Changing Landscapes in the Chicago Wilderness Region:

A Climate Change Update to the Biodiversity Recovery Plan

Version 1.0*

April 2012

Prepared by the

Chicago Wilderness

Climate Change Task Force

* This plan is the first iteration needed to create momentum for climate action for nature in the Chicago Wilderness region. Climate change science, policy responses, and funding are changing rapidly. This is considered a living plan that will remain flexible in the face of evolving circumstances.

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I. INTRODUCTION

Chicago Wilderness is a regional alliance that connects people and nature. We are more than 250 organizations that work together to restore local nature and improve the quality of life for all who live here, by protecting the lands and waters on which we all depend. Our four key **initiatives**—to restore the health of local nature, to implement the Chicago Wilderness Green Infrastructure Vision, to mitigate and adapt to climate change, and to leave no child inside—reflect our commitment to using science and emerging knowledge, a collaborative approach to conservation, and a caring for both people and nature, to benefit all the region's residents.

The actions necessary to achieve this mission were laid out in the Chicago Wilderness Biodiversity Recovery Plan in 1999 and still drive conservation strategies of the alliance today. The science driven process used to develop this plan identified habitat destruction and fragmentation, invasive species, and pollution as the major systemic threats that created vulnerability to the native terrestrial and aquatic biodiversity of the Chicago Wilderness region. There is now overwhelming scientific evidence to support that climate change is amplifying the effects of these threats, and that there will likely be synergistic effects between existing stresses and threats and climate change impacts to those threats (e.g., Opdam and Wascher, 2004; IPCC, 2007). For example, as the climate changes many species will need to shift their geographic ranges in order to track appropriate environmental conditions needed to survive. The ability of species to successfully migrate, however, may be hindered by a fragmented landscape that can inhibit or even block the migration of species. As Chicago Wilderness summers become hotter and drier due to climate change, the hydrology of wetlands will likely be altered and possibly cause some wetland areas to dry up and others to become even more isolated- further exacerbating the threat that fragmentation poses to wetland communities and species in this region.

Recognizing the potential of climate change to jeopardize the conservation investment that has taken place in our area, in 2007 the Chicago Wilderness Executive Council established Climate Change as one of four thematic initiatives, along with the Green Infrastructure Vision, Leave No Child Inside, and Restoring the Health of Local Nature. To define and carry out the work of this initiative, CW established the Climate Change Task Force (Task Force) to "study and make recommendations on adaptation strategies and models for mitigation in order to address the local impact of climate change." In 2008, the Task Force produced *Climate Change and Regional Biodiversity: A Preliminary Assessment and Recommendations for Chicago Wilderness Member Organizations* (see Box 1) that reviewed the current science of climate change and summarized the dramatic changes projected for the CW climate system and expected impacts to biodiversity.

Also in 2008, the City of Chicago launched the Chicago Climate Action Plan (CCAP) that inherently focuses on mitigating emissions from buildings and transportation, as they account for 90% of the city's total emissions. The CCAP strategies aim to reduce climate impacts on people, the built environment and city services, and also include adaptation strategies for natural areas and green spaces. Subsequently in 2010, Chicago Wilderness developed the Climate Action Plan for Nature (CAPN) that complements the CCAP by focusing exclusively on conservation of native species, natural areas, and ecosystem services (Figure 1.2). The CAPN expands the geographic scope to include the entire 6 million acre Chicago Wilderness region, and lays out specific actions for engagement, mitigation and adaptation aimed at promoting and sustaining biodiversity in a changing climate.

Sustaining the functions of ecosystems is also very important to the long-term health and well being of people in the region. By having complementary documents and processes for people and nature, we will be well positioned to identify opportunities where investments in restoring or enhancing natural systems can provide effective alternatives to investments in hard infrastructure (e.g., in areas like flood control/storm water handling, water quality), and provide additional benefits to these ecosystem services.

While there are many uncertainties about climate change impacts and how Chicago Wilderness conservation practitioners should react, the cost of doing nothing at all is likely to be far greater in the long-term than waiting until those uncertainties diminish (Karetnikov et al., 2008). Ignoring climate change may result in the failure to reach biodiversity recovery management objectives, and in fact may lead us to engage in actions that do more harm than good. Further, as some of the adaptive responses that are focused on benefiting people may be detrimental to natural systems, anticipating human responses and working pro-actively on helping communities view functioning natural systems as tools for adaptation should be a high priority for Chicago Wilderness members. The adverse effects of climate change on wildlife and their habitats may be minimized, or even prevented in some cases, through adaptation actions that we initiate now (Inkley et al., 2004).

The Chicago Wilderness Biodiversity Recovery Plan (BRP) Climate Change Review is closely connected to the CAPN mission and goals. The BRP was developed as a living document that would continue to evolve as new information and new ideas arose. Over the past decade, it has become clear that global climate change is one of the top threats facing our environment. In addition to efforts to restore biodiversity, we must also work to minimize our losses and maximize our chances for successful biodiversity adaptation. To move toward this goal, it is valuable to review the original conservation targets and threats outlined in the BRP in light of what we now know about climate change.

"It is not the strongest of the species that survive, nor the most intelligent, but the ones most responsive to change!" - Charles Darwin

Given the uncertainties in projecting the extent and rate of climate change, the Global Climate Change and Wildlife in North America technical report (Inkley et al., 2004) recommends managing for a range of possible future conditions. This means identifying actions that provide relatively high returns on the conservation investment for a relatively wide range of future climate conditions. These measures are often referred to as "no-regret" strategies, or options that would be justified under all plausible future scenarios, including the absence of human-induced climate change (Eales et al., 2006). The strategies developed for the CW Biodiversity Recovery Plan Climate Change Review are designed to reflect this conservative principle. Developing these types of strategies may involve shifting toward a risk assessment/scenario approach to management planning. For example, thinking through multiple possible future scenarios that not only include assessments of what the most likely outcome will be, but also what conditions could mean if a chosen management plan fails. Given that some actions may fail, one of the best strategies is to "hedge your bets" and add in safeguards. In short, we want to protect more than we think we will need given that uncertainties exist. Accordingly, adaptive management will play a key role in helping us learn from what seems to work and what does not. Now, more than ever, it is critical that experimental designs are employed when possible to implement changes in management, and that monitoring regimes are established to enable us to learn and change paths if needed as the climate continues to change.

The tenets of the BRP Climate Change Review (the Review) are imbedded within the CAPN adaptation section. This document, however, is intended to be a more detailed and stand-alone reference that supports the development of specific adaptation strategies for the natural communities of Chicago Wilderness. The general aim of the Review is to provide a tool that assists land managers, policy makers and individuals in creating and implementing strategies for biodiversity recovery and adaptation in Chicago Wilderness. In addition, this information is intended to encourage discourse on the ways in which climate change may influence how we think and act. For example, communities as we know them are likely to change, as all of the component species may respond to climatic changes in different ways and at different rates (Root and Schneider 2006). As such, we may need to shift from thinking about "communities" from a static perspective, to focusing more on specific conservation targets and the functionality of ecosystems. The goals of this document are to 1) discuss the impacts of climate change on specific CW conservation targets and threats 2) evaluate the conservation strategies currently being used in CW through a climate change lens and 3) outline actions and strategies that can help promote biodiversity adaptation for specific conservation targets.

The process used to carry out the Review began with the Chicago Biodiversity and Stormwater expert workshop, held in July 2009 in Chicago, IL. This workshop was led by US Environmental Protection Agency- Region 5, Chicago Department of Environment, The Nature Conservancy (TNC) and Chicago Wilderness (CW), and built from earlier TNC work summarizing impacts and discussing priority areas for adaptation action in the Great Lakes region. Based on their background and expertise, participants worked in terrestrial, aquatic, or storm water discussion groups. The groups were presented with a list of global climate change impacts gathered from the scientific literature by Dr. Kim Hall, Great Lakes Climate Change Ecologist for The Nature Conservancy, and they ranked those threats for the Great Lakes region. The CW Climate Change

Task Force further refined the “greatest impacts” list by assessing which impacts were most likely to threaten Chicago Wilderness in particular, based on projected changes in regional climate (assessment based on: Fourth Assessment Report by the International Panel on Climate Change, 2007; Confronting Climate in the US Midwest by the Union of Concerned Scientists, 2009; and information from the scientific literature). Finally, local scientists and land managers were interviewed to gather their observations and insights into how climate change is affecting specific ecosystems, communities and species in the CW region, and what tools might be needed to successfully implement biodiversity adaptation strategies.

Climate Change Issues for Illinois and the Chicago Wilderness Region

While there are limits to the accuracy of future climate projections- based mainly on the uncertainly of what future global emissions will be and current limitations in our knowledge about how the earth’s climate system will respond to it- long-term projections from global climate models (GCM’s) that are based on the average of multiple models and many climate simulations represent robust information for aspects of future climate (National Research Council, 2010). For instance, there is high confidence that the global average temperature will continue to rise (National Research Council, 2010). Projections for future precipitation, however, are more complicated. There is less certainty regarding projections for the directionality and range of annual precipitation, but agreement that the pattern is likely to shift to fewer but more extreme storm events (National Research Council, 2010).

Downscaled models are also beginning to provide useful information about future climate changes on local to regional scales as well. The consensus projections from various models for North America, including the Chicago Wilderness region, indicate there will be an increase in the average annual temperature (much of the warming concentrated during the cool season and at night), more hot extremes and fewer cold extremes, reduced daytime temperature ranges, increases in extreme precipitation events, and a seasonal shift to wetter winters and springs and more summer droughts (Field et al., 2007; Hayhoe and Wuebbles, 2008; UCS, 2009; USGCRP, 2009; Vavrus and Van Dorn, 2010; National Climate Assessment *in press*). Downscaled modeling done for Chicago based on higher (SRES A1F1) and lower

(SRES B1) greenhouse gas emissions scenarios suggests the coldest night of the year is projected to warm by 4–8 °C, while the simulated occurrence of very cold conditions (daily minimum temperature < −18 °C) declines by ~50% (5 days, B1) to nearly 90% (8 days, A1F1) relative to the late 20th century (Vavrus and Van Dorn 2010).

For a detailed look at historic temperature and rainfall maps for the Chicago Wilderness region, click here. The tool used to visualize this data set is Climate Wizard, and was developed by The Nature Conservancy to allow easy access to climate data, future projections and impacts for a given region. The data can be viewed to reflect annual, monthly, or seasonal patterns. For example, between 1953-2002 the annual average temperature across the entire CW region did not increase significantly (however parts of SE Wisconsin and NW Indiana did), but falls have become cooler while winters, springs and summers have become warmer. Looking at monthly changes during this 50-year period, it is evident that October has become significantly cooler and March has become significantly warmer. The Union of Concerned Scientists (2009) acknowledges that the climate of Illinois has already changed measurably over the last half century in the patterns of temperature and precipitation, and these changes are expected to continue (Box 1.1). For example, if current emission trends continue, by the end of the century Illinois could be facing multiple heat waves per summer with more than a month of days over 100° F, warmer winters (due to increases in the nighttime minimum temperatures) that allow many pests to expand their range, winters and springs that are 25 percent wetter, more extreme precipitation events, and drier summers (Hayhoe et al., 2010).

While much of the current climate change dialogue centers on future impacts, many of these trends have already begun (Box 1.1). For example, July 2011 broke records across the nation, including the Chicago region, with a heat wave that was characterized by unusually warm minimum temperatures during nights and early mornings. This pattern is typical of U.S. heat waves in the last decade, and consistent with increasing warm summer nighttime extremes observed across much of the country since the late 20th century (Illinois State Water Survey, 2011). In the summer of 2011, Chicago went from having the third driest to the second wettest July on record in one single event when 6.86 inches fell in 3 hours on July 23rd. In total, July

2011 accumulated 11.15 inches, surpassing the previous wettest record set in 1889 with 9.56 inches (chicagoweathercenter.com; climatestations.com).

While it is not possible to claim one particular weather event is due specifically to climate change, the types of extreme events the Chicago region has experienced (e.g., the heat wave of 1995, summer flood events of 2008, 2010, 2011) are very likely to increase in frequency with climate change in the coming decades. This expectation is based on the fact that a warmer world holds more moisture. As the climate warms, evaporation of moisture from the oceans increases, resulting in more water vapor in the air. According to the 2007 Intergovernmental Panel on Climate Change (IPCC) report, water vapor in the global atmosphere has increased by about 5% over the 20th century, and 4% since 1970. This additional moisture then comes down in larger and more extreme storm events. Heavier storms and flooding and more extreme heat events can have serious direct consequences for human health, such as deteriorating water quality, and the viability of crops and livestock. Similarly, the major threats natural communities now face, such as habitat fragmentation, invasive species and pollution, will no doubt also be exacerbated by climate change impacts (USGCRP, 2009).

Another example rapid changes are underway is illustrated by the recent shift seen in plant hardiness zones throughout the United States, a metric based on average minimum winter temperatures that determines what plant species can be cultivated in a region. The USDA released a revised plant hardiness zone map in January 2012, and when compared to the 1990 version the zone boundaries in this edition of the map have shifted in many areas. The new map is generally one 5-degree Fahrenheit half-zone warmer than the previous map throughout much of the United States. For example, Chicago shifted from a 5b to 6a zone between 1986 and 2005. This is mostly a result of using temperature data from a longer and more recent time period; the revised map uses data measured at weather stations during the 30-year period 1976-2005. In contrast, the 1990 map was based on temperature data from only a 13-year period of 1974-1986. Irrespective of future emissions scenario, plant hardiness zones are projected to continue moving northward. The extent to which plant hardiness zones shift by the middle or end of the century, however, will depend on the level of greenhouse gases that are emitted. For example, by mid-century, plant hardiness in Chicago is projected to remain at zone 6a under lower emissions and to shift further to zone 6b under higher emissions. By the end of the century, the projected hardiness zones could shift to 6b under lower and to 7a under higher emission scenarios (Hellmann et al., 2010).

The projected shifts for mid- and late-century under the lower emission scenario would make conditions in the region equivalent to present hardiness zones in southern Illinois. Under the higher emission scenario, plant hardiness zones are projected to be similar to those of western Kentucky by mid-century and to northern Alabama by the end of the century. Projected shifts in plant hardiness zones, as well as decreases in growing season moisture due to warmer, drier summers, will have implications for the nearly 100 tree species and the larger numbers of shrubby and herbaceous species, not to mention the wildlife community that depend on them, that occur in the Chicago Wilderness region (McLachlan et al., 2007; Hellmann et al., 2010).

The inability of natural communities to adapt to this rapid climate change will result in their diminishing capacity to provide many ecosystem services, such as clean water, habitat for fisheries, pollination, recreational opportunities, climate stabilization, and carbon sequestration. These losses are expected to grow as climate change deepens, along with the inherent cultural, aesthetic, and quality of life values imbedded in the very existence of natural communities.

Climate Change and Biodiversity

It has long been recognized that biodiversity at all scales (genes, species, ecosystems, etc.) is key to the health of the natural world (e.g., Rapport et al., 1998; UNDP, 2000) and, in light of our planet's rapid climate change, having healthy, resilient natural communities may now be more important to us than ever (Thomas et al., 2004; Hampe and Petit, 2005). Greater genetic biodiversity within populations will enable them to be more resilient to changing temperatures and precipitation patterns; just as recovering and conserving species biodiversity within communities will aid them in sustaining their functionality (Thomas et al., 2004). It is important that biodiversity recovery plans integrate the knowledge of how our region's climate is changing, and how our ecosystems are expected to respond to it, into their strategies and actions. In a human-dominated landscape such as Chicago Wilderness, it is especially relevant to try and anticipate human responses that may lead to increased stresses on biodiversity (e.g., natural areas adjacent to localities that are likely to be further developed could be negatively affected by stormwater runoff and flooding associated with increases in impervious surfaces).

A vital aspect to consider about climate change impacts is not just how changes in mean temperatures and precipitation patterns will affect ecosystems and wildlife, but how the resulting variability and extremes will impact them (Table 1.2, 2.1-3.2 and Appendix 3 in this document; Inkley et al., 2004). The complexity of these changes, and the interaction between them, means that some impacts are difficult to predict. Rapid changes in conditions will likely result in native species facing increasing threats from pests, diseases, and competition from non-native species moving in from warmer regions (USGCRP: Midwest Regional Climate Impacts, 2008). While it is expected that the geographic ranges of flora and fauna will shift upwards in elevation and northward (Parmesan, 2006), the pattern and extent of movement will vary tremendously among species based on factors such as dispersal ability, life history traits, genetic diversity and behavioral plasticity (Thomas et al., 2004). Ultimately, however, the ability of species to physically shift their range is dependent on the availability of migratory pathways, which are threatened by barriers such as roads, cities, and habitat fragmentation (Easterling et al., 2004).

Since temperature has played a strong role in shaping species life histories, and has been a key element in genetic, physical and behavioral adaptation over long (evolutionary) time periods (Millien et al., 2006), there is great potential for wildlife to be significantly affected by rapid temperature changes. In fact, responses to increasing temperatures have already been observed in wild animals and plants, and can be grouped into five basic, but not mutually exclusive, types (from Hall and Root, in press):

1) spatial shifts in ranges and boundaries (e.g., moving north in the Northern Hemisphere);
2) spatial shifts in the density of individual animals and plants within various subsections of a species' range;
3) changes in phenology (the timing of events), such as when leaves emerge in spring or when birds lay their eggs;
4) mismatches in the phenology of interacting species; and
5) changes in genetics.

In general, for animals, the potential effects of temperature changes will likely be most apparent for ectothermic (cold-blooded) animals such as insects, reptiles and fish because their body temperature closely tracks environmental temperature. However homeothermic, or warm-blooded, animals like birds and mammals are also at risk of heat-related stress as temperatures continue to increase, especially those that inhabit areas where they are already close to their thermal tolerance limits (Hall and Root, in press).

Observations of changes in phenology in wild animals and plants show a robust and geographically widespread trend. A recent paper by Thackeray et al. (2010) reports on the analyzed observations of more than 700 species of fish, birds, mammals, insects, amphibians, plankton and a wide variety of plants across the U.K, taken between 1976 and 2005. The authors found a consistent trend revealing more than 80% of biological events (e.g., including flowering of plants, ovulation in mammals and migration of birds) occur earlier in the annual cycle than they did in the 1970s. Changes in snowfall and temperature can delay the onset of hibernation, such as yellow-bellied marmots (*Marmota flaviventris)* in Colorado that have been observed emerging 38 days earlier compared to the 1970s (Inouye et al., 1999).

While some phenological events are occurring earlier, there is also evidence that others could be happening later. Although there have been no comprehensive studies performed in the U.S. yet, some data points toward later leaf drop. For example, researchers at the NASA Goddard Space Flight Center and at Seoul National University in South Korea used satellites to show the end of the growing season was delayed by 6.5 days from 1982 to 2008 in the Northern Hemisphere. Further support for this hypothesis comes from experimental research conducted on deciduous forest species from contrasting climates (*Liquidambar styraciflua*, *Quercus rubra*, *Populus grandidentata*, and *Betula alleghaniensis*). Researchers exposed tree species to air temperatures 2 and 4 °C above ambient controls and found chlorophyll was retained an average of 4 and 7 days longer in +2 ° and +4 °C treatments, respectively, and abscission was delayed by 8 and 13 days (Gunderson et al. 2011). This indicates temperature alone can affect later leaf drop, and that even if this pattern is not widespread now, it could be in the future.

Fall migration is also very responsive to weather and snow cover for some species. Sandhill cranes, which typically leave the Chicago region in late Fall, are staying much later into the winter and now regularly remain into late December and early January; in 2012, hundreds were still migrating south through the Chicago area as late as mid-January (D. Stotz, pers. comm.). The onset and duration of animal hibernation is tightly linked with temperature too. A long-term study on the relationship between ambient (air/soil) temperature and the torpor patterns of free-ranging Eastern chipmunks (*Tamias striatus)* in southeastern New York suggests exceptionally high winter temperatures correlate positively with reduced hibernation, resulting in a lower winter survival rate for these animals (Frank, 2012). The above patterns are consistent across different habitat types suggesting a large-scale phenomenon, and are certainly consistent with what would be expected in a warming world.

Similar observations of species at different trophic levels responding differently, and at various rates, to changes in temperature have been recently reported in the CW region. For example, in mid-March 2010 our region experienced a temperature warm-up causing trees such as white oaks to leaf out and many insects to emerge about 2.5 weeks earlier than usual. While these species responded directly to temperature cues, insectivorous migratory birds such as warblers do not. Instead, migratory birds rely on changes in photoperiods, or daylight length, as a cue to begin migration. The result was what is called a “phenophase mismatch” or the de-coupling of phenological events that have evolved together through time. The warblers arrived to the region when they usually do, but the lag-time between an earlier leaf and insect emergence and their arrival meant that food availability was reduced during critical periods for them (D. Stotz, pers. comm.). It is possible that if this type of de-synchronization continued, it could have extreme negative effects on populations of warblers. Further, if the predation by migratory birds are crucial to controlling the insect pest abundance, this timing mismatch could result in increased herbivory on the trees as they leaf out, reducing their fitness.

Warmer air temperatures overall in Illinois have also begun to affect species. Sometimes these changes can be surprising, highlighting the need for us to be agile in our management approaches. For example, recent work on red-eared sliders (aquatic turtles, *Trachemys scripta elegans*) by Tucker and colleagues (2008) found that between 1995-2006 red-eared sliders extended their breeding season by initiating earlier spring breeding, allowing the turtles to lay an additional clutch per year and potentially increase overall reproduction. However, because the sex ratio for turtles is temperature dependent, depositing eggs in belowground nests earlier in the spring, when soil temperatures are lower, can lead to a male bias in the offspring. Thus, red-eared sliders laying extra clutches could create a strong male bias in the population and if the bias became strong enough it may actually lead to population declines.

All of the broad wildlife taxonomic groups are likely to be impacted by climate change in some way in the coming decades. However the impacts will vary in kind (positive or negative) and in scale for different species. A species' vulnerability to climate change is a function of the 1) exposure to a changed climate factor, 2) sensitivity to that factor, and 3) adaptive capacity to respond to change. While it is not possible to predict exactly how species will respond to climate change, we are able to anticipate some likely responses based on our current knowledge, observations, and ecological theory. Table 1.2 lists climate change impacts for each major taxonomic group in Illinois and provides examples of the ways in which certain species are being, or likely to be, impacted by the expected changes in climate. Predicting the precise effects of climate change on plants and animals is extremely challenging and hindered in part by the lack of information on interactions among biotic and abiotic components of ecosystems, as well as the uncertainties related to non-climate stressors on ecosystems (Inkley et al., 2004). This climate change review will highlight some of the critical research and monitoring initiatives needed to address these knowledge gaps in the CW region.

It is also essential that we go beyond species-level management for natural communities and focus too on how climate change may impact biodiversity at the ecosystem level. An important challenge for us will be to scale up the relationship between ecosystem processes and biodiversity from small patches, where most empirical and theoretical studies apply, to the landscape level where most management issues are dealt with (Inchausti and Loreau, 2002). With expected migration patterns likely to reflect a decrease in species for which the CW region is at the southern end of their range and an expansion for those at the northern edge (Karl et al., 2009), individual species will shift in and out of our ecosystems. It is not individual species that are necessarily of greatest concern, but the continued overall functionality of natural communities (e.g., water cycling, nutrient cycling, energy flow, community dynamics). A broader expansion beyond plant species, a primary focus of the BRP, to assess the effectiveness of restoration methods has great merit. For example, monitoring ecosystem processes like soil biogeochemical cycling, or using terrestrial arthropod indicators in conjunction with other plant and animal indicators can be very useful in providing early warnings of ecological changes, and can be used to assess the effects of further fragmentation on natural areas that no longer support vertebrate indicator species (Beier and Brost, 2010; Kremen et al., 1993).

Experts agree that, at the site scale, most actions that are needed to help protect Chicago Wilderness biodiversity under future conditions are the same types of actions that we currently engage in to reduce the risk of a wide range of other threats (e.g., Glick et al. 2009). For example, actions such as removing invasive species and restoring fire-dependent systems "count" towards climate change adaptation. These actions strengthen native ecosystems making them better able to respond to the stresses they will face with climate change. The detailed implementation of these strategies, however, may change when viewed from the perspective of climate change adaptation. In the following sections we will review how climate change is likely to impact terrestrial and aquatic communities, as well as the threats to those communities, and outline conservative adaptation strategies aimed at helping to restore biodiversity and sustain functionality. We will also discuss how climate change may influence particular ecological concepts and review the role that climate change adaptation can play in the Green Infrastructure Vision of CW. An important resource in this document is Appendix 3, which presents both theoretical knowledge and empirical evidence on how current climate change impacts plants and natural communities around the world. The intention of this resource is to provide the best available science on this topic and foster discussion on how and in what ways this information is applicable and relevant to the natural communities in Chicago Wilderness. This information will be accessible on a WIKI, a website whose users can add or modify its content via a web browser, and a listserve similar to the Midwest Invasive Plant Network will be introduced to CW land managers to facilitate feedback on observed changes in phenology, burn windows etc. and adaptation strategies that have been implemented.

II. CLIMATE CHANGE AND TERRESTRIAL COMMUNITIES

Climate change has been referred to as a "threat multiplier" (CNA Corporation, 2007), meaning that it can exacerbate existing threats that natural communities face, increasing their vulnerability to these threats (Figure 2.1). The field of conservation ecology is in the initial phases of developing general "rules of thumb" of how species and communities are likely to respond to the most direct aspects of climate change (e.g., changes in air or water temperature) by integrating the observed changes in our ecosystems with ecological theory (Hall and Root, in press). As pointed out in the Climate Action Plan for Nature (2010), everything about climate change is fluid and evolving fast, including downscaled models, development of practical tools, policy responses, and funding for mitigation and adaptation programs. With this in mind, this Review is a living document intended to be modified and expanded as new science, tools, policies, and funding become available. In this section we review the biological significance and conservation status of terrestrial communities in the CW region and discuss what is presently known about how climate change may affect specific communities. We also examine the ways in which climate change may be expected to exacerbate existing threats that communities currently face.

The information presented in this section primarily reflects the opinions of local researchers, scientists and land managers who participated in expert workshops on climate change held in 2009 (see Introduction). A main outcome of this collaborative work was the creation of a list of climate change impacts that are thought to be of greatest concern for our region's terrestrial and aquatic systems. We present the information for terrestrial communities in Table 2.1, which lists the climate change impacts, the communities they are likely to affect, and the existing threats they are expected to amplify. Additionally, participants were asked to prioritize the top three threats from the list they felt were likely to have the greatest impact on the CW region. The top climate change related threats for terrestrial systems are (not in a ranked order):

1) Increased temperatures and changing patterns of precipitation will stress some native species and promote some invasives, suggesting that the threat of invasives will increase. Further, new natives from the south may be able to colonize, and potentially become invasive.

2) Increased temperatures will promote range shifts in sensitive species. Some species will be constrained in their response by lack of connected habitats through which to move, and others will be constrained by habitat loss, lack of mobility, or lack of genetic variation.

3) Species will respond in complex ways, and many key interactions may be disrupted (e.g. through mismatches in phenological shifts, or rate of range shifts).

Terrestrial communities can be described in terms of a shade and a moisture gradient, both of which extend across prairies, woodlands and wetlands. Each of the CW terrestrial community types, and what is known about how they may be impacted by climate change, are reviewed here. Table 2.2 summarizes these climate change impacts; presenting first the impacts expected to affect all CW terrestrial communities, followed by additional impacts that may affect specific community types. At the end of this section we outline some initial no-regret strategies and actions that land managers can implement to promote biodiversity adaptation for species and communities. Lastly, we present research questions and initiatives that have been identified by local researchers and land managers as critical to helping us move forward in our knowledge and understanding of the ways in which climate change will affect biodiversity and ecosystem functioning in our region.

PRAIRIES

There are four natural prairie communities in the CW region, which are classified by soil type (fine-textured-soil prairies, sand prairies, gravel prairies, and dolomite prairies) and range in the amount of soil moisture they contain (wet to mesic to dry). Prairies support an incredible diversity of plant species, with as many as 100 or more species occurring within just a few acres. Dolomite prairies are globally rare and habitat for federally listed species such as leafy prairie clover and lakeside daisy. The prairie grassland habitat is also one of the most endangered ecosystems in North America and extremely important for a broad variety of animals, including the smooth green snake (*Opheodrys vernalis*) that is often used as an indicator of remnant quality and prairie specialists like the aphrodite fritillary butterfly (*Speyeria aphrodite*) which cannot live on grasslands dominated by Eurasian species. Additionally, the insect assemblages found in dry and mesic prairie, dry and mesic sand prairie, and wet prairie are of global importance. Most bird species were able to adjust to Eurasian grasses such as the Hungarian brome grass (*Bromus inermis*) imported into the Midwest during the last 175 years, and even to the pastures and hay fields that rapidly began replacing prairies. However, the switch from general farming to an almost exclusive reliance on corn and soybeans drastically altered the structural habitat needed for nesting and exceeded their ability to adapt. The result has been a 90% population decline for all prairie bird species since the 1950's (Warner, 1994).

Once a defining feature of our region's landscape, the few remaining tallgrass prairie remnants in our region survive only as tiny fragments, and it is extremely challenging for seeds, or invertebrates, from small prairies to disperse successfully. These threats are likely to be compounded by the expected increases in temperature and precipitation changes that will drive human changes in land and resource use, leading to additional habitat loss. Loss of habitat has a cascading effect, meaning that greater losses of habitat will further decrease the size of prairie remnants and in turn diminish the ability of area sensitive grassland birds to survive in this region. The take home point here is that climate change compounds the existing vulnerabilities of species and ecosystems.

Given the loss of prairie habitat (i.e., less than one-hundredth of one percent of original prairie remains in Illinois), and the generally poor condition of what remains, the BRP regards all prairie types with a high level of concern and places sand prairies in dune and swale topography, dolomite, and fine textured-soil prairies at the highest priority level. The 2006 State of Our Chicago Wilderness Report Card gave prairies a grade of "D". The report cited conversion to agricultural fields, habitat degradation by past cattle grazing, overgrowth by brush and other invasive species, heavy browsing by excessive populations of white-tailed deer and changes in hydrology as the causes.

Warmer air temperature and changes in precipitation patterns are likely to affect prairies in a multitude of ways. The expected changes in climate may cause a general shift in overall species diversity and structural composition in prairie habitats, favoring warmer and drier-biome plant species and stress colder and wetter-biome species. Possible impacts to prescribed fire management could also lead to changes in community assemblages (see Appendix 3, section 3.1). Moreover, it is likely that species will exhibit differential shifts in their ranges due to differences in dispersal abilities/rates, leading to the disruption of key species interactions. This unsynchronized pattern of migration can easily lead to mismatched shifts in the timing of various ecological events and disrupt species interactions, potentially causing communities- and their system functionality- to be torn apart.

A hotly debated topic in the literature has been the use of a conservation strategy termed *assisted migration*. This strategy has been proposed for species, like many of those found in our prairie grasslands, with poor dispersal abilities that occur in highly modified landscapes subject to the effects of climate change. The concept is to facilitate or mimic natural range expansion as a direct management response to climate and the lack of landscape connectivity that prevents species from migrating appropriately (Shirey and Lamberti, 2010; Vitt et al., 2010). One of the arguments against translocating plants is the associated risk of a species becoming invasive in its introduced range. While it is true that intercontinental movement of a non-native species has resulted in problems with invasive species, the vast majority of introduced species do not become invasive. For example, less than 1 percent of species become invasive when imported to a new range (Williamson and Fitter, 1996), and only a small percent of those (7.5 percent of invasives in the US) are a result of intra-continental species introductions (Mueller and Hellmann, 2008; Vitt et al., 2010). Nonetheless, the decision to undertake assisted migration for a particular native species should be extensively researched and weighed. Vitt el al. (2010) proposed a framework for determining, prioritizing, and developing collection strategies for potential target species for assisted migration. These types of tools can greatly help in the decision making process of whether assisted migration is a viable option for a particular species.

Another climate change issue that is likely to affect prairie grasslands is higher CO_2 levels. Increasing levels of CO_2 in the atmosphere may cause a shift in species composition, but the precise way in which this will occur is uncertain. For example, many tall grass prairie species have a C_4 photosynthesis physiology that allows them to be more efficient at photosynthesizing compared to trees, shrubs and cool-season grasses with a C_3 physiology (Lattanzi, 2010). From this perspective, it's possible that C_3 plants may benefit more from an increase in atmospheric CO_2 than C_4 plants, potentially giving them a competitive advantage. On the other hand, C_4 plants have historically fared better in more arid environments than C_3 plants, which may give them an edge as prairies become drier (Lattanzi, 2010). Ultimately, increased growth and reproduction will depend on a variety of factors such as soil nutrient availability, overall precipitation and temperature. These differences in competitive abilities and potential for changes in relative advantage over time, implies that managers will need to be more agile in their management strategies.

From a climate change standpoint, while all of the prairie subtypes are still of high concern, the wetter sand and wetter fine-textured-soil prairies may face greater challenges due to changes in precipitation patterns and reduced water availability. Wet and wet-mesic plants like small sundrops (*Oenothera perennis*), listed as endangered in Illinois, and the federally threatened eastern prairie fringed orchid (*Platanthera leucophaea*) could suffer great losses. When it comes to considering "climate smart" land management strategies, one recommendation would be to focus efforts and resources towards managing for wetter habitats. Examples might be removing drain tiles, re-contouring draining ditches, or possibly altering/installing water control structures. There may be little we can do directly to reduce air temperatures, but managing for wetter habitats will not only help species that are adapted to wetter environments, but it has a dual effect to help those adapted to cooler-temperatures because wetter soils also decrease soil temperatures and cool down land areas.

Prairies contribute significant ecological benefits to humans by retaining considerable moisture on site. The deep roots of prairie plants help maintain the porosity of the soil and thus maintain recharge areas. Further illustrating the importance of prairie protection is the role they play in carbon mitigation. Grasslands store more carbon per acre than most other ecosystems because 90% of their biomass is underground, thus locking the carbon underground. As precipitation patterns shift to more extreme storm events, it will be imperative that we find ways to adapt both our built infrastructure to cope with the excess run-off, and our natural communities like prairies that provide this ecological service. It will be equally important to do this in such a way as to not turn our forest preserves into stormwater management facilities, but rather as a component of an overall regional adaptation plan.

Possible Adaptation Strategies and Actions for Prairie Grasslands

- Focus on managing for wetter habitats;
- Increase the genetic diversity of species by widening the seed source collection range, specifically to more southern populations and meta-populations. Both a defined range expansion (e.g. initially increasing a seed sourcing range from 50 to 150 miles) and a rate at which seeds from more southern populations are staggered into local CW populations needs to be determined;
- Structures and other large, long-term projects should be designed with climate change forecast in mind;
- Consider assisted migration and the use of tools to guide strategic framework for maintaining climate sensitive species in highly fragmented or isolated areas, or for which suitable habitat may no longer occur (migration (e.g., Vitt et al., 2010);
- Design and implement a monitoring protocol to evaluate climate change effects on local plants and animals and
- Maintain large patches (e.g., similar to Gooselake Prairie) to provide moisture and temperature gradients to allow species to find appropriate microclimates for survival in the face of changing climates.

WOODED COMMUNITIES

Tree dominated communities have been referred to by a variety of names, such as forested, woodland, or wooded. Forested communities broadly refer to habitats dominated by trees, with an average canopy cover greater than 50%. However, most tree-dominated communities within the CW region do not fall strictly within this category, so instead we refer to them collectively as “wooded” communities. This section describes five main community types: savannas, woodlands, upland forest, floodplain forest and flatwoods.

Savannas are wooded communities that represent a shade gradient between prairies and more forested woodlands, and often have soils that are transitional between prairie and forest and support a distinctive plant and animal assemblage. There are two savanna types in our region, sand and fine-textured soil, and subtypes that are characterized by soil moisture from dry-wet. Savannas typically have a graminoid groundcover and an average tree canopy cover of less than 50% but greater than 10%. We will first describe climate impacts on savanna communities, and move on to the more heavily forested communities.

Most of the major climate change impacts anticipated to affect prairie grasslands are also applicable to savannas and more forested communities. There is, however, the additional threat of increasing temperatures promoting increases in tree pests, and positively influencing invasives and disease vectors (Appendix 3, section 2.3). This is likely to occur through greater reproduction of tree pests due to warmer temperatures and longer growing seasons that allow for greater range expansion. Warmer temperatures and changes in precipitation patterns that would lead to an overall drier environment may shift wooded communities toward more open conditions (i.e., savanna). However changes in moisture alone are not likely to return wooded ecosystems to more open conditions; fire management and canopy manipulation would need to play a primary role in this. Burn windows may also be changing as a result of climate change (see Appendix 3, section 3.1). A warmer and drier climate will likely affect savanna communities across the board, with additional drought stress in the late summer expected to favor warmer-biome plant species over colder-biome forest species. In particular, the wet-mesic fine-textured-soil savannas are at greatest risk because once the hydrology is lost in this community it is extremely difficult to restore.

Open woodlands, with shade levels intermediate between savannas and forests, have been especially negatively impacted by changes to the landscape brought about by settlement and urban development. These systems have seen increased canopy closure due to invasion by fire-sensitive mesic species (such as sugar maple, *A. saccharum*) and exotic shrubs (e.g., buckthorn, *Rhamnus cathartica*), which has altered understory plant community composition and prevented oaks from reproducing (Packard and Mutel, 1997). Additional stress from rapid climate change may decrease the overall health of woodlands. As the health of a community declines, it could become more vulnerable to exotic species and outbreaks of pests and pathogens, further shifting species composition and structure. Controlling weedy species currently costs the United States more than $11 billion a year. The most widely used herbicide in the United States, glyphosate (RoundUp®), loses its efficacy on weeds grown at carbon dioxide levels that are projected to occur in the coming decades (Wolfe et al. 2007). Higher concentrations of the chemical and more frequent spraying thus will be needed, and both herbicide use and costs are likely to increase as temperatures and carbon dioxide levels rise (Kiely et al. 2004). Warmer winter temperatures may also limit the time period when snow cover allows for canopy manipulation treatments, which are often necessary to increase canopy openness, to be implemented without causing soil disturbance.

Climate change is expected to alter more densely forested communities as well. Wetter forest habitats may face reduced water availability due to increased temperatures and higher evaporation rates in the summer months. At the other end of the spectrum, dry habitats may get drier, leading to more stress on trees and lowering their resistance to disease as well as reducing the ability for communities to resist non-native invasions. Floodplains, a good example of wetter forest habitat, occur along rivers and streams where the frequency and duration of flooding have greatly shaped their communities. As such, floodplains are likely to be at a higher risk for increased stress on native species due to the more extreme flooding predicted for the region. Likewise, flatwoods may be at higher risk from more extreme floods, but also face challenges from increased drought stress. The reason for this is the soils of flatwoods have an impermeable, or slowly permeable layer, that causes a shallow water table and restricts the movement of water down into the ground, instead moving it laterally over the surface. This not only makes flatwoods more likely to be flooded, but also puts them at greater risk to dry up completely in the summer months. Depending on the timing of this latter scenario (little or no water availability for an extended period), it could prove problematic for amphibians like the blue-spotted salamander (*Ambystoma laterale*) that use ephemeral ponds and wetlands in flatwoods as key breeding and reproduction grounds. [Ephemeral wetlands, however, can occur in just about any terrestrial habitat type. These wetlands are crucial habitat for local amphibians, and will be one of the most vulnerable habitats to climate change.] Neither floodplains nor flatwoods were regarded as conservation priorities in the BRP, and we recommend that they be considered as such in light of the changes in climate predicted for our region.

Across the taxonomic spectrum, fauna associated with forested communities will be affected by the changes to their habitats. Amphibians like the Western chorus frog (*Pseudacris triseriata)* or spring peepers (*Pseudacris crucifer)* will face challenges due to an overall drier environment, while savanna species like the eastern bluebird (*Sialia sialis*) may be affected by shifts in plant community structure, to which they strongly respond. One group of animals that may fare quite well with climate change, however, is lumbricid earthworms (see Table 1.2). These earthworms are not native to North America, and have spread to areas where earthworms did not formerly exist in Illinois. Because lumbricid earthworms make their living decomposing forest leaf litter, they can cause a significant shift in forest soils that rely on a large amount of undecayed leaf matter for development (Seidl and Klepeis, 2011). This shift in soil ecology can result in habitats that are unsuitable for certain species of trees, ferns and wildflowers, further stressing native species.

The CW Report Card on the Health of the Region's Ecosystem's gave wooded communities of all types, including savannas, a D+ indicating that most are changing for the worse. These changes include invasive species crowding out native tree species, shrubs, grasses and wildflowers- a stress to the community that will increase with climate change.

Possible Adaptation Strategies and Actions for Wooded Communities

- Utilize river corridors to provide large-scale connectivity among these communities;
- Prioritize high quality wooded communities and maintain appropriate density of woody species present in them through active, restoration-focused management;
- Engage urban forests as genetic paths (pollen dispersal) and sources of propagules by planting native species in streets and parks; and
- Promote regional tree diversity through management in natural areas and planting in urban systems to increase resiliency of regional forest.

WETLANDS

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. The Chicago Wilderness region has one of the most diverse and highest quality collections of wetlands in North America, which are home to threatened, endangered and even globally rare species (e.g., Hine's emerald dragonfly, *Somatochlora hineana*; eastern prairie fringed orchid, *Platanthera leucophaea;* Blanding's turtle, *Emydoidea blandingii*; spotted turtle, *Clemmys guttata*; eastern massasauga, *Sistrurus catenatus*). The CW community-classification system recognizes seven major categories of wetlands: forested wetland, bog, sedge meadow, fen, marsh, panne, and seeps and springs. In addition, wet prairie is often considered a wetland type (although it is classified under prairie in this document).

Generally speaking, increased storm intensity and flooding may increase non-point source pollution from agricultural and urban areas, threatening the water quality for all wetlands. Additionally, wetland plants depend on seasonal hydrological patterns of wetlands and, in light of the expected changes in precipitation patterns and increases in evaporation rates in our region, it is very likely that hydrological cycling may change and negatively affect wetland communities. There is a possibility that some wetlands may begin to dry out as temperatures rise, evaporation rates increase and there is more pressure on groundwater resources; this could create a feedback loop that further fragments and stresses the remaining wetland habitats.

Of particular note with regard to changes in hydrology are bogs and sedge meadows. These communities were not previously listed as conservation priorities in the BRP, but they may face some of the greatest challenges due to climate-induced hydrologic changes. Bogs in the Chicago region are glacial-relict wetlands restricted to hydrologically isolated kettles as their sole source of water and may be reduced due to increased evaporation rates in the summer months. Sedge meadows exist due to groundwater seepage and/or shallow flooding (Chicago Wilderness Biodiversity Recovery Plan, 1999). It's possible that increasing temperatures and changes in lake levels (due to reduced ice cover and greater evaporation rates) may lead to increased pressure on groundwater resources and the potential for sedge meadows to dry out, threatening the existence of this system in our region.

Fens, which are groundwater-fed peatlands that are highly sensitive to hydrologic changes, may also face greater challenges because they are created and maintained by a continual internal flow of groundwater that will likely be reduced due to a variety of climate-related factors. Recharge rates and patterns will be affected by storm events and drought periods. While storm events may produce a great amount of precipitation, infiltration will not be at an equivalent rate. Furthermore, encroachment of invasive woody species (e.g., buckthorn and honeysuckle) that do not maintain infiltration as well as deep-rooted native plants will impact infiltration rates and wetland communities too. In addition, higher temperatures, earlier snowmelt and less snowpack, more severe and frequent floods that result in increased stormwater runoff and thus less groundwater recharge, and a greater demand on groundwater resources all threaten the continued existence of fens in this region. Marshes are especially important habitats for breeding and migrating wetland birds alike. The ability of marshes to achieve their maximum structural diversity, or the "hemi-marsh stage" where the surface is approximately 50% open water and 50% emergent vegetation, is critical to wetland birds. It is likely that higher evaporation rates, greater pressure on groundwater, and changes in precipitation patterns may compromise the ability for marshes to maintain, or even reach, the hemi-marsh stage for a duration that can benefit wetland birds.

Pannes are unique interdunal wetlands on calcareous, moist sands of the lake plain, generally within one mile of Lake Michigan (Chicago Wilderness Biodiversity Recovery Plan, 1999). Pannes are critical communities for species of high conservation concern, especially rare species like the Fowler's toad (*Anaxyrus fowleri)*, the northern cricket frog (*Acris blanchardi)*, and Blanding's turtle (*Emydoidea blandingii)*. These globally imperiled communities already do not have a good long-term outlook due to the physical impediments on beaches that block the natural processes that create and maintain them, and it is possible that additional stresses from climate change may exceed their ability to cope. Lastly, seeps and springs are susceptible to invasion by a number of plants including buckthorn (*Rhamnus* spp.), non-native species that may become more abundant as temperatures warm up the region and stress native species. Not only will the native plants occurring in and around seeps and springs likely be more stressed due to increasing invasions by non-native plants but, because seeps and springs are inherently very small, they are quite vulnerable to even slight changes in hydrology and increased evaporation rates.

In 2006, Chicago Wilderness experts convened to determine how we are doing as individuals and as a region in assuring the health of our unique natural areas. This collaborative work, called The State of Our Chicago Wilderness: A Report Card on the Health of the Region's Ecosystem, graded wetlands as a "D+". The report cited that remaining wetlands suffer from a number of threats, primarily altered hydrology due to intense development and the introduction of invasive species such as purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*) and common reed (*Phragmites australis*). However, in spite of the loss of more than 90 percent of our native wetlands, the Chicago Wilderness region retains one of the most diverse assemblages of wetlands in North America. It is of great value to ensure the continued survival of wetlands in the region because they not only support a great deal of biodiversity, but they also provide essential ecological services to human communities such as water purification and flood abatement. There is evidence that some wetland animal species have already responded to climate change. For example, climate change is associated with earlier breeding in amphibians (Beebee, 1995), earlier emergence of dragonflies (Odonata) (Hassall et al., 2007), and compositional shifts of entire insect communities (Burgmer et al., 2007, Rahel and Olden, 2008). It is also very clearly documented that sex determination in turtle eggs is closely linked to temperature, and this taxonomic group has already began to feel the affect of a warming environment (Tucker et al., 2008)

Possible Adaptation Strategies and Actions for Wetlands

Adapted from *Recommendations for a National Wetlands and Climate Change Initiative drafted by the Association of State Wetland Managers January 2009*.
http://aswm.org/pdf_lib/recommendations_2008_112008.pdf

- More stringently control drainage through regulation, focusing on total volume and runoff quality with consideration for how peak flow, attenuation, and timing may change due to changes in precipitation patterns;
- Prevent fragmentation of wetland ecosystems; more fully protect migration corridors;
- Prioritize wetlands with regard to management and adaptation. Establish "on the ground" priorities for the most cost effective application of protection and adaptation strategies. For example wetlands with deep carbon storage could be identified and targeted for acquisition or

more stringent regulations;

- Identify at risk ephemeral wetlands of high value, and investigate ways to either eliminate factors already limiting their hydroperiod, or to keep their hydroperiod long enough for priority species they support (e.g., in most years hydroperiod until July 1 is sufficient for blue-spotted salamanders, or August 1 for tiger salamanders);
- Adopt buffers to reduce potential for erosion and pollution, to maintain lower water temperatures, and to facilitate migration of plants and animals;
- Install water control structures at the outlets of freshwater wetlands. Such structures can, in some instances, help maintain water levels during dry periods. However, structures may be quite expensive, require maintenance, and interrupt natural succession. It also must be determined who controls the adjustments of water levels and the criteria for adjustments;
- Prioritize drainage tile removal as an effort to restore hydrology to sites;
- Identify (map through GIS) wetlands and wetland species most at risk from climate change within CW. This will require identification of plant and animal species with greatest vulnerability such as species with poor distribution and limited range. This work can build upon previous CW efforts that developed a Conservation Design for woodland communities, marsh birds has and wetland herpetofauna;
- Formulate protection plans and strategies for these wetlands or classes of wetlands that are identified; and
- Consider assisting turtles with temperature sex determination to help adapt to climate change.

SYNOPSIS

Overall, climate change impacts expected to exacerbate the greatest number of existing threats are 1) Increased temperatures promoting increases in tree pests in forested communities and 2) Increased temperatures promoting species that are invasive or act as disease vectors (Table 2.1). Both of these impacts are expected to amplify the threat of altered fire regimes, erosion and sedimentation, invasive species, and changes in structural diversity. Additionally, change to structural diversity has the potential to become the fastest growing threat to our region because it is affected by the greatest number of climate change impacts (five out of nine; Table 2.1), followed by invasive species (four out of nine; Table 2.1). How these structural changes manifest themselves, and the extent to which they occur, could greatly reshape the floral and faunal assemblages that are capable of continued survival in our region.

The range extensions of species not currently found in the CW region will likely become increasingly more pervasive due to climate change. We should expect to see spatial shifts both in range boundaries (e.g., moving north in the Northern Hemisphere) and in the density of individual animals or plants within various subsections of a species' range (Appendix 3, section 2.1). Further, it's important to recognize that shifts in density and abundance include extirpation (loss of a species from a local area) and extinction (Hall and Root, in press). A critical issue to bring up within this context is that arguably, from a functional point of view, not all species matter *per se* for the integrity or the functioning of an ecosystem, but rather it is the loss of individual *traits* that are essential for the production of organic matter and the functioning of biochemical cycles that is of greatest importance (Inchausti and Loreau, 2002). Coming from this perspective, we may need to adapt some of our longstanding species-specific management strategies and policies to focus more broadly on the *functional categories* that different species- whether they are native or migrating in from other regions- provide to an ecosystem. It is also crucial to begin managing for biodiversity by managing ecosystems from a landscape perspective to address fragmentation. This does not mean that species no longer matter, or that we completely stop species-specific management (because every natural community is of course composed of the individual species represented within them), but it does imply a broader, more flexible perspective for achieving management goals.

Given that the region is going to change and some species currently represented as part of the regional floral or faunal community may not be able to adapt to these changes, we will likely face hard decisions as to when to continue conservation efforts for a given species and when to shift focus and resources to something different. Factors that could influence continued conservation support for a species might be if the CW region represented the only remaining habitat, important migration routes, or the heart of the range for a species. On the other hand, if the CW region represented the southern range of a species distribution, or it was known that assisted migration could be implemented successfully for that species, then resources might be allocated to focus on different species. These decisions, however, will not be based on biological considerations alone, but also the societal value judgments that frame restoration and conservation priorities in this region.

Lastly, we need to begin managing ecosystems with a focus on landscapes to address fragmentation. This kind of research informed management could be challenging because the complexities of species interactions, and how these interactions influence ecosystem services, are still being discovered. As has been the case with restoration ecology, we will only arrive at these answers through adaptive management, which is the integrated process of testing, learning, and adjusting.

Below we present research questions and initiatives for terrestrial communities at large that will help us move forward and contribute to climate change adaptation management. Not surprisingly, there are more questions than there are answers at this point. Although information for best management practices in light of climate change is beginning to emerge, there will be a lag time before the data from on-going projects makes its way down the pipeline in the form of useable management strategies. In the meantime, we recommend: 1) discussing and sharing ideas on what is, and what is not, working for land managers, 2) incorporating conservative adaptation strategies into management planning, and 3) becoming involved with the much needed research initiatives.

Research Questions/Initiatives for Terrestrial Communities

- Which plant species are most sensitive to climate change and why? (see Appendix 3).
- Are plants and animals responding to changes in temperature and precipitation with the same or different strategies? For example, while many plant species respond to changes in temperature as a cue for when to emerge, the specific trigger (e.g., the total number of days above a certain temperature- or accumulated warmth- versus crossing a particular temperature threshold) may differ. Alternatively, daylight length may be the driving force behind emergence for some animal pollinators, which could lead to a timing mismatch if their host plants are instead more closely cued into temperature change. As temperatures rise and rainfall patterns

change, it is likely that some plant species may increase seed production while others decrease. Understanding how species' life history traits can influence their response to climate change is key to developing refined adaptation strategies (See Appendix 3, section 1.1).

- How will competitive interactions change with a changing climate (e.g., C_4 versus C_3 plants)?
- Gain a better understanding of community assembly information with regard to assisted migration, such as what the impact of the order of introduction will be and does this matter? What happens when we move a suite of species together?
- Most often research focuses on investigating one species at a time, holding all other factors constant. We need to focus now on interactions among species with changing climate, and especially across trophic levels.
- Design projects aimed at gaining a better understanding of seed transfer zones and addressing questions like how do we make successfully bridge the gap between the collection of bulk seeds to actual site dispersal? And what are best practices for seed collection, staggering rates, and dynamic seed transfer zones?
- Once a more complete understanding of the above questions has been gained, there should be a focus on adapting our recommendation for seed sourcing from one that suggests an "on-site policy of local is best" to one that includes the concepts of dynamic seed transfer zones, reciprocal transplants and knowledge of plant genomes of the area.
- Develop longitudinal monitoring to capture baseline information on the change in local flora/fauna in terms of distribution, abundance and phenology, and help to identify changes in species assemblages. Data can be used, for example, to match flowering phenology with bird migration data or to examine whether plant species are declining due to a loss or change in pollinator species. Currently, there are only a handful of programs that monitor plant phenology, and they do not have extensively long histories (examples of existing databases: Cook County forest Preserve database, ~ 40 yrs; Chicago Botanic Garden on-site prairie phenology, ~20 yrs; Plants of Chicago database, ~16 years; Plants of Concern database, ~9 years; Project Budburst, ~3 years).
- Coordinate and work with a resource-monitoring program in the form of an early invasive species watch program in NE Illinois/S Wisconsin to help support the Plants of Concern

and similar programs. Aim to identify a list of potential species coming into the area from the southern regions.

- Design more advanced modeling systems that take into account monitoring for a future dynamic system (as opposed to modeling for current system).
- Develop metrics for our adaptation strategies and research programs to evaluate terrestrial systems.

III. CLIMATE CHANGE AND AQUATIC COMMUNITIES

Most aquatic communities in the CW region occur within greatly altered, and often damaged, landscapes. The State of our Chicago Wilderness Report Card scored the region's rivers and streams at a C-. While most are cited as being in fair to poor condition due to landscape alteration, overharvesting, and pollution, there have been significant improvements in the condition of the upper Illinois River, as well as the Chicago and Calumet Rivers. Others, such the Fox and the Des Plaines, are not as impacted as the Chicago and Calumet River and have improved significantly over the past decade, but are still not considered high quality. Many of the remaining good quality streams and rivers lie in outlying watersheds and have not yet suffered the impacts of intense urbanization.
All of the main river courses, however, have been greatly altered, and invasive species are a threat and doing great damage throughout the region.

All aquatic communities in the CW region, including streams, rivers, inland lakes, ponds, and Lake Michigan, are likely to be impacted by the expected increase in water temperature and shift toward more extreme precipitation events. These impacts will manifest themselves in a variety of ways, with some affecting aquatic communities across the board and others tending to be more community-specific (Table 3.1). Just as the climate change impacts are expected to compound the existing threats to terrestrial communities, the same is likely to occur to the threats aquatic communities are facing, affecting both their water quality and quantity (Table 3.2).

Generally speaking, there are four main impacts likely to arise from increasing water temperature that probably will affect all aquatic communities in the CW area. The first is that increasing water temperature may favor warmer-water fish and aquatic insect species over cooler-water species due to differences in competitive ability and/or thermal tolerance among natives. Increasing temperatures could affect changes in growth rates and associated development times, allowing some species to have multiple generations per year where they have only one under existing conditions. Secondly, warmer water temperatures may offer non-native species a better chance to establish themselves, increasing the stress on native plant and animal populations. Thirdly, increased water temperature could reduce availability of dissolved oxygen for organisms because warmer water holds less oxygen. Independently or collectively, these factors could lead to changes in our aquatic species assemblages, especially through the potential for a higher incidence of invasive species. The proportional composition of the assemblage could also change, whereby the same species are present but those with greater tolerances to warmer conditions become dominant. These would likely be species with more rapid growth and shorter life cycles (e.g., *Chironomidae* [midges], *Culicidae* [mosquitoes]). Lastly, warmer air and water temperatures increase the likelihood of changes in snow patterns (longer dry spells followed by large snow falls) reduced ice cover, earlier snowmelt and/or ice breakup, and earlier peaks in spring run-off, potentially shifting the timing and the volume of stream flows and influencing water levels. These conditions can also lead to pulses of cold or warm water that provide "thermal shocks" to fish in these streams. Hydrologic changes of this type play a role in determining species composition, especially among some groups of phytoplankton, such as diatoms (IPCC, 2002).

The projected increase in heavy precipitation events is also likely to affect aquatic communities as a whole. More extreme storm events may lead to more flooding and non-point source pollution due to greater runoff from urban/agricultural areas. Not only would this situation increase the number and the severity of summertime pollution episodes in our region, such as Combined Sewer Overflow (CSO's), but it may cause extreme flow conditions that promote stream channel and lakeshore destabilization, leading to increased sedimentation and a loss of sensitive aquatic habitats (scouring). While invasive species, hydrologic change, and loss of native vegetation are common threats to both aquatic and terrestrial systems, aquatic communities are much more sensitive to sedimentation, toxic substances, and excess nutrients (Brönmark and Hansson, 2002).

Along with these broad impacts, it is likely that some climate change impacts may be community-specific. Below we outline three main aquatic community divisions in CW and discuss the specific impacts they may be facing, as well as provide initial biodiversity adaptation strategies.

Rivers and Streams

Within Chicago Wilderness, streams and rivers are grouped into four size categories (headwater stream, low-order streams, mid-order streams, and large rivers) with additional subcategories defined by flow, gradient and substrate. Rivers are inherently dynamic systems that are constantly “adjusting” to changes in sediment and water inputs by migrating across the landscape and changing the depth, width, and sinuosity of their channels (Palmer, 2008). While these changes are part of a healthy river’s response to changes in the landscape and the climate regime, the rate at which water temperature and precipitation patterns are expected to change may be much faster than historical climate shifts, exceeding the ability of the biological communities in these streams and rivers to adapt (IPCC, 2007). The degree to which this aspect of climate change could impact rivers in Illinois, which are very dynamic systems accustomed to major and fast shifts due to flooding, will likely depend on the frequency of the flooding events and the human response to additional flooding. The latter issue highlights the need to anticipate ways to minimize the impacts of flooding on both humans and river systems, for example by restoring and reconnecting floodplains to rivers in order to reduce flood risk while increasing ecological services (Opperman et al., 2009).

Today, dams, development, and other water uses that alter historic natural drainage and functions affect many of the rivers and streams in Illinois. As such, though increased temperatures may promote range shifts in sensitive species, some may be impeded by dams and other barriers and unable to shift into more appropriate areas. This issue is widely recognized and efforts have been underway to identify appropriate approaches to help alleviate dispersal boundaries without increasing the risk of pathogens and invasive species. For example, research conducted at the Fox River in Illinois supports the effectiveness of dam removal as a restoration practice in certain circumstances for impaired streams and rivers (Maloney et al., 2008). However, differences in response times of macroinvertebrates and fish coupled with the temporal effect on several habitat variables highlight the need for longer-term studies. The expected changes to the timing, frequency, and duration of precipitation events, along with warm water temperature, will likely amplify the current threats to rivers and streams. As with terrestrial systems, climate change is likely to affect rivers and stream at the level of species as well as ecosystem function.

At the species level, environmental changes that affect attributes of streams and rivers closely associated with life history traits, such as flow regime, may lead to shifts in the abundance and/or distribution of species. For example, a rapidly altered river flow regime may render species unable to find suitable flow environments for feeding, reproducing, or surviving major flood events. Higher flows, due to more extreme storm events, may also result in a higher amount of suspended sediment and bedload transport and interfere with species' ability to feed (Palmer et al., 2008). Another issue of great concern is the potential for sediment deposition to fill in interstitial spaces close to rivers. This could greatly reduce the availability of hyporheic habitat, or the narrow margins of land adjacent to river channels inhabited by riverine invertebrates (Palmer et al., 2008). Not only could this result in loss of habitat for insects and spawning areas for lithophilic fish, (i.e., fish species that lay their eggs on rocks; Pizzuto et al., 2008), but it may prove problematic for overall river ecology because the hyporheic zone provides a great deal of nutrient discharge crucial to biotic productivity in the river channel (Stanford and Ward, 1988). Whether deposition or net export of these sediments occurs will depend on the peak flows and size of the sediment moving into channels (Palmer et al., 2008). Export will occur when the amount of energy associated with the flowing water is large enough to move the particle (regardless of the size), whereas deposition occurs when there is not sufficient energy to move the particle. The characteristics of the existing discharge (flow), existing sediment load, and any new sediments moving into the channel associated with runoff (flow enhancement) will determine which of these process will occur at a specific time. Net deposition or export of sediment will depend on the relationship between the overall flow regime and sediment size distribution that makes up the stream channel and inputs from the adjoining landscape.

It is important to monitor sediment deposition and flow regime because particle size and hydraulic forces are both known to be major determinants of stream biodiversity (both in density and composition of algae, invertebrates, and fish). Failure to monitor and respond to these issues may result in excessive bottom erosion, which can decrease species diversity and lead to dominance by a few taxa (Palmer, 2008; Allan, 2007). The key point here is that the monitoring program must be integrated into the management program so that monitoring results will be used to guide management (i.e., adaptive management).

Rivers and streams provide a variety of essential ecological processes, such as ensuring clean water for drinking and supporting wildlife, that will be influenced by warmer air and water temperatures and altered flow regimes. A major concern is that hotter summers with more extreme high temperature events and greater evaporation may disconnect flowing waters from their floodplains (Palmer, 2008), which could negatively affect the ability of species to disperse, as well as the energy flow and/or nutrient cycling of ecosystems. On the other hand, because primary production in streams is very sensitive to temperature and flow levels (Lowe and Pan, 1996; Hill, 1996), climate change could lead to an increase in food availability to herbivorous biota that may in turn support higher abundances, but also shift species composition. This shift in species composition of primary producers, associated with high levels of competition for nutrients, can also lead to a decrease in food supply as many nutrient fixing algae (especially blue green algae) are relatively unpalatable to herbivorous insects and fish. If this occurs stream assemblages may have less energy available for higher trophic levels, leading to trophic cascades or shifts in species dominance.

A great deal of uncertainty exists, however, about how ecological processes such as rates of nutrient processing will be influenced by climate change (see Palmer et al., 2008 for discussion) and few studies have been conducted to simultaneously examine the many interacting factors that are both subject to change in the future and known to influence ecological processes (Palmer et al., 2008). Another layer of complexity to consider is that within the CW region few streams retain their original hydrologic regime, and much of the flow is effluent from human sources with flooding events dominated by CSO's, suggesting the timing of flooding events is already atypical. Additionally, most streams in this area have been previously decoupled from their adjoining terrestrial habitats due to channelization or dredging. These aspects combined with the issue that effluents from sources such as power plants have already introduced unnatural temperature regimes to the system, makes it difficult to determine whether climate change effects will dwarf the existing changes, or be dwarfed by them.

Climate change can interact with existing threats in two main ways. First, it can exacerbate the impacts of current threats. For example, milder winters will create conditions that will be favorable to aquatic invasive species, increasing the magnitude of this stressor on aquatic systems (Appendix 3, section 2.3). Additionally, choices made regarding how and where areas are developed and natural resources are utilized can in turn intensify the negative effects of climate change. Research has suggested that the land use change, particularly the clearing of native vegetation for urban and suburban developments, and excessive extractions of river water or groundwater that feed into streams and rivers will likely intensify the negative effects of climate change for rivers and streams (Allan, 2004; Nelson and Palmer, 2007). With the Greater Chicago region projected to experience a 25 percent increase in population growth and possibly a 55 percent increase in developed land by 2020 (SNAP, 1999), thereby increasing the stressors that amplify climate change impacts, it underscores the importance of integrating climate change adaptation strategies into current CW river and stream management plans by developing a watershed plan that relies on green infrastructure.

Below are some initial strategies for biodiversity adaptation in streams and rivers under conditions of climate change drawn from the U.S. Climate Change Science Program (Palmer et al., 2008) and the Massachusetts Climate Change Adaptation Strategies Summary (2009):

Possible Biodiversity Adaptation Strategies for Rivers and Streams
*Adapted from Glick et al. 2009**

- Increase monitoring capabilities in order to acquire adequate baseline information on water flows, water quality, and temperature, thus enabling river managers to prioritize actions and evaluate effectiveness;
- Strengthen collaborative relationships among federal, state, and local resource agencies

and stakeholders to facilitate the implementation of adaptive river management strategies;

- Forge partnerships and develop mechanisms to ensure environmental flows (i.e., the amount of water needed in a watercourse to maintain healthy ecosystems) for rivers and streams in basins that experience water stress;
- Work with land use planners to minimize additional development on parcels of land adjacent to rivers and streams. Optimally, try to acquire floodplains and nearby lands that are not currently publicly owned or ensure they are placed in protected status. Recharge areas need to be included in these types of planning activities to provide baseflow to streams beyond that from effluent discharges;

- Remove in-stream barriers (dams and undersized culverts) and re-establish in-stream flows to restore aquatic habitats. This strategy should be well researched and designed to minimize the potential for the spread of invasives and disease vectors. Locations should be carefully and strategically selected to reflect areas that would benefit the most under both current as well as future conditions;
- Protect and conserve land including remaining critical cooler-water fish habitat areas, reconnect high quality habitats, protect belt-width-based river corridors (i.e., corridors defined by the lateral extent of the river meanders), and restore floodplains;
- Work with stakeholders to develop water conservation strategies to maintain stream flow because reductions to the base flow of a river may result in the river not being able to support the current native communities;
- Develop a list of possible new invasive species – what is out there and what are their chances of survival as the conditions change;
- Work with the agricultural community to discuss alternatives to the current ways that they use water for their crops and whether more efficient water systems exist, and reducing pesticides/insecticides and nutrients into the waterways;
- Get a better handle on human water consumption - increase water use efficiency and conservation*;
- Encourage greater use of seasonal and long-term projections for streamflows in water management decisions to more proactively protect and restore flows for fish habitat*;

- Promote biological diversity by managing for invasives and maintaining in-stream habitat diversity*;
- Restore riparian vegetation. Designing riparian restoration projects to endure stream flows of increased magnitude and variability will enhance long-term restoration success and improve the quality of the aquatic ecosystem*;
- Maintain natural flood regimes in places where they are still intact;
- Incorporate forward looking assessments and longer time horizons in water resource planning (e.g., CMAP's Water 2050 became a U.S. Environmental Protection Agency WaterSense Promotional Partner to promote water efficient fixtures such as high efficiency toilets and showerheads, also use of rain barrels for watering plants, grey water for flushing local ordinances for best management practices for lawn care);
- Discourage new development in floodplains*;
- Consider future climate changes when designing and building infrastructure (water control structures, drains, pumps, etc.);
- Guide growth and incentivize Smart Growth or low impact developments outside of floodplains;
- Improve storm water management;
- Select for more water efficient crops (e.g., peas, wheat etc. https://www.certifiedcropadviser.org/files/certifications/certified/education/self-study/exam-pdfs/184.pdf)
- Buffers should be encouraged along rivers and conservation easements can encourage them;
- Partner with NRCS to help promote the Best Management Practices for agriculture appropriate for the region and water supply, including less use of nutrients and pesticides;

Lakes and Ponds

In addition to Lake Michigan, three types of natural lakes occur in the Chicago Wilderness region: bottomland lakes, ephemeral ponds, and glacial lakes. Glacial lakes are divided further into *kettle lakes*, which are isolated basins, and *flow-through lakes* that are connected to a stream system. In addition to the natural lakes, the region has a number of human-made lakes. Small lakes and ponds throughout the U.S. have been greatly modified. For example, many have historically been drained or filled in to extend arable land, regulated to reduce water-level fluctuations, used as dumps for an array of anthropogenic wastes ranging from untreated sewage to synthetic substances, and many natural populations of commercially-important freshwater species have been over- exploited (for reviews see Burkholder, 2001; Lévêque, 2001). The habitats that remain today have suffered loss of species diversity and ecological structure through introduced eutrophication, coupled with toxic pollution and the introduction of aggressive non-native species. Currently, the most severe threats to lakes are invasive species, nutrient loading, sedimentation, loss of native submerged and emergent vegetation, and management actions focused on only a narrow range of species (such as game fish).

Lakes and ponds are habitats of great human importance as they provide water for domestic, industrial and agricultural use, habitat to support an array of biodiversity, and food. In our region, glacial lakes are the most biologically diverse of the lake types. Species level biodiversity in freshwater lakes and ponds, as with other freshwater systems, is influenced by a number of factors, both abiotic (e.g., climatic factors, water chemistry, habitat heterogeneity, habitat size and isolation) and biotic (e.g., predation and competition) that operate at different spatial and temporal scales. Predation and competition are especially critical in determining species diversity and, perhaps more importantly, species composition, and thereby the function and dynamics of the whole system (Brönmark and Hansson, 2002). It's possible that environmental disturbances due to climate change may result in reduced biodiversity due to either direct lethal effects on organisms or due to more complex interactions between different factors (Brönmark and Hansson, 2002).

There are several climate change impacts that may affect lakes and ponds in particular. For example, a drier environment may reduce the extent and duration of vernal ponds, which are essential to the survival and reproduction of many amphibian species. Additionally, warmer water temperatures may exacerbate the current problem of nutrient pollution and algae growth. The 2002 IPCC report on climate change and biodiversity cautions that increasing temperatures in deeper lakes could promote a longer stratified period that results in more areas low in dissolved oxygen. Reducing oxygen concentration, especially if exacerbated by eutrophication related to land-use practices, could lead to altered community structure in the form of fewer species. In more shallow water layers, higher temperatures could reduce the nutritional quality of edible phytoplankton, or possibly shift the composition of the phytoplankton community away from more nutritious species toward less nutritious species such as cyanobacteria and green algae (IPCC, 2002). Another impact from increased water temperatures may be higher microbial respiration rates, which could increase organic-matter decomposition rates and shorten the duration that detritus is available to invertebrates (IPCC, 2002). Finally, as water levels decline due to increasing rates of evaporation and greater pressure on water resources for human use, lakes may become disconnected from their bordering wetlands and negatively impact those species that rely on the interstitial areas for spawning (e.g., trout, salmon).

The State of our Chicago Wilderness Report Card points out that our lakes, like our rivers and streams, suffer from the effects of intense urbanization. Although some isolated glacial kettle lakes are in excellent condition, the majority of our region's lakes remain in fair to poor condition. To minimize the extent of additional stress from climate change on our already vulnerable lake and pond communities, it will be imperative to integrate adaptive management strategies into our best management practices.

Possible Biodiversity Adaptation Strategies for Lakes and Ponds

- Since many of our lakes (and some ponds) are under multiple bottom ownership- meaning that the land beneath the waters is apportioned among various shoreline owners- it is imperative that partnerships and education are included in any long-term strategies, particularly with landowners;
- Develop education outreach for local entities and lake users, particularly for boat users because accidental transport by boats is one of the primary means for the introduction of invasive aquatic weeds and animals such as zebra mussels;
- Develop education for aquatic gardeners; many aquatic garden plants are semi-tropical, but may be able to survive or become invasive under conditions caused by climate change;
- Monitoring, particularly phytoplankton assemblies and invasive species, but also water quality. More intense storm events may lead to higher sedimentation rates, which will accelerate

the eutrophication process. Monitoring of native fish and aquatic plant populations will be important as well, since many of these species are at their southern range here in the CW;

- Guide growth and incentivize Smart Growth/low impact development to reduce nonpoint source pollution;
- Encourage water conservation; and
- Use native planting near/around lakes and ponds to help with runoff from communities.

Lake Michigan

Lake Michigan is a vast aquatic ecosystem often divided into three main interacting eco-zones, namely the lakeshore, the near-shore waters, and the benthic zone. The Illinois Department of Natural Resources defines the lakeshore/coastal areas as being the most biodiverse area in the state. The near-shore waters in the Chicago Wilderness region function primarily as part of the larger connected system. However, they are an important part of CW, both in their impact on adjacent ecological communities and intrinsically as an important ecological community. Lake Michigan provides a variety of ecological benefits to the CW region, including climatic diversity, sand to nourish its changing beaches and dunes, seasonal and year-to-year changes in water level to support lakeshore wetland communities, near-shore waters that provide habitat for many fish and other aquatic species and are used by migrating waterfowl and shorebirds, and drinking water for the human population and economy.

Much of the shoreline in the Chicago Wilderness area has been filled for buildings, parks, and marinas, eliminating coastal wetlands. The wetlands that do remain, however, are some of the highest quality in the state of Illinois. Additional current threats to Lake Michigan include loss of coastal habitat connected to the lake along the lakeshore, habitat degradation along the lakeshore, reduced water quality due to invasive diseases for fish (e.g., viral hemorrhagic septicemia in fish) and toxins (e.g., Polychlorinated biphenyls, or PCBs, and mercury in fish), excessive fish harvesting, and changes in the food web (e.g., decreased populations of the shrimp-like amphipod *Diporeia*, an important food source for lake fish, may be related to the introduction of zebra mussels; invasives such as lamprey and the introduction of salmon, alewives, gobies, common carp, etc.). Futhermore, both quagga and zebra mussels are invasive species that are filter feeders, and they clarify the water and allow sunlight to penetrate deeper into the lake. Their fecal matter is nutrient rich and acts as a fertilizer, whereby increasing the growth of Cladophora algae and possibly playing a role in triggering the growth of Botulism.

As is the case with terrestrial and other aquatic systems, climate change is expected to exacerbate the current threats Lake Michigan faces, and affect the near shore waters and lakeshore in the CW region. Great Lakes water usage is based on a legal compact between states, and the Supreme Court decree that governs Illinois' withdrawals, which sets the framework and process for competition for water resources likely to increase over the next several decades due to population growth and lack of water conservation measures. Climate change may intensify this competition due to reduced winter ice cover and higher evaporation rates contributing to lower lake levels and increased ground water draw down, affecting both human resource needs and natural community ecology. For example, lower water levels may shift the location of near shore habitats and expose toxic sediments. Exposing certain toxins such as PCBs can cause them to become even more volatile. Reduced lake levels may additionally expose more nearshore areas to invasion by *Phragmites,* which can be especially threatening to the sand dunes and their unique species assemblage, or reed canary grass. While new habitats can emerge as a result of lower lake levels, often the native plants will not be able to establish themselves fast enough due to current problems with aggressive invasives along the shore.

Increasing water temperatures may impact Lake Michigan in several ways. In particular, warmer water may favor invasive species like toxic Cyanobacteria algae, which can grow and bloom at faster rates in warmer water. Changes in water temperature can impact food webs, for example if the food web shifts in the phenology of important events in their life cycle, and these phenological shifts become out of phase (e.g., phytoplankton blooming, then zooplankton emergence from dormant forms…). Another major issue that warmer water temperatures could pose is the potential to exacerbate existing nutrient pollution and algae growth in freshwater lakes. Furthermore, coupling lower water levels with warmer water temperatures may accelerate the accumulation of mercury in the aquatic food chain, as it is more likely to convert into a more bio-available form. This is due to the fact that production of methyl mercury (the bio-available form) is strongly associated with factors that favor mercury methylating microbial communities, such as warmer sediment temperature and anoxic conditions (Foster et al. 2000). This effect would not be limited to Lake Michigan and would impact smaller lake and river systems as well. However, the scale of this issue would be greatest possibly in Lake Michigan.

A final point is that there is evidence from the upper Great Lakes region indicating surface water temperature may be increasing even faster than air temperatures. This situation is thought to be triggering a range of system-wide impacts such as higher wind and current speeds and longer periods of lake stratification in this region (Austin and Coleman, 2007, 2008; Desai et al., 2009; Dobiesz and Lester, 2009), and could potentially have far reaching effects to our region.

Possible Biodiversity Adaptation Strategies for Lakes Michigan

- Reduce water removal from Great Lakes;
- Reduce ground water removal and promote water conservation and efficiency;
- Reduce nutrient inflow into Lake Michigan;
- Utilize green infrastructure (wetlands, floodplains, bioswales, green roofs etc.) to capture water as it falls, which recharges groundwater for habitat and temperature modification, as well as prevents flash events that pour contaminants into the lake; and
- Develop restoration, and monitoring, standards that result and measure more resilient coastal habitats. For example we know that due to changes in lake levels, coastal restoration projects should be designed to include plants that do well under various lake level conditions.

SYNOPSIS

Overall, the climate change impacts expected to exacerbate the greatest number of existing aquatic threats are 1) Increased storm intensity and/or frequency which may increase non-point source pollution of aquatic systems and wetlands and 2) Increased temperatures that may lead to drying wetlands and ephemeral streams, further isolating and fragmenting the remaining communities (Table 3.1). Both of these impacts are expected to amplify changes in hydrology. Additionally, increased storm intensity and frequency will likely increase flooding, and consequently erosion and sedimentation, while the drying of wetlands and ephemeral streams is expected amplify fragmentation and loss of structural diversity. By altering the timing, intensity, and duration of high and low flows in streams the conditions under which native biodiversity evolved will be changed, causing an additional stress on these communities irrespective of any changes in non-point source pollution or water temperature. Furthermore, of the existing threats to aquatic communities, hydrologic change is affected by the greatest number of climate change impacts (7 out of 12; Table 3.1), further compounding one of the most severe threats to aquatic communities in our region.

It is clear that climate adaptation for stormwater management will need to play a large role in securing the future health and continued functioning of our natural aquatic communities, just as it will be key in protecting our human health. According to the US EPA (2008), The Great Lakes Region's 182 combined sewer systems, serving more than 40 million people, will see an average of 237 rainfall events per year that are too heavy for them to handle by mid-late century (2060-2099) if climate trends continue. To address this, and other climate change related issues, the Chicago Biodiversity and Stormwater expert workshop was convened in July 2009 in Chicago, IL. The workshop focused on climate adaptation planning and strategy development for biodiversity and stormwater management in the CW region. Key findings from the workshop highlighted the need to modify our existing stormwater infrastructure, including the incorporation of natural communities, to help mitigate the expected increase in extreme storm events. One of the main themes that emerged was that we should be viewing stormwater as a useful resource, seeking as much water conservation and infiltration as possible, so that groundwater can be recharged, combined sewage overflows mitigated, and ecosystems maintained. A way to achieve to this goal, and many other terrestrial and aquatic climate change adaptation management strategies, is through Green Infrastructure, which will be discussed in the next section. Below we present research questions and initiatives for aquatic communities in general that will help us move forward and contribute to climate change adaptation management.

Research Questions/Initiatives for Aquatic Communities

- Which species, both native and introduced, are most affected by expected changes in water temperature both positively and negatively?
- Model CSOs in response to a range of extreme precipitation events.

- Understand ecological effects of altered flow regime, so we can figure out what are the crucial factors to attempt to influence.
- How will different temperature regimes affect nutrient cycling?
- The current water budget was developed for monitoring diversion limits. What is the water budget we need for sustaining biodiversity? How can environmental flows be incorporated into existing and future water budgeting efforts?
- What are the aquatic food web needs for spawning in the near shore, shore, wetlands, rivers, streams, reservoirs and reef lakes? How can they be protected?
- In Toronto, they have begun building artificial spawning structures into piers and other structures. Is this working? Is it worth the expense?

IV. CLIMATE CHANGE AND GREEN INFRASTRUCTURE

Our landscapes have dramatically changed over the last century, particularly in urban regions like Chicago Wilderness. As a result of increasing development the region's natural communities, once entwined as part of a larger connected ecosystem, have been severed from one another and carved into miniature altered versions of their historic expansive landscapes. The resulting fragmentation and overall habitat loss has hindered nature's ability to respond to climatic changes. For example, viability of wildlife populations is decreasing due to reduced genetic diversity and limited wildlife movement. Though climate change will further compound the current threats of habitat fragmentation and degradation to remaining communities, it has not been addressed in many existing natural resource plans (Hannah et al., 2002). This section will discuss Green Infrastructure, both as a concept and a process, and how it plays a key role in the implementation of strategies and actions aimed at adapting biodiversity to climate change in the CW region.

At the regional scale, the concept of green infrastructure refers to an interconnected green space network created by conserving or reestablishing linkages between natural communities and other undeveloped land. (Other scales below the region at which green infrastructure can be considered are described below). The "green space" may include natural areas, public and private conservation lands, working lands with conservation values and other protected areas. This mapped network is intended to guide decisions about the creation of open space and links that support conservation and associated outdoor recreational activities (Benedict and McMahon, 2006). As a process, the green infrastructure approach enables diverse interests to collaboratively identify priority lands for protection. The overarching purpose is to provide a framework that can be used to guide future land development and land conservation decisions that accommodate population growth while still preserving community assets and natural resources (Benedict and McMahon, 2006). Previously Chicago Wilderness has defined green infrastructure in line with the consortium’s central purpose, conserving biodiversity, treating green infrastructure as “the interconnected network of land and water that supports biodiversity and provides habitat for diverse communities of native flora and fauna at the regional scale. It includes large complexes of remnant woodlands, savannas, prairies, wetlands, lakes, stream corridors and other natural communities that have been identified in the Biodiversity Recovery Plan. Green infrastructure may also include areas adjacent to and connecting these remnant natural communities that provide both buffers and opportunities for ecosystem restoration.”

Developing new and linking existing green infrastructure can reduce many of the impacts expected from climate change. It can mitigate climate change as well as help biodiversity adapt to the changes that are already happening. For example, green space networks can aid in moderating urban temperature extremes to ensure that towns and cities continue to be attractive and comfortable places to live, work, visit and invest (Benedict and McMahon, 2006). Having more green space can also reduce flood risk and manage surface water; instead of stormwater entering our streams and lakes as polluted surface run-off, it can infiltrate back into the soil and recharge our groundwater. Furthermore, functional landscape connections may allow species to move into new 'climate spaces' (Hough et al., 2010). As natural communities face further loss and fragmentation due to climate change, and the need increases for temperature-sensitive species to have migratory pathways to disperse and migrate, it will be essential to develop green infrastructure in a “climate-smart” way to help ensure long-term viability for the ecosystems of the Chicago Wilderness region.

Chicago Wilderness has been a leader in recognizing the importance of green infrastructure. The Northeastern Illinois Planning Commission completed the Green Infrastructure Vision (GIV) for the consortium in 2004, and refining and implementing the GIV is now one of the four key initiatives of CW. The GIV has been referred to as a “blueprint” for creating healthy ecosystems that contribute to economic vitality and a high quality of life for all residents. The GIV represents a major component of the implementation strategy for the Biodiversity Recovery Plan, and will support the other three initiatives of CW: Leave No Child Inside, Management and Restoration, and Climate Change. Figure 4.1 depicts a graphic representation of the GIV; the dark green areas illustrate the 360,000 acres of existing protected areas (as they existed in 2004-2004) nested within the identified Resource Protection Areas- prospective areas for protection, restoration, and compatible conservation development practices. The GIV has both a mapping and a policy component, the latter stipulating the kinds of resource protection activities needed within the Resource Protection Areas and elsewhere in the region. Beginning in 2009 Chicago Wilderness members began a coordinated effort to implement the GIV at four scales:

● **Regional**, by working with regional planning agencies to redefine how we think about sustainability and community health by incorporating conservation development principles and natural resource preservation into land use and transportation plans.

● **Community**, by incorporating principles of biodiversity conservation, sustainability, and people-friendly design into land use plans and ordinances.

● **Neighborhood**, by promoting the preservation of natural spaces, conservation design and access to nature into developing communities, and

● **Site**, by promoting native landscaping, the use of rain gardens and rain barrels, and through the greening of schoolyards and other community open spaces.

It is necessary to incorporate climate change information at each of these scales in order to have successful implementation of the biodiversity adaptation strategies and actions presented in this document for the CW region. Many of the tools needed to aid ecological adaptation to climate change have already been developed and are part of current restoration ecology practices; however, land managers will likely need to apply these tools in novel and innovative ways to meet the unprecedented challenges posed by climate change (Mawdsley et al., 2009). This applies directly to the GIV in that land managers and planners need to consider creating and connecting our green space in a way that will sustain the functionality of natural communities, now and in the future. The following are several climate change adaptation strategies that apply to wildlife management and biodiversity conservation and that represent the types of actions needed to advance the CW Green Infrastructure Vision in a climate-smart way (Mawdsley et al., 2009):

Possible Green Infrastructure Adaptation Strategies:

- Improve the ability of species to move across the landscape from a climate change perspective. There are two main aspects of this strategy that vary in scale and in the benefit they provide to organisms. The first aspect is to identify and improve major corridors that can facilitate larger-scale movement patterns to allow latitudinal movement of organisms as they try to maintain their position within the appropriate climatic envelope. An example of this would be connections along river corridors ensuring the potential for movement through the entire CW area. The second aspect of this strategy is improving connectivity among habitat patches at a local scale, allowing organisms to find favorable microclimates or specialized habitats that are declining with climate change. This involves identifying 1) species with high vulnerability to climate change (e.g., low tolerance to changes in temperature or precipitation), 2) natural areas with these species of concern and 3) movement corridors within and between reserves based on the expected changes in landscape due to climate change impacts (e.g., increased habitat loss for shallow streams, vernal ponds, fen communities and fine-textured wetter-soil prairies). An example would be routes for herp species and other animals to cross roads that go through forest preserves, similar to the road grid that breaks up Palos. These sites should be priority areas for resource management and restoration actions.

- Develop guidelines for resource managers planning large restoration actions to determine if impacts of climate change, e.g. natural resource vulnerabilities, will adversely impact primary purpose or cost/benefit analysis of restoration actions.

- Each land management agency should review current land and resource management goals, objectives, and practices relative to providing resiliency on landscape reserves and other major holdings. The CW Climate Action Plan for Nature plans to develop climate clinics aimed at helping land managers create adaptation plans that optimize resiliency and management objectives.

FUTURE DIRECTIONS

The intention of this first iteration of the BRP climate change review is to provide CW members with the necessary background to understand the threats our natural communities may face from climate change, to recognize the need to review our biodiversity recovery and conservation strategies through a climate change lens, and to present initial suggestions to help our communities adapt. In the end, our ability to be successful in the approaches we take to adapt our biodiversity will largely depend on our openness to try new strategies and our readiness to share the outcomes with one another, in terms of what is working and what is not. This is a living document, meant to promote dialogue between CW members on all facets of biodiversity adaptation in our region, from research and planning to implementation and outcomes. We envision this document as an on-line resource for two reasons. The first is to enable land managers and others who are implementing these strategies to give their feedback and, secondly, to allow the document to be kept up to date as new information becomes available.

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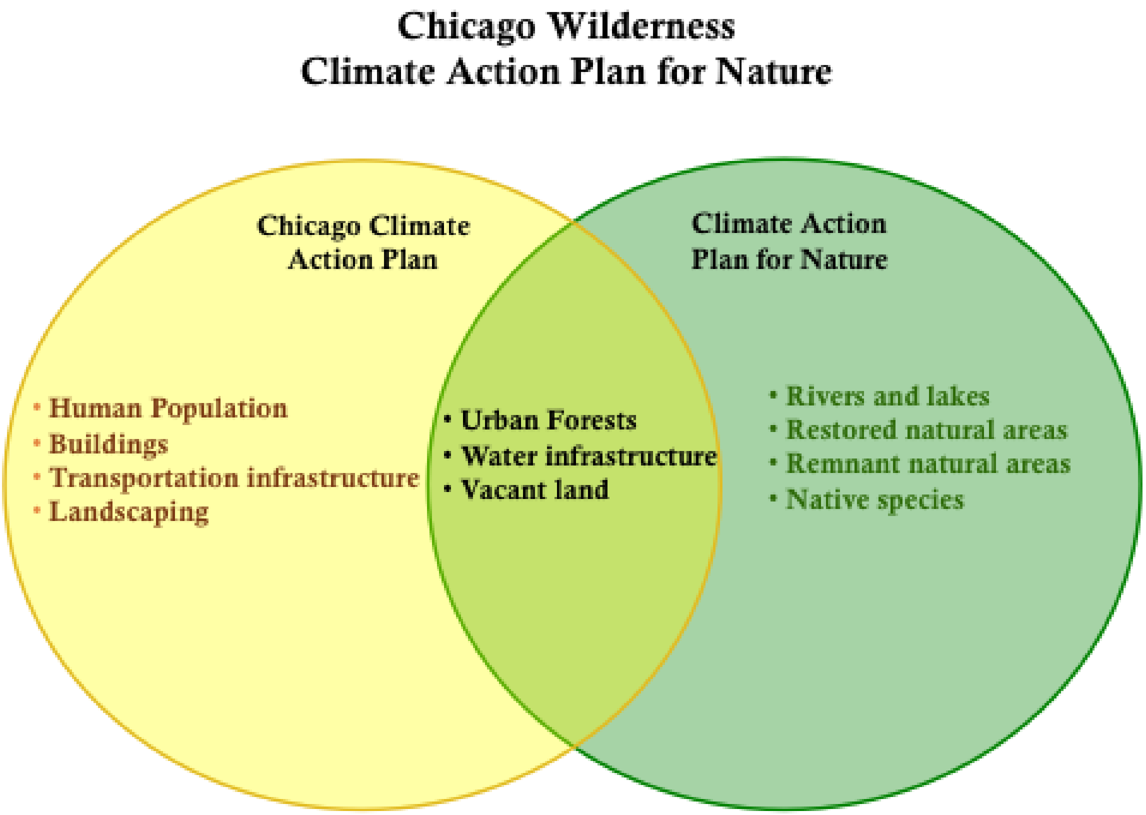
FIGURE 1.1: Map of the Chicago Wilderness Region

FIGURE 1.2: Similarities and Differences between the City of Chicago Action Plan (CCAP) and the Climate Action Plan for Nature (CAPN).



BOX 1: Past Climate Changes and Projected Future Trends in CW Climate System.

Climate System (since the mid-20th century)

Recent Changes in Climate

- Annual average temperature increase of more than 2°F since 1945;
- Increase in temperature was greater during the winter than other seasons, increasing 4°F since 1980;
- Much of the warming is concentrated during the cool season and at night;
- Fewer cold waves, and a number of major heat waves in the last few decades;
- Lengthening growing seasons (indicated by a progressive advance in the last date of spring freeze), current dates are approximately 1 week earlier compared to the beginning of the century;
- Lake Michigan ice forming later, lasting for shorter periods, with some years having almost no lake ice;
- A doubling in the frequencies of heavy rain events (defined as occurring on average once per year during the past century) since the early 1900's;
- Increases in fall precipitation resulting in increased annual mean and low flow of streams, without any changes in high annual flow;
- Increasing lake-effect snow during the twentieth century which may be a result of warmer Great Lakes surface waters and decreased ice cover; and
- Warmer and wetter growing season.

*Changes Expected by Middle to End of this Century**

- Temperature increases — Chicago could expect an annual average temperature increase ranging from 3 - 4°F under lower emissions to 7 - 8°F under higher emissions; greatest increases likely to occur during summer and winter seasons;
- Hotter summers — number of extremely hot days (over 100°F) could increase from the current 2 days per year to 8 days per year under lower emissions, or as many as 31 days per year under higher emissions;
- More heat waves —- using the catastrophic 1995 heat wave as a baseline; under higher emissions there could be several heat waves like 1995 each year and one every other year with lower emissions;
- More humidity — warmer air holds more water; increased evaporation of surface water would result in increased humidity;
- Longer growing season — last spring frost would occur from 20 days earlier under lower emissions to about 30 days earlier under higher emissions;
- Less frost — fewer frost days each year and frost depth in the soil will decrease;
- Fewer extremely cold days and cold spells — the average coldest day of the year could warm by 4 - 6°F through this century;
- Large seasonal shifts in precipitation — most precipitation occurring in winter and spring, and increased chances of drought in the summer;

- More heavy precipitation events — defined as greater than 2.5 inches, the threshold for combined sewer overflow into Lake Michigan. Slightly greater increases are expected for regions closer to the Great Lakes; and
- More lake effect snow — increasing winter precipitation (20-30% by the end of the century) combined with less ice cover could, on days when it is cold enough, lead to more lake effect snow.

* The range of values/changes represents different scenarios for greenhouse gas emissions during the 21st century.

Sources: City of Chicago (2008); Union of Concerned Scientists (2009); National Climate Assessment, 2012, in press.

FIGURE 2.1: Climate change acts as a threat amplifier. In addition to the new challenges communities will have to face due to rapid changes in temperature and precipitation, many of the existing threats natural communities currently face will also be exacerbated by climate change.

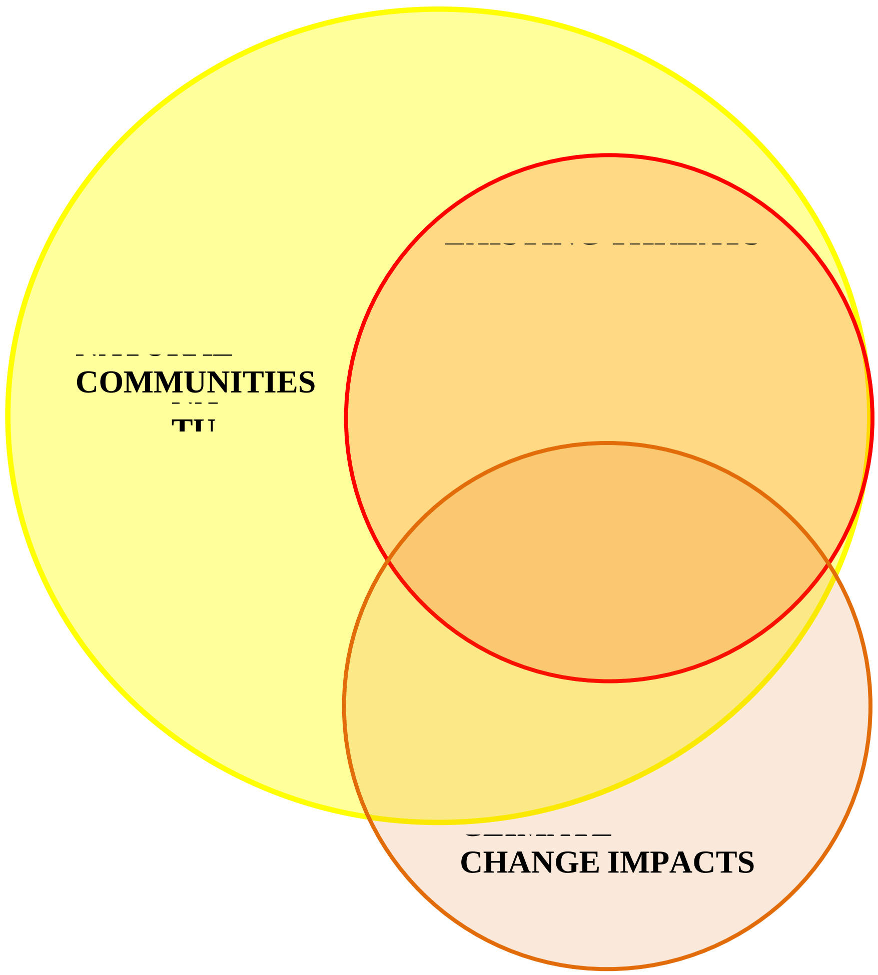


Table 2.1: Broad Brush Matrix Table of Communities X Climate Change impacts X Existing Threats

This table is based on information compiled from the literature by The Nature Conservancy's Great Lakes Climate Science Program and used as a starting point for an experts workshop on biodiversity adaptation held in Chicago on 14 July 2009. Table has been adapted to incorporate climate change impacts on the existing threats to CW natural communities.

Source: Dr. Kimberly Hall, Great Lakes Climate Scientist, The Nature Conservancy.

Communities		**Climate Change Impacts**	**To Comm**			
irie Grasslands	**nnas/Wooded Communities**	**TERRESTRIAL COMMUNTIES**	**ydrologic change**	**agmentation/Habitat loss**	**tered fire regimes**	**utrient Loading & Pollution**
		stress colder-biome forest species.				

		additional drought stress (late summer).				
		(increased reproduction due to warmer temperatures and longer growing seasons, and range shifts).				
		alter seasonal patterns of snow accumulation and snowmelt.				
		as disease vectors.				
		various ecological events (e.g., budburst), leading to disruptions in species interactions.				
		to differential shifts in ranges due to differences in dispersal abilities/rates, leading to disruption of key species interactions ("tearing apart of communities").				
		human changes in land and resource use, leading to more habitat loss.				
		stress may lead to changes in the competitive ability of native C3 and C4 plants relative to each other and to invasives (but interactions are complex).				

Table 3.1: Broad Brush Matrix Table of Aquatic Communities X Climate Change Impacts X Existing Threats

This table is based on information compiled from the literature by The Nature Conservancy's Great Lakes Climate Science Program and used as a starting point for an experts workshop on biodiversity adaptation held in Chicago on 14 July 2009. Table has been adapted to incorporate climate change impacts on the existing threats to CW natural communities.

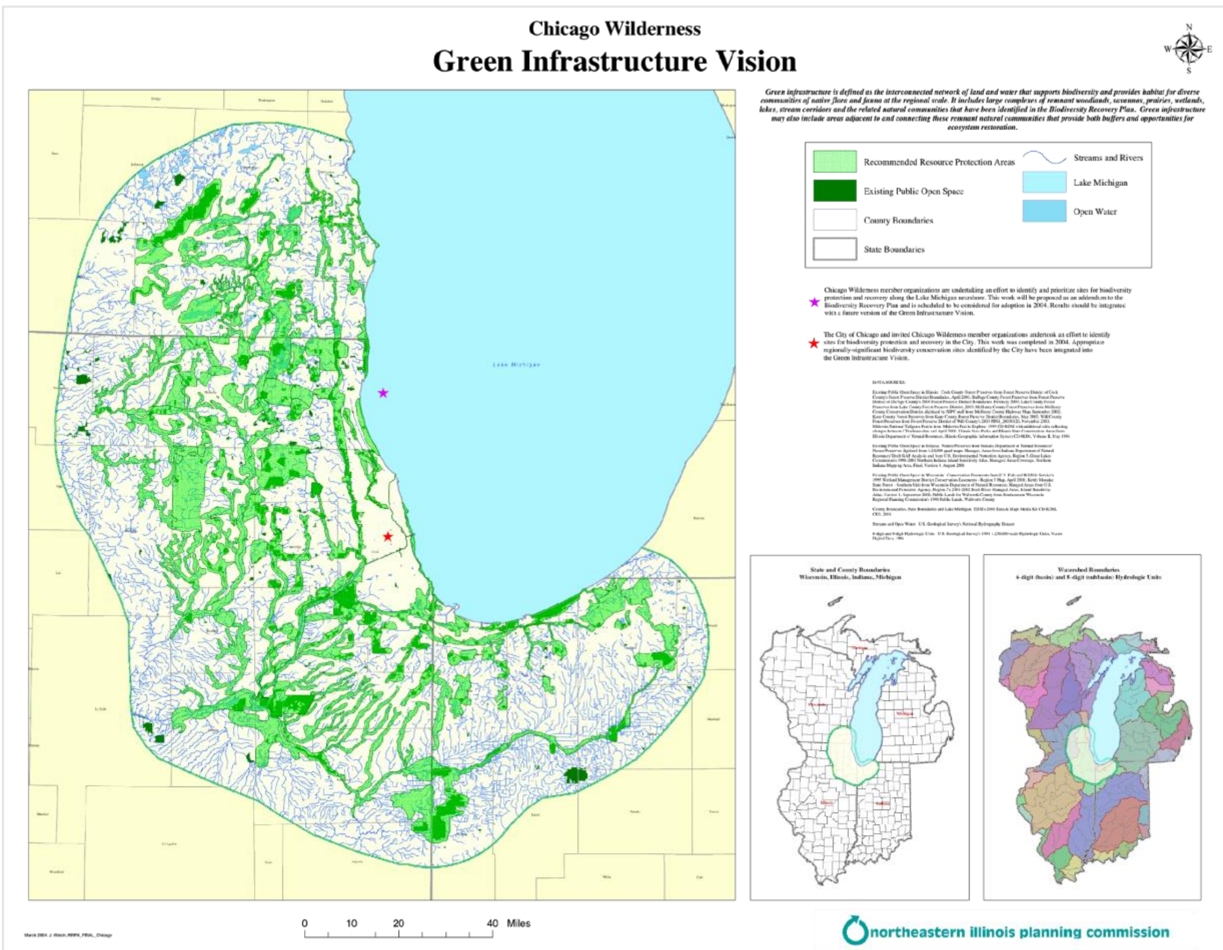
Source: Dr. Kimberly Hall, Great Lakes Climate Scientist, The Nature Conservancy.

Communities				Climate Change Threats	To C		
etlands	treams/Rivers	akes	Lakeshore	**AQUATIC COMMUNITIES**	ydrologic change	agmentation/Habitat loss	[illegible]
				pollution of aquatic systems and wetlands (nutrients, sediments...).			
				destabilization, leading to loss of aquatic habitats and sedimentation.			
				colder-water species.			
				of warm water (combination of increased temperature effect, and increased storm intensity).			

				further isolate/fragment and stress wetlands/riparian habitats that remain.			
				groundwater resources, threatening groundwater fed systems.			
				lakes.			
				circulation of water in coastal areas (bays).			
				& promote shifts in the location of coastal and nearshore habitats.			
				related impacts on aquatic systems as land is converted and usage of fertilizer and pesticides increases.			
				like *Phragmites*.			

FIGURE 4.1: Map of the Chicago Wilderness and Green Infrastructure Vision

Figure 4.1 Map of the Chicago Wilderness and Green Infrastructure Vision



APPENDIX 1

Past, Present and Future Climate Change

Variability has been a natural part of the climate system throughout earth's history, long before humans played any role in changing the climate. There are a multitude of complex interactions among the earth's solar orbit (termed the "Milankovitch Cycles"), continental ice sheets, ocean circulation, volcanic emissions and other factors that have historically accounted for different scales and patterns of climatic variation (Bennett, 1990). Climate change refers to long-term scales occurring over many decades to millennia (e.g., 1500-year cold-warm cycles within the most recent glacial period of 74,000 - 14,000 years bp). This is the scale most relevant to evolutionary adaptation in organisms (Berteaux et al., 2004). On the other hand, shorter-term patterns, such as daily temperature fluctuations or the 2-7 year El Nino-Southern Oscillation cycles, represent what we refer to as weather (NASA, 2005).

Despite the enormous complexities of climate, significant changes have been documented in climate during the past 100 years (see Box 1.2 for North American trends). It has been reported that warming during the 20th century has resulted in the warmest period during the last 1000 years, with average global surface temperatures increasing by 0.8°C (Trenberth et al., 2007). Warmer temperatures are manifested in a variety of ways, such as nighttime low temperatures increasing more than daytime high temperatures, consequently decreasing the daytime range (Karl et al., 1996). Temperatures in the winter are rising faster than any other season, which can be beneficial to agricultural systems by lengthening the frost-free growing season (Field et al., 2007) while at the same time potentially harmful by increasing survival and reproduction of crop and forest pests (CCSP, 2009).

The International Panel for Climate Change (2007) concludes that this warming is at least, in part, the result of an enhanced greenhouse effect, and the extensive release of greenhouse gases into the atmosphere through human activities has *very likely* (i.e., probability of occurrence > 90%) played a large role in contributing to it. The greenhouse effect occurs when certain atmospheric gases (e.g., carbon dioxide, methane, and nitrous oxide) absorb infrared heat emitted by the earth and, instead of allowing the heat to pass back out of the atmosphere to space, traps it and then emits the heat back toward the earth's surface. The net result is that the earth warms, which is a natural and necessary phenomenon for life as we know it to exist on earth. However, the concentrations of heat-trapping gases found in the earth's atmosphere today far exceed historical patterns.

For example, atmospheric CO_2 is 38% higher today than the maximum concentration recorded during that past half million years (385 ppm compared to 280 ppm; Hönisch et al., 2009). In fact, CO_2 levels have increased as much since the 1860's as they did for a period of 10,000 years after the most recent advance of glaciers, a rate of change that is unprecedented in the earth's recent history (Inkley et al., 2004; IPCC, 2007). Furthermore, greenhouse gas concentrations are expected to continue increasing, as much as 40% worldwide by 2030, if ways are not found to require mandatory emission reductions as the global economy recovers and continues to expand during the 21st century (US Energy Information Administration, 2009). As greenhouse gases in our atmosphere continue to increase, so will our air and water temperatures. Summertime average temperatures are projected to increase by 3.1-7.2°C (best range, extends from the midpoint of the lowest emission scenario to the midpoint of the highest; full range is 2-11.5°F) by the end of the century, leading to dramatic increases in the frequency of heat waves (IPCC, 2007; CCSP, 2009). Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern [formerly Antarctic] Ocean and parts of the North Atlantic Ocean (IPCC, 2007). There is, however, some evidence from the upper Great Lakes region indicating surface water temperature may be increasing even faster than air temperatures. This situation is thought to be triggering a range of system-wide impacts such as higher wind and current speeds and longer periods of lake stratification in this region (Austin and Coleman, 2007, 2008; Desai et al., 2009; Dobiesz and Lester, 2009).

It will be critical for policy and management guidelines to employ both mitigation as well as adaptation strategies to address climate change. This is because CO_2 has a 120-year residency time in the atmosphere (Brasseur et al., 1999), meaning that while we can potentially reduce the magnitude of future climate change impacts through mitigation actions, we still have to adapt to the changes that are occurring as a result of what has *already* been done to the planet through large-scale industrial practices over the last 150 years.

APPENDIX 2

Description of General Adaptation Strategies

The vast majority of the proposed strategies found in the literature for managing resources in a changing climate are general concepts. These concepts fall loosely into three basic types of strategies: those promoting resistance, resilience, and facilitation (Galatowitsch et al., 2010; Millar et al., 2007). The first strategy, resistance, is essentially promoting a system's ability to remain unchanged in the face of external forces (Lawler, 2009). Secondly, resilience can be defined as the ability of a system to recover from perturbations (Holling, 1973). In the context of climate change, systems that are more resilient are those that are better able to adapt to changes in climate. Systems, or species, that are more resilient will continue to function, although potentially differently, in an altered climate. Less resilient systems will likely undergo messy transitions to new states, potentially resulting in the loss of ecosystem functioning, populations, or even species (Lawler, 2009). Strategies in the third category, facilitation, are designed to help move a system from one state to another. The most commonly recommended strategies for promoting resistance, resilience, and facilitation are briefly discussed in the box below and are the basis for many of the community-specific strategies that are recommended in this document.

General Strategies to promote resistance, resilience, and facilitation of change in natural communities

- ***Removal of other, non-climate-related threats to a species or system and reducing other stresses on species*****:** reduces the impact of threats such as exotic species, habitat loss and fragmentation, overharvest and generally results in larger populations that will likely be better able to absorb perturbations (Rogers and McCarty 2000; Noss 2001; Soto 2001).

- ***Expanding reserve networks*****:** provides systems and species with room to move and places to go (also included increasing the size of existing reserves, adding buffers around existing reserves, and adding larger reserves to reserve networks). Larger reserves are more likely to preserve a greater diversity of environmental conditions and allow for movement within the reserve (Lawler, 2009). Increasing redundancy within the reserve network can also promote resilience by providing more opportunities in different places or chances in which species or communities might persist (Halpin, 1997; Shafer, 1999).

- ***Increasing connectivity*****:** removes barriers that make it difficult for species to move from areas that become unsuitable, enhancing the ability of climate sensitive species to migrate and occupy new climatic zones or habitats that emerge in the future (Hulme, 2005; Welch, 2005).

- ***Restoring Habitat and System Dynamics*****:** restores ecosystem functioning and habitats in degraded to increase resilience for systems and species. With respect to climate change, however, the basic tenets of restoration that focuses on returning communities to historic or pre-disturbance conditions and uses a species-based approach of restoring species composition may be costly and potentially ineffective (Lawler, 2009; Harris et al., 2006). Many ecologists have suggested shifting the focus of restoration ecology toward ecosystem services because ecosystems can be managed in a more flexible way in which species assemblages change with changing climates, but ecosystem functioning, although the nature of those functions might change, is still preserved (e.g., Hartig et al., 1997; Noss, 2001; Harris et al., 2006; Lawler, 2009).

- ***Adaptive Management:*** uses management actions that are applied as experiments, the system is monitored, and actions are then potentially changed to address changes in the state of the system. Both passive adaptive management, that is building a management strategy based on historic data and then altering that strategy with new data as the system is monitored over time, as well as active adaptive management, described as conscious experimentation and exploring the outcomes of multiple management strategies will likely be needed to address climate change (Kareiva et al., 2008; Lawler, 2009).

- ***Translocations:*** allows species with limited dispersal abilities and small, isolated ranges that will have trouble migrating and shifting habitats, or those may be left without suitable habitat altogether, to continue to persist within a region (e.g., Orians, 1993; Guldberg et al., 2008; Vitt et al., 2010)

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APPENDIX 3:

CLIMATE CHANGE IMPACTS TO PLANT AND NATURAL COMMUNITIES

The information in this appendix is based on the theoretical understanding of community, behavioral and restoration ecology, as well as data published in the scientific literature on how climate is affecting plant and natural communities around the globe. The goal of presenting this information is to help us think about how it specifically applies to the Chicago Wilderness region. Ultimately we need to garner the knowledge of CW's natural resource managers to capture the patterns of change happening on the ground, and use it to inform adaptive management in a rapidly changing environment. This section is intended as a platform for managers, stewards and volunteers to contribute their qualitative and quantitative knowledge of how climate change is affecting the natural communities they work at in the decades to come.

1. PHENOLOGICAL and RELATED CHANGES

1.1 Pollination: *Potential impact to Prairie Grasslands, Savannas/Wooded Communities*

One expected impact of climate change is the de-synchronization of time-sensitive relationships between species- such as the timing of when plants leaf out and flower and when animals emerge, reproduce, or migrate- termed a "phenological mismatch". An example of this type of mismatch is seen when plants and their pollinators respond differently to climate change, upsetting a long established, mutually beneficial relationship of pollination. The type of phenological mismatches likely for the Chicago Wilderness region might be expected to disproportionally impact insect pollinated life forms such as flowering shrubs and forbs, while wind-pollinated trees and grasses would be less affected, if at all.

Most animal pollinated species in the CW region have relatively open pollination systems, with a large number of potential pollinators. This means that if phenology mismatches occur between a plant's flowering period and its current primary pollinators, pollination services may be largely provided by other species and not have a particularly strong effect. On the other hand, different suites of pollinators may have different degrees of effectiveness, especially if the shift results in a significant change in the taxonomic make-up of the pollinator community on a particular species of plant. This situation could result in decreased pollination efficiency (Schemske and Horvitz,

1984) and reduced seed set. Common plant species that also rely on common pollinators may not necessarily be impacted. For example, the likelihood of a phenology mismatch between hummingbirds in the CW region (ruby-throated hummingbird; *Archilochus colubris)* and their dominant food resource (Jewelweed; *Impatiens capensis, I. pallida*) is low because both species are very common and ruby-throated hummingbirds are present throughout most of the jewelweed flowering season (May-September).

At the other end of this spectrum, the de-coupling of historically synchronized phenological events could be most damaging to conservative insect species with specific, narrow habitat requirements, host-plant specificity, and limited dispersal capabilities. However, even as evidence that species are shifting their phenologies in response to recent climate changes continues to mount (reviewed in Parmesan, 2006; Amano et al., 2010), and insect phenology in particular is showing a steeper advance than plant phenology in certain regions (Gordo and Sanz, 2005), there is little empirical data to show which species' traits might make them more sensitive to future climate change. Researchers have recently begun to address this question for species that have long-term life history data available. For example, research by Diamond and colleagues (2011) on butterflies in the U.K. indicates that species with narrower larval dietary breadth, smaller range sizes and more advanced overwintering stages experienced relatively greater advances in their date of first appearance over the last 30 years. The finding that species with a narrower larval dietary breadth would be indicative of relatively greater spring advancement was unexpected, mainly because phenological advancement may be limited by the availability of host plants (Memmott et al., 2007) and generalist host use has been observed to facilitate the climate-driven range expansion in U.K. butterfly species (Braschler and Hill, 2007). Diamond et al. (2011) suggest the advancement of specialized butterflies may in fact be *enabled* by the phenological advancement of their host plant, while species with a greater number of potential host plants may be buffered from such shifts in plant phenology. If correct, and if applicable to species in the CW region, this could mean conservative species are not necessarily more vulnerable to phenological mismatches.

This question would indeed be a research topic of great interest because while a large percentage of the plants in our region's prairies, savannas, forests, and wetlands are wind-pollinated or pollinated by generalists, some plants have developed specialized relationships with specific pollinators. In fact, there are at least 453 conservative insect species (those species largely restricted in distribution to intact natural community remnants) in prairies and savannas throughout the CW region (Panzer, 2010) that could be affected by a climate change induced phenology mismatch. A well-known example is the specialized relationship between sphinx moths (Sphingidae family) and the eastern prairie white-fringed orchid (*Platanthera leucophaea*). The specialized structure of the flowers of this federally threatened orchid limits pollination to only a few species of large sphinx moths. Further, this species exists in small isolated populations, making it difficult for pollinators to locate them. Because of this, a phenology mismatch that disrupted the interaction between the sphinx moth and orchid would compound the pollination challenges this species already faces and could result in the extinction of the eastern prairie fringed orchid (WICCI Plants and Natural Communities Working Group Report, 2011).

Phenological mismatches between pollinator and plant could occur in several ways. For example, while many species respond to changes in temperature as a cue for when to emerge, the specific trigger (e.g., the total number of days above a certain temperature- or accumulated warmth- versus crossing a particular temperature threshold) may differ. Alternatively, daylight length may be the driving force behind emergence for some pollinators, which could lead to a timing mismatch if their host plants are instead more closely cued into temperature change. Even if pollinators are capable of continuing to synchronize their phenological events with host plants that are advancing in their timing of emergence, the increased variation in precipitation (wetter winter and springs; longer dry periods in the summer interspersed with more frequent, extreme storms) and temperature fluctuations (early winter or spring warm-ups followed by cold snaps) this region is likely to experience may hinder one, or both, species from sustaining healthy populations in the long-term.

1.2 Seed production and dispersal: *Potential impact to Prairie Grasslands, Savannas/ Wooded Communities and Wetlands*

In addition to shifts in pollination opportunities, as discussed in the previous section, there are a variety of ways that changes in climate can affect seed production. For example, temperature, carbon dioxide (CO_2) levels and the timing of rainfall all influence fruit development. Warmer temperatures, along with higher CO_2 levels, have the potential to increase the number of flowers and fruits, and the number and size of seeds produced by a plants (Jablonski et al., 2002). However, wild plants (as opposed to agricultural crops) are constrained by what they can do with increased CO_2 and may use it for survival and defense rather than boost reproduction. Some research suggests that even though seed quantity and size may increase in wild plants under higher CO_2 levels, the trade-off is that they contain less nitrogen (Jablonski et al., 2002). On the other hand, more frequent and longer periods of reduced rainfall could reduce fruit size and/or the number of fruits produced both of which can impact species' dispersal ability. Changes in the number of flowers, fruits and seeds and their nutritional quality could have far-reaching consequences, since changes in the amount of nutrients in seeds could affect reproductive success and seedling survival. Such changes could also have long-term effects on ecosystem functioning.

Another consideration is that germination and seedling establishment are the highest-risk phases in the life cycle of plants (Harper, 1977) and thus mechanisms that reduce the risk, such as germination patterns that increase the probability of successful seedling establishment, are under strong selection pressure (Meyer et al., 1997). For many species, germination cues are temperature-mediated and therefore changes in temperature might be expected to have significant effects on plant distribution and survival because the timing of this key life-history trait may no longer be optimal (Gworek et al., 2006; Cochrane et al., 2010).

Plants depend on seed dispersal for colonization of new habitat patches and "tracking" their ecological niche through space under changing environmental conditions. Plant ecologists are intensively studying seed dispersal both from an empirical (how far and how fast can species spread?) and a theoretical (what is the relative importance of dispersal and niche processes for community assembly, diversity, and evolution?) perspective. Both fields of inquiry are key to understanding how climate change may alter species' distribution in time and space. Another important piece of the puzzle will be how climate shifts will in turn affect the multi-trophic interactions influencing seed dispersal. For example, many species are dispersed by frugivorous birds, which is particularly the case for invasive shrubs, like buckthorn (*Rhamnus* spp.) and certain honeysuckles (*Lonicera* spp.). As the region's winters become increasingly mild, many frugivorous bird species, including American Robin, Eastern Bluebird, Hermit Thrush, Cedar Waxwing, Yellow-shafted Flicker, and Yellow-rumped Warbler, are able to overwinter more regularly and in larger numbers in the Chicago Wilderness area. These larger winter populations may result in a greater proportion of bird-dispersed fruits moved about the landscape, resulting in a positive feedback loop between the fruiting shrubs and the fruigivorous birds. The larger population of birds may be helping to spread these invasive shrubs through the region's ecosystem, resulting in more widespread and larger populations of the fruiting shrubs the birds feed on. The larger populations of shrubs would provide a larger food supply for the birds, perhaps enabling even more birds to successfully winter in the region. For example, American Robins and Cedar Waxwings, easily the most common wintering frugivores, have increased on Illinois Christmas Bird Counts more than ten-fold and 2.5 times respectively since the 1960s. (Compared 1960s to 2000s, correcting by party-hours; D. Stotz, pers. comm.).

Ultimately, as temperatures rise and rainfall patterns change, it is likely that some plant species may increase seed production while others decrease. These types of trade-offs will influence how species abundance and composition will shift. Some species are likely to have more plasticity in their responses, or ability to adapt via natural selection, than others. There will also be species that will not be able to either respond or adapt, and consequently will become uncommon, rare or even disappear from our regional flora. This community-level trade-off in species composition and abundance will likely result in unpredictable and novel ecosystems (Cochrane et al., 2010).

1.3 Dormancy: *Potential impact to Prairie Grasslands, Savannas/Wooded Communities, and Wetlands*

Although many prairie grasses do not need cold dormancy to germinate, some terrestrial native species do require a period of cold (10-90 days) dormancy- and sometimes an interaction of cold and wet conditions - in order to break germination. Many trees, shrubs, and forbs require cold stratification prior to dormancy. For example, prairie restorationists have learned that white false indigo (*Baptisia leucantha*) requires 90 days of cold in order to foster optimal germinations. Warmer winters, along with increased seasonal temperature variability, may affect the ability of certain prairie species to fulfill their dormancy requirements. This could end up favoring species without strict dormancy requirements and alter species composition of prairies, savannas, forested communities, and wetlands.

Currently, plants in the Chicago region likely meet their dormancy and cold stratification requirements rather early in the winter season. This would mean that plants could respond to unusually early warm-ups, making them susceptible to damage during subsequent cold snaps that can occur later in the season. Plants that have a later completion of the required dormancy, however, might be less affected by these early warm-ups.

1.4 Early bud burst: *Potential impact to Savannas/Wooded Communities and Wetlands*

Trees and shrubs may break dormancy earlier in the spring in response to earlier, warmer springs. Early bud burst can impact trees and shrubs because the new growth may be killed by subsequent frosts. Early bud burst may also lead to early flowering and phenological mismatch.

For example, if plants leaf out significantly earlier with climate change, the synchrony among herbivores (mostly insects) and predators (especially birds) could deteriorate. The large majority of forest insectivorous birds are migratory, and winter in the Neotropics. Most of those migrants arrive in the Chicago area in May. Already in years when spring has been warmer than usual, the oaks were largely leafed out before most of the insectivorous migrants arrived. This is the period when the leaves are most susceptible to insect herbivory. Presumably the lack of avian predators could mean a greater degree of insect damage to these trees is possible than what historically has been the case.

The multi-trophic relationship between the region’s elm leaf beetles, American elm trees and yellow-rumped warblers illustrates this point well. In this food web scenario, the elm leaf beetle larvae emerge at the same time new leaves appear on the trees in the spring, enabling them to take advantage of this food resource (Gyllenhaal, pers. comm.). Typically appearing at this time too are migratory warblers, which feed on the larvae and act as a natural pest control for the elms. Spring green-up, however, is already shifting in this region in response to warming temperatures. Studies in Britain suggested a 5 day advance in spring phenology in response to each degree C increase in spring temperature (Amano et al., 2010). As the warm-up continues to advance, and organisms such as trees and insects responding to temperature cues begin to emerge earlier, a mismatch between food availability and that of avian migratory timing could occur.

While there is some evidence that bird migration does appear to be advancing to some degree along with bud burst (Root and Hughes, 2005; Bradley et al., 1999), the timing of these migrants is mostly set by photoperiod, especially for Neotropical migrants that have no weather cues on their wintering grounds. Because of this, it seems likely that the mismatch between leaf out and the arrival of migrating birds will become larger and more consistent, and will likely negatively impact populations of migratory birds, and in turn decrease their ability to provide natural pest control for the elms and other trees in the region's woodlands.

2. BIOTIC/ABIOTIC FACTORS

2.1 Range shift: *Potential impact to all communities*

A reasonable expectation for the region is that species assemblages will shift in response to a changing climate. While the geophysical setting of streams, rivers, and lakes will not change, the species within and around them likely will, and the resulting natural communities may be quite different from what was present here pre-settlement. This is because certain opportunistic species are likely to be able to change their ranges, while truly conservative species that rely on specific soil types, hydrologic patterns, geology, mycorrhizal associations etc. may not be able to adapt rapidly or move- resulting in a "re-shuffling" of plant assemblages and subsequent creation of novel communities.

As the region becomes hotter, drier and more extreme, plants will be faced with three options- move, adapt, or cease to exist. For those species that are able to shift, their range alterations will be influenced by competitive regimes as well as by physiological tolerances. This means that although plant species for which CW represents the southern end of their range could certainly be expected to shift northward and out of the region completely, and species either at the middle or northern end of their range may expand their distribution and/or abundance, the actual resulting patterns of range shifts are likely be more complex than simple north-south shifts. It is also possible that even as species shift their range in order to track their “climate envelope”, some remnant populations will persist near the southern limit of their distribution (e.g., similar to hemlock or tamarack currently). Wind pollinated species and generalist species will likely fare better than those with a restricted pollination or habitat requirement. This is especially true of species that occur in the dramatically altered landscapes of urban areas, where they are virtually suspended in small, isolated fragments.

2.2 Community disaggregation: *Potential impact to all communities*

Since individual species are likely to respond differently to climate change, it is possible that some level of disaggregation in all communities will occur. Some species, especially the less conservative ones, will be able to easily move between isolated and changing areas. Others will not be able to easily move if dispersal distances are too great. Even those conservative species that have highly dispersive seeds could be impacted as assemblages shift. The expectation is that new species will move into the Chicago Region while some current species will shift out, resulting in novel species assemblages and interactions, as well as opportunities for invasives to get a foothold in many communities. One of the biggest challenges community disaggregation presents is figuring out how to manage new types of communities composed of novel inter-taxa interactions (plant-animal, plant-microbe, etc.) we have never seen before (WICCI Plants and Natural Communities Working Group Report, 2011).

Changes to climate and community assemblages could likely have a ripple effect, causing changes to aspects such as 1) the decay rates of leaves and their biochemical composition, 2) rhizosphere dynamics, 3) fungal recruitment and associated nutrient acquisition capacity and 4) element cycling (e.g., K, Na, Si). These changes could in turn act upon soil fauna, microbes and geochemistry in unpredictable ways that influence cation and dissolved oxygen content (DOC)/N balances in watersheds, dynamics of soil organic matter, as well as the proportion of active and stabilized soil C pools (Filley, 2008).

2.3 Invasives/diseases/pests: *Potential impact to all communities*

Climate change is expected to create conditions that will be favorable to pests, pathogens, and invasive species. This is in part because milder winters will allow many of these species to overwinter instead of having to reestablish each year, or survive in regions that were previously too cold, enabling them to expand in range and abundance. There are also effects beyond warming that will likely be important, such as droughts, frosts following leaf out, ice storms, etc. that can stress plants and lead to greater damage from pests and pathogens. A widely known example is the mountain pine beetle (*Dendroctonus ponderosae*), native to the forests of western North America, which has dramatically increased due to the recent unusually hot, dry summers and mild winters, causing a massive die off of trees (Leatherman, 2007). An example of a pest that already occurs in the CW region that is likely to be affected by climate change is the gypsy moth (*Lymantria dispar*), which could experience population expansions in response to a longer growing season. However, the most potentially harmful interaction between climate change and invasive pathogens and pests would arguably be the establishment of species that do not currently survive here, but could thrive under warmer conditions (e.g., Sudden Oak Death [*Phytophthora ramorum*], Kudzu [*Pueraria montana*], *Hydrilla [Hydrilla verticillata]*). And because climate change will generally favor species that are very adaptable, mobile and aggressive, which are characteristic traits of many invasive and weedy species, it is a reasonable to expect many invasives will have opportunities to further increase in range and abundance.

2.4 Fragmentation/isolation: *Potential impact to all communities*

Many of the natural communities in the CW region are already highly fragmented and while climate change may exacerbate this threat, it does not cause further fragmentation and isolation. The exception, however, may be in wetland complexes. Chicago Wilderness summers are predicted to be hotter and drier, which may alter the hydrology of wetlands and cause some wetland areas to dry up and others to become more isolated. Coastal wetlands, such as those at

Illinois Beach State Park and Indiana Dunes National Lakeshore, are at risk if lake levels drop significantly; but wetlands that are no longer connected to Lake Michigan (e.g., Hegewisch Marsh) are perhaps most vulnerable because they are entirely reliant upon precipitation patterns for inundation. Wetlands that are spring-fed (e.g., fens) will not be as greatly impacted in the short-term, although sustaining groundwater aquifers in the long-term may prove challenging. Wetlands that have been disconnected from their original water source and are now regulated by pumps (e.g., Hennepin Lake is completely disconnected from the Illinois River and its water level is regulated via a pump) also may not be immediately or greatly impacted. In contrast, bogs are not linked to groundwater and receive their water through precipitation and runoff only. Thus, drier summers could affect bogs more quickly and severely than other wetlands. Isolated ephemeral wetlands in prairies and agricultural systems also may have shorter periods when they have water, or be smaller in extent. Through time, this may allow agriculture or other vegetation types to replace the wetland community currently supported by these sites. Consequently, frogs, turtles and migratory waterbirds (ducks and shorebirds primarily) that rely on these ephemeral habitats may have to look farther afield to find appropriate habitat.

Although climate change will not directly cause more fragmentation or isolation of other habitats, it will compound the effects of existing fragmentation. Most obviously, if species are tracking appropriate climatic conditions, they will need to shift geographically and fragmentation will make such movement much more difficult. Certain species will be more heavily impacted than others in this regard. For example, birds can easily move from place to place but species with limited dispersal abilities are likely to be affected more strongly by fragmentation, as will species that are more specialized in their habitat use. These features will also interact; specialized species with poor dispersal abilities will be most at risk from fragmentation under climate change.

There are a variety of indirect effects that could also occur. Any tendency of climate change to interfere with breeding success would increase the probability of local extinctions within a fragmented system. For example, phenological mismatches that result in species having a reduced seed set, or disaggregation occurring due to plants and pollinators differentially responding to climate change, would greatly increase the probability of extirpations in fragmented habitats.

Additional indirect effects might include increasing microclimatic edge effects in fragments as conditions become warmer and drier, reducing the available area appropriate for forest interior species, not just due to light levels, but also humidity and temperature, and more frequent severe storms causing an increase in wind damage to trees, which is typically most severe at edges of patches.

2.5 Herbivory: *Potential impact to Prairie Grasslands, Savannas/Wooded Communities*

Climate change could impact herbivory by insects and mammals. For insects, milder winters will enable insects to survive the winter better, and potentially become active earlier and increase in abundance, increasing the level of herbivory on trees, shrubs, and forbs. Adding to this is the fact that as the greening of local vegetation advances with milder temperatures and earlier bud burst, migrant insectivorous birds will likely be behind the leaf out of oaks. This will increase the herbivory on the young leaves (Marquis and Whelan, 1994). In addition to leaf damage, root hebivory might if larvae of native and invasive beetles, invasive worms, etc…were to cause early stress to fine root production and potentially nutrient and water uptake.

3. PRESCRIBED FIRE

3.1 Change in fire management: *Potential impact to Prairie Grasslands, Savannas/Wooded Communities*

Changing patterns of weather could greatly influence when and how fire could be used. The two main ways that climate change could influence fire regimes are 1) directly, by influencing weather patterns conducive to fire ignition and spread, and 2) indirectly, by influencing plant communities through temperature and precipitation regimes that favor or discourage fire-adapted plant species (WICCI Plant and Natural Communities Working Group, 2011).

Potential impacts are drought conditions and/or higher temperatures making fires burn hotter and more thoroughly. Changes in wind patterns could also play a role in changing the dynamics of fire. In addition to wind currents themselves undergoing changes, more energy in the atmosphere could increase wind strength, making fires hotter and more thorough. This change in conditions might be helpful in making it possible to bring fire to marginal low-fuel situations, such as unhealthy areas with little grass matrix or other natural fuel. The effects of hotter and more thorough fires are likely to be variable across taxa. For example, hotter fires might be beneficial in managing forest systems for oak dominance and may help knock back shrubs and woody growth in prairies, as long as managers were still able to get fire onto the landscape under these more challenging conditions. However, this may be less desirable from a bird or insect perspective. Both of these groups can show increased diversity with increased variation in the vegetation structure that is maintained by incomplete burning.

The combination of more frequent droughts in the summer and fall, which increases the difficulty of controlling a prescribed burn, and wetter springs could significantly reduce the number of potential days that fire can be used, especially during the traditional spring and fall burn windows. As a result, the timing of burn windows could change, with prescribed burns needing to occur earlier in spring and/or later in fall or throughout the winter, both for strictly climatic conditions, but also because of vegetation stages or activities of fire susceptible fauna. Already many Chicago Wilderness land managers are thinking of one burn season that extends from fall through spring and have been able to successfully conduct prescribed burns in late December and January due to warmer winter temperatures and snow free days.

Recent trends in earlier spring green-up and warmer temperatures have indeed shortened the spring burn window in several recent years and made spring burns more complex. Managers need to be more aware of faunal responses to warmer springs, for example snakes may be emerging from their hibernacula earlier and insects may be active earlier in the season. In the past few years the spring burn season has also been complicated by the cool, wet springs this region has experienced. This could be a short-term event, or it could be the beginning of a long-term trend related to changing climate that would require more fall burning than currently takes place. However, if more intense fires result from either 1) warmer summers and fall or 2) more dry fuel from droughts then the number of possible burn days in the fall would ultimately be reduced. Fewer appropriate prescribed burn days could mean fewer prescribed fires, which would negatively impact fire dependent forbs and grasses. Many shrubs are set back by fire so they may increase with decreased prescribed burning. What this latter point could mean for the associated impacts to soil experiencing shrub or woody encroachment is unclear; however less light reaching the ground layer due to encroachment would negatively impact the existing plant community. However, because suppression of burning in grasslands and savannas is a significant cause for the expansion of woody plants into grasslands and consequently changes the rates of the biogeochemical cycling of nitrogen and carbon in those ecosystems (Filley et al., 2008). It seems likely that changes to the long-term pools of soil carbon and feedback to local ecosystem services and to atmospheric CO_2 are already underway and could accelerate.

4. WEATHER IMPACTS & EXTREME EVENTS

4.1 Change in frost dates: *Potential impact to Savannas/Wooded Communities, Lakes and Lakeshores*

During the last several decades the Midwest has experienced a shift toward shorter winters and increased air temperatures (Sinha and Cherkauer, 2010). The length of the frost-free season has increased by over a week in this region, mainly due to earlier dates for the last spring frost (USGCRP, 2009). Longer growing seasons should provide favorable conditions during spring for planting, however, the projected rise in soil temperatures during the cold season is likely to increase the risk of pest infestation (Sinha and Cherkauer, 2010). Overall trends in extreme and mean seasonal soil temperature from 1967-2006 indicated a warming of soil temperatures at a depth of 10 cm in northwest Indiana, north-central Illinois, and southeast Minnesota, leading to a reduction in the number of soil frost days (Sinha et al., 2010). While continued future warming is likely to enhance rising soil temperatures, it’s also possible that reduced snow cover during winter could work in the opposite direction to cool soil temperatures (Sinha and Cherkauer, 2010). Both changes will cumulatively affect cold season processes in the region (e.g., soil frost days, snow accumulation, and soil temperatures).

If the date for the last spring frost (historically late April) continues to advance and/or the date for first fall frost continues to delay (historically mid-late October), this would result in an even longer growing season and a shorter winter season. Fewer days with soil frost implies higher infiltration, specifically during early spring which may result in decreased soil moisture retention and drier soils in spring owing to enhanced evapotranspiration losses as compared to the present (1977– 2006) conditions (Sinha and Cherkauer, 2010). This may also reduce the risk of soil frost enhancing winter and spring flood events; however, increased precipitation in the winter months is likely to keep river levels higher throughout the cold season (Sinha and Cherkauer, 2010).

There are a variety of additional ways that changes in frost patterns could indirectly effect natural communities. For example, researchers have found that, in arctic environments, extended frost-free time causes soils to have longer active periods when microbes can mineralize nutrients (Altrichter et al., 2010). While the soils remain frost-free longer, plants continue their normal cycle dictated by the length and intensity of daylight, which has not changed. Microbes may continue to create nutrients, but the plants no longer use them, so that when rain or snow comes the nutrients leach into the rivers and streams. For example, in the arctic concentrations of nutrients such as nitrate and ammonium in the water are substantially increasing due to extended frost-free durations (Ball et al., 2011).

Whether this would be true for mid-latitudes is uncertain. Higher temperatures and longer frost-free time would be expected to increase rates of organic matter decomposition in soils. Yet more than temperature controls soil decomposition rates, and it is unclear how factors such as soil structure, chemical make-up of soil, oxygen levels, water availability, and frost-free time will interact to influence decomposition rates in our region (Davidson and Janssens, 2006).

Aquatic plants may also have an extended growing season as ice melts earlier on lakes, and lakes and streams warm up earlier in the spring. Somewhat related to changes in frost dates, and milder winters overall, is the potential for a decrease and a delay in the amount of ice cover on local lakes and wetlands, leading to increased evaporation in the winter. This could also affect lakeshore communities as more sand and beach is exposed with lower water levels. It’s possible that winter survivorship of aquatic invasives will change as well. For example, climate change will influence the likelihood of new species becoming established by eliminating cold temperatures or winter hypoxia that currently prevent survival and by increasing the construction of reservoirs that serve as hotspots for invasive species (Rahel and Olden, 2008). Climate change could also modify the ecological impacts of invasive species by enhancing their competitive and predatory effects on native species and by increasing the virulence of some diseases (Rahel and Olden, 2008).

4.2 Change in freeze-thaw cycles affect: *Potential impact to all communities*

Increasing average temperatures, largely influenced by increasing nighttime winter temperatures (Wuebbles et al. 2010), combined with higher seasonal variability in temperature could cause a shift in the freeze-thaw cycle. The pattern has typically been characterized by one or several longer periods where land and water are completely frozen during the winter months, but this could shift to a pattern of multiple, shorter periods of freeze/thaw cycles during the next several decades (Takle and Hofstrand, 2008). This type of shift in the freeze-thaw cycle would expose plants and seeds to periods of thawing throughout the winter, and might enable some species to get a head start on spring emergence. Changes in freeze-thaw cycles can alter soil physical properties and microbial activity (e.g., a higher number of cycles would increase the risk of soil erosion by weakening soil structure; Sinha and Cherkauer, 2010). However, the overall impact of these changes on soil functioning remains unclear (Henry, 2007). In the longer-term (late 21st century), the number of freeze-thaw cycles may actually be reduced due to rising soil temperatures that provide fewer opportunities for freeze-thaw cycles to occur (Sinha and Cherkauer, 2010).

In aquatic systems, freshwater ice-covers control most major interactions between the atmosphere and the underlying systems including solar radiation, thermal regimes and oxygen levels, and therefore biological productivity (Prowse et al., 2007). In general, ice is likely to break-up earlier and freeze later and result in reduced and/or delayed ice cover in aquatic communities. It is expected that reductions in lake-ice covers will produce changes in temperature and light levels, water circulation patterns, nutrient availability, aquatic UV radiation exposure and layering of warm and cold water during the ice-off period (Prowse et al., 2007).

In smaller aquatic systems, such as rivers and streams, the risk of experiencing freeze-thaw cycle interruptions is greater due to water flow and could lead to increased evaporation in the winter and lower water levels in rivers and streams. In contrast, although Lake Michigan is already experiencing delayed and reduced ice cover, once it does freeze over it is unlikely to experience interruptions in the freeze-thaw cycle. All of the Great Lakes have experienced reduced ice cover during the last several decades. Wang (2010) has estimated total ice cover on the Great Lakes has shown an overall decline of ~15% over the period 1973-2009. Over the middle to deepest parts of the Great Lakes, the occurrence of very densely packed ice declined by more than 30% over the period 1973-2002. Near the lakeshores, the occurrence of very densely packed ice declined by ~20% over the period 1973- 2002. Lake Michigan in particular has experienced the second highest rate of ice loss among the Great Lakes, with a negative trend of -2.05 yr^{-1} between 1973-2010 (Wang et al., 2011).

How these changes may impact lake levels has been an active field of research with multiple approaches being used in modeling this function. Recent models for Lake Michigan, derived from using an energy budget-based approach to adjusting the potential evapotranspiration (PET) instead of using air temperature as a proxy to compute PET, suggest either a smaller decrease in net basin supply and smaller drop in lake levels than using the temperature proxy, or a reversal to increased net basin supply and slightly higher lake levels (Lofgren et al., 2011). In other words, lake levels are highly variable, making it imperative that we manage and restore our systems to handle that fact.

4.3 Milder winters: *Potential to impact all communities*

As discussed in several previous sections, milder winters will interact with a many of the phenological, abiotic, biotic, and weather variables. Generally, milder winters are likely to decrease and delay the amount of ice cover on lakes and wetlands- a phenomenon already occurring on Lake Michigan (Wang, 2010; Wang et al., 2011)- and lead to increased evaporation. Milder winters may also affect terrestrial communities if they impact species dormancy requirements and extend the growing season. In addition, this will almost certainly enable many pests and diseases to increase in range and abundance.

4.4 Increased evapotranspiration: *Potential to impact Prairie Grasslands, Savannas/Wooded Communities, Wetlands, Streams/Rivers, Lakes*

Evapotranspiration, driven by temperatures and solar radiation, is the amount of water evaporated from land, water, plants, and soils. It is expected that, as temperatures increase with climate change, evapotranspiration rates will also increase. Climate modelers in Wisconsin evaluated potential evapotranspiration rates using downscaled climate models considering that evapotranspiration rates will increase with increased temperature, while increased moisture or cloud cover will decrease solar radiation and evapotranspiration rates. Overall the models predict that under various emission scenarios, annual rates of potential evapotranspiration will increase with the highest rate of increase in the spring and fall when increased temperatures are less offset by increased moisture or cloud cover (WICCI Plants and Natural Communities Working Group Report [2011]).

On an ecosystem-level, increased evapotranspiration is expected to lead to lower lake levels and lower stream flows in the Great Lakes Region (Magnuson, 1997). Increased evapotranspiration may also have a drying effect on all soils, especially wetland soils. On a plant-level, the stomata in plants become smaller in response to higher levels of CO_2, thus reducing the amount of water they transpire into the atmosphere. However, rising temperatures would likely make plants transpire more, so how evapotranspiration would play out is unclear. Studies from the agricultural field have shown that overall rates of evapotranspiration decrease under elevated CO_2 due to the stomatal response (Bernacchi et al., 2007). Currently, it is not well understood how the decrease in plant transpiration from increased CO_2 levels could affect overall ecosystem level evapotranspiration rates.

4.5 Ice storms: *Potential to impact Savannas/Wooded Communities*

Increased numbers of ice storms are expected to occur with generally higher winter temperatures. This could lead to increased structural damage to trees, especially evergreens and species with brittle wood, while the coating of branches and twigs with ice could damage buds for the next growing season. Mature and stressed trees will be especially susceptible to ice damage, leading to insect outbreaks and secondary pathogens, and a loss of these trees would alter community structure. These conditions are not ideal for many tree species, and ice storms, stronger windstorms, etc. may all contribute to loss of forests or minimizing forested cover to only remain in moist river bottoms. The composition of the resulting prairie or openland areas would not be what it was pre-settlement, but instead some other assemblage of species.

4.6 Droughts (hydrology): *Potential to impact all communities*

An increase in the number and duration of droughts could stress vegetation in all terrestrial communities due to lack of water availability. Longer and more frequent droughts could shift the species composition of our region's natural communities, and favor communities adapted to drier conditions. Prairies may be more resilient to droughts as many prairie grasses and forbs have deep root systems and are adapted to withstand drier summers. In prairies where topography and hydrology combine to provide a gradient in moisture, we might expect to see a shift toward dry prairie species and away from wet prairie species. This shift could reduce the overall diversity of a prairie, potentially favoring more opportunistic species over more conservative species.

Droughts could potentially improve the chances of species that currently occur south and west of the CW region to survive well here. Ultimately, however, there are multiple requirements necessary for a species to do well in a new region, and it may be that only the most opportunistic species will be capable of successfully shifting their range.

Additionally, droughts could favor the expansion of dune and shoreline communities if lake levels were to draw down and expose more sand and substrate for colonization by lakeshore vegetation. Wetlands, including wet prairies, may be most susceptible, and mesic prairies that occur on well-drained soils might be especially difficult to maintain in the face of longer drought periods. Wet prairies have persisted with periodic severe droughts in the past, however their ability to continue to do so may largely depend on the severity, frequency, and duration of future droughts. In wetland areas, drought conditions would favor species that establish in dry soil over those that require wet soil. Many wetlands, if dry for a long enough period, will fill in with non-wetland plant species, resulting in a complete disruption of wetland conditions. Species such as cattails, *Phragmites* and reed canary grass will likely do well in wetlands that dry out more thoroughly for periods of the year, while species such as pondweeds could have a harder time maintaining themselves in many wetlands if they dry up more regularly. Reed canary grass in particular thrives in former sedge meadows that have been drained through the use of tiles and/or ditches. The projected altered hydrology- longer droughts interspersed with flashier precipitation- will be especially hard on many wetland species and tend to decrease plant diversity in wetlands.

The impact of more frequent droughts on plants would inherently have a cascading effect on the wildlife that depend on them. In the Chicago Wilderness region, for example, the pipevine swallowtail (*Battus philenor*) exclusively uses pipevines (*Aristolochia*) to lay eggs. A study looking at the effect extreme weather change had on oviposition rates of pipevine swallowtails found rates to be significantly lower during the dry period (Papaj et al. 2007). This was mainly due to a lower density and quality of pipevines during extreme dry periods. By extension, more severe droughts may be associated with more markedly reduced rates of oviposition of this species. If chronically low rates of oviposition translate to chronically low population levels, then they may be at a higher risk of population extinction, a documented consequence of climate change in butterflies and other organisms (Papaj et al. 2007).

4.7 Floods: *Potential to impact Prairie Grasslands, Savannas/Wooded Communities, Wetlands, Streams/Rivers, Lakes*

Precipitation patterns for this region are expected to shift toward an increased frequency of extreme rainfall in a short period of time (i.e. deluge rains) combined with greater incidences of consecutive rainfall of events (1-2 inches) that results in heavy saturation of soils. Increased flooding would result in greater deposition of sediments into regularly flooded areas and, because places subject to regular severe flooding tend to have poor diversity especially in the herbaceous layer, it's likely that few species will be able to tolerate those conditions, and those that are likely be opportunistic weedy species.

Increased floods would also result in more areas of standing water in prairies, savannas, forests, and wetlands near stream channels and potentially favor species that can withstand wide fluctuations in water availability. More flooding resulting from an increased frequency of extreme rain events, and associated increase in runoff, would also contribute to greater nutrient loading of streams, rivers, and lakes. It is important to define the control that changing hydrology will have on organic carbon, nutrients, and soil exported from the land in order to understand how streams rivers and lakes will respond to this aspect of climate change. In mixed land use watersheds, short duration, high discharge events are responsible for most of the introduction of soil derived materials to our waterways (Dalzell et al., 2007).

It is important to bear in mind that this region will experience changes in both precipitation and temperature, which together can result in a non-intuitive climate shift. First, more of the region's precipitation is likely to come down in fewer, but more extreme, rain events that will increase the incidence of flooding and stormwater runoff. This will in turn cause a greater percentage of water to leave the region and reduce the amount available to recharge groundwater levels. Secondly, temperatures will continue to increase, leading to higher rates of evapotranspiration. The combined effect, however, is likely to be less water available in the system annually. So, even though flooding may increase, the overall effect of anticipated precipitation and temperature changes could actually be a drier and warmer environment.

4.8 Scouring/erosion (water, ice): *Potential impacts to Streams/Rivers, Lakes and Lakeshores*

More severe storm events may lead to more scouring, possibly creating more incised stream channels in rivers and streams. Scouring can also affect the herbaceous communities in the floodplains of rivers and streams. Removing existing vegetation can cause the herbaceous layer to be dominated by a small number of early successional species either tolerant of regular disturbance, or able to quickly re-colonize. In lakes, more severe storm events can increase sand and gravel loss along lakeshores, re-shape shorelines, and prevent vegetation establishment.

4.9 High winds: *Potential impacts to Savanna/Wooded Communities and Lakeshore*

Along with increases in air and water temperatures, wind speed has also increased in Lake Michigan over the last several decades (Table 1 in Austin and Coleman, 2007). If wind patterns were to continue to increase, resulting in more extensive and stronger straight-line winds, then storm damage to large, mature trees could increase. The loss of large canopy trees is particularly concerning in many of our region's degraded forests, woodlands, and savannas, where the subcanopy and sapling trees are mostly weedy species and few native species exist to fill the gaps created when these mature trees are damaged in storms. The most susceptible species would be those with brittle wood, such as maples (although large stout trees like oaks would not be immune), and those in wetter areas that have shallow rooting and more windthrow.

High winds can result in increased windthrow in forested communities. The effects of high straight-line winds should be most severe at edges of wooded patches on the windward side. It could be that the relatively isolated trees in savannas could be more susceptible to wind damage. Interior trees in woodlands should see less damage, and less effects of increasing storm intensity. Beaches tend to accumulate less sand during windy spring and summer periods and lose sand through erosion during strong fall and winter storms.

Whether tornados or microbursts will increase in abundance and severity as a result of climate change is unclear (Trapp et al., 2009). However, if they do, it does not seem likely that there would be changes in habitat or species patterns associated with storm damage from tornados. Tornados and microbursts are a mechanism for disturbance, and this means in the short-term opportunistic/weedy species will be able to thrive after a tornado hits. This disturbance in the middle of a forest would also create more edge habitat, which then may be affected more by straight-line winds. In the long-term, stronger windstorms could possibly increase dispersal distances in wind-dispersed species and help with species migration, but because most seeds fall very close to the parent plant, even in small-seeded species, the mean dispersal distance would not change dramatically in the short-term. The species most likely to show increased dispersal distances due to increased windstorms are likely to be easily-dispersed weedy species rather than more conservative species.

4.10 Persistence of snow cover: *Potential impacts to Prairie Grasslands, Wetlands, and Savanna/Wooded Communities*

Increasing winter temperatures will eventually cause more of the winter precipitation to fall as rainfall, and as result snow cover will be generally shallower and persist for a shorter period of time. Snow acts as an insulating cover, keeping soil temperatures near 0°C thus reducing the temperature extremes experienced by vegetation and soil under the snow. Snow also protects plants from drying and desiccation (Barry et al., 2007). As temperatures increase, we could see increases in freeze-thaw cycles that would otherwise be moderated by a more typical snow cover. Thawing changes the structure of snow and reduces its insulating properties, increasing the potential for frost penetration into the soil and root damage to certain plant species (Barry et al., 2007). Spring deluge, which is key for exporting C and N-laden nutrients to rivers and streams, is also likely to occur earlier and as a smaller event due to earlier spring warm-up and less persistent snow cover.

Less snow cover and lack of frozen ground can limit management and ecological restoration activities that are best carried out under frozen ground and snow cover conditions to avoid soil damage. Overall the decrease in duration and depth of snow cover can be expected to exacerbate other stresses to terrestrial ecosystems associated with climate change.

In the lake effect region of CW (mainly Indiana lakeshore counties -Lake, Porter and La Porte, and Berrien county in Michigan), more limited ice cover on Lake Michigan could result in increased lake effect snow in the next few decades. This could result in deeper, more persistent snow cover in these parts of the region. The specific predictions will depend on the details of winter weather patterns. Important parameters include temperature and wind patterns. One study examined the correlation between air and waters temperatures, ice cover, and lake effect snow in Cleveland, OH and Buffalo, NY since 1950. The analysis showed that in years with above normal summer and fall temperatures, lake waters remained warmer into the winter. This effect combined with decreased ice cover will likely increase lake effect snowfall as long as mean winter temperatures remain below freezing (Ferian, 2009).

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Jessica Hellmann- Associate professor, Department of Biological Sciences, University of Notre Dame

Paul Heltne- President Emeritus, Chicago Academy of Sciences

Leon Hinz- Stream ecologist, Illinois Natural History Survey

Lucy Hutcherson- Director of Conservation and Communications Program, Chicago Wilderness

Kris Lah- Endangered species specialist, U.S. Fish and Wildlife Service

Angela Larsen- Coastal program manager, Alliance for the Great Lakes

Mario Longoni- Urban anthropology manager, Division of Environment, Culture and Conservation, The Field Museum

Joy Marburger- Research coordinator, Great Lakes Research and Education Center, Indiana Dunes National Lakeshore

Jeff Mengler- Botanist/Wetland ecologist, Cardno ENTRIX

Scott Namestnik- Botanist, Ecological resource specialist, Cardno JFNew

Mike Redmer- Fish and wildlife biologist, U.S. Fish and Wildlife Service

Alan Resetar- Herpetologist, Division of Amphibians and Reptiles, The Field Museum

Kristin Ross- Ecologist, University of Illinois at Chicago

Laurel Ross- Urban conservation director, Division of Environment, Culture and Conservation, The Field Museum

Rebecca Schillo- Conservation ecologist, Division of Environment, Culture and Conservation at The Field Museum

Casey Sullivan- Natural resources manager, Argonne National Laboratory

Doug Stotz- Senior conservation ecologist, Division of Environment, Culture and Conservation, The Field Museum

John Taft- Plant ecologist/botanist, Illinois Natural History Survey

Erik Ulascek- Horticulturalist, U.S. Forest Service

Lyndon Valicenti- Project coordinator, natural resources and water quality, WRD Environmental

Patti Vitt- Conservation scientist, Chicago Botanic Garden

David Wise- Professor, Department of Biological Sciences, University of Illinois at Chicago

Zhanna Yermakov- Natural resources manager, Chicago Park District