Climate Change Impacts on Wisconsin's Wildlife
A Preliminary Assessment

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Abstract

Wisconsin is world-renowned for its diversity of ecological landscapes and wildlife. As climatic fluctuations intensify, the distribution and abundance of these landscapes and associated wildlife populations will be altered. In the following report, we summarize the main issues regarding climate change impacts and adaptation as these relate to Wisconsin's wildlife. In the first part, we provide a general review of Wisconsin's climate and ecosystems, outlining trends in recent and anticipated climate change. The second part provides an overview, based on peer-reviewed research and technical publications, of direct and indirect impacts of climate change on wildlife in Wisconsin. Parts three through five illustrate the impacts of climate change using case studies from three major habitat types in the state (forests, wetlands, and grasslands). This discussion serves to highlight impacts that we anticipate across an array of species. Finally, the last part includes a review of adaptation strategies for wildlife management in an era of global environmental change.

Climate Change Impacts on Wisconsin's Wildlife: A Preliminary Assessment

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Introduction: Wisconsin Wildlife and Climate

Wisconsin northern forests, southern prairies, and interior and coastal wetlands are home to diverse number of animal species: mammals (72), birds (345), amphibians (19), reptiles (37), and a suite of invertebrates. These species supply the Wisconsin public with aesthetic, cultural, and economic benefits; our identity and economy are intertwined with these natural resources. For example, wildlife viewing for recreation, particularly of rare species, supports local economies with more than $700 million in associated expenditures per year in Wisconsin (U.S. Department of Interior and U.S. Department of Commerce 2006). Wisconsin's diverse wildlife also serve critical roles in ecosystems and society. However, climate change is altering the behavior, distribution, development, reproduction, and survival of wildlife populations. In turn, these changes alter the benefits we receive from those populations. As such, it is important that we apply the best available science from our observations of historical patterns as well as projections of future scenarios to understanding the impacts of climate change and the potential for adaptation.

Climate and Ecological Communities in Wisconsin

The intensity, frequency, and duration of short-term events (weather) are a product of long-term regional and continental atmospheric patterns (climate). With shifting climate and consequently weather, wildlife species may experience novel environmental conditions for which they are not suited. Historical records suggest that although weather in Wisconsin has been highly variable, the climate has remained within a specific range of variation and, until recently, changed at a sufficiently slow rate to allow plant and animal communities to adapt (Moran and Hopkins 2002). Recent climate records and projections of future climate conditions, however, depict rapid change in the magnitude and spatial pattern of weather events. As such, the question is not *if* climate will change but *how* is it changing (Moran and Hopkins 2002).

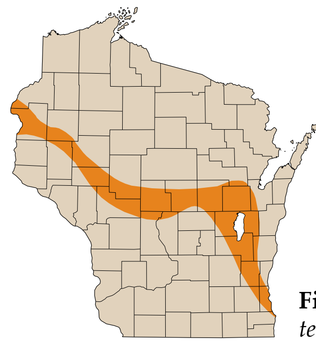

Figure 1. *Wisconsin's vegetative tension zone (after Curtis 1959).*

The modern vegetation and dependent ecological communities of Wisconsin are defined by climatic elements (such as the mean and extremes of temperature and precipitation) and are influenced by factors that also interact with climate (including wildfires and human disturbance, Moran and Hopkins 2002). At a coarse scale, the state can be delineated into northern and southern vegetation zones that experience slightly different climates. The current tension zone between these northern and southern regions originated 2,000 years ago and is in part controlled by atmospheric circulation and air masses in the late winter and early spring (Figure 1). Hence, changes in the timing and pattern of spring conditions can displace the tension zone (Griffin 1997). At a finer scale, there are multiple forest, grassland, and wetland/aquatic ecosystems within the northern and southern regions. The Wisconsin Department of Natural Resources (Wisconsin DNR) identifies 16 ecological landscapes, based in part on the distribution of hardwood and pine forests in the north and the prairie, oak-dominated forest, and savannas of the south (Wisconsin DNR 2006). Individual ecosystems within these landscapes are influenced by regional climate, which is mediated by local conditions (e.g., topographic features) as well as multiple other interacting factors (e.g., the pattern of human disturbance) such that each ecosystem can be expected to respond to climate change in unique ways.

Recent and Future Climate Trends

Climate change has already taken place over the past century in Wisconsin, as is apparent in the statewide increase in average annual temperature (1950-2006, Plate 1 on page 11, Kucharik et al. 2010a). The strongest trend has been a warming of winter and spring temperatures resulting in the lengthening of the growing season and an earlier onset of spring (Plate 2). Winter and spring temperatures have increased significantly in the northwestern and central parts of the state and nighttime minimum temperatures increased at a faster rate than daytime temperatures. There are fewer very cold nights as well; in northwestern and central Wisconsin there are 14-21 fewer nights below 0° F annually (-18° C, Kucharik et al. 2010a, WICCI 2011). Similar trends are apparent in statewide phenological records (1962-1998, Zhao and Schwartz 2003), specifically confirming the advance of spring conditions in southern Wisconsin. Furthermore, annual precipitation increased about 15% statewide and by as much as 17.7 cm (7 in) in the southern and central parts of the state, but has decreased in northern Wisconsin by as much as 10.2 cm (4 in, Plate 3, Kucharik et al. 2010a, WICCI 2010).

Projections of future climate change based on global climate assessments are consistent with the observations of recent climate change described above. In this report, we refer to the projections made by Kucharik et al. (2010b) that are downscaled for Wisconsin from global models published by the Intergovernmental Panel on Climate Change (IPCC), the standard for national climate assessment (National Research Council [NRC] 2010). The IPCC global models include several alternative scenarios based on a suite of demographic, social, economic, technological, and environmental factors that drive climate change (Nakicenovic and Swart 2000). At one extreme, climate change could plateau in response to stabilization in greenhouse gas emissions, human population size, and their effect on natural systems (B1 Scenario, Plate 4). On the other extreme, if this plateau does not occur, the current rates of change in global climate will continue to escalate (A2 Scenario, Figure 5). Because of the dynamic interplay between socio-economic and environmental-technological factors, our uncertainty about what will happen in the future also increases with time. As such, all projections suggest similar trends up to the mid-21st century, i.e. the factors that drive climate change diverge beyond this point (NRC 2010). In other words, there is high confidence in projections through the next 50 years, but uncertainty increases as we approach the next century. Uncertainty, however, should not prohibit action. Rather, we can be explicit about our uncertainty and consider the range of projected conditions from both extremes. The Kucharik et al. (2010b) projections for Wisconsin apply three of the global scenarios, at both extremes (B2, A1B, and A2 scenarios, Figure 5), and compare recent climate (1961-2000) to projections up to the mid- (2046-2065) and late 21st century (2085-2100). This analysis formed part of the first Wisconsin Initiative on Climate Change Impacts (WICCI) adaptive assessment report (WICCI 2011), and these projections can be viewed at **www.wicci.wisc.edu**.

According to global models, North America should expect less extreme cold and more extreme heat and heavy precipitation as we approach the next century. The downscaled climate models for Wisconsin suggest similar changes, including an overall increase in mean temperatures across the state of 2° to 5° C (4° to 9° F) by 2065, amplified in the latter half of this century (Kucharik et al. 2010b). Consistent with recent historical trends, these models suggest more pronounced warming trends in winter rather than summer (Plate 5, Kucharik et al. 2010a). Winter warming and changes in precipitation (Plate 6) will result in a shortening of the snowfall season, reduced snow depth (Plate 7, Notaro et al. 2011), and further lengthening of the growing season. In other words, regardless of the scenario, we can expect to see noticeable impacts to ecological communities in Wisconsin. As an illustration, this will result in a northern shift in plant hardiness zones and a climate more similar to that currently found in geographic regions to the southwest of Wisconsin (Veloz et al. 2012, Kucharik et al 2010b).

In summary, climate change is not a new phenomenon in Wisconsin, but there is a clear indication of a change in the range of variation from what we have experienced in recent history. Mitigating the forces that drive climate change is critical. Equally important is adaptation to current climate change and the identification of the direct and indirect impacts on ecosystems and wildlife that are underway already.

Direct and Indirect Impacts of Climate Change on Wildlife

Although global society is considering regulatory mechanisms to reduce greenhouse gas emissions, we will continue to experience changes in our climate for 1,000 or more years after emissions stop (Solomon et al. 2009) and the "predominantly negative consequences" for ecosystems are of great concern (IPCC 2007a). A large body of scientific work informs our understanding not only of projected effects on ecosystems, but also measured impacts (Hughes 2000, McCarty 2001, Walther et al. 2002, Parmesan and Yohe 2003, Root et al. 2003). For living organisms, the impacts of climate change may be direct (e.g., heat stress) or indirect (e.g., change in habitat), and globally, animal species are responding to both.

Direct Impacts

For species with a strong life history linkage to ambient conditions, in particular temperature and precipitation, direct consequences of climate change are of most concern. The relationship between ambient conditions and development, reproduction, and survival in animal populations is the basis of substantial climate change-wildlife research. For the majority of animals, there is a common set of weather-climate conditions that will alter their behavior, distribution, development, reproduction, and/or survival: advance of spring conditions, spatial shift in climate niche, high temperature extremes, altered snow

Figure 2. *Spruce grouse* (Falcipennis canadensis)*, an example of a species that relies on snow cover for roosting habitat.*

cover and cold exposure, drought, and heavy precipitation/flooding events.

Advance of Spring Conditions. The emergence of green shoots and arrival of birds to the breeding grounds are the hallmarks of spring. For many species, snowmelt, increased ambient temperatures, photoperiod, or changes in precipitation/moisture signal the beginning of conditions suitable for growth and reproduction (Figure 2). In response to earlier onset of these spring weather-climate signals, some wildlife species initiate migratory and breeding behavior earlier in the year (Parmesan and Yohe 2003); this shift is in progress for some plants and animals in Wisconsin. In a recent study, researchers noted an advance in phenology (i.e. life cycle timing) of 17 species in the state (Bradley et al. 1999). In some instances, the phenological shift of a species may have cultural or economic implications.

Spatial Shift in Climate Niche. For some species, particularly ectotherms (i.e. "cold-blooded" organisms), abiotic conditions, primarily temperature and precipitation patterns, directly limit their distribution on the landscape. The term "climate niche" refers to an area on the landscape where temperature and precipitation patterns are suitable for a species of interest (Pearson and Dawson 2003). Recent changes in climate have expanded, contracted, or shifted the climate niches of many species; the result is often a change in the species' geographic range (Parmesan and Yohe 2003). For example, Wisconsin is one of the few remaining states where the federally endangered Hine's emerald dragonfly (*Somatochlora hineana*) is found. Hines emerald dragonfly larvae require cool summer waters (16°-20° C) for development (Packauskas 2005, citing Walker 1925). As waters within their current distribution warm, there may be a northward shift in the species distribution to suitable thermal conditions. In a landscape altered for human use, namely residential/commercial development and agriculture, range shifts are limited and not all species will be able to respond to the novel conditions accordingly (Vos et al. 2008).

High Temperature Extremes. All organisms have an upper and lower temperature threshold and when ambient temperatures exceed these critical values, the result is physiological stress or death. While some animal species tolerate a wide range of ambient temperatures, for some the threshold is narrow. For example, moose (*Alces americanus*) have low tolerance for high ambient temperatures and consequently are experiencing changes in their populations. When winter temperatures exceed -5° C and spring-summer temperatures exceed 14°C, moose experience heat stress (Renecker and Hudson 1986). Repeated heat stress likely decreases body condition and markedly increases their susceptibility to disease and starvation (Murray et al. 2006). In Minnesota, the considerable decline in the local moose population is largely attributed to an increased frequency and magnitude of ambient temperatures exceeding the moose's narrow threshold (Murray et al. 2006, Lenarz et al. 2009). In a period of 25 years, the mid-1980s to today, the moose population in northwestern Minnesota declined from 4,000 individuals to less than 100. Although there are few moose in Wisconsin, an increase in ambient temperature and high temperature extremes could threaten what remains of the population.

Altered Snow Cover and Cold Exposure. Cold conditions, particularly in the extremes of northern Wisconsin, challenge the survival of wildlife; staying warm requires energy and exposure to cold conditions can quickly lead to death. To avoid this fate, many species employ one or a number of strategies to survive cold temperatures: leave temporarily (migrate), hibernate, or rest under snow cover for insulation. Not only will climate change alter the amount and duration of snow cover, but we anticipate more freezing rain events in winter. Shallow snow cover and freezing rain in winter may reduce the thermal benefits of snow tunnels and animals may die from cold exposure. In Wisconsin, the American marten (*Martes americana*, Figure 3), a small member of the weasel family (Mustelidae), is an example of a species with a narrow temperature threshold. Wisconsin

Figure 3. *American marten, a state endangered mammal, that is impacted directly and indirectly by climate change.*

is at the southern extent of its range and an important limitation to marten distribution is adequate snow cover that provides thermal protection from low winter temperatures. With a lean body, the marten has little fat reserves to endure the extreme winter temperatures of northern Wisconsin (Gilbert et al. 2006). Its behavioral adaptation of resting in subnivean areas (i.e. areas under the snow with woody debris) permits the marten to survive in northern climates (Buskirk et al. 1989). As winter temperatures are projected to increase in the state, the insulative properties of subnivean areas will be reduced with implications for marten persistence in Wisconsin.

Drought. Water is fundamental to cellular function and its availability determines the distribution and abundance of all living organisms. As such, moisture requirements for living organisms are extremely restrictive with relatively few species specialized to thrive under dry conditions. Amphibians are particularly sensitive to drought conditions because they have permeable skin and, depending on species, require a range of aquatic habitat types for reproduction. Nineteen amphibians are native to Wisconsin and six are of conservation concern. The northern cricket frog (*Acris crepitans*), a small treefrog, is the only amphibian listed as endangered in the state. Once common in the Upper Midwest, the species began a considerable regional decline in the late 1950s (Gray and Brown 2005). Although the exact cause remains unclear, periodic drought conditions over a period of several decades may be an important source of mortality (Hay 1998). Under more frequent drought conditions, projected to increase in severity and spatial extent (IPCC 2007b, Dai et al. 2010), local extinction is a clear possibility for many Wisconsin amphibians.

Heavy Rainfall/Flooding Events. Although water is fundamental to the persistence of life, large influxes of water in a short period of time are often detrimental. Such extreme events may damage structures for breeding or resting, inundate or destroy habitat, or injure or kill wildlife. For example, flooding is a relatively ubiquitous cause of reproductive failure in birds and complete nest loss in an entire colony, attributed to a single event, is not uncommon in waterbirds (Burger 1982). The increased risk of flooding under climate change, particularly in river and coastal systems, is an important consideration for these populations (Watkinson et al. 2004). The black tern (*Chlidonias niger*) is a colonial breeding bird that is found in wetlands across Wisconsin. In a study of black terns in Wisconsin, weather (storms and flooding) was "clearly the single most important… cause" of nest failure (Shealer et al. 2006). The black tern is in significant decline in the state and is listed as a species of greatest conservation need (Wisconsin DNR 2005). Additional mortality attributed to heavy rainfall/flooding events may hasten the decline of the species in our state.

Indirect Impacts

Wildlife Habitat. The distribution and abundance of animal species is largely defined by the type, amount, and quality of suitable vegetation. Hence, changes in vegetation result in changes in the distribution and abundance of animals. For species that are habitat specialists, restricted to a narrow range of resources, such changes are often problematic. From historical studies of vegetation, there is strong evidence that the response of vegetation to changes in temperature and precipitation patterns may be rapid (e.g., tree migration of 400-1,000 m per year) initiating a cascade of "independent responses of individual plant and animal species" (Foster et al. 2004). The result is a reassembly of community structure and species functional roles to form novel communities (Williams and Jackson 2007) and researchers are now detecting such changes in contemporary vegetation (e.g., Allen and Breshears 1998, Sturm et al. 2001). For example, in 2002-2003, after a period of depleted soil water content and anomalously high temperatures, drought-induced water stress combined with bark beetle (*Ips confusus*) infestation resulted in a mass die-off (more than 12,000 km^2) of a dominant pine species in the southwestern U.S. (Breshears et al. 2005). Such rapid, expansive changes in dominant vegetation affect the regional ecosystem, from erosion and nutrient cycling to availability of forage for wildlife. The process of vegetation change and wildlife responses is one that is still unfolding (IPCC 2007b). Currently, researchers primarily rely on ecological modeling to understand the possible implications for animal species. Towards this goal, researchers must first project changes in the structure, composition, abundance, and distribution of the novel habitat. Next, we must predict the occupancy and use of the habitat by the species of interest. Finally, we must translate the relationship between habitat and use to population trends. Given the close linkages between declines in animal populations and changes in habitat (Wilcove et al. 1998), we consider this process fundamental to projecting the future of wildlife populations in the state.

Interspecific Interactions. Changes in the distribution and abundance, in space and time, of one animal species may affect another species, "uncoupling," intensifying, or creating novel relationships (Tylianakis et al. 2008). For example, there is an anticipated intensification of insect predation and pathogens in forest ecosystems under climate change (Logan et al. 2003). Specifically, the gypsy moth (*Lymantria dispar*), a non-native tree-defoliating insect, is limited by cold temperature, but this restriction likely will lessen with climate change, posing an even more serious threat to forest ecosystems and silviculture across North America (Logan et al. 2007). As another example, some long-distance migrant birds are in decline because of mistimed food availability. Responding to ambient temperature, peak insect (i.e. prey) abundance occurs earlier, but the birds, responding to the cue of day length, do not return earlier and hence, do not advance their laying date; as a result, less food is available for chicks (Both et al. 2006). An additional noteworthy change in interspecific interactions is the relationship between wildlife disease and climate change. Climate change likely will increase the frequency and severity of disease outbreaks in wildlife populations (Harvell et al. 2002). This is particularly problematic for populations already in decline. In the Great Lakes, types C and E botulism are of increasing concern for native waterbirds. The prevalence of a toxin-producing bacterium (*Clostridium botulinum*) is closely tied to low water levels and higher water temperatures. Under such conditions, projected for our region, there may be more frequent outbreaks that result in massive avian mortality. In recent years, the number of outbreaks has become relatively common across the region and resulted in substantial bird losses (e.g., Lake Michigan 1963-2008, Lafrancois et al. 2010).

Non-climate Stressors

It is important to note that climate change is not the sole threat to wildlife populations. Currently, habitat loss/ degradation and invasive or non-native species are the primary threats to biodiversity (Wilcove et al. 1998); additional threats include pollution (including nutrient loading) and overexploitation (Groom 2006). In Wisconsin, loss of native grasslands, wetlands, and forests due to conversion to residential/commercial development or agriculture (Radeloff et al. 2005, Mladenoff et al. 2008, Sample and Mossman 2008, Zedler and Potter 2008) is currently the foremost threat to wildlife populations. It is important because such land conversion often creates "a patchwork of small isolated natural areas" surrounded by an inhospitable landscape (Noss et al. 2006); this results in a suite of negative consequences (e.g., local extinctions) for wildlife diversity in the state. Affecting nearly 50% of imperiled species in the country, the introduction and proliferation of non-native species is the second greatest threat (Wilcove et al. 1998) and the cost of environmental damage from non-native species exceeds $125 billion per year (Pimental et al. 2000). In Wisconsin, non-native species are a major threat to terrestrial and aquatic wildlife; species such as zebra mussel (*Dreissena polymorpha*) and common buckthorn (*Rhamnus cathartica*) negatively affect the local economy by out competing native species and drastically altering ecosystems (Vander Zanden and Maxted 2008, Kearns 2008). In the near future, exotic pests, such as the emerald ash borer (*Agrilus planipennis*), may eliminate a suite of tree species and consequently, important wildlife habitat from Wisconsin (Logan et al. 2003). A third threat to wildlife in Wisconsin is nutrient loading and pollution from industry and agriculture. Adverse effects of persistent bioacummulating toxic substances (PBTs), such as methylmercury, polybrominated biphenyl ethers (PBDEs), organochlorine pesticides, and polychlorinated biphenyls (PCBs) include: endocrine and immune dysfunction, reproductive impairment, and developmental abnormalities (Ross and Birnbaum 2003). Nonpoint source pollution of nutrients, namely nitrogen and phosphorus, is a "widespread problem" in aquatic ecosystems with negative implications for fisheries, recreation, industry, agriculture, and drinking (Carpenter et al. 1998). Although overexploitation (i.e. overharvest) was a concern for wildlife in Wisconsin's recent history, it is no longer a major threat to wildlife diversity in the state.

Most species experience simultaneous threats (Czech et al. 2000) that act together to rapidly advance biodiversity loss. The combination of two or more threats hastens the decline of wildlife populations. In many instances, multiple threats act synergistically; namely the presence of one threat intensifies and amplifies the other and vice versa (Myers 1987, Figure 4). This type of interaction may result in an abrupt decline to extinction, and because of their complexity, these interactions remain poorly understood. Climate change is not only an additional threat to wildlife populations, but also acts synergistically with existing threats. For example, UV-B radiation is a major threat to amphibian populations, particularly those in high elevation habitats (Blumthaler and Ambach 1990). A study in the western United States found that climate-induced changes in water depth increase the exposure of embryos to UV-B radiation and, in turn, their susceptibility to water mold; the result is high mortality of embryos and demonstrates the complexity of threats acting in concert (Kiesecker et al. 2001). In another example, like the gypsy moth, climate change will alter the restrictions (e.g., temperature, streamflow, salinity) that currently limit the distribution and abundance of aquatic invasive species, likely "enhancing their competitive and predatory effects on native species" (Rahel et al. 2008). The implication of multiple threats, acting in concert, is of great concern to natural resource managers.

"Winners and Losers"

It is important to note that climate change will not have adverse impacts on all wildlife. Although there likely will be more "losers" than "winners," some species will fare well in an era of global environmental change (McKinney and Lockwood 1999). Species that have short generation times, are widely distributed, move easily across the landscape, have general habitat requirements, and are not sensitive to human activity will fare well; conversely, species with long generation times, narrow distributions, poor dispersal ability, special habitat requirements, and that are sensitive to human activity will fare poorly (McKinney and Lockwood 1999). Reinforcing the importance of synergistic threats, most species in the latter category are already in decline from existing threats. More losers than winners will result in a homogenization

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Figure 4. *Blanding's turtle* (Emydoidea blandingii)*, a state threatened species that is impacted by multiple synergistic threats tied to human disturbance, including habitat loss, nest predation, and competition with invasive species.*

of our landscape and wildlife (McKinney and Lockwood 1999). Population increases from our most common species, such as European starling (*Sturnus vulgaris*), Canada goose (*Branta canadensis*), and gray squirrel (*Sciurus carolinensis*), will be matched by the loss of our most vulnerable species, including purple martin (*Progne subis*), black tern, and American marten. This will result in a net loss to the state's biodiversity and a simplification of our ecological communities.

For society, the negative consequences of this simplification are aesthetic and impaired use (e.g., Eurasian water-milfoil [*Myriophyllum spicatum*] in lakes), cultural (e.g., fewer species for harvest), and economic (e.g., reduced pest control or pollination, increased risk of disease outbreaks). It is also important to note that we can never anticipate the full ramifications of species loss. For example, what is the implication of widespread decline in bat populations for insect control (Blehert et al. 2009)? Until we can better estimate such impacts, it is most prudent to heed the advice of Aldo Leopold, Wisconsin's great wildlife ecologist, "to keep every cog and wheel is the first rule of intelligent tinkering" (Leopold, 1953).

Forest-Dependent Wildlife

The tree, shrub, and herbaceous species that dominate Wisconsin's forests are the product of the complex interaction between biological and geophysical conditions; climate change alters these patterns, in particular temperature, precipitation, and disturbance regimes, and the effect is a change in species composition and structure. In turn, changes in forest vegetation, from coarse to fine spatial scales, will impact forest-dependent wildlife. In northern Wisconsin, the growing season is projected to be 28-56 days longer than current conditions (reference period [1961-2000] to end of 21st century; Kucharik et al. 2010b). This, in combination with the projected moderate increases in annual precipitation of 2.5-7.6 cm (1-3 in) in the northern region (Kucharik et al. 2010b) and changes in soil moisture will likely alter forest productivity and result in shifts in climate niche for many tree and shrub species (Swanston et al. 2011). Although the aforementioned changes are relatively positive for forests, extreme events (e.g., drought, flooding), changes in disturbance regime (e.g., fires), alterations to cold exposure, and the possible expansion and proliferation of tree-defoliating insects may lead to declines in productivity and major changes in forest composition in the region. The implications of climate change and its associated impacts on Wisconsin's northern forests is the subject of multiple research projects among the academic, government, and non-profit sectors. As our knowledge of future forest composition increases, so will our understanding of the future of forest-dependent species in the state. In the following section, we discuss the implications of climate change for three forest-dependent species in Wisconsin: the American marten, the eastern red-backed salamander (*Plethodon cinereus*), and the white-tailed deer (*Odocoileus virginianus*).

American Marten

In Wisconsin, the American marten (Figure 3, page 3) was common in the mature forests of northern parts of the state. An intense period (early 1800s to the early 1920s) of timber harvest and trapping led to the extirpation of the species from the state in 1939. Since the 1950s, the marten has been the subject of multiple reintroduction efforts, with a supplemental stocking of marten currently in progress. In 1972, the marten was listed as state endangered. Currently, the few individuals in the Wisconsin population reside in the mature forests of Douglas, Bayfield, Ashland, Sawyer, Iron, Price, Vilas, Oneida, Florence, and Forest counties (Wisconsin DNR 2005). Not only is the marten of conservation interest in the state, but a key life history characteristic, low tolerance of cold-weather conditions, suggests careful consideration of future climate impacts on the species.

With a lean body, the marten requires consistent energy from prey sources and minimal exposure to the elements to endure the extreme winter temperatures of northern Wisconsin (Gilbert et al. 2006). To reduce their exposure, they inhabit subnivean areas with consistent, suitable temperatures for the winter season. These subnivean areas may vary little in temperature (e.g., -0.5° to -2.5° C, Buskirk et al. 1989) while ambient temperatures range widely (e.g., -28° to 9° C, Buskirk et al. 1989). The behavioral adaptation of resting in subnivean areas currently permits the American marten to live beyond the limit of its cold temperature thresholds (Buskirk et al. 1988). Ambient temperature, snow depth, and snow density all influence the thermal properties of subnivean areas (Marchand 1982). Shallow or dense snow cover and freezing rain reduce the thermal benefits of these underground resting sites (Marchand 1982) and the marten may die from energetic stress/cold exposure (Bull and Heater 2001). Although winter precipitation will increase slightly (<2.5 cm [1 in], mid-century and end of century B1-A2, Kucharik et al. 2010b), more will be in the form of rain. Combined with higher ambient temperatures, more rain will reduce the duration of snow cover. Maximum winter temperatures are projected to increase 3.3°-3.9° C and 3.9°-4.2° C (6°-7° F and 7°-7.5° F) in the eastern and western parts of the marten's range, respectively (Kucharik et al. 2010b). By the end of the 21st century, maximum winter temperatures may increase as much as 5.6°-6.1° C and 6.1°-6.7° C (10°-11° F and 11°-12° F) in the eastern and western parts of the marten's range, respectively (Kucharik et al. 2010b). These increases in maximum winter temperature will likely result in thawing and refreezing of the snow pack, increasing the snowpack density and reducing thermal insulation for the marten; warmer ambient temperatures will also reduce the duration of snow cover, exposing the marten to cold-weather conditions in the spring.

Marten abundance and fecundity are strongly correlated with rodent abundance (Flynn and Schumacher

2009). Anticipated changes in the thermal properties of subnivean areas and the duration of snow cover will impact this prey base (Kausrud et al. 2008), and declines in the small mammal community may result in concomitant declines in the marten population (Kausrud et al. 2008). Changes in subnivean areas and the duration of snow cover will also impact the vulnerability of small mammals to predation and the hunting efficiency of the marten (Krohn et al. 2004); in turn, this will impact the relationship between the marten and its primary competitor, the fisher (*Martes pennanti*) (Krohn et al. 2004). Although, in other regions of the country, the American marten may benefit from changes in climate via increases in prey and foraging efficiency (Yom-Tov et al. 2008), the long-term outlook for American marten persistence in Wisconsin is tentative.

Figure 5. *Eastern red-backed salamander.*

Eastern Red-backed Salamander

The eastern red-backed salamander (Figure 5) is a small, terrestrial amphibian found in the mixed coniferous-deciduous forests of northern Wisconsin. Although the species is no longer found in parts of its historic range across the eastern U.S., it is common in our state. Because they are numerous, these salamanders are an important food source for birds, reptiles, and small mammals in forest ecosystems. With permeable skin (i.e. sensitive to hot, dry conditions) and a complex life cycle, amphibians are excellent indicators of climate change (Blaustein and Wake 1990) and are an important highlight of this assessment.

The eastern red-backed salamander requires humid conditions to maintain its water balance and is rarely found when the humidity is below 85% (Heatwole 1962). The salamander's preferred ambient temperature varies by season, but ranges between 15°-21° C and it exhibits thermal stress at temperatures >32° C (Feder and Pough 1975). In warm, dry weather, individuals burrow underground and rely on soil moisture to prevent dehydration. These salamanders also rely on canopy vegetation and woody debris (e.g., moist logs) on the forest floor for cooler microclimate conditions (McKenny et al. 2006). High temperatures inhibit foraging and therefore limit growth, reproduction, and survival (Feder 1983). Within the salamander's range in Wisconsin, climate projections suggest minor decreases in summer precipitation of 0.6-1.3 cm (0.25-0.5 in, Kucharik et al. 2010b). Although seemingly negligible, this is a period with high maximum temperatures that rapidly advance water loss in amphibians. In the region, average summer temperatures currently range from 18°-20° C (64°-68° F) and the average maximum temperature reaches 26°-28° C (78°-82° F) in July (Wisconsin State Climatology Office, unpublished data). In the eastern red-backed salamander's range, the average maximum temperature in July may increase as much as 4.4°-5.6° C (8°-10° F, A2 emission scenario, Kucharik et al. 2010b). In late summer, these salamanders will likely experience both heat and water stress, resulting in low reproductive and survival rates. As we noted earlier, declines in this population will impact the larger forest ecosystem with the loss of an important food source. This scenario also illustrates the potential for common species to become rare or extinct under future climate conditions.

Although many other species may move to more suitable climatic conditions, this likely is not an option for the eastern red-backed salamander. This species is considered a poor disperser; because it is sensitive to water loss from exertion and exposure, movements are restricted to within 55 m (Marsh et al. 2004). This situation poses a challenge to local populations. The eastern red-backed salamander must have viable habitat within dispersal range to survive as a population. Yet the broader scale over which projected climate change impacts will occur overshadows the dispersal distances achievable by this salamander to colonize within a suitable climate niche. Such conditions often lead to local extinction (Blaustein et al. 1994). This fate is not unique to the eastern red-backed salamander, rather it will be shared by many amphibian species and other poor dispersers (Hecnar and McCloskey 1996).

White-tailed Deer

White-tailed deer, a harvested mammal, is widely distributed across the eastern and central United States. In Wisconsin, it is listed as the official "State Wildlife Animal" and is the subject of an extensive harvest management program. The harvest of deer contributes about $482 million to the state economy (Bishop 2002); conversely, large deer herds may damage crops and native vegetation by overgrazing, resulting in tens of millions of dollars in damage (Bartelt et al. 2003) and alteration of native ecosystems (Côté et al. 2004, Craven and Van Deelen 2008). Given the species' influence on the local economy and native ecosystems, it is important to consider how a changing climate will impact Wisconsin's deer population.

Similar to many other species, winter survival for white-tailed deer is a challenge in northern latitudes. Ambient temperatures in winter and snow depth (i.e. winter severity) are strongly associated with deer overwinter survival (Verme 1968) in northern forested regions. Cold temperatures increase energetic requirements of the deer (Mautz 1978) and deep snow limits access to forage and increases the energetic cost of locomotion; the result of such conditions, acting in concert with predation, is high mortality (DelGiudice 1998, DelGiudice et al. 2006). In a study in north-central Minnesota, winter severity explains more than 50% of the variability in adult female mortality (DelGiudice et al. 2006). In Wisconsin, the projected winter warming of 2.8°-3.9° C (5°-7° F) in the southeastern portion of the state and 3.3°-4.4° C (6°-8° F) in the northwestern portion of the state (Kucharik et al. 2010b) will reduce this source of mortality in the deer population. Although winter precipitation will increase slightly (<2.5 cm [1 in], Kucharik et al. 2010b), more will be in the form of rain and higher ambient temperatures will reduce the duration of snow cover. Therefore, with the exception of rain-on-snow events, white-tailed deer will likely have greater access to forage and reduced energy losses under future temperature and precipitation regimes. As deer abundance increases on the landscape, wildlife managers will need to consider these changes in weather-related mortality and the potential impacts of larger deer herds on croplands, forests, and native vegetation, especially in northern Wisconsin.

It is also important to note that white-tailed deer populations may experience increased mortality due to disease outbreaks under novel temperature and precipitation patterns. For example, epizootic hemorrhagic disease (EHD) is an infectious viral disease prevalent in white-tailed deer (Sleeman et al. 2009). The virus is transmitted by biting midges (Ceratopogonidae), primarily in late summer and early fall; insects are sensitive to weather-climate conditions and this time period reflects suitable breeding conditions for midges. Higher temperatures in winter and summer, and lower precipitation in summer favor midge populations (Sleeman et al. 2009). These conditions match the future projections for Wisconsin's climate and an increase in the frequency and/or severity of EHD is a reasonable prediction (Sleeman et al. 2009). As with the likely reduction in overwinter mortality, wildlife managers will need to consider the possible impacts of increases in disease outbreaks for populations of this species under climate change.

Wetland/Aquatic-Dependent Wildlife

Wisconsin contains a diverse mix of wetland and aquatic habitats, from small tamarack swamps to the vast Great Lakes. Since European settlement, wetland area declined by nearly 50% in the state to approximately 5 million acres; the majority of these wetlands are found in the northern portion of the state (Dahl 1990). These areas host diverse, often rare, species and 32% of the state's listed species are wetland-dependent (Wisconsin DNR 2005). Wetlands are sensitive to changes in hydrology and elevated temperatures; climate change alters the timing and availability of water with serious consequences for wetland composition and structure (Burkett and Kusler 2000, Winter 2000). In the northern portion of the state, projected increases in annual precipitation are modest at 2.5-5 cm (1-2 in, B1 emission scenario; Kucharik et al. 2010b) and slightly increase 5-7.6 cm (2-3 in) under intensive greenhouse gas emission scenarios (A2 emission scenario, Kucharik et al. 2010b). Under all emission scenarios, summer precipitation is projected to experience no change or decrease (Kucharik et al. 2010b); in summer, average temperatures are projected to rise 2.8°-5.6° C (5°-10° F, Kucharik et al. 2010b). The result is faster evaporation of water and the rapid drying of our wetlands. With declining water levels and poor vegetation quality, many wetland-dependent species will no longer thrive in these areas. How climate change will alter the hydrological cycle of our wetlands and lakes is the subject of many research projects in our region. As hydrological projections become available, they will inform our assessment of climate impacts on wetland-dependent wildlife.

Black Tern

The black tern is a small waterbird that breeds in wetlands of the northern U.S. and winters along the Gulf Coast of the U.S. and in the coastal areas of Central and South America. Black terns form breeding colonies in large wetlands, preferring shallow marshes with open water vegetation, and will abandon these wetlands when the vegetation is not suitable for nesting (Heath et al. 2009). Once common and found more widely across the state, the species is now in steep decline. Terns have largely disappeared from many small wetlands and have become more concentrated into a few suitable large wetland complexes (Matteson and Mossman 2000). The decline is likely attributable to the conversion of wetlands to agricultural and urban development and the spread of invasive plants (Heath et al. 2009). Black tern is now listed as a species of greatest conservation need in Wisconsin (Wisconsin DNR 2005). Because of changes in precipitation, climate change may accelerate the decline of this species.

Black terns build precarious nests–small, shallow cups on floating vegetation–to hold three eggs (Heath et al. 2009). As a result, nests are vulnerable to flooding. Loss to flooding is a common occurrence and reflects spring precipitation patterns (Gilbert and Servello 2005). In a study of black terns in Wisconsin, weather (storms and flooding) was "clearly the single most important… cause" of nest failure (Shealer et al. 2006). The impacts on a colony depend on the frequency and intensity of heavy precipitation events and climate change is increasing the number of such events. For example, the number of 5-cm (2-in) precipitation events will increase by up to four days/decade across the range of the species in Wisconsin (Kucharik et al. 2010b); the Northern Lake Michigan Coastal and Superior Coastal Plains ecological landscape units are projected to receive the greatest increases. Moderate precipitation events can result in loss of more than 50% of nests (Gilbert and Servello 2005) and heavy precipitation may result in complete nest loss. Historically populations accommodated such events, but the increase in the frequency of heavy rainfall events diminishes the ability of our declining population to rebound from major reproductive failures.

Like most waterbirds, black terns are susceptible to the paralytic disease, avian botulism (Friend and Franson 1999). The bacterium produces a toxin that birds may directly or indirectly (from prey) ingest. Shallow water, fluctuations in water level, and high ambient temperatures promote bacterial growth (Rocke and Samuel 1999). Under such conditions, outbreaks of the disease may occur, resulting in mass mortality of tens of thousands of waterbirds (Friend et al. 2001). The risk of outbreak for one form, type C, is high from July through September, coinciding with the tern's breeding season in Wisconsin (Marion et al. 1983). Botulism outbreaks are increasing in frequency in our region (Lafrancois et al. 2010) and many anticipate this pattern to continue under projected climate conditions. By mid-century, summer precipitation in the tern's range will experience no changes to a modest decline of 1.27 cm (0.5 in, Kucharik et al. 2010b). However, the average summer temperature in the area will increase 1.7°-2.8° C (3°-5° F, Kucharik et al. 2010b). The result is warmer, shallower waters that favor bacterial growth.

Common Loon

The common loon (*Gavia immer,* Figure 6) is a large, migratory waterbird that nests on inland lakes in northern Wisconsin and winters on the ocean coasts of South Carolina south through the Gulf of Mexico. In the breeding season, loons strongly prefer water bodies with moderate to deep lake depth, complex shorelines, and high water clarity (Meyer 2006, Found et al. 2008). Although the total population of common loons breeding in Wisconsin is currently stable or slowly increasing (Grear et al. 2009), their distribution, formerly statewide, is now primarily restricted to northern counties. Development of lakeshores for housing and agriculture reduced available nesting habitat and decreased water clarity on many historic breeding territories. Climate change will alter the hydrological, chemical, and physical properties of inland lakes important for breeding common loons in northern Wisconsin, with potentially negative implications. Common loons are the most southerly nesting of five *Gavia* species breeding in the northern hemisphere – ranging from the arctic (yellow-billed loon [*G. adamsii*] to 78° N latitude) south to 44° N latitude (southern extent of breeding common loons). It is unknown whether current distribution is limited by critical temperature during breeding season or other factors.

Climate projections of increased precipitation anomalies, namely drought, heavy rain events, and coastal storms, may reduce available habitat, nest success, and survival in upcoming years. Weather is one of the primary factors limiting reproductive success in common loons. Heavy floods and elevated water levels destroy nests; loons may renest, but when heavy rains occur in mid- to late June, loons have no time for a second nesting attempt (McIntyre and Barr 1997). In Minnesota's Voyageurs National Park, on Rainy, Namakan, and Kabetogoma Lakes, an average of 60-70% of common loon nests failed due to water level fluctuations (Reiser 1988) and in one year, flooding caused 53% of nest failures in New Hampshire (Taylor and Vogel, unpublished data). In the late 1990s in Wisconsin, many nests failed due to flooding, but the current moderate-severe drought in northern Wisconsin is altering nest success in the population. Because adults are not suited for movement on land, they nest within 0.9-1.8 m (3-6 ft) of the water's edge. In some northern Wisconsin lakes, the water line has receded >6 m (20 ft) over the past five years (M. Meyer, Wisconsin DNR, personal observation) and, consequently, suitable nesting sites are inaccessible. The drought in northern Wisconsin is the product of declining precipitation (15-20%) over the past 50 years (Kucharik et al. 2010b) and climate projections indicate more frequent and serve droughts (IPCC 2007b). Both the increase in heavy precipitation events (3-5 days/decade, Kucharik et al. 2010b) in the common loon's range and the increasing frequency of drought will likely reduce loon productivity in Wisconsin.

During nesting, loons are vulnerable to parasitism by black flies (*Simulium euryadminiculum*). It is common to observe loons covered with feeding black flies and subsequent nest abandonment from the disturbance (McIntyre 1988). The documented impacts of black flies on other bird species include decreased productivity (Bukacinski and Bukacinska 2000) and the transmission of disease (Hunter et al. 1997). *Simulium annulus* (Lundström) (junior synonym *S. euryadminiculum* Davies), is host-specific, and feeds exclusively on the common loon (Adler et al. 2004, Weinandt 2007). The presence of swarming, biting black flies directly affects loon productivity and fitness. Weinandt (2007) found increased disease prevalence in loons with high blood mercury levels and indicated black flies could be the vector. During warm springs, black fly swarms peak in mid-late May in northern Wisconsin, coinciding with the peak of loon nest initiation. In such spring conditions, nest abandonment from black fly predation is most severe (M. Meyer, Wisconsin DNR, personal observation). Because of the close linkage between insect populations and temperature and precipitation patterns (Bale et al. 2002), changes in the timing and severity of black fly outbreaks are anticipated.

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Figure 6. *Common loon.*

Wood Frog

The wood frog (*Lithobates sylvaticus,* Figure 7) is a small amphibian that is widely distributed across the northeastern U.S. and Canada. A unique adaptation, the ability to survive freezing of blood and tissues, permits the species to survive winter in the coldest regions of the continent. The wood frog is one of the first amphibians to emerge from hibernation for breeding, beginning within a few days of snowmelt (Waldman 1982). For survival, wood frogs require temporary ponds in close proximity to woodlands (Regosin et al. 2003, Porej et al. 2004); because of predation by fish, wood frogs are rarely found in permanent water bodies. The species is common in Wisconsin and widely distributed across the state. Given its wide distribution, dual habitat requirements, and sensitivity to ambient conditions, the wood frog is a model organism for understanding climate impacts. Most juvenile wood frogs die in their first year of life (75%, Rittenhouse et al. 2008). Most wood frogs reach sexual maturity at two years of age and few survive beyond their first breeding season (Berven 1990). In rare instances, a wood frog may survive to age four (Berven 1990). The result is a narrow breeding window for the average wood frog. For this reason, survival of juvenile wood frogs to reproduction is the most important factor regulating the size of a population (Berven 1990, Biek et al. 2002). A major cause of juvenile mortality is desiccation or deep freezing (Rittenhouse et al. 2009). Wood frogs rely on soil burrows, leaf litter, and snow cover to buffer their bodies from these extreme ambient conditions (O'Connor et al. 2006, Rittenhouse et al. 2008). In summer, moist soils and leaf litter protect against rapid water loss; in winter, snow cover provides thermal insulation from Wisconsin's cold extremes. Given the frog's reliance on ambient conditions for juvenile survival, we anticipate substantial changes in the wood frog population. For example, mortality of closely-monitored wood frogs was directly attributable to recent drought conditions in Missouri (Rittenhouse et al. 2009). Under future climate scenarios, drought conditions are projected to increase in frequency, severity, and spatial extent (IPCC 2007b, Dai 2010) with serious ramifications for amphibians (McMenamin et al. 2008). Although it is difficult to predict the location or timing of upcoming droughts, recent history gives us some information. From the 1950s to 2006, precipitation in the northern portion of the state declined 15-20% percent (Kucharik et al. 2010b). This decline is one of the main contributors to the prolonged moderate-severe drought recently experienced across northern Wisconsin. Wood frog dispersal distances are generally less than 1,600 m (Berven and Grudzien 1990), therefore they cannot move away from widespread drought conditions. For wood frogs in the northern region of the state, the result is a high probability of death due to water loss, particularly in hot summers. Drought conditions will also alter the number and condition of breeding sites for wood frogs. Because there is minimal exchange between local wood frog populations, the result will likely be the loss of small isolated populations with no opportunity for recolonization (Hecnar and McCloskey 1996).


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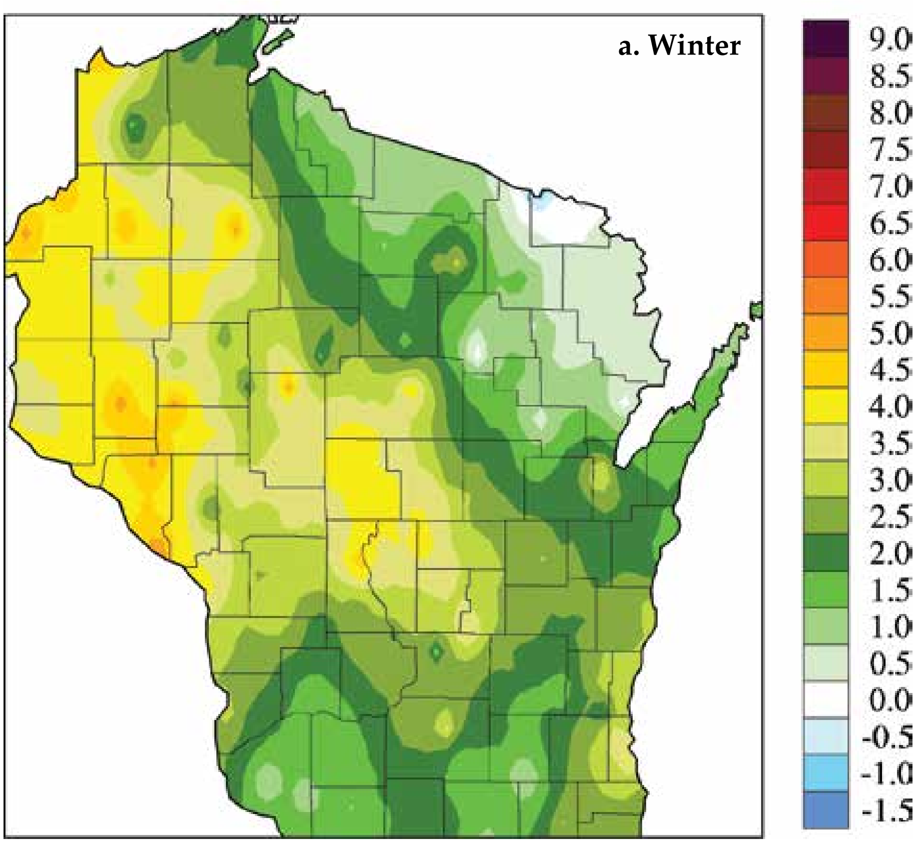
Figure 7. *Wood frog.*

It is also important to note that drought is one of many factors that we anticipate will alter the distribution and abundance of wood frogs under climate change. Changing water levels and periodicity, from high temperatures and precipitation fluxes, will "tax [wood frogs] beyond their capacity to adapt, especially in smaller, more ephemeral pools" (Brooks 2004); they will be unable to reproduce successfully. Moreover, under "unseasonable and prolonged high temperatures" there may be mass mortality of wood frog embryos (Zweifel 1977). In addition, disease is an important consideration for global amphibian populations, especially since changes in temperature may increase the prevalence and incidence of numerous amphibian diseases (Harvell et al. 2002); for example, growth of the chytrid fungus (*Batrachochytrium dendrobatidis*), which is associated with global extinction of amphibian species, is regulated by temperature and moisture (Pounds et al. 2006). Accurate predictions for future populations require careful consideration of these and other factors likely to influence the survival and reproduction of Wisconsin wood frogs.

Grassland-Dependent Wildlife

Prairies are one of the most extensively altered systems due to Native American management practices and subsequent settlement and development of agriculture by Europeans (Samson and Knopf 1994, Johnson 1996, Askins et al. 2007). The large-scale conversion of prairie for cropland is the leading cause of prairie loss, and the native prairie ecosystem is one of the most endangered ecosystems in North America (Samson and Knopf 1994, Noss et al. 1995, Samson and Knopf 1996, Samson et al. 2004, Askins et al. 2007). In Wisconsin only 0.5% of original prairie remains, fragmented into small patches (Henderson and Sample 1995). Along with the loss of the original prairie ecosystem came changes in the associated flora and fauna. For example, grassland birds have declined more than most other bird groups in the past 40 years (Droege and Sauer 1994, Knopf 1994, Sauer et al.

Color Plates



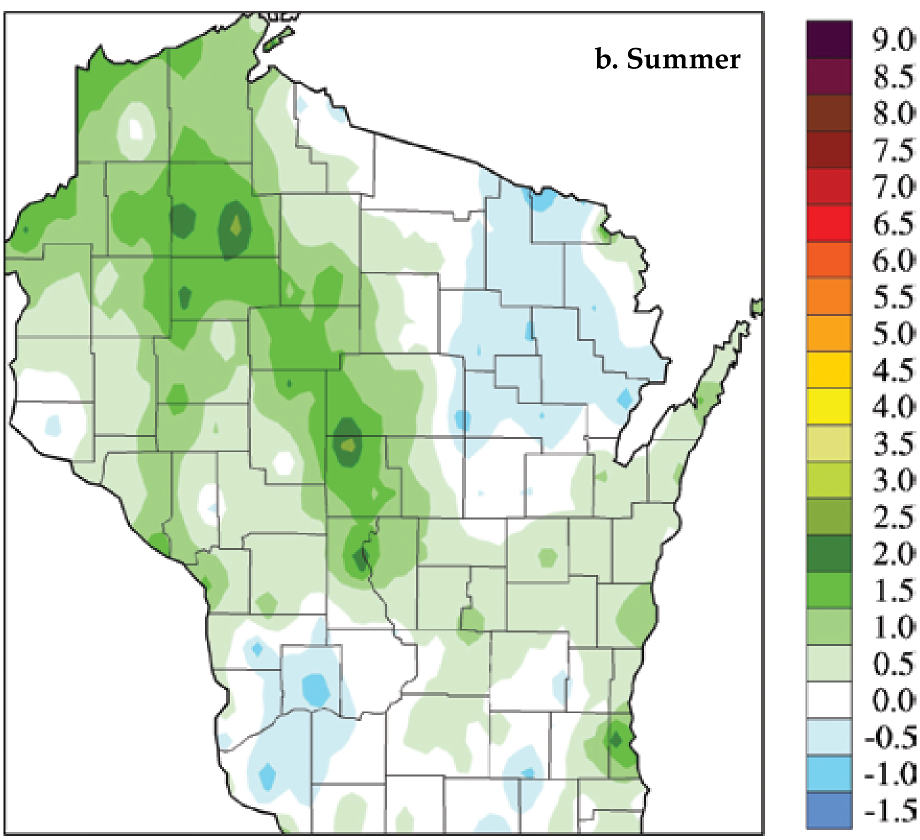


Plate 1. *Change in winter (a) and summer (b) average temperature (°F) from 1950 to 2006 (adapted from Kucharik et al. 2010a, b).*

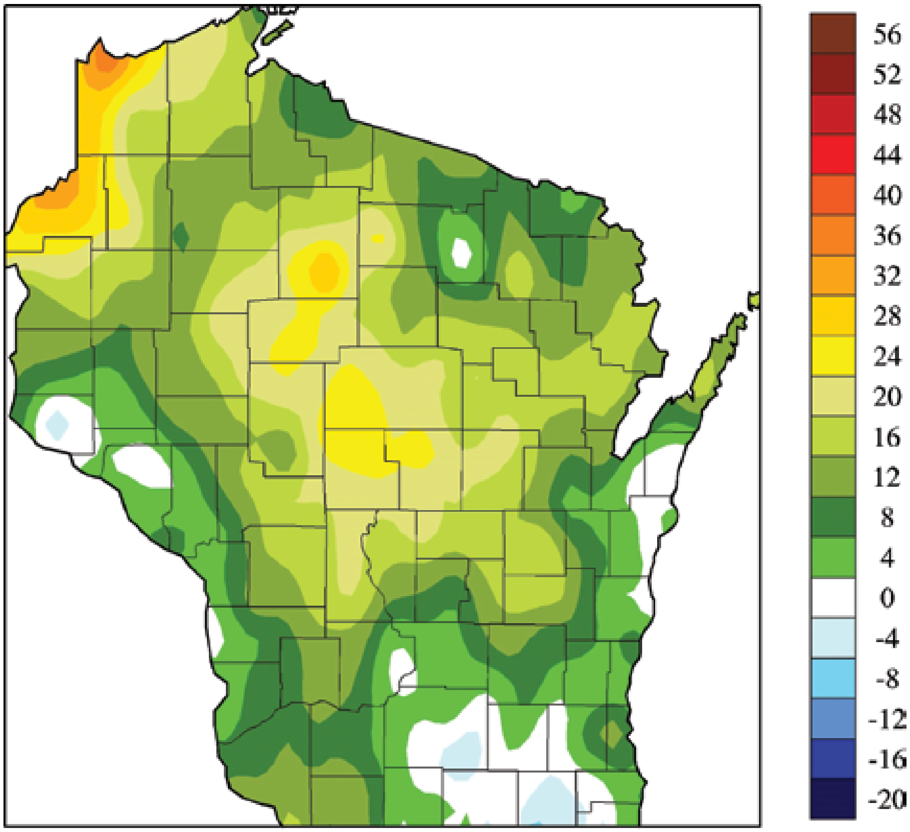


Plate 2. *Change in the length of the growing season in days from 1950 to 2006 (adapted from Kucharik et al. 2010a, b).*

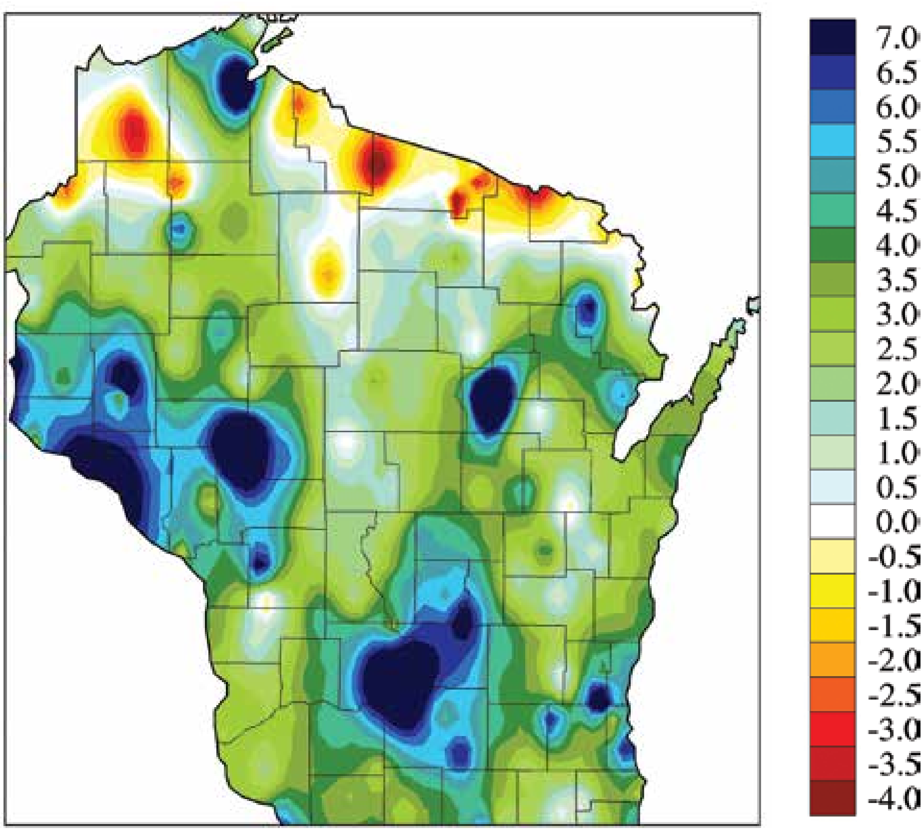


Plate 3. *Change in annual average precipitation (inches) from 1950 to 2006 (adapted from Kucharik et al. 2010a, b).*

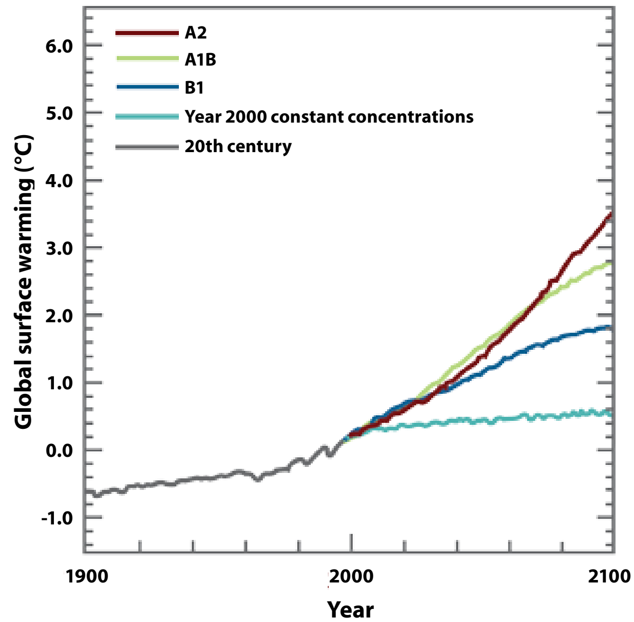


Plate 4. *Global climate predictions based on three scenarios (adapted from IPCC 2007).*

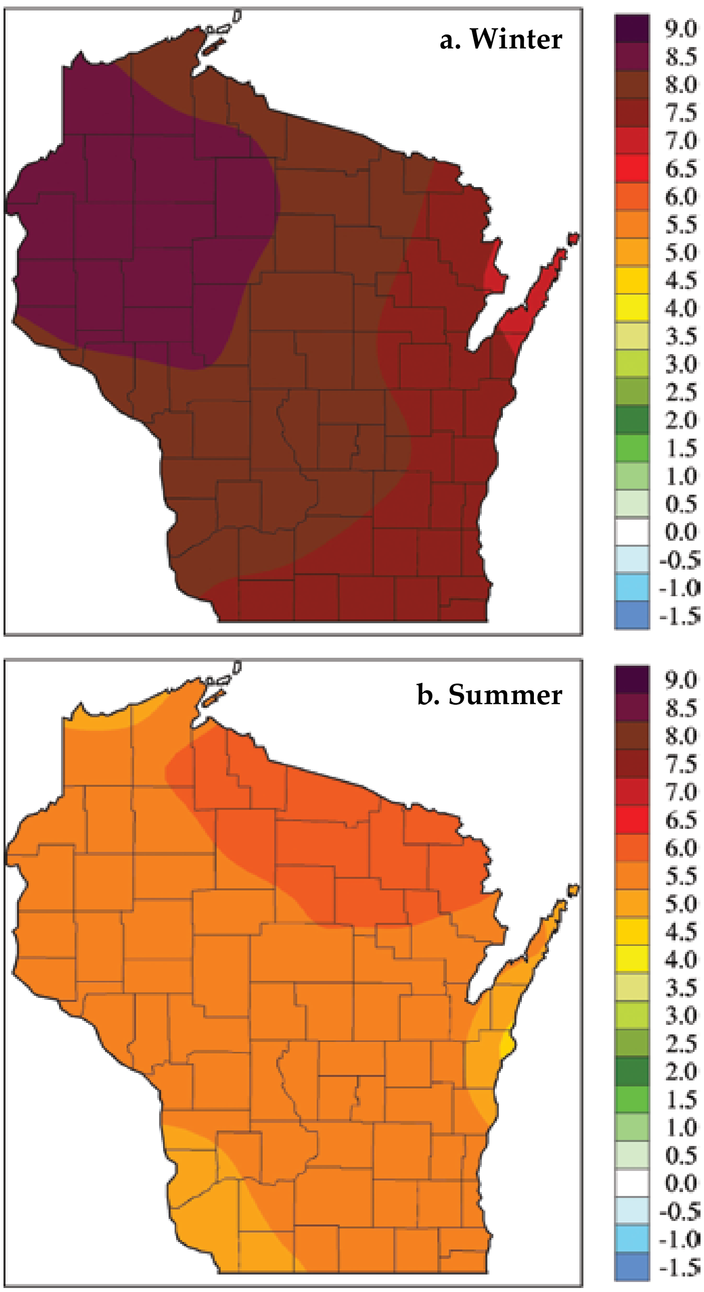


Plate 5. *Projected change in winter (a) and summer (b) average temperature (°F) from 1980 to 2055 (adapted from Kucharik et al. 2010a, b).*

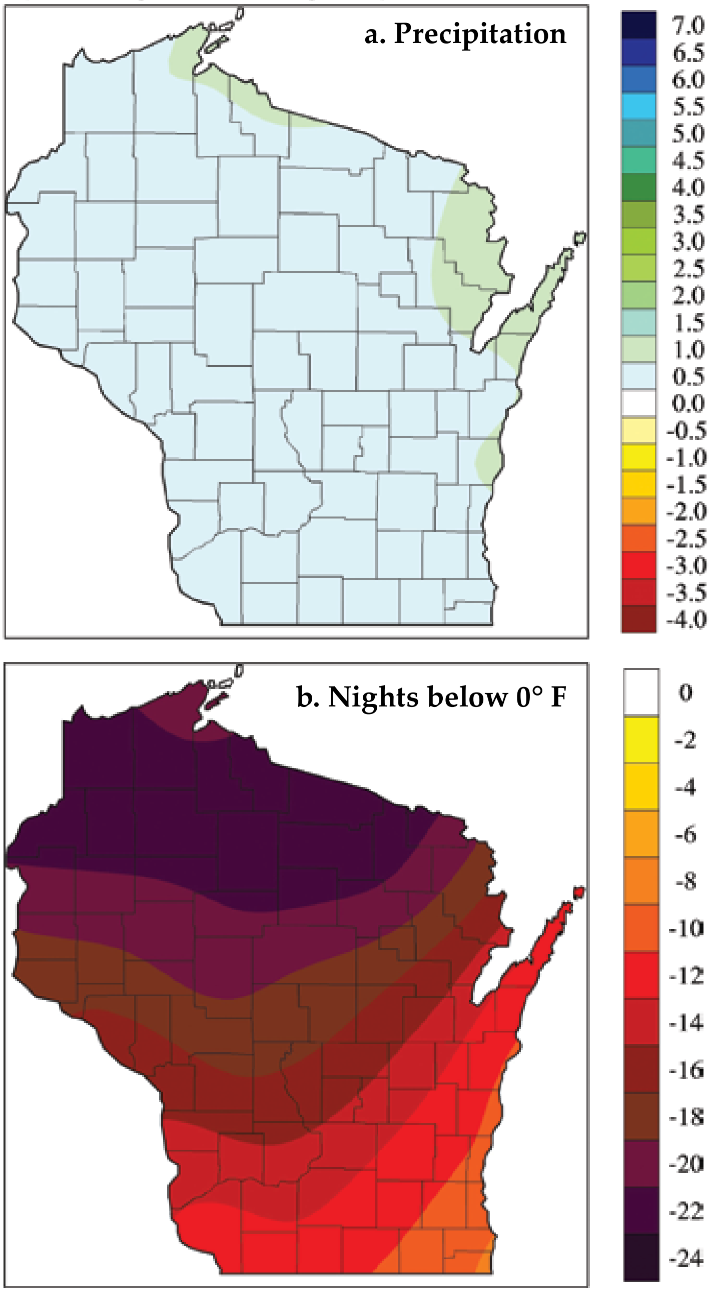


Plate 6. *Projected change in (a) winter average precipitation (in) and (b) frequency of nights below 0° F per year from 1980 to 2055 (adapted from Kucharik et al. 2010a, b).*

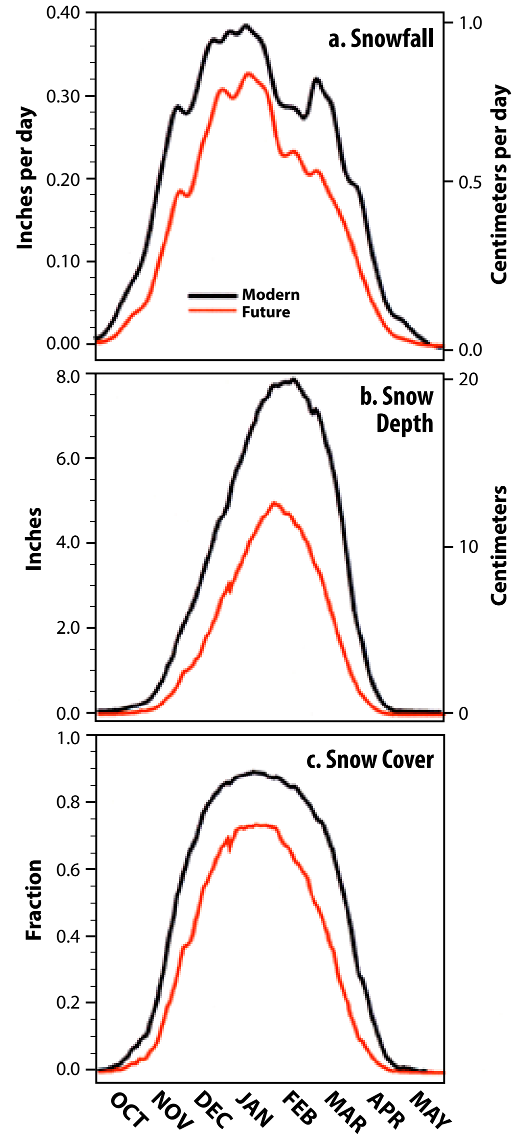


Plate 7. *Projections of (a) snowfall, (b) snow depth, and (c) snow cover (in and cm) for Wisconsin for the mid-21st century (A2 scenario, redrawn from Notaro et al. 2011).*

2003). These changes continue as the grass-based agriculture that initially replaced prairie changes and becomes dominated by intensively farmed row crops. Currently, planted or surrogate grasslands dominate the remaining eastern grassland systems (Warner 1994, Askins et al. 2007). These surrogate grasslands are important for the survival of grassland-dependent fauna (Sample and Mossman 1997, North American Bird Conservation Initiative 2009); however, even the surrogate grasslands are disappearing from the landscape. Between 1982 and 2002, more than 10 million acres of pasture were lost (Natural Resources Conservation Service 2004). In addition, between 2010 and 2012, Wisconsin could lose up to 83% (>300,000 acres) of its grasslands protected under the Conservation Reserve Program (U.S. Department of Agriculture 2012). Conservation of the grassland system and its associated flora and fauna in Wisconsin depends heavily on management practices implemented on privately owned lands within the agricultural landscape (Sample et al. 2003). Because of this, the effects of climate change on the grassland system are inextricably linked to changes in the agricultural system. Changes in current land use, particularly for bioenergy development, may result in the loss or gain of grasslands and are an emerging conservation issue (e.g., Fargione et al. 2008, Fargione et al. 2009, North American Bird Conservation Initiative 2009). Such changes in land use may constrain the suite of climate change adaptation strategies available to grassland managers.

Greater Prairie-Chicken

The greater prairie-chicken (*Tympanuchus cupido*, Figure 8) is a large, formerly hunted, gamefowl. Currently, the greater prairie-chicken is extirpated or nearing extirpation in 15 states and Canadian provinces (Schroeder and Robb 1993). Once abundant in Wisconsin, the conversion of mid-tall grass prairie to cropland and forest regeneration led to a dramatic population decline; the small population of approximately 700 individuals is now restricted to the central region of the state. The prairie-chicken is "especially vulnerable" to climate change (North American Bird Conservation Initiative 2010). Limited dispersal ability, current land use (i.e. intensive agriculture and increased amounts of woodland and development in the landscape), and the projected conversion of grasslands for bioenergy crops (Tilman et al. 2009; Fargione et al. 2009) compromise the Wisconsin prairie-chicken population's ability to respond to novel conditions and/or shift its distribution. Furthermore, reduced connectivity within the Wisconsin population could lead to losses in genetic variability, individual fitness, and a consequent reduction in the ability to cope with additional stressors, as previously occurred in Illinois (Warnke 2004). The primary management strategies to sustain prairie-chicken populations in the state focus on protection/restoration of habitat and maintenance of genetic diversity. Given the species' sensitivity to weather extremes (Flanders-Wanner et al. 2004) and current conservation status, the impacts of climate change on the greater prairie-chicken requires careful consideration.

On average, prairie-chickens live less than two years and less than half of the juveniles survive their first year (Schroeder and Robb 1993). Like the wood frog, survival of juveniles to reproductive age is the most important factor regulating the size of a population (Fefferman and Reed 2006). Although predation is the primary source of mortality for juveniles (Bergerud 1988a), survival in the first year is sensitive to rainfall and ambient temperature (Shelford and Yeatter 1955). In the early breeding season, heavy rain may drown or chill young birds (Horak and Applegate 1998). By mid-century, climate projections indicate more heavy rainfall events in central Wisconsin (+2 days/decade of 2 in [5 cm] precipitation events; A1B emission scenario, Kucharik et al. 2010b). In addition to heavy rainfall events, heat stress in the first 10 days after hatch may result in high juvenile losses (Flanders-Wanner et al. 2004). Also by mid-century, prairie-chickens breeding in Wisconsin will experience five to eight more days of temperatures >38° C (100° F, A1B emission scenario, Kucharik et al. 2010b). Although they are long-recognized sources of mortality for prairie-chickens, these moderate increases in temperature pose a serious challenge to conservation efforts. Slight but consistent increases in juvenile mortality may result in rapid, large declines in the population (Fefferman and Reed 2006).

Although greater prairie-chickens initially expanded their range after Euro-American settlement due to the expansion of grass-based agriculture into the logged and burned-over lands in northern Wisconsin (Henderson and Sample 1995), given the intensity of current land use and reforestation that has occurred, it is unlikely that the greater prairie-chicken will be able to shift its geographic distribution to more suitable climatic conditions. In Wisconsin, prairie-chicken dispersal is poor (Halfmann et al. 2001); moreover, they require open spaces for movement and will not disperse through extensive woodlands. Their requirement of large, contiguous grassland landscapes with management areas of at least 4,600 ha in size (Hamerstom et al. 1957) further limits their capacity to adapt to short-term (i.e. land-use changes) and long-term (i.e. climate) stressors.

It is important to note that changes in the composition, configuration, and management of both public and private lands will continue to impact the Wisconsin prairie-chicken population. Grasslands are essential habitat

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Figure 8. *Greater prairie-chicken.*

for greater prairie-chicken in Wisconsin (Hamerstrom 1939), required for reproduction, foraging, and predator avoidance. Prairie-chickens select large, high-quality grassland areas with suitable vegetation for cover (Kirsch 1974, Niemuth 2000, 2003); croplands are also used for foraging (Svedarsky et al. 2003). Society's need to meet food production, alternative fuel, and conservation demands will shift agricultural land use (Tilman et al. 2009); the result will be changes in the distribution and abundance of wildlife populations (Fargione et al. 2009). Given its requirement of large areas of grassland for survival and reproduction, the greater prairie-chicken acts as an umbrella species for the conservation of other native grassland-dependent birds in central Wisconsin (Poiani et al. 2001); when the habitat requirements of the prairie-chicken are met, a suite of grassland-obligate species such as eastern meadowlark (*Sturnella magna*) and bobolink (*Dolichonyx oryzivorus*) (Sample and Mossman 1997) will likely be protected.

Karner Blue Butterfly

Karner blue butterfly (*Lycaeides melissa samuelis,* Figure 9) is a small, federally and state endangered butterfly found in the eastern and midwestern U.S.; in Wisconsin, the species is found in the central and northwestern regions of the state. Wisconsin is home to the world's largest populations of Karner blue butterflies (e.g., Necedah National Wildlife Refuge, Wisconsin DNR 2010). The Karner blue butterfly is found in grassland and barrens habitats (Swengel 1991). Because one plant, the wild lupine (*Lupinus perennis*), is the sole larval (i.e. caterpillar) food source, it is an essential component of the landscape for the species. In our region, loss of grassland vegetation from land conversion and fire suppression led to the decline of the Karner blue butterfly (Grundel et al. 1998a). Although far lower in abundance than in historic times, the Wisconsin population is arguably the most viable in the world. Observed and projected changes in temperature and precipitation threaten this stability. Because of its endangered status and importance to the global population, the Karner blue butterfly in Wisconsin is an appropriate subject to consider potential climate impacts.

Karner blue butterfly is a bivoltine butterfly, reproducing in two bouts in April and June; eggs that hatch in April transition from larvae to adults which lay the eggs that hatch in June. Adults live for only a few days, but the final set of eggs, laid by adults of the June hatch, must survive the winter to hatch the next April. The survival of eggs and larvae are central to population persistence (Fuller 2008) and as noted earlier, lupine is essential to larval survival. Karner blue butterflies prefer landscapes with a mixture of open grasslands and some forest growth (Grundel et al. 1998b); open areas contain more lupine, but lupine in moderate forest cover is of higher quality (Grundel et al. 1998a). The larval stage of the butterfly is sensitive to both the availability and quality of lupine. The emergence of wild lupine is linked to ambient temperature (Pavlovic and Grundel 2008), and high temperatures advance the senescence (i.e. seasonal aging) of wild lupine, reducing its nutritional quality


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Figure 9. *Karner blue butterfly.*

(Grundel 1998a). Low precipitation or drought conditions also reduce lupine availability and quality. There is a clear link between lupine quality and Karner blue larval survival as a diet of poor quality lupine considerably reduces larval survival (Grundel et al. 1998b, Lane and Andow 2003). The availability of high quality lupine throughout the breeding season is a concern for managers of Karner blue butterfly, particularly for the eggs hatching in June. In mid-late summer, drought conditions lead to little or poor quality lupine for the second reproductive bout. Such conditions are implicated in large Karner blue butterfly declines across its range (Grundel et al. 1998a). From the 1950s to 2006, precipitation in the northern portion of the state declined 15-20% (Kucharik et al. 2010b). This precipitation decline is one of the main contributors to the prolonged moderate-severe drought across northern Wisconsin and may be the source of declining productivity in the Karner blue populations in the northern part of the state (e.g., Crex Meadows in northwest Wisconsin).

In addition to increases in larval mortality, increases in adult mortality are predicted. Adults exhibit heat stress at 35.6°-36.8° C (Lane 1999), reducing foraging activity. By the end of the century, butterfly populations in northern Wisconsin may experience an additional 2-9 days of temperatures 38° C (>100° F, Kucharik et al. 2010b); in the central region, climate projections indicate greater increases, 2-13 days >38° C (Kucharik et al. 2010b). Karner blue butterflies, like many of the species already mentioned, are not considered good dispersers, moving no more than 2 km between sites (U.S. Fish and Wildlife Service 2003). Moreover, suitable habitats should be less than 300 m apart to facilitate movement (Knutson et al. 1999). Because they are poor dispersers in a fragmented landscape, we do not anticipate a shift in climate niche for the Karner blue butterfly; rather population declines are likely under future climate conditions.

Bullsnake

The bullsnake (*Pituophis catenifer sayi*) is a large, non-venomous snake found in the open bluffs, sand prairies, oak savannas, and pine/oak barrens of western Wisconsin. The species is listed as a species of greatest conservation need (Wisconsin DNR 2005) and protected wild animal (s. NR 19.001(14), *Wis. Admin. Code*) in the state. Although we provided detailed examples of possible effects of climate change on other grassland species, the bullsnake is emblematic of a challenge to this effort; there is little information on which to assess impacts due to climate change. Many animals, particularly reptiles, amphibians, and invertebrates are not common research subjects. If they are the subjects of research, often it is restricted in scope, working to locate and identify habitat preferences of the species. For this reason, there is a limited ability to anticipate the impacts of climate change on data-poor species.

Adaptation Strategies

Climate change introduces new and unparalleled challenges to wildlife and land managers, namely high uncertainty of future conditions. Furthermore, our understanding of the indirect effects of climate change is limited. Climate change is not "well-bounded, clearly defined, relatively simple, and generally linear" (Holling and Meffe 1996), and natural resource management that assumes a static system "will need to alter fundamentally to face the challenge" (Brooke 2008). This requires a reassessment of our wildlife conservation and land management practices: protected areas (e.g., Halpin 1997, Araujo et al. 2004), invasive species management (Bierwagen et al. 2008, Pyke et al. 2008), restoration (Harris et al. 2006), monitoring (Lee et al. 2008), and natural resource extraction (Noss 2001). The development of species-specific adaptation strategies requires a detailed understanding of the direct and indirect impacts of climate change and other stressors on the distribution and abundance of populations. It also requires some understanding of the relative benefits of multiple management options. Because this assessment process is in its infancy, we do not yet have detailed, species-specific recommendations. In the following section, we discuss broad wildlife and land management principles demonstrated to be beneficial to wildlife health and diversity.

The prevailing question is: how does one manage for climate change? A concise description of the task is "not to prevent change. It is to keep rates, scales, and intensities of change in ecosystems within the historic range of variability for those systems—or, at least, to come close" (Noss 2001). Disturbance to ecosystems is not a new concept for natural resource managers. Invasive species, land conversion, and pollution, are among a suite of factors that threaten the structure and function of ecosystems. Although the scale of climate change is unlike any other threat, we have decades of management experience to draw upon in anticipation of negative impacts. Owing to the work of many academics, federal and state governments, and nongovernmental organizations, particularly in the last 3-6 years, we have some guidance on a management framework in light of climate change.

Drawing upon this body of work and the disciplines of natural resource management, conservation biology, and restoration ecology, the following land protection and management principles are important to consider for wildlife management in an era of climate change.

Land Protection

How will climate change alter the conservation value of our reserves, and should we alter how we select protected areas to accommodate climate change? Although there is no unanimous recommendation on the process, experts convey the importance of "protect[ing] more land rapidly" but due to financial constraints this process "must be guided by targeted, well-informed strategies likely to maximize effectiveness in the face of climate change" (Heller and Zavaleta 2009). The following three principles support this goal.

Representation and Replication. Multiple examples of a habitat type or multiple populations of a species across a reserve system guards against extinction, particularly in regions subject to drastic change (Margules et al. 1988); this approach "reduces the risk of any one type being totally lost [due to a major disturbance event]" and "maximize[s] the probability that— across species and habitats— there will be sufficient survival and recovery" (West et al. 2006). This is particularly important for depressed species, like the Karner blue butterfly, where one anomalous event, such as the present drought, could eliminate a local population.

Connectivity. The ability of individuals to move from one protected area to another enhances population viability. A corridor is a strip of habitat that connects two or more larger blocks of habitats to facilitate animal movement between the blocks (see review in Beier and Noss 1998). As a conservation tool, corridors are beneficial to wildlife. For species that are poor dispersers, like the wood frog, this offers some opportunity to move to more suitable habitats.

Functional Importance. Keystone species are important to the continued function of an ecosystem. When more than one species can fulfill this role, this redundancy of purpose buffers against change and provides opportunities for adaptation (Walker 1995). Given limited resources, managers may prioritize management for those species with an important role in the ecosystem (i.e. keystone species) with a focus on functional redundancy in the system (Walker 1995).

Habitat Management

How should we manage for wildlife under a changing climate? Although there is no single answer to the question, "through proper stewardship, protected habitats can be maintained at the highest level of natural resilience to change" (Halpin 1997). The following five principles are best practices towards the goal of stewardship for ecological resilience.

Adaptive and Strategic Management. Our knowledge of the system of interest is always incomplete and ecosystems respond to changes in complex ways. In response, natural resource management, including management of wildlife habitats, should be flexible and responsive

(Williams et al. 2009). For example, in the management of deer harvest, managers will need to respond to changes in climate conditions and disease outbreaks to better manage abundance. Fortunately there are a variety of decision-making tools that incorporate learning into management practice and effectively reduce uncertainty.

Formal 'adaptive management' is one frequently cited tool in which predictive models based on our current knowledge are tested using well-planned experiments. This type of management is best suited for situations in which both uncertainty and controllability, or our ability to implement management planning, are high (Williams et al. 2009). However, natural resource management is commonly limited by only partial controllability and the formal adaptive management process is unlikely to succeed (Allen and Gunderson 2011). For example, adaptive management is not the appropriate tool if the system cannot be modeled, monitoring cannot be implemented, and management will not be adjusted in light of new information (Williams et al. 2009). Despite these difficulties, other tools are available that can be used in a strategic decision-making framework that address the additional constraints on management (e.g., scenario planning, Williams et al. 2009). Clearly, successful habitat management under climate change will require strategic and adaptive planning, and this should be carefully considered before proceeding with 'business as usual' management actions (Mawdsley et al. 2009).

Cumulative and Synergistic Threats. Currently, habitat loss/degradation and invasive species are the primary threats to biodiversity (Wilcove et al. 1998); additional broad threats include pollution, overexploitation, and disease. Sala et al. (2000) estimate that, in order of importance, land-use change, climate change, nitrogen deposition, species introductions, and change in atmospheric carbon dioxide concentration will impact global biodiversity by 2100. The maintenance of biological diversity and ecosystem function will "require increasing human involvement" (Vitousek et al. 1997) and reduction of non-climate threats should be a major component of management activities. For species like the black tern, reducing wetland loss would help buffer the species from future declines.


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Figure 10. *Prescribed burning is used to maintain native grasslands in the Roche-a-Cri Fishery Area.*

Approximate Natural Disturbance Regimes. Biodiversity and its corollary, ecological resilience, are the products of disturbance on the landscape (Connell 1978). For optimum biodiversity, management practices should mimic natural disturbance regimes of ecosystems, but "it can be difficult to adequately define the historical frequency, magnitude, and extent of natural disturbances, and then more difficult to mimic them" (Meffe et al. 2006). In this context, the management objective should be to create disturbances that approximate the naturally occurring pattern (Meffe et al. 2006, Lindenmayer et al. 2008). For grassland-dependent species, this is particularly important to maintain habitat quality (Figure 10).

Private-Public Partnerships. In agricultural regions, and in other fragmented landscapes in general, private lands are of increasing importance to wildlife. Local communities "must have a stake in conservation and management" and partnership of government agencies with local users is "essential" (Berkes 1997). Engaging the public, with "cooperation, consensus, and inclusion" in the management of wildlife habitats is a "surer road to success" (Meffe et al. 2006). For example, with species like the common loon, working with private landowners who have significant control over shoreline development practices will likely improve the prospects for the species under climate change.

Education and Outreach. From volunteer time to support for both increased funding and passage of conservation legislation, the capacity of natural resource managers depends upon the general public. The successful inclusion of citizens in natural resource management requires a measure of ecological literacy; the result is more informed decision-making and likely, more support for management plans (Grumbine 1994). J. Millar, who studies the relationship between science and the public, notes: "there's a lot of work to be done for us to tell people what we do, why we do it, and why it's important" (Gross 2006). Building a stronger relationship with the public is critical for establishing a collective critical mass of ecological knowledge in the community.

Management-Intensive Options

In some instances, managers can assume an even more active role in species conservation. Assisted colonization and ex situ conservation (e.g., zoos, sanctuaries) are additional options in cases where the survival of a species in question is severely threatened; this is in sharp contrast to a focus on preserving or maintaining ecosystem function. Management-intensive options require precise knowledge of the species and substantial resources—often both are in limited supply.

Research and Monitoring for Decision Making

Assessing the risks to Wisconsin's wildlife from climate change and generating effective climate change adaptation strategies is an incredibly complex task. Towards either goal, we must adopt a strategy for making short and long-term management decisions that integrates high-quality scientific research with comprehensive, inter-agency planning and implementation efforts. The absence of a strong, scientifically based foundation for risk assessment and adaptation will limit our capacity to respond to future environmental conditions with high confidence in our decisions. It is because of this that strategic and adaptive management is more likely to be successful in the future than reliance on even long-practiced approaches that have been successful in the past (Inkley et al. 2004). It is also important that research and monitoring efforts are well planned and address management objectives (Yoccoz et al. 2001). Not all information has equal value; information and learning activities that directly inform management action are most likely to be important for decision-making (Runge et al. 2011). Furthermore, it is increasingly apparent that successful adaptation occurs when policy makers, managers, and stakeholders participate in the learning process (as in Williams et al.'s 2009 recommendations to the Department of the Interior).

The Wisconsin Initiative on Climate Change Impacts (**http://www.wicci.wisc.edu**) offers an opportunity to develop a strategic, adaptive vision whereby management decisions benefit from high-quality science and monitoring efforts. As our scientific understanding increases over time, we will work with other scientists, policymakers, and natural resource managers to identify gaps in our understanding, facilitate joint learning, and incorporate new knowledge into planning and implementation efforts.

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Appendix A.
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Appendix B.
Common and Scientific Names of Organisms Mentioned in Text

Mammals
moose (*Alces americanus*)
American marten (*Martes americana*)
fisher (*Martes pennanti*)
white-tailed deer (*Odocoileus virginianus*)
gray squirrel (*Sciurus carolinensis*)

Birds
Canada goose (*Branta canadensis*)
black tern (*Chlidonias niger*)
spruce grouse (*Falcipennis canadensis*)
bobolink (*Dolichonyx oryzivorus*)
yellow-billed loon (*Gavia adamsii*)
common loon (*Gavia immer*)
European starling (*Sturnus vulgaris*)
purple martin (*Progne subis*)
eastern meadowlark (*Sturnella magna*)
greater prairie-chicken (*Tympanuchus cupido*)

Reptiles
bullsnake (*Pituophis catenifer sayi*)
Blanding's turtle (*Emydoidea blandingii*)

Amphibians
northern cricket frog (*Acris crepitans*)
eastern red-backed salamander (*Plethodon cinereus*)
wood frog (*Lithobates sylvaticus*)

Insects and Other Invertebrates
emerald ash borer (*Agrilus planipennis*)
biting midges (Ceratopogonidae)
zebra mussel (*Dreissena polymorpha*)
bark beetle (*Ips confusus*)
Karner blue butterfly (*Lycaeides melissa samuelis*)
gypsy moth (*Lymantria dispar*)
black flies (*Simulium euryadminiculum*)
Hine's emerald dragonfly (*Somatochlora hineana*)

Plants
wild lupine (*Lupinus perennis*)
Eurasian water-milfoil (*Myriophyllum spicatum*)
common buckthorn (*Rhamnus cathartica*)

Pathogens and Micro-organisms
chytrid fungus (*Batrachochytrium dendrobatidis*)
toxin-producing bacterium (*Clostridium botulinum*)

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