Levels of educational attainment are influenced by social and economic factors, but it is reasonable to expect this trend will continue.

Projected demographic changes are likely to influence societal values, attitudes, and beliefs about natural resource management issues. This may result in changes in outdoor recreation and support for wildlife management programs. For example, Minnesota's movement toward a population that is older, more urban/suburban, and comprised of increased numbers of non-white and Latino members suggests that rates of outdoor recreation will be lower in the future. Although overall sales of hunting licenses in Minnesota did not decline during 2000–2005, it is likely they will decline in the future because rates of hunting participation by younger adults (ages 16 to 44) is declining (Kelly 2005).

*2.2.2. Land use conversion and intensification*

Loss of habitat is the greatest immediate threat to wildlife populations (Czech et al. 2000). Habitat loss and fragmentation are often driven by changes in land use by humans. The most obvious and detrimental changes are conversions of land to uses that are not compatible with maintaining wildlife habitat, such as expansion of new infrastructure (e.g., houses, retail stores, roads; Radeloff et al. 2005) and conversion of small farms with crop fields, grasslands, and woodlots to suburban developments.

Intensifying particular land uses may have substantial negative impacts on wildlife conservation. For example, pressures to produce more energy from renewable sources is changing land uses in agriculture and forestry (Westcott 2007). There is concern that perennial grasses (e.g., on lands enrolled in the Conservation Reserve Program, or CRP) will be replaced by additional row crops or other feedstocks for ethanol production (Bies 2006). Burning biomass to produce heat and electricity will lead to collection of additional woody debris after timber cuts and the harvesting of shrubs from brushlands. Whereas the effect on wildlife habitat of specific land use changes may differ, the net effect of intensifying land use could be detrimental. On the other hand, special attention to bioenergy derived from low-input, high-diversity native grasslands (Tilman et al. 2006) could conceivably be managed to expand wildlife habitat while providing biofuel and other ecosystem services.

*2.2.3. Costs of energy*

Costs of energy are increasing and will continue to do so as fossil fuels, particularly conventional oil, become more scarce and transitions to alternative energy sources and technologies occur (EIA 2007), barring some unforeseeable event. This trend has already resulted in plans within the MNDNR to investigate ways in which we can use energy more efficiently (e.g., using more fuel-efficient vehicles) and reduce energy consumption (e.g., turning off lights and computers when they are not being used). Predictions about future energy availability vary widely, but it may become necessary to dramatically reduce even further the rates and overall amount of energy we consume, which may require changes in how we conduct our work. Another important consideration is that the increasing scarcity of oil and major shifts in energy production and use are likely to have even broader impacts on the economy (Cleveland et al. 1984, Hallock et al. 2004) and levels of future greenhouse gas emissions (Brandt and Farrell 2007).

## 3. EFFECTS OF CLIMATE CHANGE ON LANDSCAPES AND WILDLIFE IN MINNESOTA

Climate changes and their effects on wildlife and other natural resources have been observed and documented already (Parmesan and Galbraith 2004). Based on these observations, broad climate change predictions, and ecological theory, we can describe potential impacts on Minnesota's biological communities and wildlife populations. Models that can be used to predict specific outcomes of climate change at small spatial scales, however, do not exist yet.

### 3.1. General responses of plant and animal species to climate change

#### *3.1.1. Adaptation*

Species may adapt to climate change in various ways, including acclimatization, genetic evolution, and shifts in geographic distribution (i.e., range) to suitable sites (Noss 2001). Failure to adapt may result in population declines and extinction. Most species responded to past climate changes primarily by shifting their ranges (Noss 2001). However, current climate change is predicted to occur faster than previous changes during the Quaternary Period (1.8 million years ago to present), so it is uncertain whether rates of range shifts will be sufficient. Furthermore, range shifts may be difficult for species with poor dispersal abilities such as plants with large seeds, small forest vertebrates, and flightless invertebrates (Noss 2001).

Peters and Darling (1985) also believed that range shifts may be too slow for predicted climate changes, especially considering barriers to dispersal and migration. Even if native species can migrate, the high fecundity of invasive species makes it highly probable that invasives will be the first to arrive and dominate new sites. Habitat fragmentation, especially by agricultural and urban development, has created many barriers to movements of plants and animals (Noss and Csuti 1997, Iverson et al. 1999). Lack of appropriate soils, including moisture conditions, may be another barrier for plants. The Great Lakes pose a formidable barrier to species movements from the U.S. into Canada.

In Minnesota, it is likely that ranges of some species will shift generally from south to north with increasing temperatures and perhaps from west to east if summers become drier. It is predicted that ranges of many species may become smaller (Parmesan and Galbraith 2004). As the spatial distribution of species change, some species will become extirpated from Minnesota and others will move into Minnesota (Price and Glick 2002). More locally, especially in southeastern Minnesota and the North Shore where topographic relief is relatively pronounced, north slopes may act as refugia, allowing individuals and populations to remain in suitable microclimates by moving from south to north slopes.

Genetic adaptation in response to warming temperatures has been demonstrated by some species (Nowak et al. 1994, Hughes 2000) and depends on generation time as well as adequate levels of genetic variation within and among populations (Noss 2001). Species whose range and populations increase under climate change, such as many insects, may adapt well. For other species, however, genetic adaptation will be limited by anticipated declines in abundance and genetic variation as a consequence of selection imposed by climate change (Noss 2001).

Some wildlife species are distributed throughout most or all of Minnesota (Appendix A). These habitat generalists will be affected by climate change, but the effects may be less severe or more difficult to monitor than effects on species that are habitat specialists. Many habitat generalists demonstrate great adaptability to different levels of human development, including urban landscapes. Some of these species, however, may require management attention if climate change causes their populations to exceed acceptable levels. For example, managing white-tailed deer populations within goals will continue to be important (scientific names are provided in Appendix B). Survival of white-tailed deer is related to the frequency and severity of winter weather (DelGiudice et al. 2002) and could increase due to climate change. Impacts on deer may depend on specific moisture regimes. For example, increased winter precipitation may cause deeper snow pack, which reduces deer survival. As a large herbivore, deer have the potential to impact plant communities and species diversity. Over-wintering populations greater than 9.7–13.5 deer/mi$^2$ (25–35 deer/km$^2$) in fragmented forests result in local extirpation of trillium and other understory forbs and inhibit plant and forest restoration efforts (Augustine and Frelich 1998).

### *3.1.2. Biodiversity and new biological communities*

Moisture, minimum and maximum temperatures, soils, and length of the growing season largely determine the composition and distribution of biological communities in Minnesota. Natural and human-induced disturbance regimes also influence our present and future natural environment.

Currie (2001) and Hansen et al. (2001) compared the predictions of various climate change models to known relationships between climate and species richness for the continental U.S. They noted that species richness of both endothermic and ectothermic species is strongly correlated with temperature. Endothermic species richness is greatest in moderately warm areas and decreases in hotter areas, suggesting that bird and mammal species richness may decline in temperate regions in response to global warming. Ectothermic species richness increases with temperature, and the richness-temperature relationship is even stronger than it is for endotherms. Species richness of ectotherms, therefore, may increase throughout the continental U.S. It is uncertain, however, whether temperature increases alone will be sufficient for amphibian populations to overcome recent population declines, numerous threats (e.g., disease, habitat loss), and potentially drier surface conditions due to climate change.

Changes in moisture and temperature associated with global climate change are likely to affect reproduction and survival in amphibians and reptiles. Rain and temperature trigger chorusing in some frogs, which is an important component of breeding (Busby and Brecheisen 1997). Temperature and water levels also affect predation on amphibians by affecting the length of vulnerable larval stages (Manjarrez 1996, Moore and Townsend 1998) and periods of activity (Bider and Morrison 1981). Temperature is related to sex ratios in some reptiles, and it is related to sexual maturation rate, overwinter survival, metamorphosis size (Werner 1986, Smith 1987), and mating success as it relates to body size and fecundity in amphibians (Berven 1981).

In response to climate change, some of the biological communities we currently manage will cease to exist, and new combinations of plant and animal species will emerge (Schugart et al. 2003, Inkley et al. 2004). The new communities may be simpler (e.g., contain fewer species) than the communities they replace and communities that develop as better competitors arrive (Hansen et al. 2001). Species' responses to climate change will depend on the specific characteristics, favoring generalists that can disperse effectively and adapt rapidly. In a few cases, species with similar characteristics and environmental requirements could occur in assemblages similar to those seen in current native plant communities. However, there will likely be unpredicted interactions between microbes, plants, and animals that create challenging management scenarios.

New biological communities may be dominated by plant and animal species best able to disperse, including many of the invasive species we are currently managing. Climate change will likely increase the number of invasive species in Minnesota, but it will also increase the reproductive capacity, survival, and competitiveness of existing invasive species and some non-native species that have been innocuous. It is likely that invasive species will disperse faster than the rate of climate change and be better able than other species to disperse in human-dominated and climate-altered landscapes (Hansen et al. 2001, Kusler 2006). A combination of climate change, invasive species, and decreased area of native habitats will likely promote homogenization of native plant communities, ultimately favoring the invasive species. Negative effects of invasive non-natives on native species, especially endangered species, are well documented (Pimentel et al. 2000) and can be expected to increase.

Changes in the relationships among pests and their hosts and predators can be expected, which may amplify the magnitude of natural disturbance regimes and hasten large scale community changes. Modeling by Logan et al. (2003) indicated that all aspects of insect outbreak behavior would intensify as the climate warms. Warmer temperatures are providing the opportunity for additional breeding cycles within a year. Price (2002) suggested that spruce budworm outbreaks can be expected to become more significant because of the species' response to warmer temperatures and a northward shift in the ranges of several of its major avian predators (e.g., wood warblers). Coupled with the expected increases in drought and fire, this asynchrony between predator and prey could hasten the loss of the southern boreal forest.

### 3.2. Potential effects of climate change on ecological provinces and systems in Minnesota

Following a national framework, the MNDNR and the U.S. Forest Service developed an Ecological Classification System (ECS) for ecological mapping and landscape classification in Minnesota (MNDNR 2008*a*). The system uses associations of biotic and abiotic environmental factors, including climate, geology, topography, soils, hydrology, and vegetation. There are 8 hierarchical levels of ECS units in the United States. Map units for 6 of these levels occur in Minnesota. In order from least to most specific (i.e., from top to bottom), they are Provinces, Sections, Subsections, Land Type Associations, Land Types, and Land Type Phases. Provinces are units of land defined using major climate zones, native vegetation, and biomes such as prairies, deciduous forests, or boreal forests (MNDNR 2008*a*). There are 4 provinces in Minnesota—Laurentian Mixed Forest, Eastern Broadleaf Forest, Tallgrass Aspen Parklands, and

Prairie Parkland (Figure 1, MNDNR 2006). This section of our report (3.2) is organized by provinces of the ECS.

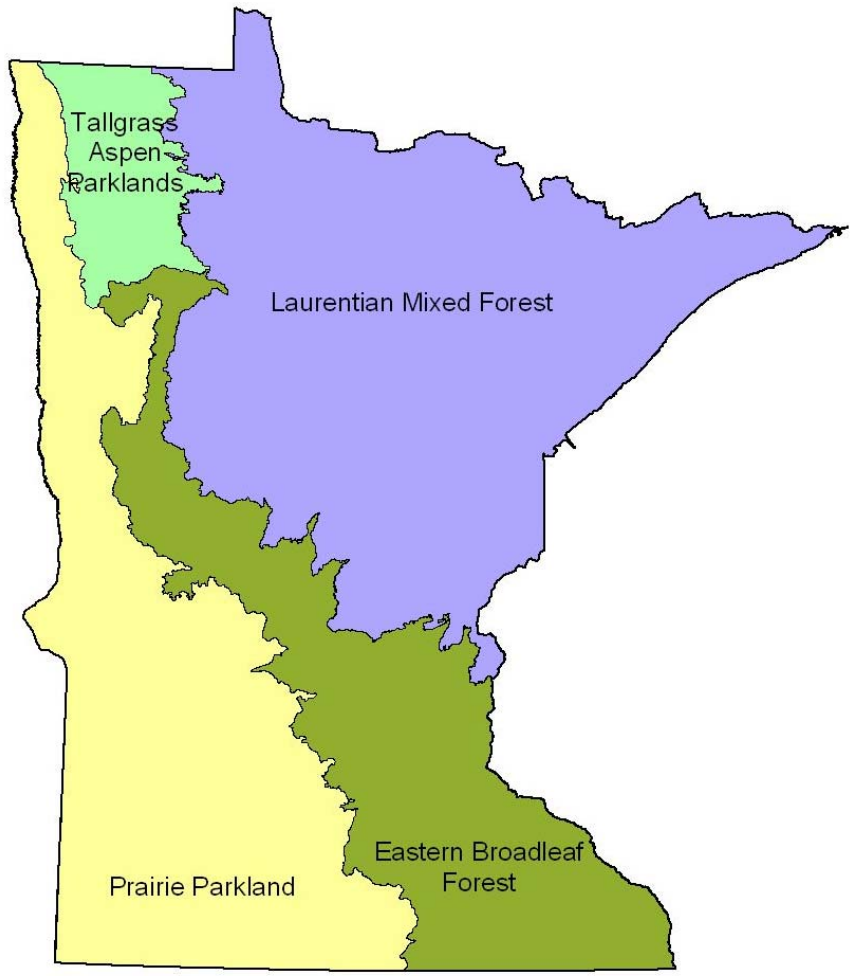


Figure 1. Provinces of the Ecological Classification System of Minnesota.

Nearly all ecological systems occur in more than 1 province. We tried to minimize redundancy, however, by discussing some of the main ecological systems in the context of only 1 province. We discuss upland coniferous forests, mixed coniferous-deciduous forests, and lowland coniferous forests in Section 3.2.1 (*Laurentian Mixed Forest Province*). We discuss deciduous forests and oak savannas in Section 3.2.2 (*Eastern Broadleaf Forest Province*). Our main treatment of lakes and wetlands is also in Section 3.2.2, but we discuss wetland issues in the sections for other provinces as well.

Minnesota DNR ecologists recently completed a new classification of the native vegetation of Minnesota (MNDNR 2008*b*). The new classification is intended to provide a framework and common language for management of native vegetation in Minnesota. The classification is hierarchical, with vegetation units described at levels ranging from broad landscape-level ecological systems to local communities. One of the most important features of the new classification is the inclusion of ecological processes as an organizing principle. The classification has 6 levels. In order from least to most specific (i.e., from top to bottom), they are System Group, Ecological System, Floristic Region, Native Plant Community (NPC) Class, NPC Type, and NPC Subtype (MNDNR 2003). The NPC classification system levels are referenced in the following discussion on impacts to ecological systems. We used plant and community descriptions contained in the Field Guides to Native Plant Communities of Minnesota (MNDNR 2003; MNDNR 2005*a*, *b*), especially fire dependence and soil characteristics, to make predictions of potential range shifts. The data and plant community knowledge acquired to develop the NPC classification system and the implementation of the system will be helpful as the MNDNR continues to analyze the potential effects of climate change on natural resources. In describing how provinces and ecological systems might be affected by climate change, we based our discussion on the available literature and our best professional judgment.

Many models of the effects of climate change exist, with some emphasizing impacts on particular ecological systems [e.g., DISTURB (Iverson and Prasad 2001), WETS (Johnson et al. 2005)] and others focusing on coarser scale changes in temperature and precipitation [e.g., Hadley Center model, Canadian Climate Center model (MacCracken et al. 2000)]. Models are simplified representations of reality and rely on assumptions that may limit their applicability and testability. For example, most of the ecological impacts models assume that habitat suitability is characterized by a few key parameters and that all available habitats will be colonized (Iverson and Prasad 2001).

### *3.2.1. Laurentian Mixed Forest Province*

The Laurentian Mixed Forest Province is the largest of Minnesota's 4 provinces, covering two-fifths of the state (Figure 1). This province is characterized by broad areas of conifer forest, mixed coniferous-deciduous forests, and conifer bogs and swamps. The landscape ranges from rugged lake-dotted terrain with thin glacial deposits over bedrock, to hummocky or undulating plains with deep glacial drift. The highest and lowest elevations in Minnesota both occur in this province (MNDNR 2006). The province supports many industries, including recreation, tourism, mining, and forestry. While the majority of the land remains forested, the age and species composition of trees have changed.

A distinct suite of boreal forest species inhabits this province. Animal species include great gray owl, Connecticut warbler, boreal owl, boreal chickadee, black-backed woodpecker, northern goshawk, spruce grouse, moose, gray fox, pine marten, and Canada lynx (scientific names are provided in Appendix B). Species of greatest conservation need (SGCN) are "animals whose populations are rare, declining, or vulnerable to decline and are below levels desirable to ensure their long-term health and stability." The Laurentian Mixed Forest Province is home to 171 SGCN, 47 of which are found only in this province (Table 2). Habitat loss (75%) and degradation (83%) are the greatest immediate threats to these species (MNDNR 2006).

Table 2. Animal species in greatest conservation need (SGCN) in the ecological provinces of Minnesota (MNDNR 2006).

| Province | Number of species | Number unique to province | Percent unique to province |
|---|---|---|---|
| Laurentian Mixed Forest | 171 | 47 | 27 |
| Eastern Broadleaf Forest | 205 | 51 | 25 |
| Tallgrass Aspen Parklands | 85 | 2 | 2 |
| Prairie Parkland | 139 | 13 | 9 |

#### 3.2.1.1. Upland forests in the Laurentian Mixed Forest Province

Warmer temperatures associated with climate change will clearly affect forest and woodland systems. Changes in precipitation will also have great impacts, but they will be more difficult to predict (see Section 2 above). Brush cover types may increase as the climate changes (Iverson et al. 2007). Climate change may alter the frequency and intensity of forest disturbances (Dale et al. 2001). Predictions include changes in the frequency, duration, and severity of fires, tornadoes, outbreaks of insects and pathogens, thunderstorms, drought, and ice storms. A higher frequency or intensity of disturbances could alter the way that forests recover from disturbances (Dale et al. 2001).

Of particular importance as a source of forest disturbance are insects, whose geographic ranges are largely determined by temperature. Short generation times and high reproductive rates result in rapid responses by insects to changing conditions, more rapid than those of their slow-growing tree hosts (Logan et al. 2003). Thus, insects will likely expand into forest communities that have previously been outside their range. This may disrupt the synchrony and associations between forest plant communities and forest pests that have formed over long periods of time, which may cause infestations to become persistent rather than episodic (USGAO 2007). Adverse effects of insects or other forest pests can appear suddenly, occurring when a temperature limit or other climatic threshold is passed and can include changes out of proportion to the relatively small climatic change that induced the effect.

###### 3.2.1.1.1. Coniferous forests

Coniferous forests in Minnesota occur almost exclusively in the Laurentian Mixed Forest Province. Dominant conifer species in the province include white, jack, and red pines in uplands, where fire was the main historical disturbance, and black spruce, tamarack, and white cedar in lowlands, where small-scale blowdown was the main historical disturbance (MNDNR 2006).

Changes in plant species abundance and distribution will depend on species dispersal ability and moisture regimes, which are determined not only by precipitation but also by temperature, topography, evapotranspiration, and soils. Fire dependent forest systems (many pine types) will be particularly sensitive to a change in moisture regimes that result in wetter conditions and less frequent or less intense fires. If this scenario is realized, fire dependent forest systems will become less abundant in the Laurentian Mixed Forest Province. Mesic hardwood systems (e.g., red oak-sugar maple types) would likely experience a range expansion. Generally, a shift northward for spruce-fir forests is predicted (Hansen et al. 2003, Iverson and Prasad 2001). Tree species associated with lowland coniferous forests are predicted to decline in abundance and may convert to lowland hardwood forests (Hogg and Hurdle 1995). New combinations of plant and animal communities should be anticipated as species' ranges (described here primarily as tree species) shift. It is likely that global warming will cause the southern boundary of the near-boreal forest to migrate northward out of Minnesota.

If conditions in the Laurentian Mixed Forest Province are warmer and drier, fire dependent hardwood systems (e.g., bur oak) will likely increase with a range shift to the north and east. Jack and red pine woodland types (fire dependent on dry, nutrient poor soils) may persist or expand. The likely increase in fire frequency and intensity with warmer, drier conditions will influence fire dependent forest systems, both coniferous and deciduous. It is possible, however, that site specific characteristics (e.g., slope, aspect, soil type) and their influence on moisture availability will be particularly significant under this scenario. New associations of plants and animals are likely with the potential for dominance by invasive species.

Declines of coniferous forests will have negative impacts on the plant and animal communities associated with them. For example, spruce grouse feed on pine or spruce needles during much of the year (Boag and Schroeder 1992). Moose populations are declining (Lenarz 2008), perhaps due to heat stress (Murray et al. 2006). Habitat changes in northeastern Minnesota induced by climate change may also negatively affect moose populations. Wildlife associated with coniferous forests may be under the greatest threat of extirpation from Minnesota due to climate change.

3.2.1.1.2. Mixed coniferous-deciduous forests

Mixed coniferous-deciduous forests of Minnesota are located primarily within the Laurentian Mixed Forest Province. Typical trees in these forests include pine, spruce, balsam fir, oak, aspen, and maple. The mix of tree species and their relative importance within the canopy vary with the age, disturbance history, soil, and geographic location of the forest stand.

Warmer, drier conditions will likely favor fire dependent deciduous trees such as oaks and hickory (more commonly associated with the Eastern Broadleaf Forest Province) over aspen and birch. Jack pine woodlands may expand under this scenario, depending on how dry it becomes and how rich the soils are. Shifts in plant species' ranges, diseases, pests, disturbances, and invasive species may contribute to the emergence of new and unpredictable species associations.

Warmer, wetter conditions would likely favor mesic hardwood types, which currently occur in but are not relatively abundant in the Laurentian Mixed Forest Province. Fires would likely be less frequent and intense under wetter conditions. Species that favor wetter sites include aspen, birch, and sugar maple. Soil characteristics and nutrients will also change species associations. Emerging combinations of plant and animals may be quite new and strongly influenced by invasive species, disease, and pests.

Global warming will likely cause some animal species associated with the mixed coniferous-deciduous forests to move northward and others to enter the province from the south. Because of the significant amount of public forestland in the Laurentian Mixed Forest Province, connectivity to the north is likely adequate but needs to be specifically maintained as part of forest management activities. Connectivity to the south likely is not as secure due to changes in ownership patterns, land use, and human population densities. Changes in distributions of plants and animals, as well as functional relationships among them, may take centuries to develop.

The impact of climate change on wildlife species will depend upon many factors, especially changes in plant communities with which they are associated. Ruffed grouse and snowshoe hares may decline in abundance and distribution as climate change reduces the dominance and shifts the ranges of aspen, birch, and balsam fir (Iverson and Prasad 2001). Breeding American woodcock also favor young aspen and paper birch stands (MNDNR 2006). The persistence of lynx in Minnesota, especially during low periods of the lynx–hare population cycles, may be less likely due to changes in habitat and snow depth patterns associated with climate change. Several wildlife species have expanded into the Laurentian Mixed Forest Province from the south during recent decades, presumably due to warmer temperatures and mild winters. Examples include mourning doves, ring-necked pheasants, northern cardinals, and opossums.

#### 3.2.1.2. Lowland forests and wetlands in the Laurentian Mixed Forest Province

Wetlands within the boreal and near-boreal forests play an important role in the carbon cycle due to large accumulations of peat (Burkett and Kusler 2000), which are estimated to contain the equivalent of nearly 100 times the annual emissions of carbon dioxide from burning fossil fuels (Bridgham et al. 1995). Decomposition of peat is expected to accelerate under warmer, drier conditions, which will result in the release of carbon from these historical carbon sinks (Burkett and Kusler 2000). Climate change is also likely to alter water flow in peatlands, which influences water chemistry, peat accumulation and decay, and the species of trees that can grow (Heinselman 1970). Cash et al. (2007) pointed out that lakes contain 15% of the boreal carbon pool and should not be overlooked when considering the carbon cycle. Release of this carbon may have important feedback effects on climate change.

Lakes and wetlands in the boreal forest are the second most important area for breeding ducks (14 million waterfowl, USFWS 2002), yet survival and reproductive rates of ducks and other breeding birds in the boreal forest are poorly understood. Other species dependent on these wetlands in Minnesota include mink frogs, northern bog lemmings, and four-toed salamanders. The way these species will be affected by climate change is still unknown.

Non-boreal forested wetlands are also common in the Laurentian Mixed Forest Province. These wetlands and associated wildlife are also susceptible to drying under warmer, drier conditions. Wetlands dominated by ash trees, however, are also at risk of future infestations by the emerald ash borer, an exotic beetle from China that has killed >30 million ash trees in Michigan (USFS 2006).

Lowland conifers occur in the Laurentian Mixed Forest Province and the Tallgrass Aspen Parkland Province. Many ecologically important lowland conifers or bogs associated with large Scientific and Natural Areas (SNAs) may be affected by temperature increases more slowly than adjacent uplands due to their microclimate. Similarly, forest reserves and corridors closely associated with the microclimate of Lake Superior may be affected more slowly than forests further inland. These areas may serve as refugia from climate change and may support some species that might otherwise be extirpated.

#### *3.2.2. Eastern Broadleaf Forest Province*

The Eastern Broadleaf Forest Province is a transition zone between the prairie to the west and the mixed coniferous-deciduous forest to the northeast (Figure 1). The deciduous forests of this province are a species-rich extension of the eastern U.S. deciduous forest. Topography varies from level plains to steep blufflands along the Mississippi River, with major landforms of outwash plains, end moraines, ground moraines, and drumlin fields (MNDNR 2006).

The Eastern Broadleaf Forest Province coincides roughly with the part of Minnesota where precipitation approximately equals evapotranspiration. It seems likely that this aspect of climate has an important influence on plants because many forest species reach their western range limits and several prairie species reach their eastern range limits within the province. Precipitation in the province increases from about 24 inches (60 cm) annually in the northwestern portion to 35 inches (90 cm) in the southeast. Normal annual temperatures range from 38°F (3°C) in the northwest to 46°F (8°C) in the southeast (MNDNR 2003). Row crop agriculture is one of the major land uses in this province. Recreation and tourism are important industries, especially surrounding the many lakes and wetlands. Most Minnesotans live in this province, which encompasses the Twin Cities, St. Cloud and Rochester (MNDNR 2006).

The Eastern Broadleaf Forest Province is home to many wildlife species, including the red-shouldered hawk, cerulean warbler, Louisiana waterthrush, wild turkey, ruffed grouse, American woodcock, wood duck, and Blanding's turtle (scientific names are provided in Appendix B). Species of greatest conservation need in this province number 205, with 51 unique to the province (Table 2). Fourteen of the unique SGCN occur in the blufflands of southeastern Minnesota. Habitat loss (82%) and degradation (88%) are the greatest immediate threats to these species (MNDNR 2006).

#### 3.2.2.1. Upland forests in the Eastern Broadleaf Forest Province

Site-specific characteristics such as soil type, evapotranspiration rates, aspect, and slope may be significant in determining climate-induced shifts in plant communities in this province, where fire disturbance is less widespread, primarily due to human influence. The western boundary of the Eastern Broadleaf Forest Province is sharply delineated with non-forested areas, whereas the northeastern edge is a diffuse transition from deciduous to mixed forests. Warmer, wetter conditions would likely favor mesic hardwood tree species, which are currently common in the Eastern Broadleaf Forest Province. Fires would likely be less frequent and intense under wetter conditions. Species that favor wetter sites include aspen, birch, and sugar maple. Soil characteristics and nutrients will also change species associations. Emerging combinations of plant and animals may be new and strongly influenced by invasive species, diseases, and pests.

Several climate change models predict warmer, drier conditions for existing deciduous forests. Under this scenario, deciduous forests will tend toward savanna types (fire dependent hardwood systems), if managed with fire, and the range of mesic hardwood forests will likely contract. If not managed with fire, these areas will likely become brushlands or become dominated by non-native woody invasive species. Iverson and Prasad (2001) predict expansions of oak-hickory and oak-pine forests (fire dependent-drier forest types) as well as reductions in aspen-birch forests (a mesic hardwood type).

Animal species associated with mesic hardwood systems (e.g., wood thrush, ovenbird, and red-backed salamanders) will likely decline. Birds such as cerulean warblers and red-shouldered hawks generally require large areas of contiguous mature or old growth hardwood forest and may be negatively impacted by climate change. An expansion of drier deciduous forests may result in an expansion in the ranges of animal species dependent upon them, provided the transition and climax forests include adequate habitat. The eastern hognose snake is an example of a species that may benefit from expanding dry oak forests.

Minnesota's deciduous forests have been severely fragmented by agriculture and urban/suburban expansion. They are at risk of further fragmentation and habitat degradation, especially near urban centers. Lack of habitat corridors and ongoing land development may compromise the ability of many species in deciduous forests to adapt to climate change. Furthermore, competition for groundwater resources may affect soil moisture regimes.

#### 3.2.2.2. Oak savannas

Oak savanna plant communities occur in the Eastern Broadleaf Forest, Tallgrass Aspen Parklands, and Prairie Parkland Provinces. Oak savannas exist between forests and prairies and support biological communities from both adjacent biomes. Oak savannas, which have 10–70% canopy closure, are dominated by big and little bluestem, porcupine grass, Indian grass, bur oak, northern pin oak, and black oak in Minnesota (Taft 1997, Anderson 1998, MNDNR 2006). So few of the historical oak savanna NPCs remain (MNDNR 2006) that changes in land use are more likely than climate change to affect this biological community. Over 80% of the former oak savanna in Minnesota is now farmed, and the Minneapolis-St. Paul metro area is at its northern boundary (MNDNR 2006).

As in other prairie-forest transition communities, moisture is the most important limiting factor and fire is the most important disturbance (MNDNR 2008*c*). Warmer temperatures and wetter conditions could allow expansion of more mesic hardwood species at the expense of bur, northern pin, and black oak associated with oak savannas. This conversion is already occurring due to the lack of fire. Greater soil moisture would favor woody plants over herbaceous plants associated with oak savannas. New and more homogenous biological communities may emerge.

If the change is toward a warmer, drier climate in Minnesota, the oak savanna range may shift to the north and east, expanding further into the Eastern Broadleaf Forest Province and moving out of the Prairie Parkland Province. Drought conditions in general would favor growth of herbaceous rather than woody plants. Under warmer, drier conditions the frequency and intensity of fires would likely increase (Schwarz and Wein 1990). Depending on how fire is used as a land management tool, burning could contribute to conversion of forest to savannas and prairie. Without fire, there will likely be a slow transition to brushland systems potentially dominated by non-native species. Although oaks favoring drier sites may shift into historic mesic hardwood regions, it is unknown whether native herbaceous plants associated with oak savannas will also be able to shift in the presence of fast dispersing invasive plants. New combinations of species that are strongly influenced by invasive species, disease, and pests should be anticipated. One of the few animals linked closely with oak savannas is the red-headed woodpecker (Brawn 2006). Expansion of oak savanna range would likely benefit this bird.

#### 3.2.2.3. Lakes and wetlands

Minnesota is at the latitude where the greatest impacts of climate change on aquatic ecosystems are predicted to occur (Stefan et al. 1996). Meyer et al. (1999) emphasized that these impacts must be assessed in the context of the massive anthropogenic changes in land and water use that will be occurring simultaneously.

Projected temperature increases will likely result in soil moisture deficits throughout Minnesota due to increased rates of evaporation and transpiration (Johnson et al. 2003, Kling et al. 2003, Johnson et al. 2005), although predictions of changing precipitation patterns are somewhat uncertain. Moisture deficits would reduce groundwater recharge, wetland area and water quality, and dry small streams (Hostetler and Small 1999, Johnson et al. 2003, Kling et al. 2003). Semi-permanent wetlands could be reduced in size and number (Johnson et al. 2005, Kusler 2006). Warmer average temperatures could also result in changes in native wetland communities through new opportunities for invasive species (both native and exotic) to expand their range northward (Kusler 2006). These changes could result in the loss of rare or range-restricted native species or regional losses of entire wetland communities.

Wetlands sequester large amounts of carbon, primarily as organic sediment and methane (Burkett and Kusler 2000). The net effect of climate change on carbon sequestration in wetlands, however, is still uncertain. Increases in atmospheric $CO_2$ concentrations will likely increase the primary productivity of wetlands, unless other factors such as moisture or temperature are limiting (Kusler 2006). Where moisture deficits occur, wetlands—especially peatlands—may become sources rather than sinks for atmospheric carbon due to increased decomposition (Burkett and Kusler 2000, Camill and Clark 2000).

The impacts of climate change on Minnesota lakes are expected to vary with latitude, trophic state, and lake morphometry (Stefan et al. 1996, Hostetler and Small 1999, Kling et al. 2003, Magnuson et al. 2003). In general, though, climate change will result in warmer, more productive waters, and eutrophication has implications for overall fish community integrity (Drake and Valley 2005). Temperature increases could increase annual evaporative water losses by as much as 30 cm (Stefan et al. 1996) and reduce summer water levels. Predicted increases in water temperatures, stratification (Stefan et al. 1996), and anoxic conditions would cause pronounced changes in aquatic habitats. Estimates of the increase in the ice-free season range from 40 to >100 days (Hostetler and Small 1999, Magnuson et al. 2003), and the frequency of winterkill of fish in some lakes will decline. Cold-water fish are predicted to lose habitat while cool- and warm-water fish gain habitat (Stefan et al. 1996). Cool- and warm-water fish, however, may actually realize a net loss of productivity if more favorable temperatures are not accompanied by increased food availability (Hostetler and Small 1999, Kling et al. 2003, Shuter et al. 2003).

### *3.2.3. Tallgrass Aspen Parklands Province*

The Tallgrass Aspen Parklands Province in northwestern Minnesota is characterized by low, flat topography that was once part of Glacial Lake Agassiz (Figure 1). The portion of this province that is in Minnesota is the southern end of a much larger area that stretches north and west into Canada and serves as the transition zone between the prairie and forest, much like the Eastern Broadleaf Forest Province to the south. Historically, fire created a complex mosaic of prairie, brushland, and forest in the Tallgrass Aspen Parklands Province. Extensive peatlands occur in this province as well (MNDNR 2006). Over 60% of the province is used for agriculture (MNDNR 2006). Recreation, especially wildlife viewing, is an increasing industry. Large state and federal wildlife areas exist, which facilitates wildlife-related recreation.

Wildlife species of the Tallgrass Aspen Parkland Province include the sharp-tailed grouse, elk, moose, marbled godwit, bobolink, and upland sandpiper (scientific names are provided in Appendix B). Breeding waterbirds occurring here include the horned grebe, Franklin's gull, American white pelican, yellow rail, Forster's tern, trumpeter swan, and American bittern. A total of 85 species of greatest conservation need can be found in this province. Two of these are unique to the province (Table 2). Habitat loss (90%) and degradation (95%) are the greatest immediate threats to these species (MNDNR 2006). Common plant species in Tallgrass Aspen Parklands Province include aspen, paper birch, bur oak, black spruce, tamarack, big and little bluestem, cattail, and smooth brome (MNDNR 2005*b*, Appendix B).

#### 3.2.3.1. Uplands in the Tallgrass Aspen Parklands Province

Moisture is the most important limiting factor and fire is the most important disturbance in forest-prairie transition zones (MNDNR 2008*d*). Climate change, therefore, may have dramatic impacts in these zones. Warmer temperatures coupled with wetter conditions could allow expansion of deciduous forests (Iverson and Prasad 2001) and brushlands into the remnant prairies and grasslands of the province. Greater soil moisture would favor growth of woody over herbaceous plants, resulting in canopied systems rather than open systems. Wetter conditions may reduce the frequency and intensity of fires. Higher rates of evapotranspiration under warmer temperatures will also be a factor influencing plant communities. Wildlife species that depend upon grasslands, including the chestnut-collared longspur, Baird's sparrow, and several species of butterflies, would be negatively affected by additional losses of grasslands in the Tallgrass Aspen Parklands Province (MNDNR 2006).

If changes are toward a warmer, drier climate, the impacts on wildlife in forest-prairie transitions would be different but still substantial. Deciduous forests in the Tallgrass Aspen Parkland Province would likely decline as the landscape becomes drier. Deciduous trees, especially aspens, would be subject to drought stress (Hogg and Hurdle 1995) and potentially more abundant insect defoliators and fungal diseases (Ives 1981, Zoltai et al. 1991, Peterson and Peterson 1992). Drought conditions in general would favor growth of grasses and other herbaceous plants rather than woody species. Under warmer, drier conditions the frequency and intensity of fires may increase and contribute to conversion of forest to prairie, especially if fire is used as a land management tool (Schwarz and Wein 1990).

Warmer, drier conditions could exclude wildlife that require cool, moist conditions, such as northern bog lemmings. Species like sharp-tailed grouse and white-tailed jackrabbits, however, would benefit from more open landscapes. In the Tallgrass Aspen Parkland Province large blocks of wildlife habitat exist that may facilitate the northward range shift of wildlife populations due to a warming climate.

#### 3.2.3.2. Wetlands in the Tallgrass Aspen Parklands Province

Specific information on the impacts of climate change on aspen parkland wetlands is limited. Larsen (1995) modeled the relationship between climate variables and the percentage of wet basins and found that aspen parklands may be much more vulnerable to increased temperatures than either Canadian or U.S. grasslands. Camill and Clark (2000) argued that the complex ecological dynamics of the prairie-forest interface may include lags and thresholds that make it subject to sudden large responses that are difficult to discern from current vegetation.

### *3.2.4. Prairie Parkland Province*

The Prairie Parkland Province stretches across most of southern and western Minnesota (Figure 1). Before European settlement the area was mostly covered by tallgrass prairies and wetlands, including sparsely vegetated sand dunes, vast expanses of tallgrass prairie, sedge meadows and marshes, and short-grass prairies on the Prairie Coteau. Major land forms of lake plains and ground moraines exist across land that is mostly level to gently rolling. Much of the flat, fertile land has been plowed for agriculture. Less than 1% (about 150,000 acres) of the original 18 million acres of prairie remains, and many grasses that persist are not native. Agriculture is the primary industry in the province (MNDNR 2006).

Ring-necked pheasants, gray partridge, and greater prairie-chickens occur in mixed crop-grass landscapes in Minnesota. Pheasants and partridge tolerate greater proportions of crop fields, whereas prairie-chickens and many grassland songbirds (e.g., bobolink) require more grass in larger patches. Other grassland wildlife species include the marbled godwit, upland sandpiper, Sprague's pipit, chestnut-collared longspur, western meadowlark, Franklin's and Richardson's ground squirrels, and badger (scientific names are provided in Appendix B). Waterfowl and shorebirds that breed in the province include the trumpeter swan, Canada goose, mallard, northern pintail, canvasback, blue-winged teal, gadwall, redhead, northern shoveler, western grebe, Wilson's snipe, American bittern, sora, and Virginia rail. Species of greatest conservation need total 139 for the province, with 13 being unique to this province only (Table 2). Habitat loss (88%) and degradation (92%) are the greatest immediate threats to these species (MNDNR 2006).

3.2.4.1. Grasslands and agricultural lands in the Prairie Parkland Province

Hansen et al. (2003) reviewed potential effects of climate change on grasslands around the world. Where precipitation is likely to decline grasslands may experience decreased productivity and increased vulnerability to invasive species and wildfires. Populations of many wildlife species in the Prairie Parkland Province have responded to changes in agricultural policies and land-use practices (e.g., the Conservation Reserve Program). Given the intensive use of land by humans and paucity of native vegetation in this part of Minnesota, such policies and practices are likely to continue being the primary force affecting wildlife habitat. Climate change is unlikely to cause a dramatic change in potential native vegetation (e.g., from grass and forbs to trees) or a reduction in the proportion of land allocated to production of agricultural commodities in this province.

Rising interest in and development of renewable sources of energy, partially due to desires to mitigate for climate change, are influencing land-use decisions that affect wildlife. For example, commercial wind turbine projects and planting feedstocks for ethanol fuel and biomass (e.g., corn, switchgrass) are becoming more common. As mentioned in Section 2 above, however, opportunities exist to produce biofuels, sequester carbon from the atmosphere, and provide other ecosystem services using high-diversity plantings of native grassland perennials (Tilman et al. 2006).

3.2.4.2. Wetlands in the Prairie Parkland Province

The Prairie Pothole Region (PPR) is an area within central North America that is defined by glacially formed wetlands within a matrix of grassland and agriculture. The PPR, also called the "duck factory," is the most important area for breeding ducks. Currently, western Minnesota is the most eastern extent of the PPR. Climate change, however, is expected to bring drier conditions to the western PPR and shift the distribution of moisture in the PPR to the east into Minnesota. Nearly all models suggest soil moisture declines, fewer wetlands, shorter hydroperiods for temporary wetlands, more variation in the extent of surface water, and changes in depth, salinity, temperature, and aquatic plants in the PPR (Poiani and Johnson 1991, Larsen 1995, Poiani et al. 1995, Clair et al. 1998, Johnson et al. 2005).

Changes for prairie wetlands in Minnesota are difficult to predict because changes in precipitation are uncertain in climate models. If precipitation decreases, wetland conditions are expected to be too dry to provide good breeding habitat for waterfowl in most years (Johnson et al. 2005). Dry conditions have been linked to smaller clutch sizes, less reproductive effort, and reduced offspring survival and recruitment in waterfowl (Dzus and Clark 1998, Anderson et al. 2001). If precipitation increases, habitat conditions for waterfowl may improve in western Minnesota (Johnson et al. 2005).

Wetland losses in the western portion of the PPR, however, are not likely to be offset by gains in the east because many wetlands in western Minnesota have been drained for agriculture. As a result, duck distributions on the landscape are expected to change and duck populations are anticipated to decline (Bethke and Nudds 1995, Sorenson et al. 1998). Wetland protection and restoration in Minnesota are even more urgent in light of expected changes in wetland conditions in the PPR associated with climate change.

Climate change may affect other wildlife species associated with prairie wetlands. Wetland birds may experience mismatches between the timing of breeding and the availability of prey for offspring (Visser et al. 1998). Murphy-Klassen et al. (2005) documented that the first spring sightings of 27 of 96 migrant bird species at Delta Marsh, Manitoba, were significantly correlated with a trend of increased spring temperatures.

## 4. SUGGESTIONS FOR THE SECTION OF WILDLIFE'S APPROACH TO CLIMATE CHANGE

### 4.1. Organization transitions

Future climate conditions will present dramatic social, ecological, and economic changes for both individual Minnesota citizens and agencies mandated with management of Minnesota's natural resources. Individual adjustments to life-changing events or processes have been recognized to occur in a sequence of stages manifested as denial, anger, bargaining, depression, and finally acceptance (Kubler-Ross 1969). In discussions with staff and stakeholders about changing conditions, it will be important to understand and accept that individuals are at different stages along this continuum.

Bryson (2004) advises that organizations need to respond to dramatic changes or challenges in order to "survive, prosper and do good and important work." Organizational responses to challenges range from maintaining the status quo, maintaining previous approaches but increasing the intensity or volume of work, to shifting focus and strategies, or a combination of the latter 2. Organizational responses to dramatic and rapid changes can produce anxiety and decrease effectiveness in accomplishing the organization's mission. To be successful in realizing its mission, vision, and goals, an organization must also be aware of and manage these periods of transition.

Managing organizational change has been described as an 8-step process (Kotter 1996). The initial 4 steps focus on revisiting the status quo and energizing the organization around a new vision. The last 4 steps move the organization to the desired state, implements new practices, and reinforces changes in the organizational culture (Figure 2). A first step for Minnesota DNR was creating a Wildlife Climate Change Working Group to guide the Division of Fish and Wildlife in describing climate change in Minnesota, its effects on wildlife species and habitat, and the development of wildlife management and monitoring actions needed to respond to this unprecedented wildlife management challenge. The recommendations in this report begin to articulate a vision and strategies for conserving wildlife populations and habitats in the face of changing climate conditions.

### 4.2. Vision statement

As presented in Kotter's step 3 (Kotter 1996; Figure 2 here), creating a shared vision of a desirable future is a critical aspect of organizational change. Costanza (2000) discussed the importance of visioning in the context of conserving natural resources. The Wildlife Climate Change Working Group believes that communicating a clear vision and establishing a shared vision within the Section of Wildlife (or higher level within MNDNR) about climate change is important. We suggest the following vision statement to help guide the Section of Wildlife's approach to climate change:

*The Minnesota Department of Natural Resources Section of Wildlife will continue to accomplish its mission*[1] *in the face of climate change. Despite uncertainties about the future, staff within the Section will be proactive in identifying and implementing responsible, science-based strategies for mitigating climate change and adapting to unavoidable climate changes. Staff, others in public service, stakeholders, and the general public will understand the unprecedented challenges to wildlife conservation posed by climate change, and they will support the Section's decisions and initiatives related to climate change. Populations of diverse wildlife species will continue to be a critical component of the high quality of life of the citizens of Minnesota.*

## 4.3. Recommendations to Section and Division leaders

First and foremost, we in the Wildlife Climate Change Working Group think the significance of climate change to the management and conservation of wildlife—and natural resources in general—warrants making a proactive response to climate change an explicit priority of the Section, Division, and Department based upon our missions and legal mandates.

A few guiding principles—sufficiently important and general to be useful in most or all situations—provide a good place to start when considering additional ideas and priorities for approaching the unique challenge of climate change. The Section of Wildlife should:

(1) focus on objectives that help the Section accomplish its mission and mandates;

(2) acknowledge uncertainty when making decisions and confront it in a logical, productive manner; and

(3) strive to work effectively with colleagues and stakeholders to achieve wildlife management goals.

Options for addressing climate change fall into 2 broad categories—mitigation and adaptation. Climate change mitigation includes actions taken to avoid or minimize the change. Most directly, mitigation actions reduce emissions of greenhouse gases or reduce concentrations of greenhouse gases in the atmosphere (e.g., carbon sequestration). Adaptation refers to actions

[1] The mission of the Section of Wildlife is "*to work with the people of Minnesota to conserve and manage wildlife populations and habitats, to provide wildlife-related recreation, and to preserve Minnesota's hunting and trapping heritage*."

**Step 1. Establish the Priority**

- Examine the natural resource and recreational realities
- Identify and discuss crises, potential crises, or major opportunities in the context of risk

**Step 2. Develop Scientific Guidance**

- Charge a group to develop biological and social science based guidance
- Identify network of experts and resources

**Step 3. Develop a Vision and Strategy**

- Create a vision to help direct the change effort
- Develop strategies for achieving vision

**Step 4. Communicate the Change Vision**

- Use multiple venues to communicate the new vision and strategies with staff and stakeholders
- Provide opportunities for staff and stakeholders discussion of new vision and strategies

**Step 5. Empower Broad-Based Action**

- Charge Operations, Programs, and Research with next steps
- Utilize biennial budget and annual spending plans to incorporate approaches
- Encourage risk taking and nontraditional ideas, activities, and actions

**Step 6. Take Initial Implementation Steps**

- Identify objectives
- Implement steps

**Step 7. Evaluate, Adjust, and Expand Change Efforts**

- Evaluate and adapt existing and new approaches, programs, projects, and policies
- Communicate findings and status
- Use increased credibility to change all systems, structures, and policies that don't fit together and don't fit the transformation vision
- Consider needs in workforce planning (i.e., new hires, promotions, and training)
- Reinvigorate the process with new projects, themes, and change agents

**Step 8. Operationalize Approaches**

- Create better performance through customer- and productivity-oriented behavior, more and better leadership, and more efficient management
- Articulate the connections between new behaviors and organization success
- Develop means to ensure leadership development and succession

Figure 2. A process for creating major organizational change [adapted from Kotter (1996) for wildlife professionals].

taken to manage the unavoidable impacts of climate change. We classified our remaining recommendations as either mitigation or adaptation.

### *4.3.1. Mitigation*

- Accomplish gubernatorial mandates to reduce energy consumption and increase efficiency of energy use by staff (Pawlenty 2004*a*,*b*; 2005; 2006). Consider and educate others about potential impacts of the production of renewable transportation fuels on wildlife and other natural resources. To reduce fuel consumption, staff should first try to reduce the number of miles they drive, then try to use the most fuel-efficient vehicle for a particular task. We should also continue to identify and prioritize specific actions, in addition to those related to fleet and facilities management.
- Develop recommendations for personal choices by staff, those participating in wildlife-related recreation, and the general public to reduce direct and indirect consumption of fossil fuels (e.g., strategies for driving fewer miles, reducing use of electricity). We should encourage the use of fuel-efficient and low-emission vehicles for personal travel by the millions of hunters, trappers, and wildlife watchers in Minnesota. Specifically for staff, we should consider evaluating and drafting policies regarding telecommuting from home rather than driving to work every day, use of telephone and video conferencing for meetings, and the net effect on climate change of various practices.
- Develop more wildlife-related recreational opportunities near urban population centers to reduce travel distance or the need to travel (Schultz et al. 2003).
- Seek carbon sequestration opportunities that do not conflict with or diminish wildlife conservation.
- Use the Division's outreach capacity to inform constituents and other citizens about how they can reduce their contributions to climate change.

### *4.3.2. Adaptation*

#### 4.3.2.1. Administration

- Develop, utilize, and communicate transparent decision processes. This will be important for documenting climate-related decisions and ensuring support for the decisions from staff and stakeholders. We must confront uncertainty in a logical, productive manner when making decisions (e.g., employ adaptive management when appropriate; Inkley et al. 2004:20, Williams et al. 2007). In the face of uncertainty about climate change, preserve future options and be cautious by anticipating threats to natural resources, acting to conserve resources despite the uncertainty, and explicitly valuing long-term benefits. Consider risk management to identify risk potential and consequences for habitat and population management actions. Consider triage—a decision framework for classifying relative priorities during emergencies—when appropriate (Millar et al. 2007). Although triage decisions may affect single species, multiple species (i.e., competing priorities) should be considered explicitly during the decision process.

- Identify important decisions and decision thresholds, so management and monitoring objectives can be specified.
- Establish interdisciplinary teams to collaborate on climate change issues. For example, we encourage initiation of a Department-wide team to address climate change and seek participation on interagency climate change teams. Unified approaches and sharing of information and other resources among a wide variety of organizations [e.g., MNDNR divisions, state and federal agencies, universities, and nongovernmental organizations (NGOs)] will be necessary to manage wildlife successfully in the face of climate change.
- Provide specific guidance to staff, programs, and projects about whether or how to address climate change in management actions and planning efforts (USGAO 2007).
- Complete a more comprehensive assessment of recent and on-going initiatives and research related to climate change and wildlife impacts.
- Communicate with public, stakeholders, and elected officials about habitat and population impacts and management implications (using practical examples).
- Improve communication and coordination (as distinct from collaboration) among disciplines and organizations.
- Assign specific staff to stay abreast of the large and growing body of literature on climate change.
- Consider desirable expertise and staffing plans during workforce planning.
- Consider reducing workloads related to short-terms goals to focus sufficient effort on climate change and other long-term issues (USGAO 2007).

- Dedicate 1 new FTE position at the Program level in the Section of Wildlife or the Division of Fish and Wildlife to lead and coordinate climate change efforts. This person should chair a standing committee to address climate change issues and develop strategic approaches for responding to climate change impacts.
- Address funding needs through reallocation of existing appropriations or new state/federal appropriations and grants.
- Support a review and update of Minnesota's Comprehensive Wildlife Conservation Strategy in terms of climate changes.

#### 4.3.2.2. Research and Policy

- Link monitoring programs to specific management decisions or scientific hypotheses (Yoccoz et al. 2001, Inkley et al. 2004:20). Interest in and ideas for monitoring will likely exceed the available resources. It will be imperative, therefore, to carefully identify and prioritize monitoring needs based on the potential impact on future decisions and management activities.
- Identify species, communities, and ecosystems that are most vulnerable to climate change or are the best indicators of climate change effects (Noss 2001), identify ecological thresholds at which significant climate-induced changes may be particularly abrupt (Halpin 1997), and identify species and communities that may migrate into Minnesota.
- Expand the focus of habitat management evaluation biologists in Wildlife Research to include consideration of carbon sequestration and energy footprint for land management practices.
- Support the development and use of models to provide local projections of expected changes.
- Develop new tools and approaches for determining the appropriate type and amount of resource management efforts. For example, a decision tree may help staff determine the best management practices for systems in transition.

#### 4.3.2.3. Operations and Programs

- Continue to acquire and manage land for wildlife purposes as part of the Outdoor Recreation System to "protect those lands and waters which have a high potential for wildlife production" as directed by Minnesota Statute 86A.

- Maintain ecological structures and functions (e.g., water quality, biodiversity), not just specific components (e.g., individual species; Inkley et al. 2004:20). For example, individual wildlife species have great value, but conserving the ecosystem processes upon which humans and wildlife depend is more fundamental and important. We will need a better understanding of ecological systems to be successful. We will need to improve our understanding of community ecology and the likely succession of communities through climate change (Noss 2001). Managing communities and ecosystems requires working with large areas, so we will need to develop programs to manage habitat at the landscape level with multiple land ownership types (e.g., state, federal, county, private, NGO).
- Maintain connected, diverse populations of wildlife, so they can adapt and migrate. This should include ensuring that land acquisition policies consider climate change and support biodiversity and connectivity now and in the future (Inkley et al. 2004:19). Subsection Forest Resource Management Plans and the Forest Resource Council's Landscape Teams should consider and address habitat connectivity issues. Bioreserve programs such as the Wildlife Management Area (WMA), Aquatic Management Area, and SNA programs should be expanded because, in addition to protecting native biodiversity, these parcels may contribute to potential migration corridors.
- Reduce nonclimate stressors that we can influence now (Inkley et al. 2004:18). For example, we can minimize habitat loss, degradation, and fragmentation near WMAs and other public lands, thereby conserving more habitat for wildlife adapting to a changing climate. We should focus on major disturbance agents that we can influence now, such as preventing and controlling catastrophic fire and invasive species (Inkley et al. 2004:19, MNDNR Operational Order #113). More specifically, we should continue to manage deer for population goals that do not negatively impact plant communities.
- Proactively choose where and when to resist climate-induced changes, encourage resilience of systems to change, or enable climate-induced changes (Millar et al. 2007). Resist climate-induced changes only temporarily and only for resources of high value (e.g., endangered species). Interdisciplinary work is needed to identify management practices (e.g., elimination of invasive species versus integration into habitat frameworks) that contribute to resilient systems and functions with the objective of maintaining or increasing resilience where and when it's appropriate (e.g., site prep for forest stand regeneration, reducing

contributions to shallow lake eutrophication). In most cases, strongly consider enabling community transitions (e.g., planting trees north of their current distribution).

- Prepare to manage for more frequent "extreme" events (e.g., flood, drought; Inkley et al. 2004:18).
- Do not rely solely on the historical range of variability to plan or make predictions. The future range of variability may be quite different and have no historical analogs (Inkley et al. 2004:18).
- Identify and discuss climate change in long-term management plans, programs, and policies where appropriate.
- Revisit management plans and population goals more frequently (Inkley et al. 2004:19).

**ACKNOWLEDGMENTS**

We thank Charlotte Roy for significant contributions to the working group and Rich Baker for helping us identify appropriate nongame species for Appendix A. We appreciated presentations by Peter Ciborowski (MN Pollution Control Agency), Tim Cross, Wayne Edgerton, Mark Lindquist, Dave Schad, Dave Schiller, Brian Stenquist, Lise Trudeau (MN Dept. of Commerce), and Clarence Turner during our first working group meeting. Critical reviews by Peter Ciborowski, Chuck Collins (Florida Fish and Wildlife Conservation Commission), Lee Frelich (University of Minnesota), Lucinda Johnson (Natural Resources Research Institute), Clarence Lehman (University of Minnesota), Jon Nelson, Amber Pairis (California Dept. of Fish and Game), Doug Parsons (Florida Fish and Wildlife Conservation Commission), Ann Pierce, Kurt Rusterholz, Clarence Turner, Ray Valley, and the Working Group Advisors helped us improve a previous draft of this report. So did discussions with Dan Wovcha. Any opinions, interpretations, and remaining errors, however, are the sole responsibility of the working group.

**LITERATURE CITED**

Anderson, R. C. 1998. Overview of Midwestern oak savannas. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 86:1–18.

Anderson, M. G., M. S. Lindberg, and R. B. Emery. 2001. Probability of survival and breeding for juvenile female canvasbacks. Journal of Wildlife Management 65:385–397.

Augustine, D. J., and L. E. Frelich. 1998. Effects of white-tailed deer on populations of an understory forb in fragmented deciduous forests. Conservation Biology 12:995–1004.

Austin, J. A., and S. Colman. 2007. Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: a positive ice-albedo feedback. Geophysical Research Letters 34:L06604, doi:10.1029/2006GL029021.

Berven, K. A. 1981. Mate choice in the wood frog, *Rana sylvatica*. Evolution 35:707–722.

Bethke, R. W., and T. D. Nudds. 1995. Effects of climate change and land use on duck abundance in Canadian prairie-parklands. Ecological Applications 5:588–600.

Bider, J. R., and L. A. Morrison. 1981. Changes in the toad (*Bufo americanus*) responses to abiotic factors at the northern limit of their distribution. American Midland Naturalist 106:293–304.

Bies, L. 2006. The biofuels explosion: is green energy good for wildlife? Wildlife Society Bulletin 34:1203–1205.

Boag, D. A., and M. A. Schroeder. 1992. Spruce grouse. Number 5 *in* A. Poole, P. Stettenheim, and F. Gill, editors. The birds of North America. Academy of Natural Sciences, Philadelphia, Pennsylvania, and American Ornithologists' Union, Washington, D.C.

Brandt, A. R., and A. E. Farrell. 2007. Scraping the bottom of the barrel: greenhouse gas emission consequences of a transition to low-quality and synthetic petroleum resources. Climate Change 84:241–263.

Brawn, J. D. 2006. Effects of restoring oak savannas on bird communities and populations. Conservation Biology 20:460–469.

Bridgham, S. D., C. A. Johnston, J. Pastor, and K. Updegraff. 1995. Potential feedbacks of northern wetlands on climate change: an outline of an approach to predict climate-change impact. Bioscience 45:262–274.

Bryson, J. M. 2004. Strategic planning for public and nonprofit organizations: a guide to strengthening and sustaining organizational achievement. 3rd edition. John Wiley and Sons, Inc., San Francisco, California.

Burkett, V., and J. Kusler. 2000. Climate change: potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association 36:313–320.

Busby, W. H., and W. R. Brecheisen. 1997. Chorusing phenology and habitat associations of the crawfish frog, *Rana areolata* (Anura:Ranidae) in Kansas. Southwestern Naturalist 42:210–217.

Camill, P., and J. S. Clark. 2000. Long-term perspectives on lagged ecosystem responses to climate change: permafrost in boreal peatlands and the grassland/woody boundary. Ecosystems 3:534–544.

Cash, K., E. McCauley, F. Wrona, and G. Benoy. 2007. Carbon dynamics in lakes of the boreal forest under a changing climate. Environmental Reviews 15:175–189.

Clair, T. A., B. G. Warner, R. Robarts, H. Murkin, J. Lilley, L. Mortsch, and C. Rubec. 1998. Canadian inland wetlands and climate change. Pages 189–218 *in* G. Koshida and W. Avis, editors. The Canada country study: climate impacts and adaptation. National sectoral volume. Environment Canada, Ottawa, Ontario, Canada.

Cleveland, C. J., R. Costanza, C. A. S. Hall, and R. Kaufmann. 1984. Energy and the U.S. economy: a biophysical perspective. Science 225:890–897.

Costanza, R. 2000. Visions of alternative (unpredictable) futures and their use in policy analysis. Conservation Ecology 4:5 < www.ecologyandsociety.org/vol4/iss1/art5/ >

Currie, D. J. 2001. Projected effects of climate change on patterns of vertebrate and tree species richness in the conterminous United States. Ecosystems 4:216–225.

Czech, B., P. R. Krausman, and P. K. Devers. 2000. Economic associations among causes of species endangerment in the United States. BioScience 50:593–601.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton. 2001. Climate change and forest disturbances. BioScience 51:723–734.

DelGiudice, G. D., M. R. Riggs, P. Joly, and W. Pan. 2002. Winter severity, survival, and cause-specific mortality of female white-tailed deer in north-central Minnesota. Journal of Wildlife Management 66:698–717.

Drake, M. T., and R. D. Valley. 2005. Validation and application of a fish-based index of biotic integrity for small central Minnesota lakes. North American Journal of Fisheries Management 25:1095–1111.

Dzus, E. H., and R. G. Clark. 1998. Brood survival and recruitment of mallards in relation to wetland density and hatching date. Auk 115:311–318.

EIA. 2007. Annual energy outlook 2007 with projections to 2030. Energy Information Administration report DOE/EIA-0383. U.S. Department of Energy, Washington, D.C.

Hallock, J. L., P. J. Tharakan, C. A. S. Hall, M. Jefferson, and W. Wu. 2004. Forecasting the limits to the availability and diversity of global conventional oil supply. Energy 29:1673–1696.

Halpin, P. N. 1997. Global climate change and natural-area protection: management responses and research directions. Ecological Applications 7:828–843.

Hansen, A. J., R. P. Neilson, V. H. Dale, C. H. Flather, L. R. Iverson, D. J. Currie, S. Shafer, R. Cook, and P. J. Bartlein. 2001. Global change in forests: responses of species, communities and biomes. BioScience 51:765–779.

Hansen, L. J., J. L. Biringer, and J. R. Hoffman. 2003. Buying time: a user's manual for building resistance and resilience to climate change in natural systems. World Wildlife Fund, Berlin, Germany.
< www.panda.org/news_facts/publications/index.cfm?uNewsID=8678 >

Heinselman, M. L. 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatlands Natural Area, Minnesota. Ecological Monographs 40:235–261.

Hogg, E. H., and P. A. Hurdle. 1995. The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest? Water, Air, and Soil Pollution 82:391–400.

Hostetler, S. W., and E. E. Small. 1999. Response of North American freshwater lakes to simulated future climates. Journal of the American Water Resources Association 35:1625–1637.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution 15:56–61.

Inkley, D. B., M. G. Anderson, A. R. Blaustein, V. R. Burkett, B. Felzer, B. Griffith, J. Price, and T. L. Root. 2004. Global climate change and wildlife in North America. Technical Review 04-2. The Wildlife Society, Bethesda, Maryland.

IPCC. 2000. Special report on emissions scenarios. A contribution of Working Group III of the Intergovernmental Panel on Climate Change, Geneva, Switzerland.
< http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf >

IPCC. 2007. Climate change 2007: synthesis report. Contribution of Working Groups I, II and

III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R. K. Pachauri, and A. Reisinger, editors. IPCC, Geneva, Switzerland. < http://www.ipcc.ch/ipccreports/ar4-syr.htm >

Iverson, L. R., and A. M. Prasad. 2001. Potential changes in tree species richness and forest community types following climate change. Ecosystems 4:186–199.

Iverson, L. R., A. M. Prasad, B. J. Hale, and E. K. Sutherland. 1999. Modeling potential future individual tree-species distributions in the eastern United States under a climate change scenario: a case study with *Pinus virginiana*. Ecological Modelling 115:77–93.

Iverson, L. R., A. M. Prasad, and M. Peters. 2007. Climate change tree atlas. USDA Forest Service, Northern Research Station, Newtown Square, Pennsylvania. < www.nrs.fs.fed.us/atlas/index.html > accessed on 12 March 2008.

Ives, W. G. H. 1981. Environmental factors affecting 21 forest insect defoliators in Manitoba and Saskatchewan 1945–1969. Canadian Forest Service Informal Report NOR-X-233, Canadian Forest Service, Edmonton, Alberta, Canada.

Johnson, L. B., K. Hayhoe, G. W. Kling, J. J. Magnuson, and B. J. Shuter. 2003. Confronting climate change in the Great Lakes region: technical appendix – wetland ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. < www.ucsusa.org/greatlakes/pdf/wetlands.pdf >

Johnson, W. C., B. V. Millett, T. Gilmanov, R. A. Voldseth, G. R. Guntenspergen, and D. E. Naugle. 2005. Vulnerability of northern prairie wetlands to climate change. BioScience 55:863–872.

Kelly, T. 2005. The 2004 outdoor recreation participation survey of Minnesotans: report on findings. Minnesota Department of Natural Resources, St. Paul.

Kling, G. W., K. Hayhoe, L. B. Johnson, J. J. Magnuson, S. Polasky, S. K. Robinson, B. J. Shuter, M. M. Wander, D. J. Wuebbles, and D. R. Zak. 2003. Confronting climate change in the Great Lakes region: impacts on our communities and ecosystems. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. < www.ucsusa.org/greatlakes/glchallengereport.html >

Kotter, J. P. 1996. Leading change. Harvard Business School Press, Boston, Massachusetts.

Kubler-Ross, E. 1969. On death and dying. Macmillan, New York.

Kusler, J. 2006. Common questions: wetland, climate change and carbon sequestering. Association of State Wetland Managers, Inc., Berne, New York.

Larsen, D. L. 1995. Effects of climate change on numbers of northern prairie wetlands. Climatic Change 30:169–180.

Lenarz, M. S. 2008. 2008 aerial moose survey. Minnesota Department of Natural Resources, St. Paul.

Logan, J. A., J. Regniere, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 1:130–137.

MacCracken M., E. Barron, D. Easterling, B. Felzer, and T. Karl. 2000. Scenarios for climate variability and change: the potential consequences of climate variability and change for the United States. U.S. Global Change Research Program, National Science Foundation, Washington, D.C.

Magnuson, J. J., K. Hayhoe, L. B. Johnson, G. W. Kling, and B. J. Shuter. 2003. Confronting climate change in the Great Lakes region: technical appendix – impacts of climate change on lake and river ice cover. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. < http://www.ucsusa.org/greatlakes/pdf/ice_cover.pdf >

Manjarrez, J. 1996. Temperature limited activity in the garter snake, *Thamnophis melanogaster* (Colubridae). Ethology 102:146–156.

Meyer, J. L., M. J. Sale, P. J. Mulholland, and N. L. Poff. 1999. Impacts of climate change on aquatic ecosystem functioning and health. Journal of the American Water Resources Association 35:1373–1386.

Millar, C. I., N. L. Stephenson, and S. L. Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145–2151.

MNDNR. 2003. Field guide to the native plant communities of Minnesota: the Laurentian Mixed Forest Province. Minnesota County Biological Survey and Natural Heritage and Nongame Research Program, Minnesota Department of Natural Resources, St. Paul.

MNDNR. 2005*a*. Field guide to the native plant communities of Minnesota: the Eastern Broadleaf Forest Province. Minnesota County Biological Survey and Natural Heritage and Nongame Research Program, Minnesota Department of Natural Resources, St. Paul.

MNDNR. 2005*b*. Field guide to the native plant communities of Minnesota: the Prairie Parkland and Tallgrass Aspen Parklands Provinces. Minnesota County Biological Survey and Natural Heritage and Nongame Research Program, Minnesota Department of Natural Resources, St. Paul.

MNDNR. 2006. Tomorrow's habitat for the wild and rare: an action plan for Minnesota wildlife. Comprehensive Wildlife Conservation Strategy, Division of Ecological Services, Minnesota Department of Natural Resources, St. Paul.

MNDNR. 2008*a*. Ecological Classification System. Minnesota Department of Natural Resources, St. Paul. < www.dnr.state.mn.us/ecs/index.html >

MNDNR. 2008*b*. Minnesota's native plant community classification, Version 2.0. Minnesota Department of Natural Resources, St. Paul. < www.dnr.state.mn.us/npc/classification.html >

MNDNR. 2008*c*. Oak Savanna Subsection. Minnesota Department of Natural Resources, St. Paul. < www.dnr.state.mn.us/ecs/222me/index.html >

MNDNR. 2008*d*. Tallgrass Aspen Parkland Province. Minnesota Department of Natural Resources, St. Paul. < http://www.dnr.state.mn.us/ecs/223/index.html >

Moore, M. K., and V. R. Townsend. 1998. The interaction of temperature, dissolved oxygen and predation pressure in an aquatic predator-prey system. Oikos 81:329–336.

Murphy-Classen, H. M., T. J. Underwood, S. G. Sealy, and A. A. Czyrnyj. 2005. Long-term trends in spring arrival dates of migrant birds at Delta Marsh, Manitoba, in relation to climate change. Auk 122:1130–1148.

Murray, D. L., E. W. Cox, W. B. Ballard, H. A. Whitlaw, M. S. Lenarz, T. W. Custer, T. Barnett, and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. Wildlife Monographs 166.

Noss, R. F. 2001. Beyond Kyoto: forest management in a time of rapid climate change. Conservation Biology 15:578–590.

Noss, R. F., and B. Csuti. 1997. Habitat fragmentation. Pages 269–304 *in* G. K. Meffe and R. C. Carroll., editors. Principles of conservation biology, 2nd edition. Sinauer Associates, Sunderland, Massachusetts.

Nowak, C. L., R. S. Nowak, R. J. Tausch, and P. E. Wigand. 1994. Tree and shrub dynamics in NW Great Basin woodland and shrub steppe during the Late-Pleistocene and Holocene. American Journal of Botany 81:265–277.

NRC. 2003. Understanding climate change feedbacks. Panel on climate change feedbacks, Climate Research Committee, National Research Council, National Academy of Sciences, Washington, D.C.

Parmesan, C., and H. Galbraith. 2004. Observed impacts of global climate change in the U.S. Pew Center on Global Climate Change, Arlington, Virginia.

Pawlenty, T. J. 2004*a*. Providing for state departments to take actions to reduce air pollution in daily operations. Minnesota Executive Order 04-08 (August 6). < www.governor.state.mn.us/priorities/governorsorders/executiveorders/2004/ >

Pawlenty, T. J. 2004*b*. Providing for state departments to improve fleet and travel management. Minnesota Executive Order 04-10 (September 27). < www.governor.state.mn.us/priorities/governorsorders/executiveorders/2004/ >

Pawlenty, T. J. 2005. Providing for energy conservation measures for state owned buildings. Minnesota Executive Order 05-16. < www.governor.state.mn.us/priorities/governorsorders/executiveorders/2005/ >

Pawlenty, T. J. 2006. Increasing use of renewable fuels by state agencies. Minnesota Executive Order 06-03 (March 10). < www.governor.state.mn.us/priorities/governorsorders/executiveorders/2006/march/ >

Peters, R. L., and J. D. S. Darling. 1985. The greenhouse effect and nature reserves. BioScience 35:69–72.

Peterson, E. B., and N. M. Peterson. 1992. Ecology, management, and use of aspen and balsam poplar in the prairie provinces, Canada. Forestry Canada, Northwest Region, Special Report 1, Edmonton, Alberta, Canada.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53–65.

Poiani, K. A., and W. C. Johnson. 1991. Global warming and prairie wetlands: potential consequences for waterfowl habitat. Bioscience 14:611–618.

Poiani, K. A., W. C. Johnson, and T. G. F. Kittel. 1995. Sensitivity of prairie wetland to increased temperature and seasonal precipitation changes. Water Resources Bulletin 31:283–294.

Price, J. 2002. Climate change, birds and ecosystems – why should we care? Pages 471–475 *in* D. J. Rapport, W. L. Lasley, D. E. Rolston, N. O. Nielsen, C. O. Qualset, and A. B. Damania, editors. Managing for healthy ecosystems. Lewis Publishers, Boca Raton, Florida.

Price, J., and P. Glick. 2002. The birdwatcher's guide to global warming. National Wildlife Federation, Reston, Virginia, and American Bird Conservancy, The Plains, Virginia.

Radeloff, V. C., R. B. Hammer, and S. I. Stewart. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and its relation to forest fragmentation. Conservation Biology 19:793–805.

Schugart, H., R. Sedjo, and B. Sohnjen. 2003. Forest and global climate change – potential impacts on U. S. forest resources. Environmental Impacts Report No. 9, Pew Center on Global Climate Change, Arlington, Virginia.

Schultz, J. H., J. J. Millspaugh, D. T. Zekor, and B. E. Washburn. 2003. Enhancing sport-hunting opportunities for urbanites. Wildlife Society Bulletin 31:565–573.

Schwarz, A. G., and R. W. Wein. 1990. Pages 1–4 *in* D. D. Smith and C. A. Jacobs, editors. Proceedings of the 12th North American Prairie Conference, August 5–9, 1990, University of Iowa, Cedar Falls.

Shuter, B. J., L. B. Johnson, G. W. Kling, and J. J. Magnuson. 2003. Confronting climate change in the Great Lakes region: technical appendix – fish responses to climate change. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. < www.ucsusa.org/greatlakes/pdf/fish_responses.pdf >

Smith, D. C. 1987. Adult recruitment in chorus frogs: effects of size and date on metamorphosis. Ecology 68:344–350.

Sorenson, L. G., R. Goldberg, T. L. Root, and M. G. Anderson. 1998. Potential effects of global warming on waterfowl populations breeding in the northern Great Plains. Climatic Change 40:343–369.

Stefan, H. G., M. Hondzo, X. Fang, J. G. Eaton, and J. H. McCormick. 1996. Simulated long-term temperature and dissolved oxygen characteristics of lakes in the north-central

United States and associated fish habitat limits. Limnology and Oceanography 41:1124–1135.

Stott, P. A., S. F. B. Tett, G. S. Jones, M. R. Allen, J. F. B. Mitchell, and G. J. Jenkins. 2000. External control of 20th century temperature by natural and anthropogenic forcings. Science 290:2133–2137.

Taft, J. B. 1997. Savanna and open-woodland communities. Pages 24–54 *in* M. Schwartz, editor. Conservation in highly fragmented landscapes. Chapman and Hall, New York.

Thorpe, A. J. 2005. Climate change prediction: a challenging scientific problem. Institute of Physics, Bristol, United Kingdom. < www.iop.org/activity/policy/Publications/file_4147.pdf > accessed 20 September 2007.

Tilman, D., J. Hill, and C. Lehman. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314:1598–1600.

USFS. 2006. Northeast area forest health protection: emerald ash borer. < www.na.fs.fed.us/fhp/eab/ >

USFWS. 2002. Waterfowl population status, 2002. U.S. Fish and Wildlife Service, Department of Interior, Washington, D.C.

USGAO. 2007. Climate change: agencies should develop guidance for addressing the effects on federal land and water resources. GAO-07-863. Government Accountability Office, Washington, D.C.

Valley, R. 2008. Sustaining lakes in a changing environment – SLICE: an operational research plan for conserving Minnesota lake resources while confronting major ecological drivers of change. Division of Fish and Wildlife, Minnesota Department of Natural Resources, St. Paul.

Visser, M. E., A. J. Vannoordwijk, J. M. Tinbergen, and C. M. Lessells. 1998. Warmer springs lead to mistimed reproduction in Great Tits (*Parus major*). Proceedings of the Royal Society of London Series B:Biological Sciences 265:1867–1870.

Vitousek, P. M., H. A. Mooney, J. Luchenko, and J. M. Melillo. 1997. Human domination of earth’s ecosystems. Science 277:494–499.

Werner, E. E. 1986. Amphibian metamorphosis: growth rate, predation risk, and the optimal size at transformation. American Naturalist 128:319–341.

Westcott, P. C. 2007. U.S. ethanol expansion driving changes throughout the agricultural sector. Amber Waves 5:10–15. < www.ers.usda.gov/AmberWaves/September07/Features/Ethanol.htm >

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive Management: the U.S. Department of the Interior technical guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C. < http://www.doi.gov/initiatives/AdaptiveManagement/index.html >

Yoccoz, N. G., J. D. Nichols, and T. Boulinier. 2001. Monitoring of biological diversity in space and time. Trends in Ecology and Evolution 16:446–453.

Zoltai, S. C., T. Singh, and M. J. Apps. 1991. Pages 143–152 *in* S. Navratil and P. B. Chapman, editors. Aspen management for the 21st century. Forestry Canada, Northwest region, Edmonton, Alberta, Canada.

**APPENDIX A: Key Species**

This is a list of plant and animal species that the MNDNR Division of Fish and Wildlife manages for recreational harvest and nongame wildlife species that have restricted ranges in Minnesota and are being monitored by the Division of Ecological Resources. The 4 provinces are the Laurentian Mixed Forest (LMF), Eastern Broadleaf Forest (EBF), Tallgrass Aspen Parklands (TAP), and Prairie Parkland (PP) Province. SGCN = Species in Greatest Conservation Need (MNDNR 2006).

| Scientific Name | Common Name | LMF Province | EBF Province | TAP Province | PP Province | Northern Part of Range | Southern Part of Range | Eastern Part of Range | Western Part of Range | Habitat Generalist | SGCN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Accipiter gentilis* | Northern Goshawk | x | | | | | x | | | | x |
| *Aegolius acadicus* | Northern Saw-whet Owl | x | | | | | x | | | | |
| *Aix sponsa* | Wood Duck | x | x | x | x | | | | | x | |
| *Alces alces* | Moose | x | | x | | | x | | x | | |
| *Anas acuta* | Northern Pintail | | | x | | | | x | | | x |
| *Anas americana* | Widgeon | | | x | | | x | | | | |
| *Anas clypeata* | Northern Shoveler | | x | x | | | | x | x | | |
| *Anas discors* | Blue-winged Teal | | | x | | | | | x | | |
| *Anas platyrhynchos* | Mallard | x | x | x | x | | | | | x | |
| *Anas strepera* | Gadwall | | | | x | | | | | x | |
| *Aythya collaris* | Ring-necked Duck | x | | | | | x | | | | |
| *Aythya valisineria* | Canvasback | | | x | | | | x | | | |
| *Bonasa umbellus* | Ruffed Grouse | x | x | x | | | x | | | x | |
| *Branta canadensis* | Canada Goose | x | x | x | x | | | | | x | |

| Scientific Name | Common Name | LMF Province | EBF Province | TAP Province | PP Province | Northern Part of Range | Southern Part of Range | Eastern Part of Range | Western Part of Range | Habitat Generalist | SGCN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bucephala clangula* | Common Goldeneye | x | | | | | x | | | | |
| *Bufo cognatus* | Great Plains Toad | | | | x | | | x | | | |
| *Buteo lineatus* | Red-Shouldered Hawk | | x | | | x | | | | | x |
| *Canis latrans* | Coyote | x | x | x | x | | | | | x | |
| *Canis lupus* | Gray Wolf | x | | x | | | | | x | x | x |
| *Capella gallinago* | Snipe | x | x | x | x | | | | | | |
| *Castor canadensis* | Beaver | x | x | x | x | | | | | x | |
| *Cervus canadensis* | Elk | | | x | x | | | | | x | x |
| *Corvus brachyrhynchos* | Crow | x | x | x | x | | | | | x | |
| *Dendroica cerulea* | Cerulean Warbler | | x | | | | | | x | | x |
| *Didelphis marsupialis* | Opossum | x | x | | x | | | | | x | |
| *Falcipennis canadensis* | Spruce Grouse | x | | x | | | x | | | | x |
| *Fulica americana* | Coot | | | x | | | | x | | | |
| *Gavia immer* | Common Loon | x | | | | | x | | | | x |
| *Hemidactylium scutatum* | Four-toed Salamander | x | | | | | x | | | | x |
| *Hesperia dacotae* | Dakota Skipper Butterfly | | | | x | | | x | | | x |
| *Larus pipixcan* | Franklin's Gull | | x | | | | x | | | | x |
| *Lepus americanus* | Snowshoe Hare | x | | x | | | x | | | x | |
| *Lepus townsendii* | White-tailed Jackrabbit | | | | x | | | x | | | |

| Scientific Name | Common Name | LMF Province | EBF Province | TAP Province | PP Province | Northern Part of Range | Southern Part of Range | Eastern Part of Range | Western Part of Range | Habitat Generalist | SGCN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lontra canadensis* | River Otter | x | x | x | x | | | | | x | |
| *Lophodytes cucullatus* | Hooded Merganser | x | x | | | | | | | x | |
| *Lynx canadensis* | Lynx | x | | | | | x | | | | x |
| *Lynx rufus* | Bobcat | x | x | x | | | x | | x | x | |
| *Martes americana* | Pine Marten | x | | x | x | | x | | x | x | |
| *Martes pennanti* | Fisher | x | | x | | | | | x | x | |
| *Meleagris gallopavo* | Wild Turkey | x | x | | | x | | | | x | |
| *Mephitis mephitis* | Striped Skunk | x | x | x | x | | | | | x | |
| *Microtus ochrogaster* | Prairie Vole | | | | x | | | x | | | x |
| *Mustela erminea* | Short-tailed Weasel | x | x | x | x | | | | | x | |
| *Mustela frenata* | Long-tailed Weasel | x | x | x | x | | | | | x | |
| *Mustela rixosa* | Least Weasel | x | x | x | x | | | | | x | x |
| *Neovison vison* | Mink | x | x | x | x | | | | | x | |
| *Odocoileus virginianus* | White-tailed Deer | x | x | x | x | | | | | x | |
| *Ondatra zibethicus* | Muskrat | x | x | x | x | | | | | x | |
| *Panax quinquefolius* | Ginseng | x | x | | | | | | | x | |
| *Perdix perdix* | Gray Partridge | | | | x | x | | | | | |
| *Phasianus colchicus* | Ring-necked Pheasant | x | x | | x | x | | | | x | |
| *Porzana carolina* | Sora Rail | x | x | x | x | | | | | | |
| *Procyon lotor* | Raccoon | x | x | x | x | | | | | x | |
| *Rallus limicola* | Virginia Rail | | | | x | | | | | x | x |
| *Rana palustris* | Pickerel Frog | | ? | | | x | | | | | x |
| *Rana septentrionalis* | Mink Frog | x | | | | | x | | | | |

| Scientific Name | Common Name | LMF Province | EBF Province | TAP Province | PP Province | Northern Part of Range | Southern Part of Range | Eastern Part of Range | Western Part of Range | Habitat Generalist | SGCN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sciurus carolinensis* | Gray Squirrel | x | x | x | x | | | | | x | |
| *Sciurus niger* | Fox Squirrel | x | x | x | x | | | | | x | |
| *Scolopax minor* | American Woodcock | x | x | x | | | x | | x | x | x |
| *Seiurus mutacilla* | Louisiana Water Thrush | | x | | | x | | | | | x |
| *Spilogale putorius* | Eastern Spotted Skunk | x | x | | x | | | | | | x |
| *Sterna huryndo* | Common Tern | | x | | | | x | | | | x |
| *Sylvilagus floridanus* | Cottontail | x | x | x | x | x | | | | x | |
| *Synaptomys borealis* | Northern Bog Lemming | x | | | | | x | | | | |
| *Tamiasciurus hudsonicus* | Red Squirrel | x | x | x | x | | | | | x | |
| *Taxidea taxus* | Badger | x | x | x | x | | | | | x | x |
| *Tympanuchus cupido* | Greater Prairie-Chicken | | | | x | | | | | | x |
| *Tympanuchus phasianellus* | Sharp-tailed Grouse | x | | x | | | | | x | x | x |
| *Urocyon cinereoargenteus* | Gray Fox | x | x | x | x | x | | x | | x | |
| *Ursus americanus* | Black bear | x | x | x | | | x | | x | x | |
| *Vulpes fulva* | Red Fox | x | x | x | x | | | | | x | |
| *Zenaida macroura* | Mourning Dove | x | x | x | x | | | | | x | |
| *Zizania palustris* | Wild Rice | x | x | x | x | | x | | x | x | |

**APPENDIX B: Scientific Names of Species**

The following species are mentioned by common name in the report.

| | |
|---|---|
| Mammals | |
| Badger | *Taxidea taxus* |
| Canada lynx | *Lynx canadensis* |
| Elk | *Cervus canadensis* |
| Franklin's ground squirrel | *Spermophilus franklinii* |
| Gray fox | *Urocyon cinereoargenteus* |
| Moose | *Alces alces* |
| Northern bog lemming | *Synaptomys borealis* |
| Opossum | *Didelphis marsupialis* |
| Pine marten | *Martes americana* |
| Richardson's ground squirrel | *Spermophilus richardsonii* |
| Snowshoe hare | *Lepus americanus* |
| White-tailed deer | *Odocoileus virginianus* |
| White-tailed jackrabbit | *Lepus townsendii* |
| | |
| Birds | |
| American bittern | *Botaurus lentiginosus* |
| American white pelican | *Pelecanus erythrorhynchos* |
| American woodcock | *Scolopax minor* |
| Baird’s sparrow | *Ammodramus bairdii* |
| Black-backed woodpecker | *Picoides arcticus* |
| Blue-winged teal | *Anas discors* |
| Bobolink | *Dolichonyx oryzivorus* |
| Boreal chickadee | *Poecile hudsonicus* |
| Boreal owl | *Aegolius funereus* |
| Canada goose | *Branta canadensis* |
| Canvasback | *Aythya valisineria* |
| Cerulean warbler | *Dendroica cerulea* |
| Chestnut-collared longspur | *Calcarius ornatus* |
| Connecticut warbler | *Oporornis agilis* |
| Forester’s tern | *Sterna hirundo* |
| Franklin’s gull | *Larus pipixcan* |
| Gadwall | *Anas strepera* |
| Gray partridge | *Perdix perdix* |
| Great gray owl | *Strix nebulosa* |
| Greater prairie-chicken | *Tympanuchus cupido* |

| | |
|---|---|
| Horned grebe | *Podiceps auritus* |
| Louisiana waterthrush | *Seiurus mutacilla* |
| Mallard | *Anas platyrhynchos* |
| Marbled godwit | *Limosa fedoa* |
| Meadowlark | *Sturnella neglecta* |
| Mourning dove | *Zenaida macroura* |
| Northern cardinal | *Cardinalis cardinalis* |
| Northern goshawk | *Accipiter gentilis* |
| Northern pintail | *Anas acuta* |
| Northern shoveler | *Anas clypeata* |
| Ovenbird | *Seiurus aurocapillus* |
| Redhead duck | *Aytha americana* |
| Red-headed woodpecker | *Melanerpes erythrocephalus* |
| Red-shouldered hawk | *Buteo lineatus* |
| Ring-necked pheasant | *Phasianus colchicus* |
| Ruffed grouse | *Bonasa umbellus* |
| Sharp-tailed grouse | *Tympanuchus phasianellus* |
| Sora rail | *Porzana carolina* |
| Sprague's pipit | *Anthus spragueii* |
| Spruce grouse | *Falcipennis canadensis* |
| Trumpeter swan | *Cygnus buccinator* |
| Upland sandpiper | *Bartramia longicauda* |
| Virginia rail | *Rallus limicola* |
| Western grebe | *Aechmophorus occidentalis* |
| Wild turkey | *Meleagris gallopavo* |
| Wilson snipe | *Gallinago gallinago* |
| Wood duck | *Aix sponsa* |
| Wood thrush | *Hylocichla mustelina* |
| Wood warblers | Family Parulidae |
| Yellow rail | *Coturnicops noveboracensis* |

<u>Reptiles</u>

| | |
|---|---|
| Blanding’s turtle | *Emydoidea blandingii* |
| Eastern hognose snake | *Heterodon platyrhinos* |

<u>Amphibians</u>

| | |
|---|---|
| Four-toed salamander | *Hemidactylium scutatum* |
| Mink frog | *Rana septentrionalis* |
| Red-backed salamander | *Plethodon cinereus* |

<u>Insects</u>

| | |
|---|---|
| Emerald ash borer | *Agrilus planipennis* |
| Spruce budworm | *Choristoneura fumiferana* |

<u>Plants</u>

| | |
|---|---|
| Aspen | *Populus spp.* |
| Balsam fir | *Abies balsamea* |
| Basswood | *Tilia americana* |
| Beech | *Fagus spp.* |
| Big bluestem | *Andropogon gerardii* |
| Birch | *Betula spp.* |
| Black oak | *Quercus velutina* |
| Black spruce | *Picea mariana* |
| Bur oak | *Quercus macrocarpa* |
| Cattail | *Typhus spp.* |
| Fir | *Abies spp.* |
| Hickory | *Carya ovata* |
| Indian grass | *Sorghastrum nutrans* |
| Jack pine | *Pinus banksiana* |
| Little bluestem | *Schizachyrium scoparium* |
| Maple | *Acer spp.* |
| Northern pin oak | *Quercus ellipsoidalis* |
| Oak | *Quercus spp.* |
| Paper birch | *Betula papyrifera* |
| Pine | *Pinus spp.* |
| Porcupine grass | *Stipa spartea* |
| Red oak | *Quercus rubra* |
| Red pine | *Pinus resinosa* |
| Smooth brome | *Bromus inermis* |
| Spruce | *Picea spp.* |
| Sugar maple | *Acer saccharum* |
| Switchgrass | *Panicum virgatum* |
| Tamarack | *Larix laricina* |
| Trillium | *Trillium spp.* |
| White cedar | *Thuja occidentalis* |
| White pine | *Pinus strobus* |