



Plants and Natural Communities Working Group Report

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WICCI Plants and Natural Communities Working Group



First Adaptive Assessment Report



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Executive Summary – Plants and Natural Communities Working Group

The warming of Earth's climate system is unequivocal, as evidenced by increases in global average air and ocean temperatures, extensive melting of snow and ice, and the increasing global average sea level. The evidence from a wide variety of plant species and communities shows that warming is strongly affecting natural biological systems. The ability of plants and natural communities to respond to climate change will depend in part on the rate and magnitude at which climate change occurs. Different species, populations, and individuals migrate and disperse at different rates, and land use patterns will complicate ecosystem adaptation to climate change by hindering migration. The synergism of rapid temperature rise and other existing stressors could easily disrupt the connectedness among species, leading to the reformulation of species communities.

In Wisconsin, as well as globally, climate change is likely to result in a reduction of biological diversity through the extinction of individual species, the displacement of others, and the disruption of species interactions. Recognizing and adapting to these changes may help maintain important ecological, biological, and social functions and values. To assess the impacts of climate change on plants and natural communities, the Plant and Natural Community Working Group (PNC), comprised of scientists from the University of Wisconsin-Madison and state and federal agencies, developed a matrix of impacts that could affect groups of natural communities (Table 1). The impacts were not meant to be all-inclusive but rather to include many of the major impacts that could result from climate change. We chose six impacts (pollination, range shift, disaggregation of species within natural communities, invasive species, fragmentation, and change in fire regime) to scrutinize more closely. This approach is not meant to diminish the importance of the other impacts, but is instead an opportunity to scrutinize selected impacts in greater detail.

Pollination

Scientists have observed substantial shifts in flowering phenology -- the timing of biological events over the course of a year -- that have the potential to disrupt the relationships that plants have with the animals, fungi, and bacteria that act as pollinators, seeds dispersers, predators, herbivores, and pathogens. Climate change could directly disrupt or eliminate mutually beneficial interactions like pollination between species. Southern upland forests, savannas, barrens, grasslands, and northern and southern wetlands could be moderately to greatly impacted by climate change. Due to their species composition and structure it seems likely that impacts may be low in the remainder of the community groups.

Range Shift

Many of the rare and native plant species are at the edges of their distributional ranges in Wisconsin and are often more abundant outside of the state. The response of species to a rapidly changing environment is likely to be determined largely by population responses at range margins. Isolated or peripheral populations of common species and rare species may be the first of Wisconsin's flora to show the effects of climate change because they occur more sporadically and often occupy less suitable habitat. The rate of migration will depend on a number of factors including dispersal barriers, suitable habitat for germination and establishment, and seed dispersal capabilities of the species. Climate change may affect not only individual species, but also their associated natural communities that are on the edge of their range.

Disaggregation

Climate change will likely fundamentally transform Wisconsin's ecological communities and landscapes, and some may change so much that they will disappear or disaggregate, being replaced by "novel" communities. The distribution and abundance of each species is governed by

its unique sensitivities to climate, local physical variables such as soil characteristics and topography, interactions with other species, and human action. The problem of climate-driven community disaggregation and formation of “novel” ecosystems poses a fundamental challenge to efforts to steward Wisconsin’s natural resources. We have a very limited capability for predicting the indirect effects of climate change, for example, those in which climate change affects communities by mediating existing interactions among species or by enabling new interactions among newly associated species within novel ecosystems.

Invasive Species

Invasive species, pathogens, and insect pests have long been recognized to have substantial human health, economic, and ecological impacts on the flora of North America. Increased carbon dioxide levels and nitrogen deposition could drive changes in ecosystem nutrient cycling that make such a system more vulnerable to invasive species. While some effects of invasive species might be more direct and obvious, such as competition, displacement, and usurpation of pollinators and other resources, others might be more unobtrusive. Climate change effects from invasive species, pathogens, and insect pests may pose moderate to high risks for all of the natural community groups in Wisconsin.

Fragmentation

The intricate mosaic of the natural communities of Wisconsin has greatly changed since statehood (Figure 1). Widespread urbanization, the development of a complex road network throughout the state, conversion for agricultural purposes, and other alterations that affect natural communities have resulted in a wholesale fragmentation of the natural landscape (Figure 2). Species in landscapes that are more intact with connected patches of suitable habitat might fare better than those that are in landscapes that have significant barriers to dispersal. Climate change could moderately to highly affect all of the natural community groups (Table 1). The combination of climate change and increased fragmentation could affect species and natural communities statewide. Reducing fragmentation and increasing connectivity could reduce the peril for some plant species.

Change in Fire Regime

Climate influences fire regimes in two ways: directly, by influencing weather patterns conducive to fire ignition and spread, and indirectly, by influencing plant communities through temperature and precipitation trends that favor or discourage fire-adapted plant species. Changes in fire regime could be most apparent for the most fire-prone natural communities, particularly in landscapes not fragmented such as the jack pine-dominated barrens in central and northern Wisconsin. Increased potential for fire may benefit certain community groups like grasslands (e.g., dry prairies), savannas and barrens (e.g., oak woodlands, oak and pine barrens), and some communities within the northern and southern wetlands (e.g., sedge meadows). Increased potential for fire may be detrimental to communities within other groups. Fire on the Wisconsin landscape has been limited by human control practices that focus on human safety and property.

Adaptation Strategies

The initial adaptation strategies for the WICCI Plants and Natural Communities Working Group are, by necessity, fairly broad, in part because this is the first step in the long-term process of developing risk assessments for individual species and natural communities. There are many aspects of the interactions and biology that are not known thereby making recommendations for specific plants or communities difficult. Here the PNC lays out a framework by which we will develop comprehensive plant species and natural community adaptation strategies.

Adaptation actions can be categorized in three groups. First, **resistance** adaptation actions are those defensive actions intended to resist the influence of climate change; they are intended to forestall impacts and protect highly-valued resources. Second, **resilience** actions improve the ability of ecosystems to return to desired conditions after disturbances. Finally, **response** or facilitation actions help facilitate the transition of ecosystems from the current to new conditions. The adaptation strategies below can be in more than one of these categories.

1. Risk Assessments

While it will clearly be impossible to eliminate uncertainty, to help reduce the amount of uncertainty in making decisions about resource allocations, risk assessments will be made of the vulnerability of individual species and natural communities to changing environmental conditions based on climate projections. The assessments could be used in prioritizing management and other adaptation actions. It is anticipated that vulnerability assessments resulting from the PNC Working Group would be useful for other WICCI working groups, including Forestry and Wildlife. Risk assessments can lead to short and long-term decisions and can contribute to the resistance, resilience, and response categories.

Evaluation of existing sites for buffers, connectivity, management needs, and other factors can point toward appropriate actions and allocation of resources. Small sites that have a high concentration of rare species having limited habitat availability may need additional buffer surrounding the site to reduce the influence of external stressors. Early response to invasive species may be critical for such sites.

Recognizing that resources are and will likely continue to be limited for conservation actions, site analyses can be used to prioritize decisions about land acquisition or easements. If two sites are roughly the same size, but one is relatively uniform in natural community types and distribution and the other has greater complexity due to factors like topographic relief, the latter property may have longer term conservation value. The more heterogeneous and complex a site, the more microhabitats are likely present that can meet more habitat and other requirements for a wide range of organisms.

A landscape evaluation would include many of the factors listed above but especially look at connectivity between sites and the range in size of individual sites in the landscape. The results of a larger-scale analysis can identify opportunities to collaborate among units of government and private landholders; it may also be able to suggest cross-border actions with neighboring states. A landscape assessment would also examine the degree of redundancy of sites because redundant sites can help spread risk instead of depending on only one or a few good quality sites.

An analysis of connectivity at landscape levels can identify important long-term opportunities for conservation actions. Depending on the species, its ability to disperse, and the relative permeability of the matrix, connectivity may not be as important for long distance dispersal as for other aspects of connecting sites. Corridors of natural habitat along natural environmental continuums can provide room for movement and provide favorable conditions for local adaptations.

2. Protection and Management

Existing conservation properties should be evaluated, both on a local, individual basis as well as in a landscape context. Assessments of individual sites would include an analysis of size, surrounding land use and degree of buffer, site heterogeneity and complexity, site integrity, exposure to external stressors, current management regimes, and connectivity to other local sites. After evaluations are completed, management activities can be prioritized. For example, if an

external stressor is identified as invasive species, property managers could work to reduce or eliminate the invasive species thereby contributing to the resistance and resilience of the property. Opportunities that were identified in the evaluation could lead to the protection of additional property by public or private organizations that increase the buffer or connectivity of the property.

Once adaptation actions have begun, it is important that researchers and land managers are able to determine the effectiveness of those actions. Monitoring, both on the ground and using remote imagery, will help guide adaptive management decision making. Adaptive management can help in the short and intermediate term (resistance and resilience) as well informing response actions for the longer term.

3. Assisted Migration

The actions above are well-established and widely applied in conservation biology. Other proposed actions, however, are much more divisive. One such proposal that is being widely debated in the conservation community is that of assisted migration, the idea that plants and animals should be moved geographically ahead of the projected wave of climate change. Rather than being a resistance or resilience action, assisted migration would be considered a facilitation action and therefore perhaps be considered for the long-term. Again, because we lack basic biological information about many species, including those that are rare, assisted migration may create more problems than they solve. It is probable that if assisted migration is deemed an appropriate measure, decisions will have to be made on an individual species basis.

Figure 1. Original vegetation of Wisconsin

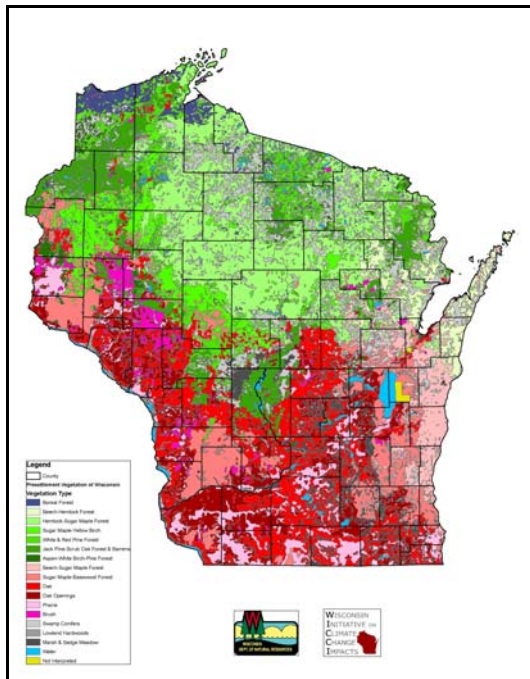


Figure 2. Modern land cover in Wisconsin

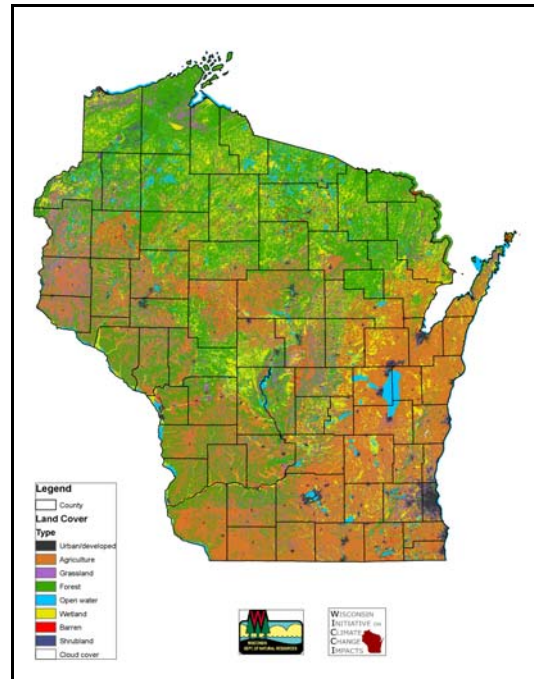


Table 1. Impact versus natural community group. The scale for impact levels is 0-3, with 3 having the highest impact.

Impact	Northern Upland Forests	Northern Lowland Forests	Southern Upland Forests	Southern Lowland Forests	Savannas & Barrens	Grasslands	Northern Wetlands	Southern Wetlands	Great Lakes Shore	Aquatic	TOTAL
<i>Phenological & related changes</i>											
Pollination	1	1	2	1	3	3	2	2	3	1	19
Shifts in dispersal	1	0	2	0	0	0	0	0	0	3	6
Early bud burst	2	0	2	0	0	0	0	0	0	0	4
<i>Biotic/abiotic factors</i>											
Range shift	3	3	2	2	0	0	2	3	2	1	18
Community disaggregation	3	3	3	3	3	3	3	3	3	3	30
Invasives/diseases/pests	2	2	3	3	3	3	2	3	2	3	26
Fragmentation/isolation	2	2	3	3	3	3	2	3	2	3	26
Herbivory	3	3	3	3	2	1	2	2	0	0	19
Soil distribution	1	0	1	0	0	0	1	3	0	0	6
<i>Fire</i>											
Change in fire frequency/intensity	3	1	2	1	3	3	1	1	0	0	15
<i>Weather impacts & extreme events</i>											
Change in frost dates	2	2	0	0	0	0	0	0	0	0	4
Extreme winter	0	0	2	2	0	0	0	2	0	0	6
Increased evapo-transpiration	1	1	1	0	0	0	3	3	0	0	9
Ice storms	3	1	1	1	0	0	0	0	0	0	6
Droughts (hydrology)	1	3	2	3	0	2	3	3	3	3	23
Floods & wetlands	0	2	0	3	0	2	3	3	3	0	16
Scouring (water, ice)	0	3	0	3	0	0	0	0	2	2	10
TOTAL	28	27	29	28	17	20	24	31	20	19	

Participants of Plants and Natural Communities Working Group

Craig Anderson – Wisconsin DNR (Chair)
Jim Bennett – UW-Madison and USGS
Owen Boyle – Wisconsin DNR
Richard Henderson – Wisconsin DNR
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Gregor Schuurman – Wisconsin DNR
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Joy Zedler – UW-Madison

Description of Plants and Natural Communities Topic Area

Plants are perhaps the most important species in shaping habitats and determining the physical environments that all species need for survival (Heimann and Reichstein 2008). Plant diversity is the foundation of all terrestrial natural communities. These ecosystems provide a range of critical services upon which all life depends. The ecosystem services include those that could be considered provisions (e.g., food, fiber), regulating like water purification and flood control, and cultural including recreation and aesthetic values (MEA 2005). Shifts in the spatial distribution of natural communities signal significant changes in the underlying ecosystems with effects on many different species (Lucht et al. 2006). Changes in climate and land use result in changes in ecosystem services and increased vulnerability (Schröter et al. 2005). Diverse and functional natural communities are more likely to be able to adapt to future climate change and to continue to provide us with crucial ecosystem functions (Hawkins et al. 2008).

The Plants and Natural Communities (PNC) working group’s mission is to focus on plants and their natural communities including ecological function and processes. The working group will address the use of natural areas (including State Natural Areas) in studying and measuring climate change on plants and natural communities and in maintaining viable populations of rare species. The working group recognizes that natural areas may play critical roles in supplying habitat and connectivity to many species that could help ensure long-term survival of species.

The Plants and Natural Communities Working Group will focus on the plants, both native and non-native, and natural communities of Wisconsin. The working group will analyze factors that contribute to the long-term viability of individual species and natural communities such as dispersal ability, habitat requirements, and pollinator specificity.

Future Climate Impacts

Climate change potentially could affect plants and natural communities in Wisconsin in a variety of ways, both directly by changing habitat suitability and indirectly by altering species interactions such as pollination. Potential climate change impacts and their effects on natural community groups are discussed in further detail below.

Sensitivity Analysis and Uncertainty

For this first assessment, the PNC working group analyzed potential climate change impacts on the fairly coarse scale of groups of natural communities. Although we have robust information about some species, we know little about the basic biology, ecological interactions, or migratory capacity of many other species, and our assessment identifies and describes these uncertainties.

Projections of the down-scaled climate models also include uncertainty - for example, under the moderate CO₂ emission scenario, the annual average temperature increase could range from about 3 to over 9°F.

Introduction

The vegetation of Wisconsin, like all of eastern North America, was considerably different when the most recent glaciation retreated. Species composition changed as the climate became suitable for colonization. Different species of trees migrated at different rates and from different locations. Many of the plant communities that look similar today have had different histories even within the last few thousand years (Davis 1983, Overpeck et al. 1992). During the past 10,000 years, climate has varied and species have responded individually. For example, about 5,000 years ago, the climate was warmer and the range of white pine (*Pinus strobus*) was further to the north. As the climate cooled, white pine contracted its range to the south. What is unusual about the modern climate change is the projected rate and magnitude of the change which could have profound consequences for plants and natural communities. After deglaciation, beech (*Fagus grandifolia*) and hemlock (*Tsuga canadensis*) extended their ranges north at average rate of about 20-25km per century. Today, however, those same species would need to be able migrate at a rate of about 300km per century (Davis 1989).

The warming of Earth's climate system is unequivocal, as evidenced by increases in global average air and ocean temperatures, extensive melting of snow and ice, and the increasing global average sea level (IPCC 2007). Except for northeastern Wisconsin, most of Wisconsin has warmed since 1950, with the most warming in the northwest. Thus far, the greatest warming has occurred during winter-spring rather than in summer, and average nighttime low temperatures have increased more than daytime high temperatures (WICCI 2010). Thus, it could be said that Wisconsin is becoming "less cold".

Biological as well as physical systems on all continents are being affected by recent climate change. The evidence from a wide variety of species and communities shows that warming is strongly affecting natural biological systems (IPCC 2007). Using a meta-analysis, Parmesan (2006) found that changes in phenology and distribution of a wide variety of plants and animals are occurring. These changes are heavily biased in the directions predicted by global warming. In Wisconsin, Bradley et al. (1999) looked at phenological records kept from 1936-1947 and 1976-1998 and found that of the 55 species (plants and animals) observed at their site, 17 showed earlier onset of seasonal biological activities like plant bud burst.

For Wisconsin, a recent down-scaled climate modeling initiative projects that average temperature could continue to increase. This model also predicts that heavy precipitation events and days over 90°F may become more frequent, but cold days less than 0°F could decrease in frequency (WICCI 2010). Continued climate change could affect biological systems which could continue to change. How biological systems and entities adapt, migrate, and disperse in response to climate change will depend, in part, on the rate and magnitude and pattern at which climate change occurs. Different species, populations, and individuals migrate and disperse at different rates, and land use patterns will influence ecosystem adaptation to climate change, probably hindering migration of some species (Higgins & Harte 2006). An increase in extinction risk may result (Jump and Peñuelas, 2005), particularly when climate change amplifies other stressors to rare species (Brook et al. 2008). Parmesan (2006) noted that for many species the primary impact of climate change might be mediated through effects on the synchrony with a species' food and habitat resources; potential disruption in the timing between predators and prey; insect pollinators with plants; and other interspecific interactions. In fragmented landscapes, which hinder the dispersal ability of species, rapid climate change is likely to overwhelm the capacity for

adaptation in many plant populations driving them to extirpation. The synergism of rapid temperature rise and other existing stressors could easily disrupt the connectedness among species, leading to the reformulation of species communities (Root et al 2003, Williams et al. 2004, Hobbs et al. 2006, Watling and Donnelly 2006, Williams and Jackson 2007). If climate change is rapid and large, some species likely will benefit, while others likely will decline or perish.

Methods

In order to assess the potential effects of climate change on the plants and natural communities of Wisconsin, the Plant and Natural Community working group (PNC) developed a matrix of impacts that could affect groups of natural communities (Table 1). The impacts were not meant to be all-inclusive but rather to include many of the potential major impacts that could result from climate change. Some of the impacts, such as invasive species, are applicable at larger scales such as statewide or ecological landscapes (<http://dnr.wi.gov/landscapes/>). Others such as ice storms might be more applicable at smaller, local scales. Many of the impacts, however, could be applicable at multiple scales and interact with one another.

The working group chose to use the Wisconsin Natural Heritage Inventory natural community classification systems (<http://dnr.wi.gov/org/land/er/communities/>) as a standard. Table 2 shows the placement of individual natural community types into ten broad community groups. The assignment of forested and wetland natural communities in the northern versus the southern community group was based on community distribution in the northern and southern ecological provinces (<http://dnr.wi.gov/forestry/ecolandclass/elcprovince.htm>). Note that some communities, e.g., talus forest, occur in both ecological provinces. Generally those in more than one group are minor community types that did not affect the assessment impacts of individual community groups. Impact types were clustered together as much as possible in four general categories (Table 1, indicated by different colors). While many of the impacts are interrelated and could lead to greater cumulative effects, each impact was assessed individually. For each impact type, the working group assigned a numerical score (0-3, with 3 indicating there could be the greatest impact resulting from climate change), based on available information and the knowledge and opinions of working group members, to each community group. In the course of the assessment, some impacts were thought to pose little or no impacts to individual community groups and hence were assigned a score of zero. In some cases, the working group did not have enough information to make an informed assessment and assigned an initial score of zero to those impacts.

Once a score was assigned to each cell in the matrix, a total was tallied for each impact and each community group (Table 1). After examining the results, the working group noted that a number of impacts were important for multiple community groups and decided to focus further analysis on impacts across community groups rather than by individual groups. The working group used the total impact scores (right-hand column in Table 1) within each of the four impact categories to determine which impacts should be further discussed for this first assessment. This approach is not meant to diminish the importance of the other impacts, but is instead an opportunity to scrutinize selected impacts in greater detail. The potential impacts that were chosen are pollination, range shift, disaggregation of species within natural communities, fragmentation and isolation, and change in fire frequency and intensity. Assessments for these impacts were done using a variety of sources including down-scaled climate projections produced by the WICCI Climate working group, scientific literature, and professional judgment.

Table 1. Impact versus natural community group. The scale for impact levels is 0-3, with 3 potentially having the greatest impact.

Impact	Northern Upland Forests	Northern Lowland Forests	Southern Upland Forests	Southern Lowland Forests	Savannas & Barrens	Grasslands	Northern Wetlands	Southern Wetlands	Great Lakes Shore	Aquatic	TOTAL
<i>Phenological & related changes</i>											
Pollination	1	1	2	1	3	3	2	2	3	1	19
Shifts in dispersal	1	0	2	0	0	0	0	0	0	3	6
Early bud burst	2	0	2	0	0	0	0	0	0	0	4
<i>Biotic/abiotic factors</i>											
Range shift	3	3	2	2	0	0	2	3	2	1	18
Community disaggregation	3	3	3	3	3	3	3	3	3	3	30
Invasives/diseases/pests	2	2	3	3	3	3	2	3	2	3	26
Fragmentation/isolation	2	2	3	3	3	3	2	3	2	3	26
Herbivory	3	3	3	3	2	1	2	2	0	0	19
Soil distribution	1	0	1	0	0	0	1	3	0	0	6
<i>Fire</i>											
Change in fire frequency/intensity	3	1	2	1	3	3	1	1	0	0	15
<i>Weather impacts & extreme events</i>											
Change in frost dates	2	2	0	0	0	0	0	0	0	0	4
Extreme winter	0	0	2	2	0	0	0	2	0	0	6
Increased evapo-transpiration	1	1	1	0	0	0	3	3	0	0	9
Ice storms	3	1	1	1	0	0	0	0	0	0	6
Droughts (hydrology)	1	3	2	3	0	2	3	3	3	3	23
Floods & wetlands	0	2	0	3	0	2	3	3	3	0	16
Scouring (water, ice)	0	3	0	3	0	0	0	0	2	2	10
TOTAL	28	27	29	28	17	20	24	31	20	19	

Table 2. Distribution of natural communities into community groups. The ten community groups are **bolded**. Descriptions of the individual natural communities can be found at <http://dnr.wi.gov/org/land/er/communities/>.

Northern Upland Forests	Northern Lowland Forests	Southern Upland Forests	Aquatic
Boreal forest	Black spruce swamp	Central Sands pine-oak forest	Coldwater streams
Mesic cedar forest	Forested seep	Hemlock relict	Coolwater streams
Mesic floodplain terrace	Northern hardwood swamp	Pine relict	Impoundments/reservoirs
Northern dry forest	Northern wet forest	Southern dry forest	Inland lakes (all types)
Northern dry-mesic forest	Northern wet-mesic forest	Southern dry-mesic forest	Lake Michigan
Northern mesic forest	Tamarack (poor) swamp	Southern mesic forest	Lake Superior
Talus forest		Talus forest	Warmwater streams
			Warmwater rivers
Southern Lowland Forests	Savannas & Barrens	Grasslands	Spring ponds
Floodplain forest	Cedar glade	Bracken grassland	Springs & spring runs
Southern hardwood swamp	Oak Opening	Dry prairie	
Southern tamarack swamp (rich)	Oak Woodland	Dry-mesic prairie	
White pine-red maple swamp	Great Lakes Barrens	Mesic prairie	
	Oak Barrens	Sand prairie	
	Pine Barrens	Surrogate grassland	
	Sand Barrens		
Northern Wetlands	Southern Wetlands	Great Lakes Shore	
Alder thicket	Bog relict	Bedrock shore	
Boreal rich fen	Calcareous fen	Great Lakes alkaline rockshore	
Emergent marsh	Central poor fen	Great Lakes beach	
Emergent marsh-wild rice	Coastal plain marsh	Great Lakes dune	
Ephemeral pond	Emergent marsh	Great Lakes ridge & swale	
Muskeg	Emergent marsh-wild rice	Interdunal wetland	
Northern sedge meadow	Ephemeral pond	Shore fen	
Open bog	Moist sandy meadow		
Poor fen	Patterned peatland		
Patterned peatland	Shrub-carr		
Shrub-carr	Southern sedge meadow		
	Wet prairie		
	Wet-mesic prairie		

Impacts

Pollination

Temperature has an important influence on many plant development processes, and governs the timing of many plant phenological events (Badeck 2004). In a meta-analysis of advancement of spring events, Parmesan (2007) found that across all taxa globally, including vascular plants, the mean response is between a 2.3 and 2.8 days/decade. The response of individual species varies around the average (Memmott et al. 2007). If there are substantial shifts in flowering phenology it could disrupt relationships between plants and the animals, fungi, and bacteria that act as pollinators, seeds dispersers and predators, herbivores, and pathogens (Dunne et al. 2003).

Climate change could disrupt or eliminate mutually beneficial interactions between species (Memmott et al. 2007) including pollination. About 70-90% of all angiosperms are pollinated by animals (Fontaine 2006), primarily insects. Host plants potentially benefit from pollen exchange, and animals benefit nutritionally. The vast majority of insect pollination is carried out by Hymenoptera (bees, wasps, and hornets) and Lepidoptera (moths and butterflies), with lesser amounts by flies and beetles. Nearly 400 species of bees occur in Wisconsin (Wolf and Ascher 2008). The vascular plants of Wisconsin consist of over 2600 species (Wetter et al. 2001), and changes in phenological timing could have significant impacts in natural communities.

Pollinators generally outnumber plants by about three to one (Memmott et al. 2004), and most plants have multiple pollinators and vice versa (Memmott et al. 2004). However, there are well-known instances of specialist pollinators associated with certain plants, and such specific relationships can be highly vulnerable to disruptions leading to the extinction of species (Harrison 2000). Pollinator-plant relationships are very diverse, and the details of those interactions are important. For example, creosotebush (*Larrea tridentata*) is a locally abundant and geographically widespread shrub in the southwestern deserts of the United States (Figure 1). It is pollinated by about 120 bee species, many of which are specialists on creosotebush (Vázquez and Aizen 2004). While creosotebush is not dependent on any single bee species, the extirpation of the shrub could affect many local pollinators that specialize on creosotebush.

In general, Wisconsin's ecosystems are relatively young and species tend to be less specialized and habitat dependent than in many other regions, however, even here there are concerns. For example, the specialized structure of the flowers of the Midwest-endemic eastern prairie fringed orchid (*Platanthera leucophaea*, Figure 2) limits pollination of this federally threatened species to only a few species of hawkmoth (Crosson et al. 1999). Any disruption of this interaction between the hawkmoth and the orchid could result in the extinction of the eastern prairie fringed orchid. Gordo and Sanz (2005) observed that insect phenology is showing a steeper advance than plant phenology, suggesting the possibility of a phenological decoupling between pollinators and flowers. Similarly, Biesmeijer et al. (2006) found that outcrossing-dependent plant species that rely on pollinator species that are in decline have themselves declined relative to other plant species. They also noted that in Britain plant species that are reliant on abiotic (e.g., wind) pollination are increasing.

Memmott et al. (2007) simulated future phenological shifts using data from a natural community in Illinois. Their simulation indicates that shifts in phenology could potentially disrupt the temporal overlap between pollinators and flowers. If phenological changes result in a decline in pollinator functional diversity then plant population declines or extirpations are likely to follow, and ultimately the structure and composition of natural communities will change (Fontaine et al. 2006).

Figure 1.a. Distribution of creosotebush the southwestern United States. Dark green indicates that it is present in a state and considered native, light green is present in a county and is not considered rare. Source: BONAP 2010. b. Flowers of creosotebush.

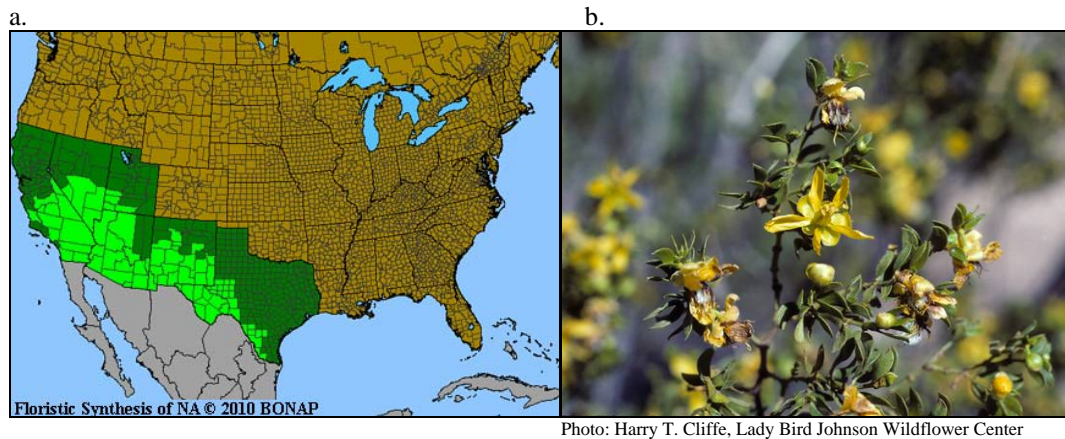
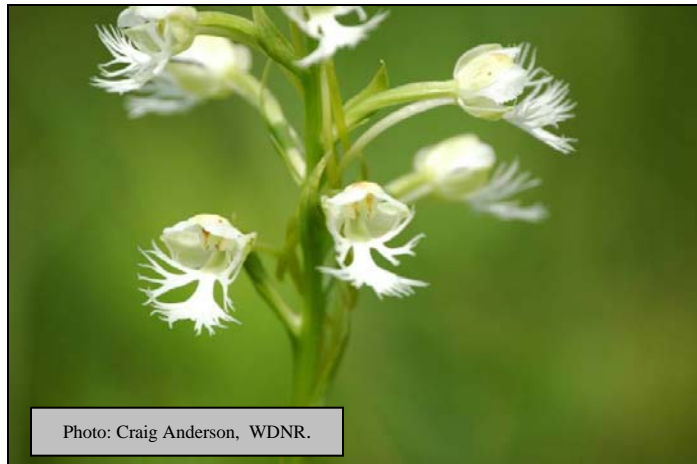


Figure 2. Eastern prairie fringed orchid in flower. Note the long nectar spur protruding from the back of the flowers.



Many studies show a correlation between pollinator populations and flowering time (Rathcke and Lacey 1985). Sometimes, however, the synchrony between the pollinators and flowers is not very strongly coupled. For example, larvae of the winter moth have been observed to suffer mortality rates $\geq 90\%$ when phenological mismatches occur between egg hatch and oak leaf bud burst (Feeny 1970). When such mismatches already exist, insect pollinators may be highly vulnerable to small changes in synchrony with their hosts, and flowering plants may be very vulnerable to small changes in synchrony with their pollinators (Parmesan 2007).

Although the overall trend is toward advanced spring phenological events, the rate and severity of change in the inter-annual variation in the onset of spring can affect the responses of pollinators and flowering plants. Wall et al. (2003) found that the onset of flowering of *Clematis socialis* varied by about three weeks, and that this variation affected the relative importance of individual species of pollinators. The instability of spring conditions in a deciduous forest can affect the reproductive success of spring ephemeral herbs by at least two biological mechanisms: the asynchronization of flowering with pollinator activity and the asynchronization of flowering with canopy closure (Kudo et al. 2008).

According to projections by the WICCI Climate working group, spring temperatures across the state could increase by 3-9°F by the mid-century (WICCI 2010). Spring onset could occur earlier and the growing season could be longer. Flowering plants and their pollinators will respond individually, with some species advancing, others maintaining a similar phenology, and possibly some even showing a retarded spring phenology. Changes that result in the decoupling of species interactions could have not only the direct effects of reduced species fitness and perhaps extirpation, but also a host of indirect cascade effects if the structure and function of the natural communities are also affected. The impacts of asynchrony between an individual pollinator may be ameliorated by a redundancy of other pollinators. Pollinator visit frequency and efficiency are important considerations; efficient pollinators will have a stronger interaction with individual plant species than will rare visitors or frequent, inefficient visitors (Vásquez and Aizen 2004).

Insect-pollinated species are present in all native plant communities of the state, but communities with higher light levels tend to have a higher proportion of insect-pollinated plants. High light-level communities include prairies, savannas, barrens, sedge meadows, and dune communities. Deciduous forest communities may also have higher light levels in the spring of the year. Natural community groups (Table 1) that could be moderately or highly impacted by changes in pollination include Southern Upland Forests, Savannas & Barrens, Grasslands, and Northern and Southern Wetlands. Species composition and structure of the other community groups suggest that impacts could be low.

As with all of the impacts assessed by this working group, there is a recognition that each factor can interact with other stressors on the landscape. In the instance of pollination, existing plant populations may already be vulnerable, exclusive of potential climate change impacts, because of small population size or insufficient density to attract pollinators to begin with (Steven et al. 2003). Also, effective population sizes might be reduced due to herbivory, especially by deer, which reduces the number of flowers.

In summary, animals, especially insects, are important pollinators of plants. Potential changes in phenology could affect plant-pollinator interactions. Some species, especially those with specialized relationships, could be negatively impacted leading to population declines, extirpation, or even extinction.

Edge of Range Effects

Worldwide, recent observed changes in the distribution of multiple plant and animal species are consistent with global-warming predictions. Range-restricted species, especially those in the polar regions and on mountaintops, have shown severe range contractions (Parmesan 2006). In one analysis, Parmesan and Yohe (2003) found significant range shifts that averaged 6.1km/decade toward the poles.

Wisconsin is at an ecological crossroads because of its geographic position and geological and climatic history. Much of the current native flora of Wisconsin resulted from plant migrations that occurred (and continue) after the last glacial retreat from the Allegheny Mountains, Ozark Mountains, and the prairies and remnant boreal elements (Curtis 1959). Most of the rare and many of the common native plant species in Wisconsin are at or near the edges of their continental distributional ranges and are often more abundant outside of the state. The northern ecological province has many species, including those with boreal affinities, that are at the southern edge of their range; likewise, the southern ecological province has species that are at the northern edge of their range; there are plants in western Wisconsin that are more typically found in the Great Plains.

From the center to the edge of a species' range, typically both the proportion of sites occupied and the average population density decreases (Lawton 1993). Genetically isolated populations and those on the extreme margins of their ranges are expected to diverge from the core-range populations as a result of isolation, genetic drift, and natural selection (Lesica & Allendorf 1995). These isolated and peripheral populations present both constraints and opportunities for the conservation and management of individual species (Lesica & Allendorf 1995).

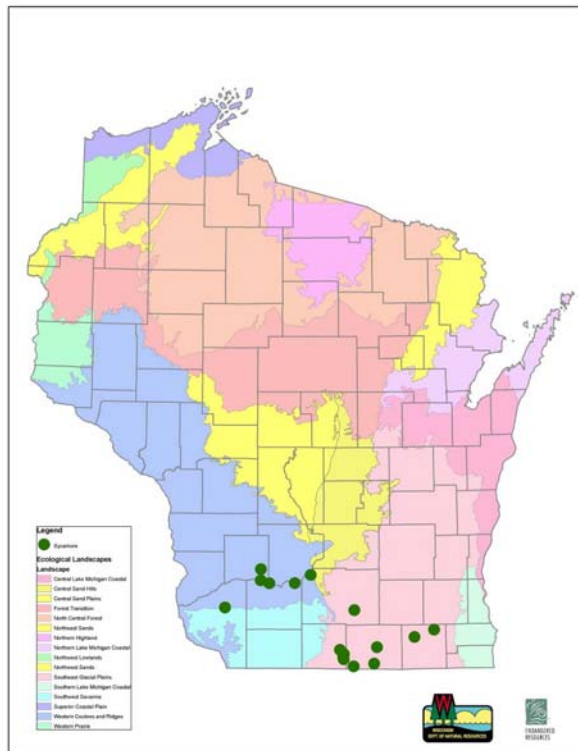
Even species that have the core of their range in Wisconsin may experience distributional shifts within the state as climate changes. Isolated and peripheral populations and rare species may be the first of Wisconsin's flora to show the effects of climate change because they occur more sporadically, occupy uncommon niche environments, or occupy less suitable habitat (Lesica & Allendorf 1995). For example, dwarf huckleberry (*Vaccinium cespitosum*) is widespread in Canada and occupies a variety of habitats. In Wisconsin, however, this species is found at a very limited number of sites in openings in pine barrens in the northeastern part of the state. Some species that occur today in the Driftless Area of southwestern Wisconsin may have survived there during the last ice age. Some of those species subsequently expanded their range into other parts of the state. Other species were more sedentary and remain confined to the Driftless region. For example Lapland azalea (*Rhododendron lapponicum*), is a circumboreal species that is only known from two locations in Wisconsin where it is likely a relict species remaining from the last recession of the glaciers. If temperatures and precipitation patterns change, Lapland azalea may be extirpated from Wisconsin.

As climate changes, species currently occurring south of the state could move into Wisconsin, and species at the southern edge of their range in northern Wisconsin could move out of the state. Species that occur at few locations or that are present in low numbers in Wisconsin, such as sycamore (*Platanus occidentalis*; Figure 3), could expand their ranges in the state. The rate of migration will depend on many variables including dispersal barriers and opportunities, human activities, suitable habitat for germination and establishment, and species specific dispersal mechanisms.

Plant species are dispersed by animals, have very light wind-disseminated seeds, or are propagated by spores may be able to exploit new habitat by their ability to migrate and establish the fastest. Such a group would include vascular plants like orchids (which have dust-like seeds) and asters (which have airborne seeds) as well as the spore-producing ferns, mosses, and lichens. Mosses, lichens, ferns, and annual herbs are often the first groups of species to pioneer new habitat (Connell & Slatyer 1977, Shure & Ragsdale 1997). An example of a southern lichen species moving into Wisconsin is the gold-eye lichen (*Teloschistes chrysophthalmus*). A small number of recent reports indicate that gold-eye lichen may be moving into Wisconsin from the southwest and plains states, the core of its range. One vascular plant that appears to be expanding in the state is pokeweed (*Phytolacca americana*). Within the past 30 years it is slowly expanding from its previous range in the lower tier of southwestern Wisconsin toward the north with recent observations in Richland, Sauk, and La Crosse counties (T. Cochrane pers. comm.).

Conversely, other species that might be predicted to migrate easily could become extirpated due to a loss of habitat in parts of the state. In Wisconsin, horsehair lichen (*Bryoria* species) is a genus that only grows on conifer tree species in the northern part of the state. This genus used to be common in the north and scattered elsewhere in Wisconsin (Figure 4), but is extremely rare now, and could become extirpated in the state with climate warming. It's not known if *Bryoria* species are as important to the diet of northern flying squirrels as it is for those in the western United States (Dubay et al. 2008), but if so, loss of horsehair lichens could generate cascading ecological effects.

Figure 3. Documented occurrences of sycamore in Wisconsin. Data are from Wisconsin Natural Heritage Inventory (<http://dnr.wi.gov/org/land/er/nhi/>).



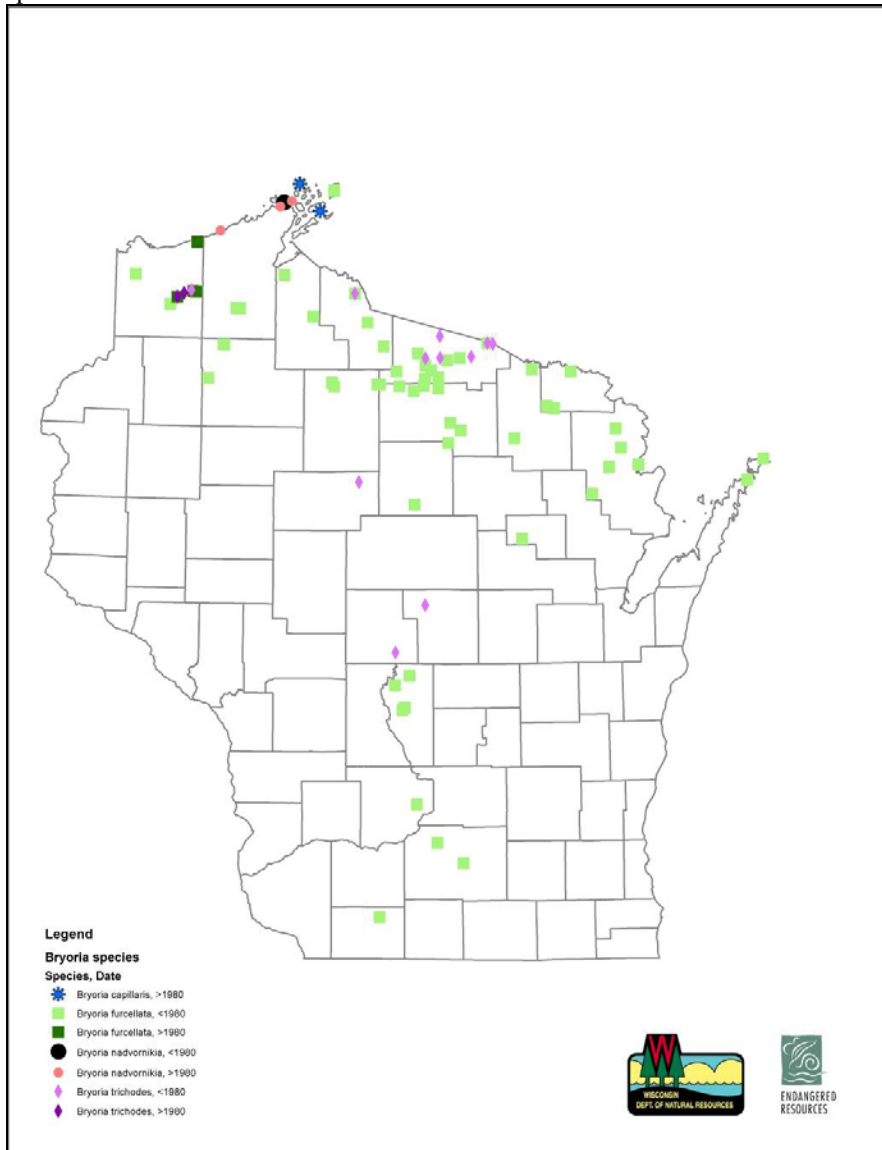
Natural communities that are on the edge of their range may also be affected by climate change. The southern tamarack swamp (rich) is part of the Southern lowland forests community group and, as implied by the name, is dominated by tamarack. Tamarack swamps were formerly abundant in the southern ecological province. However, many stands in southern Wisconsin appear to be in marginal condition at present, having already been affected by hydrological alterations, recent colonization by invasive plants, and insect infestations (e.g., larch sawfly in coniferous wetlands). Some models project (Prasad et al. 2007, http://www.planthardiness.gc.ca/ph_main.pl?lang=en) that the bioclimatic envelope required by tamarack could shift north leading to the extirpation of the species and the associated species that form its natural community in southern Wisconsin.

Natural community groups (Table 1) that could be highly impacted by shifts in range include northern upland and lowland forests and southern wetlands. Southern upland and lowland forests, northern wetlands, and Great Lakes shore natural community groups could be moderately impacted by range shift.

In summary, common species in isolated or peripheral populations and rare plant species could be the first to show the effects of climate change. If climate change continues and is rapid and severe, then rare plants with specialized habitat requirements or limited dispersal capabilities are of concern, especially in fragmented landscapes. Additionally, species that are at the southern edge of their ranges could be vulnerable. Plant species at the northern edge of their ranges could increase and expand their ranges. Such an expansion would depend on the ability of the plants to

disperse to and establish in suitable habitat. Depending on the individual species responses, natural communities could be affected.

Figure 4. Map of pre- and post-1980 collections in the Wisconsin State Herbarium of four *Bryoria* lichen species in Wisconsin.



Community disaggregation and novel ecosystems

Uncertainty language in this section follows the definitions of the IPCC 2007 report as shown in Table 3. Beyond the threats posed to the specific natural community types of Wisconsin, we potentially face a deeper, more fundamental change: under business-as-usual climate-change scenarios (e.g., A2, A1B from the IPCC 2007 report), Wisconsin's ecological communities and landscapes likely will be fundamentally transformed by climate change, and some may change so much that in essence they will disappear or disaggregate, and be replaced by new community associations (types). The potential disaggregation of communities and formation of novel communities raises fundamental questions for management – how to manage types of

communities that we've never seen? – and heightens the risk of surprises arising from new interactions among species (Hobbs et al. 2006, Williams and Jackson 2007).

Table 3. Uncertainty language from IPCC 2007, Technical Summary, Box TS-1.

Likelihood Terminology: Likelihood of the occurrence/ outcome	
<i>Virtually certain</i>	> 99% probability
<i>Extremely likely</i>	> 95% probability
<i>Very likely</i>	> 90% probability
<i>Likely</i>	> 66% probability
<i>More likely than not</i>	> 50% probability
<i>About as likely as not</i>	33 to 66% probability
<i>Unlikely</i>	< 33% probability
<i>Very unlikely</i>	< 10% probability
<i>Extremely unlikely</i>	< 5% probability
<i>Exceptionally unlikely</i>	< 1% probability

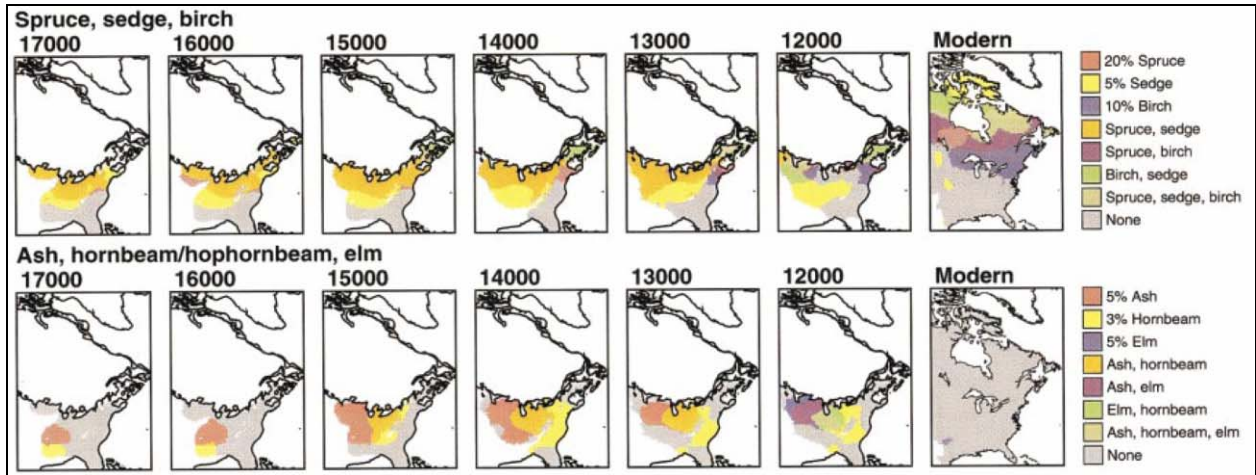
Communities are unique, ephemeral mixtures of species. The distribution and abundance of each species is governed by its environmental adaptations, such as sensitivities to climate, local physical variables such as soil characteristics and topography, interactions with other species, and human action. It is extremely likely that even under the most moderate climate-change scenarios for this century, species distributions will change significantly. Indeed, there is already evidence that climate change is causing shifts in forest population demographics (e.g., elevated rates of mortality) and tree species ranges (van Mantgem et al. 2009, Harsch et al. 2009). Although some species are highly interdependent (e.g., some plants and their pollinators, parasites and their hosts), for many species these interdependencies are weak or indirect (Inouye 2001, Lortie et al. 2004). Given this, communities are best viewed as temporary associations of species, subject to change as species respond individually to environmental change (Gleason 1917, 1926).

This individualistic perspective, and the transitory nature of communities, is strongly supported by the history of species responses to the climate changes accompanying the last deglaciation. Species-level shifts in range and abundance were highly individualistic, and communities did not migrate as intact units (Davis 1981, Williams et al. 2004). Rather, the rates and routes of migration varied widely among species, new communities emerged, and other communities disaggregated (Figure 5).

The problem of climate-driven community disaggregation and formation of ‘novel’ ecosystems poses a fundamental challenge to our efforts to steward Wisconsin’s natural resource. Current management practices are based upon more than a century of hard-won experience observing, experimenting with, and managing Wisconsin’s ecological landscapes (e.g., Curtis 1959). Based on this experience, we can identify specific natural community types, populations, and species that may be particularly vulnerable to the direct effects of climate change, e.g., populations of individuals that are already near the temperature tolerance limits for that species, species with specific habitat requirements, or species that are drought-intolerant or vulnerable to increased hydrological variability. For example, northern monkshood (*Aconitum noveboracense*) is a highly disjunct species of eastern North America (Figure 6 from BONAP 2010). Its current distribution borders the furthest extent of the last glaciation (see maps in Figure 5). The few Wisconsin populations are all associated with areas of cold air drainage in the Driftless area. In the down-scaled climate projections produced by the WICCI Climate working group (WICCI 2010), it is

virtually certain that winter temperature could continue to increase this century, which is more than likely than not to cause the loss of the microhabitat conditions needed by monkshood.

Figure 5. Maps illustrating the shifting associations among plant taxa over time. The maps are based on networks of fossil pollen records collected from lake and mire sediments, and each row maps the shifting combinations of three plant taxa. Each column represents a different time period, with numbers indicating the age in thousands of years before present. Each plant taxon is mapped as “abundant” or “rare” using a threshold value of relative pollen abundance, and each combination of plant taxa is represented by a unique color (Jacobson et al. 1987). Color changes among maps thus indicate changes in associations among species. Source: Williams et al. (2001).



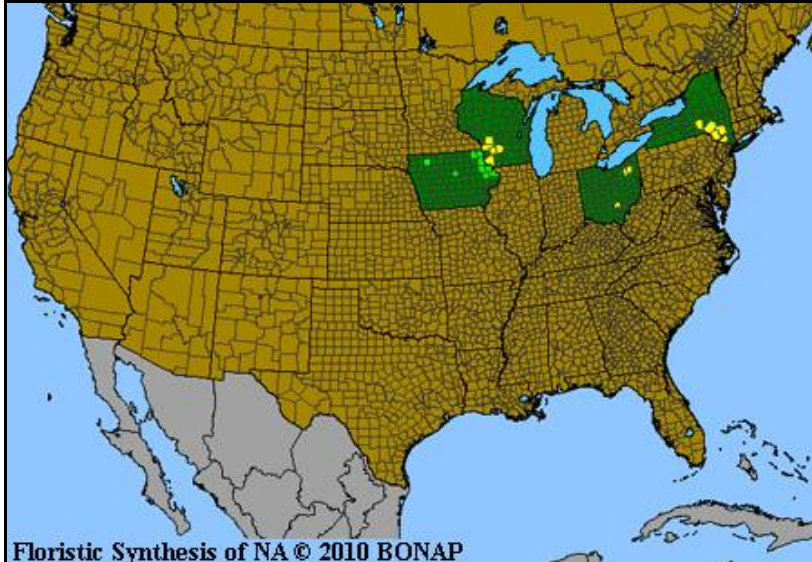
However, we have a very limited capability for predicting the indirect effects of climate change, i.e., those in which climate change affects communities by mediating existing interactions among species or by enabling new interactions among newly associated species within novel ecosystems. The introduction of non-native species into Wisconsin and elsewhere offers numerous examples of how even a single species can transform the composition and function of ecosystems. For example, damage estimates associated with the inadvertent introduction of emerald ash borer are already estimated at tens of millions of dollars in a relatively small geographic area. (<http://www.emeraldashborer.info/>).

Even among native species, climate change could trigger unexpected consequences. For example, bark beetles are native to the western US, but their recent outbreaks and the high rates of death in conifer trees, has been linked to warmer temperatures (which has increased winter survival rates for beetles and shortened generation times) and drought (reducing the defensive capabilities of trees) (Raffa et al. 2008). The uncertainty arising from novel ecological interactions is difficult to quantify, but is similar in magnitude to the uncertainties arising from physical modeling of 21st-century climate change and the scenarios of 21st-century trajectories of greenhouse gas emissions. Much of the ecological impacts of future climate change cannot be closely predicted in advance – we must be prepared to expect the unexpected. All natural community groups (Table 1) could be highly impacted by disaggregation.

In summary, even the relatively moderate climate-change scenarios projected for this century are *extremely likely* to cause changes in the abundance and range of species. Responses of species to past climate changes have been highly individualistic, resulting in the formation of communities unlike any today. Therefore, 21st-century climate change is *likely* to affect species

interrelationships within communities, resulting in significant changes within many community types, the effective disappearance of others, and the development of new community types.

Figure 6. The worldwide distribution of northern monkshood. Dark green indicates that it is present in a state and considered native, light green is present in a county and is not considered rare, and yellow is present in a county and considered rare. Source: BONAP 2010.



Invasive species, pathogens, and insect pests

Invasive species, pathogens, and insect pests have long been recognized to have substantial economic, human health, and ecological impacts on the flora of North America. Invasive species alone cause billions of dollars worth of damage annually in the United States (Simberloff 2000; Pimental et al. 2005). Many of the exotic plant species in the United States have been introduced deliberately, for agricultural, ornamental, conservation, or other purposes. Others have been accidentally introduced in contaminated seed mixes or packing materials. The majority of the exotic species introduced to the United States do not become invasive, at least under current conditions due, perhaps in part, to their climatic tolerances. Long distance dispersal barriers continue to lessen for exotic species due to increased human connectivity and travel leading to the introduction of exotics into new areas where they then may be able to establish and expand.

Many native species are threatened by competition and predation from invasive species, and other species are endangered by hybridization with alien species (Pimental et al 2001). For example, purple loosestrife was introduced originally as an ornamental and has out-competed native wetland species across significant acreage in North America. Invasive species, pathogens, and insect pests can cause significant changes in ecosystem composition and function like nutrient cycling and fire frequency. In the space of about 50 years, Asian chestnut blight virtually eliminated American chestnut, a formerly dominant or co-dominant tree in millions of acres of forest, across the eastern United States (Simberloff 2000).

Elevated carbon dioxide (CO₂) levels associated with climate change may intensify the invasion of exotic species if they are able respond more rapidly than native species. Many invasive plants may respond favorably to higher CO₂ by increasing aboveground production and seed rain, depending in part on local availability of other nutrients and precipitation (Dukes & Mooney 1999; Smith et al 2000). Increased CO₂ levels and nitrogen deposition can drive changes in

ecosystem nutrient cycling that make such a system more vulnerable to invasive species (Dukes & Mooney 1999, Craine et al. 2003). Climate projections indicate that available nitrogen in the soils could increase. Some plant groups, such as weedy species, benefit from increased nitrogen availability (Euskirchen et al. 2009).

Climate change could interact with other environmental variables to affect the abundance, distribution, spread, and impact of invasive species. Hellman et al. (2008) proposed five potential consequences of climate change for invasive species. The first is altered transportation of invasive species with examples including longer Great Lakes shipping seasons creating greater propagule pressure or widespread planting of species outside of their native range for biofuels. Secondly, altered climatic constraints could allow invasive species to establish or persist, such as warmer winters could allow cold-temperature sensitive species to establish further north (Owens et al. 2004). Third, altered distributions of existing invasive species could lead species to either advance or contract their ranges; Bradley et al. (2009) developed bioclimatic models that indicate that yellow starthistle could expand its range, and leafy spurge (*Euphorbia esula*) could contract its range in the western United States. Fourth, altered impact of existing invasive species; impact will depend on range size, abundance in range, and per capita effect. The significance of the impact on native species and ecosystems will depend on the size of the native populations and scarcity of native resources, both of which can be affected by climate change. The last consequence is the altered effectiveness of management strategies. For example, a biocontrol agent that is effective today might have temperature limits that could be exceeded in the future consequently managers might have to use more aggressive and sustained control efforts.

While some effects of invasive species might be more direct and obvious, such as competition and displacement and usurpation of pollinators and other resources, others might be more unobtrusive. Researchers at Walden Pond in Concord, MA (Willis et al. 2008, Willis et al. 2010) used long-term phenological observations that were first collected by Henry David Thoreau in the 1850s and updated periodically since then. They found a number of interesting things. First, invasive exotic species have, in slightly over 150 years, shifted their flowering time to be 11 days earlier than native species. Non-native species that are able to shift have good potential to become invasive. Some of these non-native species appear to possess a common set of phenological traits that give them advantages over many native species (Willis et al. 2010). The earlier flowering period may permit the invasive species to exploit pollinators and other resources to the disadvantage of native species (Willis et al. 2010; see also Pollination section above). Also, flowering-time response to temperature is shared among closely related species; some species groups, such as asters and orchids, do not respond strongly to temperature, and Willis et al (2008) found that those groups have declined in abundance. Climate change appears to have affected and will likely continue to steer the phylogenetic composition of native and non-native plants.

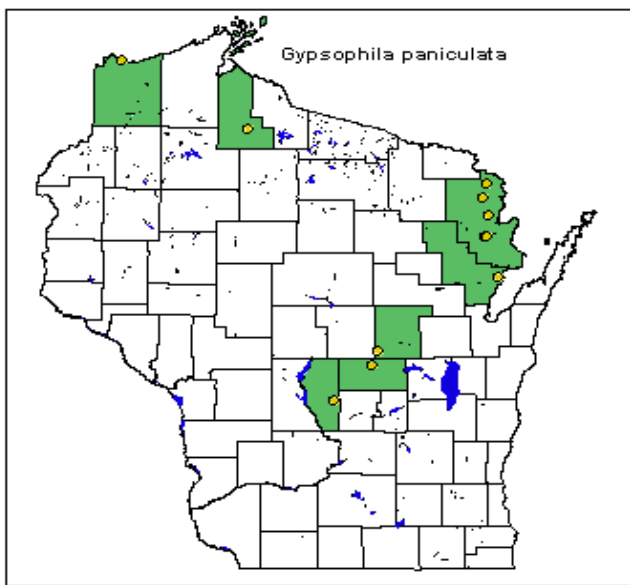
Climate change effects from invasive species, pathogens, and insect pests could pose moderate to high risks for all of the natural community groups in Wisconsin (Table 1). Down-scaled climate projections produced by the WICCI Climate Working Group (WICCI 2010) forecast that by mid-century overall temperature could rise. Perhaps most significantly, winters could be warmer and nights that drop below 0°F may be less common, especially in northern Wisconsin. Spring is also projected to arrive earlier. Warmer overwintering temperatures may allow invasive species that are already established in southern and western Wisconsin to expand their ranges north and east, and those species that lie to the south or west of the border of the state to invade and become established.

The Wisconsin Department of Natural Resources in collaboration with other partners has developed an invasive plant species early detection project. The goals of the project are to

identify and report populations of species of targeted invasive plants, eliminate or contain those populations before they spread, and coordinate long-term monitoring of occurrence sites. The WDNR recently implemented a rule (NR40, <http://dnr.wi.gov/invasives/classification/>) that lists most of these early detection species as “Prohibited” and requires their control wherever they establish in the state. Species that are included on the early detection list include those that already occur in small areas in the state but are likely to expand and those that are likely to enter and establish in Wisconsin.

An example of a species already established but in widely scattered locations (Figure 7) is baby’s-breath (*Gypsophila paniculata*). Baby’s-breath may be especially problematic for natural communities in the Great Lakes Shore Community group. The coarse, sandy soil of the Great Lakes sand dunes provides a good habitat for baby’s breath. This possibility is troublesome because baby’s-breath’s long tap-root can stabilize naturally shifting sand dunes to the point of significantly changing the open dune habitat that certain native plants need as is the case with the federally threatened dune thistle (*Cirsium pitcheri*). Baby’s-breath is currently invading the east shore of Lake Michigan, but has not yet been found on the Wisconsin side of the lake.

Figure 7. Distribution of baby’s-breath in Wisconsin. Source: Wisconsin State Herbarium (<http://www.botany.wisc.edu/wisflora/>).

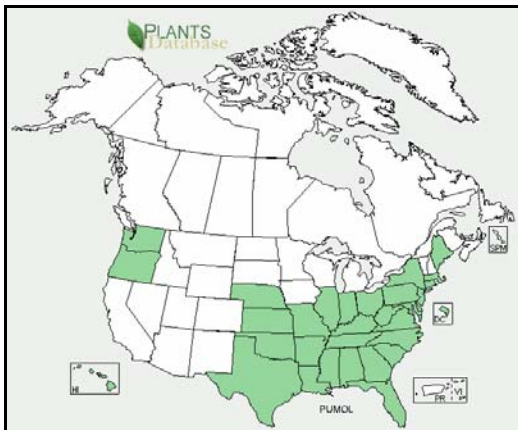


Kudzu (*Pueraria lobata*) has also not been found in the state, yet, but already occurs as far north as Chicago. Kudzu grows in much of the eastern United States and the Pacific Northwest (Figure 8), where it appears in forest edges, abandoned fields, roadsides, and disturbed areas.

Kudzu infests many acres of land, especially in the southeastern United States and completely replaces the existing vegetation. If the bioclimatic environment becomes favorable for kudzu in Wisconsin, it could become established in the state and could affect natural communities by outcompeting and replacing some species

All natural community groups could be moderately to highly impacted by invasive species.

Figure 8. Distribution of kudzu in North America. Source: U.S. Department of Agriculture (<http://plants.usda.gov/java/profile?symbol=PUMO>).



In summary, invasive species already have substantial economic and ecological impacts in Wisconsin. Significant climate change could further the expansion of invasive species. Increased range and populations of invasive species could further affect native species and result in further management issues. The displacement of native plants can alter the composition and function of natural communities.

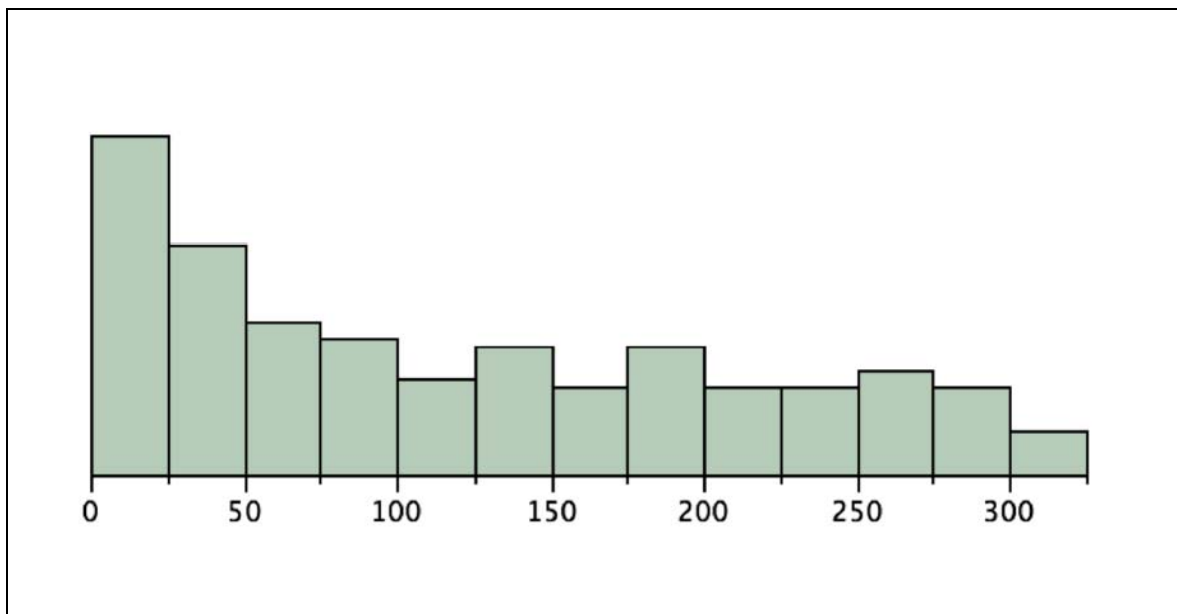
Fragmentation and Habitat Loss

Fragmentation and habitat loss are widely recognized as the primary cause of threats to and losses of biological diversity both globally and in the U.S. (Wilcove et al. 1986, Wilson 1992, Wilcove et al. 1998). Declines in habitat area and increased isolation among habitats threaten biological diversity locally and directly by reducing population size and thus demographic viability, particularly in species that are sparse, slow to mature, and specialized in their habitat needs. Reduced habitats and isolation further threaten the persistence of populations by reducing their genetic diversity, increasing levels of inbreeding, and reducing opportunities for local recolonization, often termed the 'rescue effect' (Brown and Kodric-Brown 1977). The importance of habitat area and among-population connections are now heavily emphasized in conservation biology (Groom et al. 2006, Primack 2008). In such landscapes, the ability of species to persist often depends on effective dispersal and the relative rates of colonization and extirpation. Not surprisingly, island biogeography and meta-population models are now used extensively to forecast effects of habitat fragmentation. If populations occupy semi-isolated patches of habitat that only occasionally exchange migrant propagules, local populations will wink extinct faster than recolonization occurs, causing populations to disappear.

Smaller and more isolated fragments also typically lose larger and more specialized species first (as expected given their reduced demographic resilience and smaller population sizes). These losses, in turn, alter trophic interactions, further affecting species abundances and interactions, potentially leading to cascading waves of local extinction. Fragmentation has been explicitly linked to species losses in birds (Blake and Karr 1987, Robbins et al. 1989, Andr n 1994, Donovan et al. 1995, Tewksbury et al. 2002) and plants (Vellend et al. 2006) including losses in Wisconsin forest fragments (Rogers et al. 2009). The distribution of forest patch sizes for stands sampled originally by John Curtis and colleagues reveal the degree of forest fragmentation and many forest stands of small size (Figure 9).

The pattern of habitat loss on the landscape is an important consideration when assessing the effects of fragmentation (Fahrig 2003). Not all species and natural communities are affected equally. Those that more adapted to unpredictable disturbances and species that are mobile may be less impacted by fragmentation than those that developed under more stable conditions (Opdam and Wascher 2003, Cagnolo 2009). However, even disturbance-prone communities are adversely affected by fragmentation. With numerous edges relative to their size, prairie and savanna remnants are particularly susceptible to invasion by invasive species (Apfelbaum and Haney 1991), which tend to colonize habitat edges first where dispersal is more probable and competition is lower. The interactions of fragmentation and other factors can be important drivers in species and natural community persistence. Ross et al. (2002) noted that human disturbance coupled with fragmentation had stronger and more immediate negative impacts on native species and positive impacts on non-native species richness than did fragmentation alone. The intricate mosaic of the natural communities of Wisconsin has greatly changed since statehood (Figure 10, Curtis 1959, Finley 1976).

Figure 9. Distribution of forest patch sizes for 199 remaining upland forest sites in Wisconsin. Graph shows the frequency of patches of various sizes (in hectares). Mean stand size is 119 ha with a S.D. of 93.8 ha, although stands in southern Wisconsin are far smaller than those in northern Wisconsin. These forest patches were originally sampled by J.T. Curtis and colleagues. Data courtesy of D. Rogers and D. Waller, University of Wisconsin.

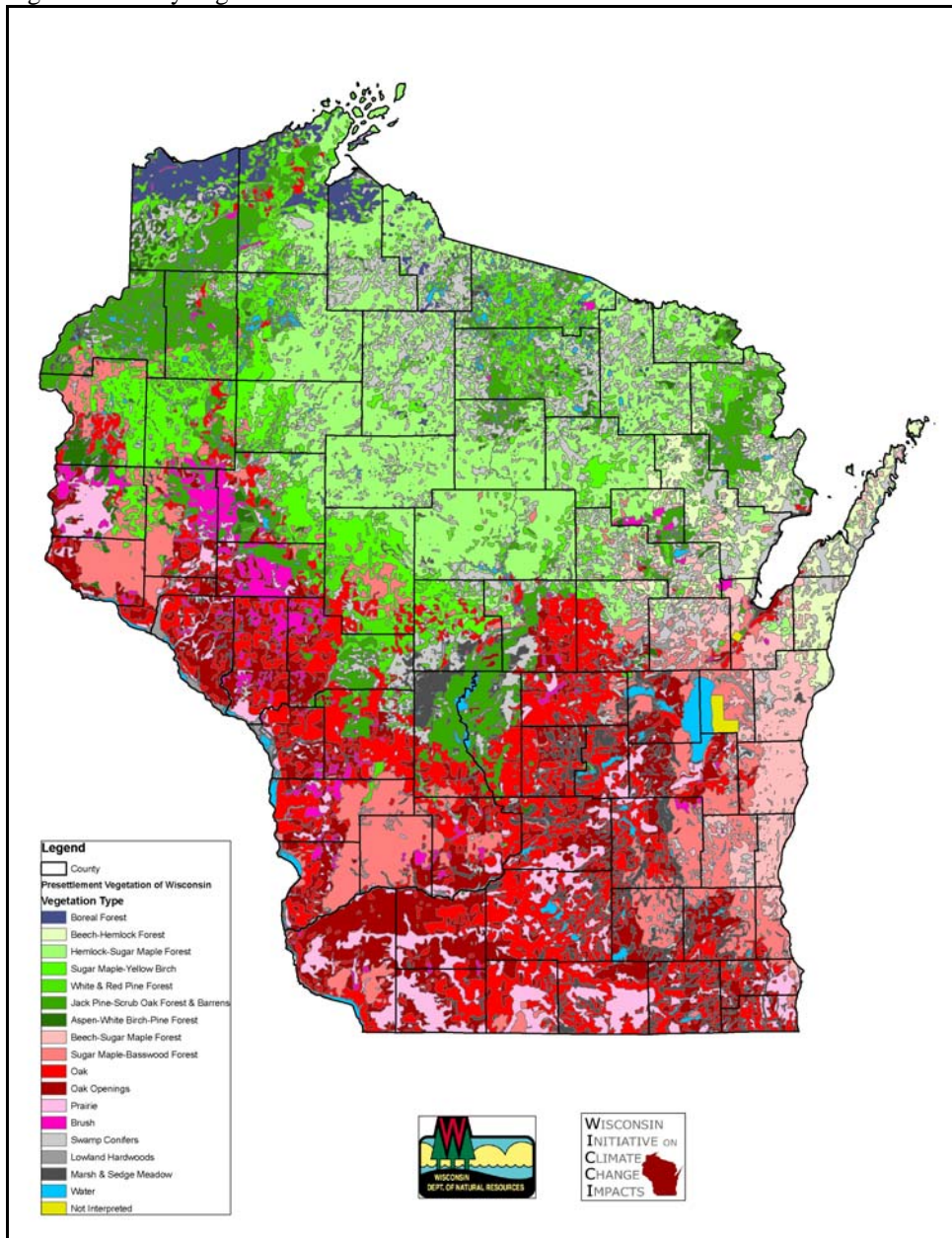


Widespread urbanization, the development of a complex road network throughout the state, conversion for agricultural purposes, and other alterations that affect natural communities have resulted in a wholesale fragmentation of the natural landscape as shown in Figure 11 of the current land use cover developed from remote sensing.

Long-term studies in Wisconsin have shown the vulnerability of natural communities to isolation and fragmentation. Kraszewski and Waller (2008) found that in small dry prairie remnants native species richness decreased since they were originally sampled in 1950. Much of the decline resulted from the loss of shorter-statured and rare forbs. The isolation of the fragments might also restrict pollinator availability and seed set creating a feedback loop that could further reduce native species richness. Conversely, larger forests and those within surrounding forest cover in

southern Wisconsin lost fewer native species, were more likely to recruit new species, and had slower rates of homogenization than smaller forests in more fragmented landscapes (Rogers et al. 2009). Climate change could represent a second major threat to species persistence (Thomas et al. 2004). Species must also now either migrate or adapt to rapid climate change if they are to avoid going locally extinct, much as they did following the rapid glacial retreats 10-15 thousand years ago (Davis et al. 1986, Davis et al. 2000, Davis et al. 2005). In addition, climatic changes could interact with habitat loss and fragmentation to create more powerful combined threats to

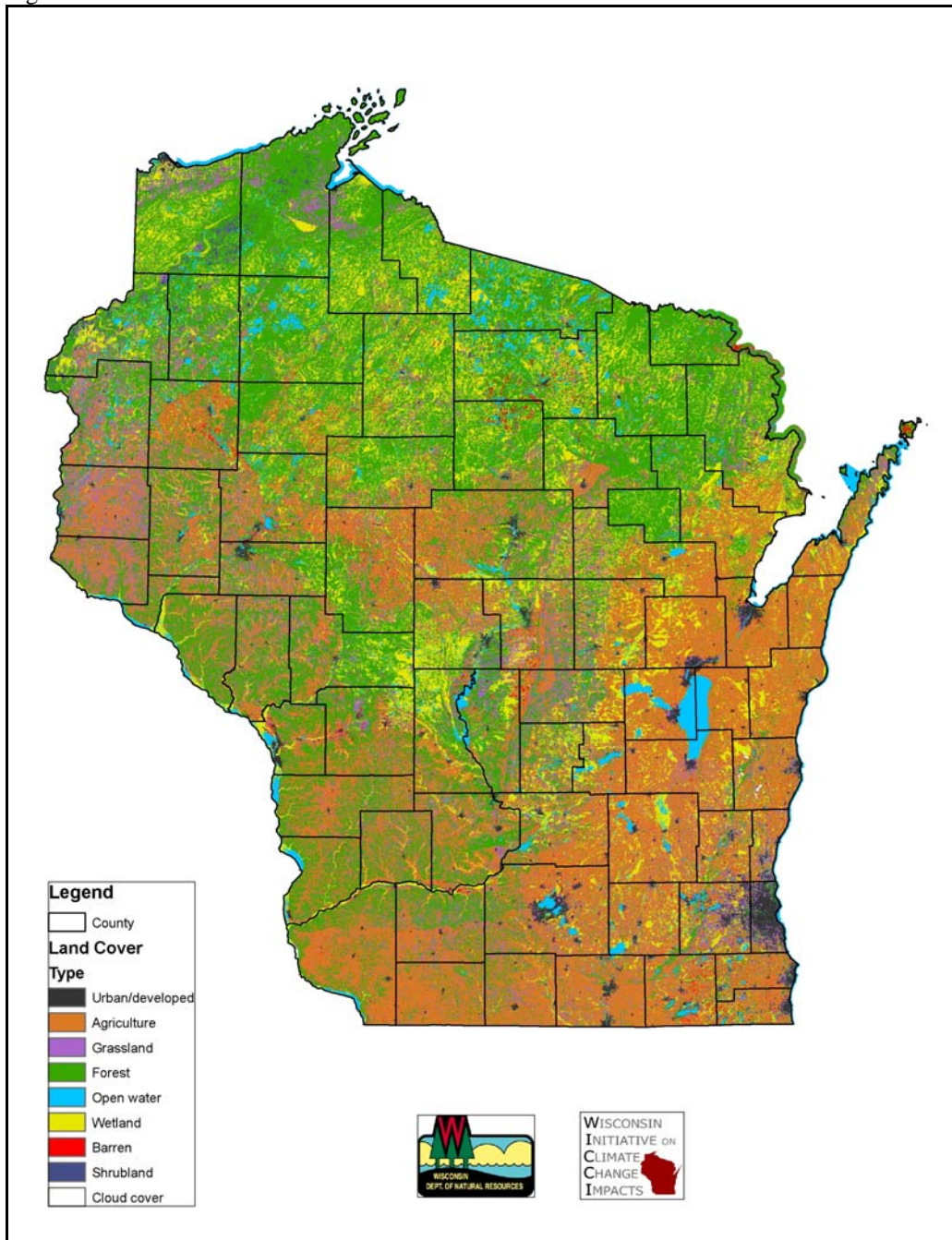
Figure 10. Early vegetation of Wisconsin.



species persistence. This occurs because climate change could act to reduce the suitability of many patches, particularly those sensitive to climatic conditions, including many specialized

species. This increases the importance of connections among habitat patches as these allow species to migrate to more climatically more suitable locations. Fragmentation, however, decreases habitat connectivity, reducing migration and thus increasing the vulnerability of isolated populations to the impacts of climatic changes. With reduced re-colonization, 'rescue effects' will also diminish, meaning that localized patches of habitat could suffer double reductions in species diversity.

Figure 11. Land cover in Wisconsin.



Responses of species to climate change could include toleration of the new environmental conditions and dispersal to more favorable locations. In the former case, genetic constraints on

adaptation in conjunction with fragmentation could reduce the rate of adaptation well below the pace required by climate change (Opdam and Wascher 2003). Species in landscapes that are more intact with connected patches of suitable habitat might fare better than those that are in landscapes that have significant barriers to dispersal. Limitations on the ability to disperse will likely be more important than any limitations on establishment. In a study of Belgian forest species in a fragmented landscape, Honnay et al. (2002) found that about 85% of the species had a very low rate of success in colonizing suitable habitat after 40 years had elapsed. They estimated that rate of colonization was about two orders of magnitude less than what would be needed to keep up with the projected changes in climate.

What is described as a shift in the range of a species might also be thought of in terms of metapopulations with a complex result of the extirpation of species at the trailing edge of the range and establishment of new populations at the leading edge. The persistence of the metapopulations could be determined by the spatial cohesion of a network of habitat within the landscape (Opdam and Wascher 2003). Such cohesion is lacking in a fragmented landscape.

The combination of climate change and increased fragmentation is could affect species and natural communities statewide, both directly and through cascading effects. All of the southern natural community groups (Table 1) could be highly affected by climate change. The northern groups (upland and lowland forests, wetlands) and the Great Lake shore group may be moderately affected, at least immediately, due to more continuous habitat being present (Figure 11). The impacts of fragmentation could be reduced if connectivity was increased between remnant natural communities.

Long-distance dispersal has the potential to help alleviate the effects of habitat fragmentation by increasing the ability of species to migrate rapidly. There continues to be some discussion about the role and importance of long-distance dispersal for driving rapid migrations (Pearson and Dawson 2004). It's generally understood that some groups of species, such as those with light or bird-dispersed seeds, would be better able to overcome the effects of fragmentation by colonizing scattered patches of suitable habitat via long distance dispersal. Often, however, those are weedy native and non-native species. Species groups with poor dispersal abilities are expected to be more affected by rapid climate change.

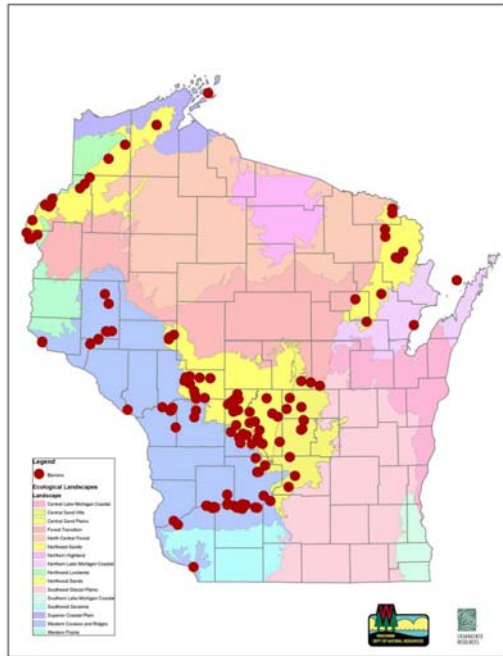
In summary, the mosaic of natural communities in Wisconsin has changed greatly since statehood. Fragmentation and habitat loss are major threats to conserving biological diversity in the state, and climate change could exacerbate the problem. Reducing fragmentation and increasing connectivity could help diminish the peril for some species.

Change in Fire Regime

Observations across Wisconsin over the past 50-plus years show that the state's climate is changing. The average temperature has increased. Overall the state has become wetter although parts of the north have become drier (WICCI 2010). Down-scaled climate projections produced by the WICCI Climate Working Group indicate that the fire regime in Wisconsin could be altered due to changes in temperature and precipitation. Climate influences fire regimes in two ways: directly, by influencing weather patterns conducive to fire ignition and spread, and indirectly, by influencing plant communities through temperature and precipitation regimes that favor (or discourage) fire-adapted plant species. Fire, in turn, exerts a powerful feedback that perpetuates fire-adapted plant communities. However, as a natural disturbance that shapes landscape and community composition and structure, fire has been severely limited by human control practices that focus on the protection of human safety and property.

be reduced due to increased fire hazard and the need to reserve personnel and resources to combat wildfires.

Figure 13. The distribution of good quality sand, oak, and pine barrens (shown as red dots) across Wisconsin. Note that most of the barrens occur in Ecological Landscapes dominated by sand (shaded in yellow). The remaining barrens often are found along large rivers like the Wisconsin and Chippewa. Data are from Wisconsin Natural Heritage Inventory (<http://dnr.wi.gov/org/land/er/nhi/>).



In summary, climate change could alter current fire regimes in Wisconsin. The greatest changes could occur in fire seasonality and in the most fire-prone plant communities. Although there is still uncertainty in fire-related climate variables, changes in fire regimes could affect plant communities and facilitate the maintenance and possible expansion of fire-adapted communities such as prairies, savannas, barrens, and oak woodlands. Finally, the ability of managers to conduct prescribed burns to maintain and restore fire-dependant plant communities will likely be affected both positively and negatively.

Figure 14. Prescribed fire.



Adaptation strategies

The initial adaptation strategies for the WICCI Plants and Natural Communities Working Group (PNC) are, by necessity, be fairly broad, in part because this is the first step in the long-term process of developing risk assessments for individual species and natural communities. There are many aspects of the interactions and biology that are not known thereby making recommendations for specific plants or communities difficult. Here the PNC lays out a framework by which we will develop comprehensive plant species and natural community adaptation strategies.

Adaptation actions can be categorized in three groups. First, resistance adaptation actions are those defensive actions intended to resist the influence of climate change; they are intended to forestall impacts and protect highly valued resources. Second, resilience actions improve the ability of ecosystems to return to desired conditions after disturbances. Finally, response or facilitation actions help facilitate the transition of ecosystems from the current to new conditions. Adaptation strategies can be in more than one category (Millar et al. 2007, Galatowistch et al. 2009).

1. Risk Assessments

While it will clearly be impossible to eliminate uncertainty, to help reduce the amount of uncertainty in making decisions about resource allocations, risk assessments will be made of the vulnerability of individual species and natural communities to changing environmental conditions based on climate projections. The assessments could be used in prioritizing management and other adaptation actions. It is anticipated that vulnerability assessments resulting from the PNC Working Group would be useful for other WICCI working groups, including Forestry and Wildlife. Risk assessments can lead to short and long-term decisions and can contribute to the resistance, resilience, and response categories.

Evaluation of existing sites for buffers, connectivity, management needs, and other factors can point toward appropriate actions and allocation of resources. Small sites that have a high concentration of rare species having limited habitat availability may need additional buffer surrounding the site to reduce the influence of external stressors (Galatowistch et al. 2009). Early response to invasive species may be critical for such sites.

Recognizing that resources are and will likely continue to be limited for conservation actions, site analyses can be used to prioritize decisions about land acquisition or easements. If two sites are roughly the same size, but one is relatively uniform in natural community types and distribution and the other has greater complexity due to factors like topographic relief, the latter property may have longer term conservation value. The more heterogeneous and complex a site, the more microhabitats are likely present that can meet more habitat and other requirements for a wide range of organisms.

A landscape evaluation would include many of the factors listed above but especially look at connectivity between sites and the range in size of individual sites in the landscape. The results of a larger-scale analysis can identify opportunities to collaborate among units of government and private landholders; it may also be able to suggest cross-border actions with neighboring states. A landscape assessment would also examine the degree of redundancy of sites because redundant sites can help spread risk instead of depending on only one or a few good quality sites.

An analysis of connectivity at landscape levels can identify important long-term opportunities for conservation actions. Depending on the species, its ability to disperse, and the relative permeability of the matrix, connectivity may not be as important for long distance dispersal as for

other aspects of connecting sites. Corridors of natural habitat along natural environmental continuums can provide room for movement and provide favorable conditions for local adaptations (Olson et al. 2009).

2. Protection and Management

Existing conservation properties should be evaluated, both on a local, individual basis as well as in a landscape context. Assessments of individual sites would include an analysis of size, surrounding land use and degree of buffer, site heterogeneity and complexity, site integrity, exposure to external stressors, current management regimes, and connectivity to other, local sites. After evaluations are completed, management activities can be prioritized. For example, if an external stressor is identified as invasive species, property managers could work to reduce or eliminate the invasive species thereby contributing to the resistance and resilience of the property. Opportunities that were identified in the evaluation could lead to the protection of additional property by public or private organizations that increase the buffer or connectivity of the property.

Modeling can provide valuable insights to our responses to climate change. We can improve our tools for modeling and forecasting species and community responses to climate change (Clark et al., 2001). Efforts to improve models should focus both on improving their representation of ecological processes and the validation of these models against records of ecological dynamics during periods of historic and pre-historic climate change (e.g. Hotchkiss et al., 2007).

Once adaptation actions have begun, it is important that researchers and land managers are able to determine the effectiveness of those actions. There is a need to increase capacity for long-term monitoring of population abundances and distributions, in order to detect climate-driven shifts in population demography. Monitoring, both on the ground and using remote imagery, will help guide adaptive management decision making. Adaptive management can help in the short and intermediate term (resistance and resilience) as well informing response actions for the longer term. Adaptive management is an iterative learning process that promotes flexible decision making and stakeholder involvement, and produces improved understanding and management over time (Williams et al. 2009). It does so through what can be termed the adaptive management cycle: exploring alternative ways to meet management objectives, predicting the outcomes of the alternatives under consideration based on the current state of knowledge (and uncertainty), implementing one or more of the alternatives, careful monitoring and evaluation of responses to management, and then using what is learned to update knowledge and adjust management actions and begin the cycle again (Williams et al. 2009). Adaptive management can be a powerful tool for adapting to climate change because the current levels of uncertainty and the rapid rate of increasing knowledge will necessitate frequent evaluation and adjustment of management. One outcome of adaptive management might be that we orient management priorities away from the preservation of particular landscapes and communities and towards the preservation of biodiversity (i.e. the preservation of species and the genetic diversity within species) and the maintenance of the services provided by Wisconsin's ecosystems. Managing resource in a changing climate will be like hitting at a moving target. Our degree of success at maintaining biodiversity into the future will depend not just on our ability to predict where the target will move next, but how well we are prepared to react when the target moves in a direction we did not predict.

3. Assisted Migration

The actions above are well-established and widely applied in conservation biology (Hannah et al. 2002, Mansourian et al. 2009). Other proposed actions, however, are much more divisive. One such proposal that is being widely debated in the conservation community is that of assisted

migration, the idea that plants and animals should be moved geographically ahead of the projected wave of climate change. Rather than being a resistance or resilience action, assisted migration would be considered a facilitation action and therefore perhaps be considered for the long-term (Millar et al. 2007). Again, because we lack basic biological information about many species, including those that are rare, assisted migration may create more problems than they solve (McLachlan et al. 2007). It is probable that if assisted migration is deemed an appropriate measure, decisions will have to be made on an individual species basis.

In summary, the initial adaptation strategies for the PNC Working Group are fairly broad. They include risk assessments multiple scales ranging from individual conservation lands to landscape. Assessment needs include ecological condition, buffer, connectivity, and management needs. The assessments will help prioritize protection and management decisions. Monitoring will help guide adaptive management responses. Other adaptation strategies, such as assisted migration, may be more divisive.

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