Forestry Sector
Midwest Technical Input Report
National Climate Assessment

CLIMATE CHANGE VULNERABILITIES WITHIN THE FORESTRY SECTOR FOR THE MIDWESTERN UNITED STATES

WHITE PAPER PREPARED FOR THE U.S. GLOBAL CHANGE RESEARCH PROGRAM
NATIONAL CLIMATE ASSESSMENT
MIDWEST TECHNICAL INPUT REPORT

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At the request of the U.S. Global Change Research Program, the Great Lakes Integrated Sciences and Assessments Center (GLISA) and the National Laboratory for Agriculture and the Environment formed a Midwest regional team to provide technical input to the National Climate Assessment (NCA). In March 2012, the team submitted their report to the NCA Development and Advisory Committee. This whitepaper is one chapter from the report, focusing on potential impacts, vulnerabilities, and adaptation options to climate variability and change for the forestry sector.

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Contents

Summary

The statements below represent our assessment of potential ecosystem responses and vulnerabilities within the Forestry Sector of the Midwest Region of the United States. These statements are based on our review of available scientific literature, including both empirical studies of observed changes over the past several years as well as modeling studies that offer future projections under a range of future climates. In summarizing this information, we aim to help decision makers evaluate potential climate-related vulnerabilities through the end of the century.

Key Vulnerabilities across the Midwest Region:

1. Climate change will amplify many **existing stressors** to forest ecosystems, such as invasive species, insect pests and pathogens, and disturbance regimes (very likely).

2. Climate change will result in **ecosystem shifts and conversions** (likely).

3. Many tree species will have **insufficient migration rates** to keep pace with climate change (likely).

4. Climate change will amplify existing stressors to **urban forests** (very likely).

5. Forests will be less able to provide a consistent supply of some **forest products** (likely).

6. Climate change impacts on forests will impair the ability of many forested watersheds to produce reliable supplies of **clean water** (possible).

7. Climate change will result in a widespread decline in **carbon storage** in forest ecosystems across the region (very unlikely).

8. Many contemporary and iconic forms of **recreation** within forest ecosystems will change in extent and timing due to climate change (very likely).

9. Climate change will alter many traditional and modern **cultural connections** to forest ecosystems (likely).

Organization

This white paper on the Forestry Sector was prepared as an input to the National Climate Assessment (NCA; http://www.globalchange.gov/what-we-do/assessment). Specifically, this paper is a contribution to the Midwest Technical Input Team, which will be integrated into the Midwest Chapter of the NCA. Therefore, we have followed guidelines related to framing key conclusions, communicating uncertainty, and ensuring information quality as presented by the NCA Development and Advisory Committee. The guidelines for author teams can be viewed here: http://www.globalchange.gov/what-we-do/assessment/nca-activities/guidance.

We have organized this white paper to enable the Midwest Technical Input Team to easily identify priority themes and key vulnerabilities. We draw a distinction between vulnerabilities related to forest ecosystems (Forest Ecosystems), and vulnerabilities related to ecosystem services derived from forests (Benefits from Forests). We categorize Urban Forests as a distinct class of Forested Ecosystems, because of specific risks, consequences, and vulnerabilities associated with these types of forests. The Adaptation section describes general concepts and actions for responding to these vulnerabilities, but it is outside the scope of this report to make recommendations or cite specific actions.

Each key vulnerability statement is followed by our qualitative view of its likelihood of occurring, using specific language established by the Intergovernmental Panel on Climate Change (Backlund, Janetos, and Schimel 2008; Intergovernmental Panel on Climate Change 2005). Our use of these confidence statements is similar to Backlund, Janetos, and Schimel (2008); the statements reflect our judgment as authors and we have not applied this terminology to previously published studies. Figure 1 presents the spectrum of confidence terms used in this white paper.

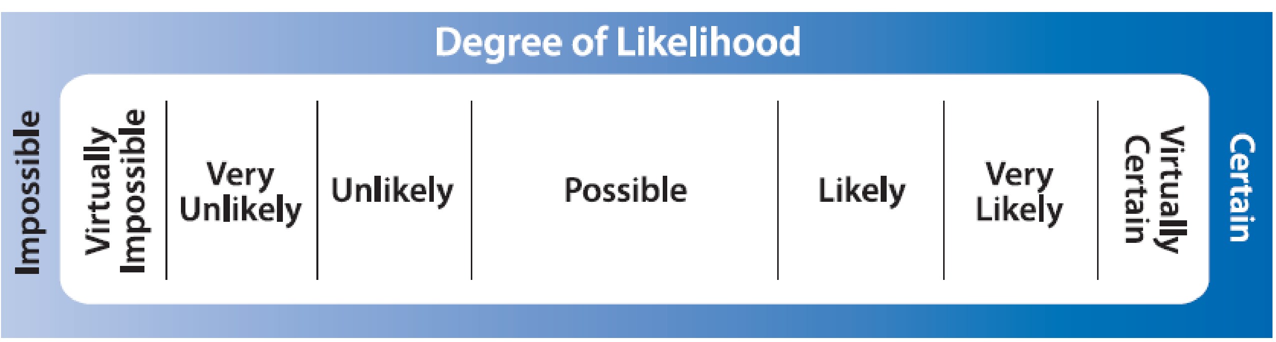

***Figure 1**: Language for describing confidence in findings, from Backlund, Janetos, and Schimel (2008).*

Introduction

Forests are a defining landscape feature for much of the Midwest, from boreal forests surrounding the northern Great Lakes to oak-hickory forests blanketing the Ozarks. Savannahs and open woodlands within this region mark a major transition zone between forest and grassland biomes within the United States. Forests help sustain human communities in the region, ecologically, economically, and culturally.

Climate change is anticipated to have a pervasive influence on forests in this region over the coming decades. In recent years, a growing field of study has emerged to categorize and predict the consequences of climate-related changes in forest systems (Clark et al. 2011; Fischlin et al. 2009; Glick et al. 2011; Parry, Canziani, and Palutikof 2007; Schwartz et al. 2006; Swanston et al. 2011). Two metrics that are often used to assess the outcome of climate-related changes in natural systems are "vulnerability" and "risk." In this paper, we define vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (Intergovernmental Panel on Climate Change 2007). Vulnerability is a function of the degree of climate change a system is exposed to, as well as the system's sensitivity and capacity to adapt with minimal disruption (Glick, Stein, and Edelson 2011; Swanston et al. 2011). Also, it is important to note that vulnerability can refer to a decline in vigor and productivity in addition to more severely altered community composition or ecosystem function (Swanston et al. 2011). That is to say, a species or ecosystem may be considered vulnerable to climate change by virtue of decreased well-being even it is not projected to disappear completely from the landscape.

Risk offers an additional approach to describe the potential consequences of climate change in forest ecosystems. Risk includes an estimate of the likelihood or probability of an event occurring, in combination with the consequences or severity of impacts of that event (Glick, Stein, and Edelson 2011). This approach explicitly considers uncertainty, although clearly communicating uncertainties is necessary for describing both vulnerability and risk in the context of natural resource planning.

This white paper summarizes recent information related to the major potential vulnerabilities associated with climate change in the forestry sector, organized according to "Key Vulnerabilities." For the purposes of this white paper, Key Vulnerabilities are those that have particular importance due to the anticipated magnitude, timing, persistence, irreversibility, distributional aspects, likelihood, and/or perceived importance. Rather than attempting to quantify these risks, this assessment focuses on the question, "What is at risk?" This paper does not attempt to make new estimations of vulnerability or risk for the forestry sector, but rather synthesizes recent information to provide a useful summary.

The Midwest Region, as defined for the purposes of the NCA, covers the states of Minnesota, Wisconsin, Michigan, Iowa, Missouri, Illinois, Indiana, and Ohio. Forest ecosystems are not organized along political boundaries, but are distributed according to patterns of climate, moisture, soils, and disturbance. Therefore, we present information on important climate change-related vulnerabilities according to ecological regions (ecoregions), as defined by Bailey et al. (1995). The Midwest's 8-state footprint includes five distinct ecoregions, which are delineated according to associations of biotic and environmental factors that determine the structure and function of ecosystems (Figure 2). The species, disturbance regimes, existing stressors, and potential exposure to climate change are different for each of these ecoregions. Therefore, we present Key Vulnerabilities that capture broad concerns across the Midwest and include ecoregion-specific information for greater depth and context where available.

Because of the numerous connections between the forestry sector, other elements of the natural environment, and other sectors of human activity, there is necessarily some overlap between this white paper and other white paper

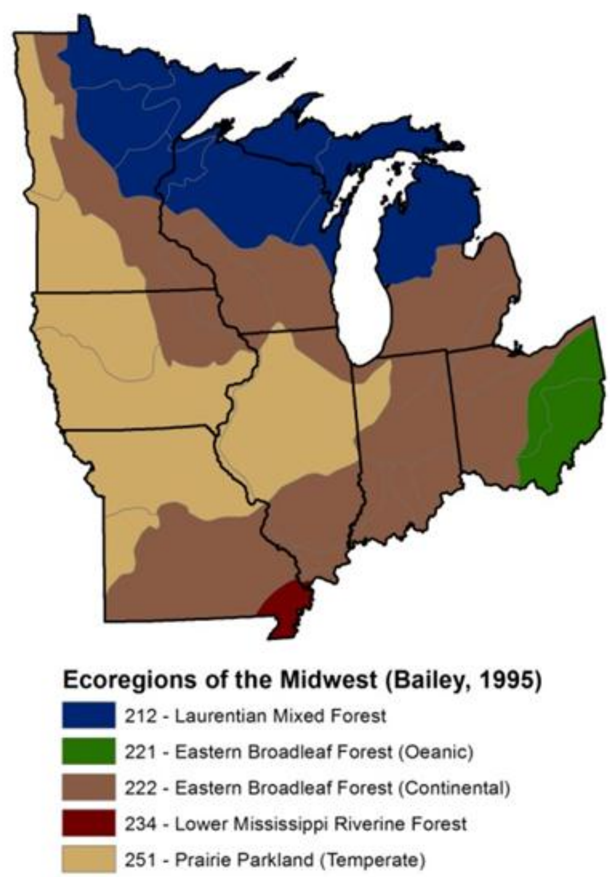

***Figure 2**: Ecoregions within the Midwest Region, according to Bailey et al (1995).*

contributions for the Midwest Chapter of the NCA. Readers who are interested in these connections may find supplementary information in these companion white papers prepared for the Midwest Chapter of the NCA, or in sector-specific chapters of the larger NCA.

Considerations and Caveats

The conclusions drawn in this white paper are predicated upon the future projections of global and regional climate models. As discussed in the companion white paper by Winkler, Arritt, and Pryor (2012), these climate projections must be interpreted with an understanding of the inherent uncertainties associated with making long-term projections for the complex global and regional climate system, as well as the uncertainties associated with particular aspects of climate models and downscaling procedures. Despite the uncertainties, there is widespread consensus among the scientific community that these models provide reliable projections of future climate. Although we are synthesizing research that utilizes numerous general circulation models, future emissions scenarios, and downscaling methods, we attempt to refer to the standard set of climate projections prepared for the Midwest Region for the National Climate Assessment (Kunkel 2011; Winkler, Arritt, and Pryor 2012). These projections rely on a suite of climate model simulations using the B1 and A2 emissions scenarios as "low" and "high" climate futures, respectively.

The companion white paper by Andresen, Hilberg, and Kunkel (2012) includes a discussion of historical climate during the previous 12,000 years in addition to observed trends during the 20th century. When contrasting projected future changes with historic climate records, it is important to note that both the magnitude and rate of change are influencing forest ecosystems, in addition to new interacting stressors that have not previously impacted forests in this region. Substantial change in climate has occurred throughout the Midwest Region during the past 12,000 years, but a major consideration is that in past millennia these changes were driven by natural phenomena, and resulting ecological changes occurred across a matrix that was comparatively free of human modification and development. Contemporary and future changes are occurring within a complex socioeconomic framework, such that future changes in Midwestern forests may have profound impacts on interrelated economic, social, and demographic systems. Recent published studies have concluded that climate change is already happening, and some of the observed indicators of change include severe weather patterns (Changnon 2011; Coumou and Rahmstorf 2012), lake ice timing (Johnson and Stefan 2006; Magnuson et al. 2000), tree phenology (Andresen, Hilberg, and Kunkel 2012; Dragoni and Rahman 2012), and wildlife distributions (Myers et al. 2009; Rempel 2011).

Our Key Vulnerability statements consider outcomes projected in ecosystem models in addition to empirical data gathered in recent years. All models have limitations, but they are useful tools to examine scenarios that are not possible to test directly. For example, statistical niche models such as the Climate Change Tree Atlas (Prasad et al. 2007-ongoing) rely on statistical relationships between the observed range of a species and several determining variables, including climate variables. The relationships accounted for by the model can only describe the realized range of a species, rather than the full potential range. Additionally, the contemporary relationships which determine habitat suitability for a particular species might not hold true in the future. Ecological process models like LANDIS (Scheller et al. 2007) also have inherent limitations to bear in mind, such as the inability to incorporate a full suite of disturbances and stressors into projections of forest growth and survival. Simulations from models should be treated as simplified scenarios to explore a range of outcomes, rather than concrete predictions.

The Key Vulnerabilities in this white paper, and the confidence statements applied to each, reflect our professional consideration of these multiple formats of evidence and projections, along with their associated uncertainties and caveats.

Forest Ecosystems

Key Vulnerabilities across the Midwest Region

This section covers broad Key Vulnerabilities that are expected to be common to forest ecosystems across the entire Midwest Region. We have divided these region-wide vulnerabilities between "Forest Ecosystems" and "Urban Forests."

Forest Ecosystems

1. ***Key Vulnerability: Climate change will amplify many existing stressors to forest ecosystems, such as invasive species, insect pests and pathogens, and disturbance regimes (very likely).***

Forest ecosystems throughout the Midwest Region are exposed to a range of natural, introduced, and anthropogenic stressors. These include invasive flora and fauna, natural and exotic pests and diseases, altered disturbance regimes, land-use change, forest fragmentation, atmospheric pollutants, and others. Decades of research has revealed numerous individual and combined effects of many of these stressors on a variety of forest types. A more recent and rapidly growing area of this research, including experimental, observational, and modeling studies, includes the interaction of changing climate with existing stressors.

Anthropogenic changes in forest ecosystems are diverse and pervasive throughout the Midwest Region, including land conversion, fragmentation, timber harvesting, and fire suppression (Flickinger 2010; Minnesota Department of Natural Resources 2010). The Midwest has experienced large reductions in forest cover from pre-European settlement to the present, with the most dramatic declines occurring in Ohio (95% forest cover reduced to 30.2%) and Illinois (40% forest cover reduced to 13%) (Illinios Department of Natural Resources 2010; Ohio Department of Natural Resources 2010). Open woodlands and savannahs have been lost to agricultural expansion and fire suppression, while fragmentation has reduced overall forest patch size and resulted in more edge habitats (Nowacki and Abrams 2008; Radeloff, Hammer, and Stewart 2005). Compared to other parts of the country, the Midwest Region stands out as one of the most concentrated areas of ecosystem conversion and alteration. A recent analysis by Swaty et al. (2011) highlighted this trend by integrating the combined effects of outright land conversion with the more subtle influences of fire suppression and forest management. Several studies from around the globe have illustrated the negative influence that habitat fragmentation will likely have on range expansion and colonization of new habitats by a variety of tree species (Honnay et al. 2002; Iverson, Schwartz, and Prasad 2004; Scheller and Mladenoff 2008). Habitat loss and fragmentation are two primary reasons that tree species may not be able to naturally colonize newly suitable habitats in the future quickly enough to keep pace with the rate of climate change.

In general, anthropogenic impacts have reduced diversity across forest ecosystems (Nowacki and Abrams 2008). Less diverse ecosystems inherently have greater susceptibility to future changes and stressors (Swanston et al. 2011). Elmqvist et al. (2003) emphasize that "response diversity," or the diversity of potential responses of a system to environmental change, is a critical component of ecosystem resilience. Response diversity is generally reduced in less diverse ecological systems. Therefore, climate change represents an even larger potential stressor for systems heavily disrupted by human activities.

Climate change is also changing the disturbance regimes that influence forest ecosystems across the United States, including fire occurrence and severity, drought, floods, and ice storms (Dale et al. 2001). The Midwest has experienced increasing frequency and/or intensity in severe weather events in recent decades, including catastrophic storms (Changnon 2011; Changnon 2009), extreme precipitation events (Kunkel et al. 2008; Kunkel, Andsager, and Easterling 1999) and floods (Cartwright 2005; Tomer and Schilling 2009). For each decade from 1961 to 2010, the Midwest Region experienced more frequent rainfall events greater than 1 in./day (Saunders et al. 2012). The frequency of rainfall events greater than 3 in./day increased by 103% over this time period. States with the largest increases include Indiana (160%), Michigan (180%), and Wisconsin (203%). These high-intensity rainfall events are linked to both flash flooding and widespread floods, depending on soil saturation and stream levels at the time of the event. The total amount of precipitation in the Midwest Region increased by 23% from 1961-2010. Conversely, drought frequency declined slightly over the 20th century for the Midwest Region (Kunkel et al. 2008). Sparse long-term data on intense wind storms make it difficult to determine if these events are occurring more frequently (Peterson 2000).

While it might seem counter-intuitive given the increase in overall precipitation across the Midwest Region, moisture limitations on forest ecosystems are projected to be more common by mid-century under likely future climate scenarios. This is due to a combination of factors: extended growing seasons, increased summer temperatures, and more episodic precipitation patterns (Hanson and Weltzin 2000). Cherkauer and Sinha (2010) examined streamflow patterns based on downscaled climate projections in four states surrounding Lake Michigan and found that projected summer low flows decreased, summer high flows increased, and overall flashiness increased in summer months. When overlaid with projected increases in temperature for the region (Kunkel 2011; Winkler, Arritt, and Pryor 2012), there appears to be increased potential for late-summer droughts and decreased moisture availability for forests, particularly at the end of the growing season. The consequence of moisture stress on forest ecosystems depends on a range of factors, but this disturbance can lead to substantial declines in productivity and increases in mortality. This is especially the case for seedlings, drought-intolerant species, and drought-intolerant forest types (Hanson and Weltzin 2000).

Among natural disturbances, fire has been the most manageable and fire suppression is likely to continue for most of the Midwest Region. The maximum duration of multi-day periods with temperatures >95°F is projected to increase by 85-245% across the entire Midwest Region by mid-century, according to a range of climate projections (Kunkel 2011). A greater frequency of high-temperature days, in combination with dry late summer conditions, could lead to more active fire seasons across the region (Bowman et al. 2009). Increased investment in fire suppression and preparedness would likely minimize impacts to ecosystems for some time, but future decades may see much greater fire severity as seen in modeling projections (Lenihan et al. 2008) and western examples of near-term stress combined with long-term fire suppression (Peterson et al. 2005).

Dukes et al. (2009) reviewed the state of knowledge regarding climate change on insect pests, pathogens, and nuisance plant species, and on the resulting impacts on forest ecosystems throughout the eastern half of the US.

Under the A2 emissions scenario, they forecast more insect pest damage due to increased metabolic activity in active periods and increased winter survival, although effects of climate on forest insects remain uncertain. Additionally, changes in phenology due to climate change could result in timing mismatches with beneficial insects such as pollinators (Dragoni and Rahman 2012; Forkner et al. 2008). It is more difficult to anticipate the response of forest pathogens under a warmer future due to complex modes of infection, transmission, survival, and tree response (Dukes et al. 2009). These researchers also generally expected invasive plants to "disproportionally benefit" due to more effective exploitation of changed environments and more aggressive colonization of new areas. For each of these categories of forest stressors, uncertainty limits the ability to make confident predictions.

Kling et al. (2003) also reviewed interactions between forest insect pests, atmospheric pollutants, elevated CO2, and climate change. They suggested increased drought stress may make forests more susceptible to both fires and pests, but elevated CO_2 could speed forest succession after these disturbances. They anticipated, however, that ground-level ozone could counteract any short-term increase in forest growth due to elevated CO_2 or nitrogen deposition. Results from several Free-Air CO_2 Enrichment (FACE) experiments add insight to the potential for elevated CO_2 levels to alter the functioning of forest ecosystems – perhaps most importantly that observed responses in these field trials cannot simply be extrapolated to all forests (Norby and Zak 2011). Results from the Rhinelander FACE experiment indicate that aspen forests exposed to elevated CO_2 levels experienced an overall increase in productivity over 12 years (Zak et al. 2011). While increased ozone levels reduced plant growth in early years of the study, high growth of ozone-tolerant genotypes and species compensated for this decline.

The interactions between these stressors are complex, with some ecosystems potentially experiencing increases in forest health and vigor, while others are more likely to show a loss of ecological function or identity. Less diverse forests are generally considered more vulnerable to climate change if they are at all maladapted (Swanston et al. 2011), and may warrant greater scrutiny as systemic changes to stressors continue.

2. *Key Vulnerability: Climate change will result in ecosystem shifts and conversions (likely).*

As temperature and precipitation patterns continue to change (Andresen, Hilberg, and Kunkel 2012; Winkler, Arritt, and Pryor 2012), it is possible that large ecosystem shifts and conversions will accompany the changes. Ecosystems are complex assemblages of species, and so the response of individual species will strongly affect how ecosystems respond as a whole. Additionally, climate pressure on changing forests will continue within the context of forest management, possibly including active and widespread adaptation efforts. Changes in broad ecosystem types will thus vary from one place to another based on local management decisions and specific influences of site-level environmental factors.

Examination of simulated ecosystem responses to a range of climate projections can be used to assess large-scale trends that may be expected in forest systems. Lenihan et al. (2008) used the dynamic vegetation model MC1 to examine potential changes in vegetation classes at the end of the 21st century due to climate change and fire suppression (Figure 3). Under future emissions scenarios comparable to Kunkel (2011) with continued fire suppression, they projected that the Midwest Region would lose most boreal (labeled subalpine) forests, with a majority of the region transitioning to a temperate deciduous forest (SF-A and SF-B, Figure 3). In future scenarios with more wildfire activity the boreal forest types were similarly diminished in the Midwest Region, but they were replaced in western portions of the region by woodlands, savannahs, and grasslands. Temperate deciduous forests were projected to move northward and occupy much of Indiana, Ohio, and Michigan under both high (USF-A) and low (USF-B) emissions scenarios.

Simulation results from Lenihan et al. (2008) also showed a large expansion of woodland/savanna and grassland vegetation types in the Midwest under the unsuppressed fire scenarios (Fig. 3: USF-A and USF-B). This work is largely consistent with results from the systems mapping approach of Frelich and Reich (2010), which showed a broad shift from forest to savanna along the prairie-forest border in the Midwest. The systems mapping approach did not include explicit consideration of fire suppression. These studies illustrate the potential for major shifts in vegetation types even under lower emissions scenarios, but also that societal investment into management efforts such as fire suppression may have equally strong influence.

When considering the potential for ecosystem conversions, species migration is a critical issue. It is not necessarily communities that move, but instead species that move and then form new communities. Re-constructions of vegetation response to past climate change indicate that the species forming forest communities have disassembled and re-aggregated in different permutations (Davis, Shaw, and Etterson 2005). Species distribution models have also indicated that species may respond individually to future climate change, with suitable habitat expanding for some species and declining for others (Iverson, Prasad, and Matthews 2008; Morin, Viner, and Chuine 2008; Walker, Davis, and Sugita 2002). For the majority of 134 tree species across the eastern US, the Climate Change Tree Atlas estimates that mean centers of suitable habitat will migrate between 100-600 km to the northeast under a high emissions scenario and between 50-400 km under a more mild climate change scenario (Prasad et al. 2007-ongoing). Similarly, a process-based distribution model incorporating phenological timing, reproductive success, and dispersal ability (PHENOFIT) projects a general northward expansion among 14 widespread Midwestern tree species, with local extinctions at southern range extents (Morin, Viner, and Chuine 2008). The interacting factors of unprecedented local climates, habitat fragmentation, widespread forest management, and adaptation actions will greatly influence how species migrate, colonize, or survive in current and future habitats. Taken together, this raises the possibility that unprecedented assemblages of species could form novel ecosystems.

3. *Key Vulnerability: Many tree species will have insufficient migration rates to keep pace with climate change (likely).*

Analysis of forest species responses to past climatic change has highlighted the fact that contemporary rates of temperature change will make it very difficult for trees to migrate fast enough to track changes (Davis, Shaw, and Etterson 2005; Davis 1989). Studies utilizing species distribution models have projected that tree species in the eastern US have a low probability of colonizing habitat beyond their existing ranges over the next 100 years (Iverson, Schwartz, and Prasad 2004). Habitat loss and forest fragmentation are two primary reasons for this expected inability to migrate, with the actual movement of tree species being substantially slower compared to the shifts in optimum latitudes based on temperature and precipitation. Iverson, Schwartz, and Prasad (2004) estimated that less than 15% of newly available habitat would be colonized over 100 years in a study of five eastern tree species, using future temperature projections similar to Kunkel (2011). The high degree of fragmentation in natural ecosystems across the Midwest means that widespread vegetation migration will be less able to occur in response to projected climate change (Honnay et al. 2002; Iverson, Schwartz, and Prasad 2004; Scheller and Mladenoff 2008).

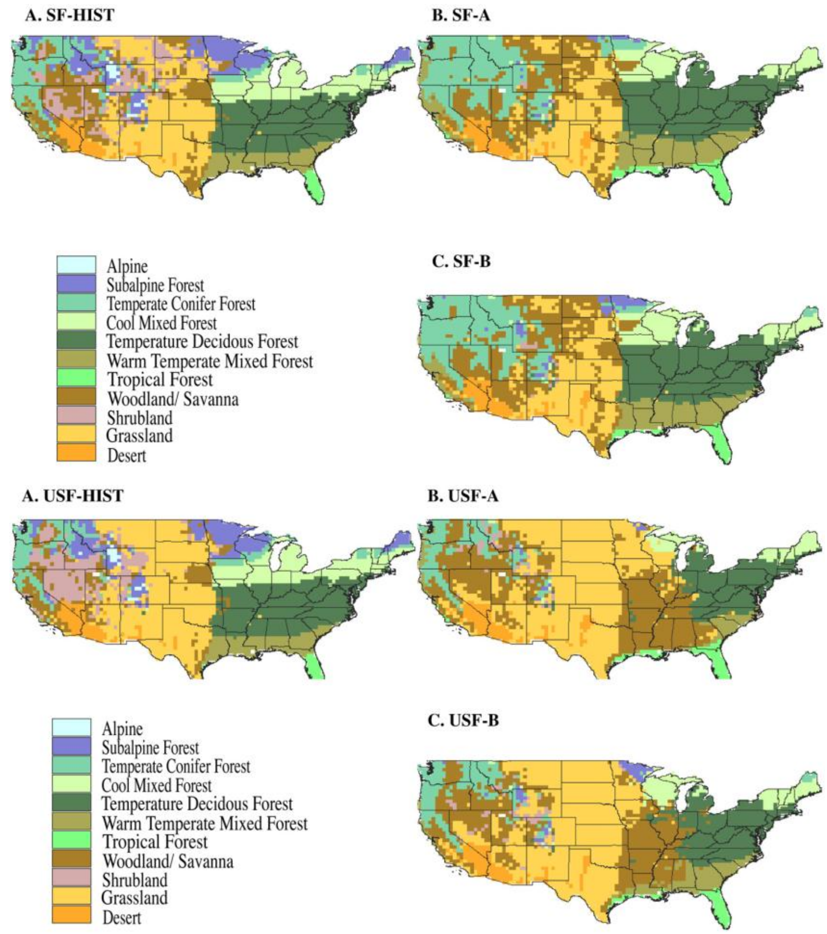

***Figure 3**: Model simulated vegetation type with suppressed fire (SF) and unsuppressed fire (USF) for 1971–2000 historical period (HIST) and 2070–2099 future period. A: SRES-A2 emissions scenario (high climate change), B: SRES-B2 emissions scenario (low climate change). From Lenihan et al. (2008).*

Studies are beginning to emerge that examine whether observed tree distribution shifts match the anticipated trends. These studies largely serve as a reminder to avoid an oversimplified view of northward range shifts. Some work has found evidence of an expansion northward of northern species, with less evidence of a strong response by southern species (Woodall et al. 2009), but northward range expansions may be limited to a small percentage of species (Zhu, Woodall, and Clark 2011). Range contractions along the southern edge of several species' distributions have also been documented (Zhu, Woodall, and Clark 2011; Murphy, VanDerWal, and Lovett-Doust 2010). Based on gathered data of seedling distributions, Woodall et al. (2009) estimated that many northern tree species could possibly migrate northward at a rate of 100km per century. Other studies have estimated that suitable habitat for tree species in the Midwest Region will shift as much as 400-600km by 2100, suggesting that natural migration rates will not be suffienct to keep pace with climate change (Prasad et al. 2007-ongoing). Researchers have raised the possibility that human-facilitated migration could allow more rapid species movement (Woodall et al. 2009), but widespread assisted migration would require a concerted effort across the region.

Plants that are "left behind" by a shifting habitat will not necessarily become extirpated from a site, especially if there are no better-adapted species to out-compete them. Better-adapted species may fail to successfully migrate and establish due to several factors, such as habitat fragmentation, land-use change, or moisture patterns (Crimmins et al. 2011; Honnay et al. 2002; Iverson, Schwartz, and Prasad 2004; Scheller and Mladenoff 2008). Even without strong competitors, plants living outside their suitable habitat may decline in vigor or have lower resilience to a variety of stressors. In the long run, ecosystem shifts may take place not through climate-related mortality, but instead through poor recruitment of young trees.

Urban Forests

4. ***Key Vulnerability: Climate change will amplify existing stressors to urban forests (very likely).***

Urban forests are distinct from natural or managed forest ecosystems, partly because of their structure and composition, and partly because of the many specialized benefits they provide for residents of cities and towns.

The Midwest is home to several major metropolitan areas, including Chicago, Indianapolis, Columbus, Detroit, Milwaukee, Kansas City, Cleveland, and Minneapolis. According to 2010 US Census data, over 45 million people live in urban areas of the eight states in this region, almost 75% of the region's total population (U.S. Census Bureau 2011). Urban areas occupy 3.9% of the total land area in the Midwest, with an average tree cover of 33.2% (Nowak and Crane 2002). This is a higher proportion of urban tree cover than the US average, and the second highest proportion among all the major regions of the country.

Forests in metropolitan areas typically occur in unnatural mixed assemblages with ornamental and understory species (Woodall et al. 2010). These forests usually have 50-80% less biomass per area than is typical in forest areas. While large numbers of different species may occur in urban settings, a few primary species represent the majority of trees. The state of Indiana illustrates this pattern, with maple and ash species making up the bulk of trees found within municipalities, while 3 of the top 11 most frequent species are non-native to the state (Indiana Department of Natural Resources 2010).

Benefits of urban forests include decreased heating and cooling demands for neighboring buildings; recreational opportunities found within urban green spaces and trails; and mental, physical, and emotional well-being of the general public (McPherson et al. 1997; Nowak and Crane 2002; Younger et al. 2008). These specialized values are important in large metropolitan areas as well as smaller communities throughout the Midwest Region.

Climate change will have direct and indirect consequences for urban forests. Climate change is expected to amplify existing stressors that urban forest communities currently face, similar to forests in natural environments (Roloff, Korn, and Gillner 2009). Expected consequences of climate change include increased activity of insect pests and diseases, more frequent exposure to heat waves and drought, and phenological mismatches with pollinators and dispersal agents. Additional stresses faced by urban forests include increased atmospheric pollution, heat island effects, salt damage, highly variable hydrologic regimes, and frequent exposure to novel pests and diseases.

A recent study of urban forests throughout the eastern US provides some interesting context for how these forests may adapt to climate change (Woodall et al. 2010). For example, greater than 10% of trees species that currently comprise urban forests in Minneapolis are found far northward of their natural ranges. This subset of the urban forest canopy may therefore be more amenable to future changes in temperature and precipitation. Researchers examined the possibility for urban forests to act as refugia for natural ecosystems or as northern dispersal centers to facilitate future migration, but ultimately concluded that these potential benefits are unlikely to be realized. This conclusion was due in large part to the physical limitations of urban forests – few candidate species for migration, low overall abundance of suitable species, and isolation from the surrounding forest matrix.

Considerations Within Particular Ecoregions

This section presents specific considerations of climate change vulnerabilities for the particular ecoregions located within the larger Midwest Region. Where available, information has been organized according to the same Key Vulnerabilities mentioned above, to aid comparing ecoregional specifics to larger regional trends.

Ecological Province 212: Laurentian Mixed Forest

The recent vulnerability assessment by Swanston et al. (2011) includes a list of important vulnerabilities identified for forest ecosystems in northern Wisconsin, which may be generally applied to the ecoregion. This assessment relied on a combination of model results and expert input to compile the following list of vulnerabilities. Parenthetical confidence statements reflect the judgment of the authors, based on specific language established by the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change 2005).

- Risk will be greater in *low diversity ecosystems* (very likely).
- Disturbance will destabilize *static ecosystems* (very likely).
- Climate change will exacerbate problems for *species already in decline* (very likely).
- Resilience will be weakened in *fragmented ecosystems* (very likely).
- Altered hydrology will jeopardize *lowland forests* (very likely).
- Changes in habitat will disproportionately affect *boreal species* (virtually certain).

- Further reductions in habitat will impact *threatened, endangered, and rare species* (virtually certain).
- Ecosystem changes will have significant effects on *wildlife* (very likely).

Similarly, this assessment includes a list of characteristics or components that may enable certain species, communities, and ecosystems to better accommodate change (Swanston et al. 2011). More adaptive ecosystems include:

- Species that are currently increasing
- Species with a wider ecological range of tolerances
- Species with greater genetic diversity
- Species and ecosystems adapted to disturbances
- Species and ecosystems adapted to warmer, drier climates
- Species in the middle or northern extent of their range
- Diverse communities and species
- Habitats within larger, contiguous blocks

*Laurentian Mixed Forest: Climate change will amplify many **existing stressors** to forest ecosystems, such as invasive species, insect pests and pathogens, and disturbance regimes (very likely)*

Similar to the trend for the entire Midwest Region, future climate change may amplify existing stressors for forests in the Laurentian Mixed Forest province. A recent example of this synergistic effect is a study from northern hardwood stands recently invaded by exotic earthworms (Larson et al. 2010). Sugar maple trees were more sensitive to drought in invaded stands relative to non-invaded stands, exhibiting more reduced growth during these dry periods. Studies have also highlighted the potential for white-tailed deer (*Odocoileus virginianus*) to alter forest composition due to preferential browsing of seedlings (Salk et al. 2011). Preferential herbivory can ultimately lead to stand conversion, and is a potential multiplier of climate change influences. Gypsy moth (*Lymantria dispar*) is currently limited by cold winter temperatures across the Midwest Region, and is anticipated to expand its range northward under future climate change scenarios (Vanhanen et al. 2007).

There is already a recognized trend toward less diverse forests in the Laurentian hardwoods, though not necessarily due to changing climate. Schulte et al. (2007) compared early settlement records to contemporary conditions throughout the Laurentian Mixed Forest province and found an overall trend toward reduced forest diversity, reduced forest area, and a greater tendency toward deciduous broadleaf species. They attribute these changes primarily to human land use and persistent herbivory by white-tailed deer. Less diverse systems are generally understood to be more susceptible to increased stresses associated with future climate change (Swanston et al. 2011), which may in turn exacerbate historical trends of decreasing forest land and species diversity.

*Laurentian Mixed Forest: Climate change will result in **ecosystem shifts and conversions** (very likely)*

Researchers using LANDIS, a spatially interactive landscape model, across a large region in northeastern Minnesota projected declines in boreal species under both high (A2) and low (B2) emissions scenarios (Ravenscroft et al. 2010). Management treatments that mimicked previous natural disturbance regimes maintained a wider variety of species across the landscape, especially in the low climate change scenario. Under high emissions, however, a much greater proportion of the simulated landscape was converted to non-forested habitats. In general, simulated forest systems across the landscape under both scenarios became more homogenous maple stands (*Acer* spp.) with decreasing proportions of pines (*Pinus* spp.) and hemlock (*Tsuga canadensis*).

*Laurentian Mixed Forest: Many tree species will have **insufficient migration rates** to keep pace with climate change (likely)*

Simulations examining forest ecosystem composition and change using LANDIS have reinforced the expectation that

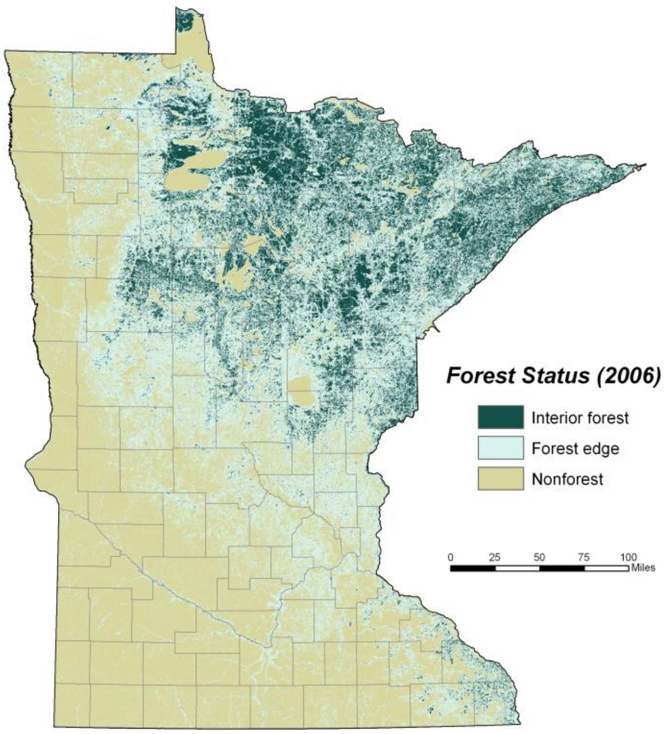

***Figure 4**: Fragmentation of forest land in Minnesota, based on the 2006 National Land Cover Database. Land cover data were classified using a 7x7 analysis window, meaning that forested areas would have to be larger than 10 acres to be considered interior forest. This method does not distinguish between forest edges caused by natural versus developed land cover. Source: Dacia Meneguzzo, USFS*

forest communities will not be influenced only by shifts in habitat ranges, but also by species' ability to actually migrate and establish in new areas. For the Boundary Waters Canoe Area in northern Minnesota, Xu, Gertner, and Scheller (2011) found that with increased wind and fire disturbance expected with climate change, forest composition change was influenced more by colonization of new species than competition among existing species. Additionally, LANDIS simulations in northern Wisconsin found that species migration is negatively correlated with habitat fragmentation (Scheller and Mladenoff 2008).

This is an important consideration because of the amount of fragmented forest in the region. Figure 4 shows the status of forest fragmentation in Minnesota, where two major factors contributing to forest fragmentation are large-scale divestiture of forest industry land and parcelization of non-industrial private forest land (Minnesota Department of Natural Resources 2010). Parcelization is the division of larger landholdings into smaller units. The average landholding size in Minnesota has decreased from 39 acres in 1982 to 31 acres in 2003, and a similar trend is present in Wisconsin where average parcel size decreased from 41 to 30 acres during 1997 to 2006 (Minnesota Department of Natural Resources 2010, Wisconsin Department of Natural Resources 2010). While parcelization may not immediately result in direct impacts to forest ecosystems, this pattern often results in consequences for forest ecosystems as well as forest industry (Gobster and Rickenbach 2004; Haines, Kennedy, and McFarlane 2011). Long-term studies in northern Wisconsin have shown that parcelization is often a precursor to fragmentation and land-use change in forest ecosystems (Haines, Kennedy, and McFarlane 2011). Therefore, contemporary demographic and land ownership trends may make it increasingly difficult for forest species to migrate fast enough to keep pace with climate-related shifts.

Ecological Province 221 & 222: Eastern Broadleaf Forest (Oceanic & Continental)

Eastern Broadleaf Forest: Climate change will amplify many ***existing stressors*** *to forest ecosystems, such as invasive species, insect pests and pathogens, and disturbance regimes (very likely).*

Climate change is likely to cause similar stress on forests in the Eastern Broadleaf province as in the rest of the Midwest Region, including drought, forest pests and diseases, non-native species, and altered disturbance regimes. Oak decline is a major stressor throughout the southern half of the Midwest Region. This condition is correlated with drought periods (Dwyer, Cutter, and Wetteroff 1995; Fan, Kabrick, and Shifley 2006; Wang, He, and Kabrick 2008). Species in the red oak group (*Quercus rubra*, *Quercus coccinea*, *Quercus velutina*) are particularly susceptible to decline and make up a large proportion of upland forests in this ecoregion. Decline begins with stressed trees that are then attacked by insects and diseases. If droughts become more frequent or severe, oak decline could worsen. A buildup of fine and coarse fuels could result from increased tree mortality, increasing the risk of wildfire in the area.

Existing forests may have to compete with undesirable species under warmer future conditions. Kudzu (*Pueraria lobata*) is an invasive vine that typically transforms invaded forests in the southeastern US by quickly overgrowing and smothering even mature overstory trees. Kudzu-related economic damage to managed forests and agricultural land is currently estimated at $100-500 million per year in the southeastern US (Bradley, Wilcove, and Oppenheimer 2010). Kudzu's current northern distribution is limited by winter temperatures. It occurs nowhere in the Midwest Region except for the southern portion of Missouri. Modeling suggests the risk for kudzu invasion into the Continental and Oceanic Eastern Broadleaf ecoregions could be heightened under future warming (Bradley, Wilcove, and Oppenheimer 2010; Jarnevich and Stohlgren 2009). The aggregate of the models suggests a medium risk for invasion for Missouri, Indiana, Illinois, and Ohio over the next century. Studies have also projected that Chinese and European privet (*Ligustrum sinense and L. vulgare,* respectively), highly invasive shrubs, could expand to new territory across the Midwest Region over the next century (Bradley, Wilcove, and Oppenheimer 2010).

Eastern Broadleaf Forest: Climate change will result in ***ecosystem shifts and conversions*** *(likely).*

Forests in the Eastern Broadleaf Forest ecoregion may be at risk of losing keystone species or converting to different ecosystem types. Based on dendrochronological research, white oak (*Quercus alba*) may have reduced growth in the future at the western extent of its range (IL, IA, MO). This is due to a negative correlation between growth and June and July temperatures, which are projected to increase (Goldblum 2010). Decreased habitat suitability for white oak is also projected by species distribution models (Iverson et al. 2008). A decrease in white oak could make way for other species more suited to higher summer temperatures. As mentioned above, a shift in the prairie-forest border could dramatically alter the makeup of ecosystems in the Prairie Parkland and Eastern Broadleaf ecoregions (Frelich and Reich 2010).

Fire has historically been a common disturbance agent within the Broadleaf Forest ecoregions, particularly along grassland transition zones. Fire suppression during the past century has favored shade-tolerant species like maple, while placing fire-adapted tree species like oaks and shortleaf pine at a competitive disadvantage. This trend is illustrated by the large increase in maple species across the Midwest, especially in smaller size classes (Illinios Department of Natural Resources 2010; Ohio Department of Natural Resources 2010; Raeker et al. 2010). This ongoing ecosystem conversion, in combination with existing stressors facing oaks, may make it more difficult for fire-adapted species to expand into available habitat in the future. Lenihan et al. (2008) projected that woodlands and savannahs could occupy a majority of the Eastern Broadleaf Forest province in both high and low future climate scenarios in the absence of extensive fire suppression (Figure 3). If fire-dependent forests continue to decline, these forest types may not be available to occupy future suitable habitat in the ecoregion. This scenario could result in unanticipated conversions favoring non-forest systems or non-native species.

Lowland forest systems in this ecoregion may also be subject to conversions due to climate change. Bald cypress (*Taxodium distichum*) swamps, located in far southern IL, IN, and MO are highly dependent on precipitation patterns and periodic flooding, which are likely to change across the Eastern Broadleaf region based on current climate projections (Middleton and Wu 2008; Middleton 2000). The southern extent of the range is likely the most vulnerable, while the northern extent may serve as a refuge to more southern associated species (Middleton 2006).

Eastern Broadleaf Forest: Many tree species will have ***insufficient migration rates*** *to keep pace with climate change (likely).*

Habitat suitability for shortleaf pine (*Pinus echinata)*, which currently is at its northern extent in southern Missouri, may increase in northern Missouri, southern Illinois, and Indiana (Iverson et al. 2008). However, habitat fragmentation and past management that favored oaks instead of pine could hamper the migration of shortleaf pine into newly suitable areas.

Bald cypress also presents an example of migration barriers that may prevent species from successfully tracking changes in temperature and precipitation. Seeds of bald cypress disperse by water, and most of the watersheds where they are located flow southward (Middleton and McKee 2004). In addition, bald cypress swamps have become increasingly fragmented in the north as they have been drained to make use for agriculture and local rivers have been dammed, making northward dispersal even more difficult (Middleton and Wu 2008).

Ecological Province 251: Prairie Parkland (Temperate)

Prairie Parkland: Many tree species will have ***insufficient migration rates*** *to keep pace with climate change (likely).*

Fragmentation and parcelization of forest ecosystems is more drastic in the Prairie Parkland than other ecoregions throughout the Midwest. For example, over 90% of forestland in Iowa is currently divided into private holdings averaging less than 17 acres (Flickinger 2010). Parcelization frequently leads to fragmentation in forest ecosystems, even though land use change may not immediately follow ownership transfers (Haines, Kennedy, and McFarlane 2011). Combined with extensive conversion of available land to agricultural monocultures, this ecoregion currently exists as a highly fragmented landscape for forest ecosystems. This condition raises the possibility that tree species in the Prairie Parkland ecoregion may be unable to migrate successfully to future suitable habitat, perhaps more so than other ecoregions in the Midwest.

Benefits from Forests

This section presents information on Key Vulnerabilities that are related to major ecosystem services provided by forest ecosystems. This information in the following sections is relevant across the Midwest Region, therefore we do not provide additional ecoregion-specific context.

Forest Products

5. ***Key Vulnerability: Forest ecosystems will be less able to provide a consistent supply of some forest products (likely).***

One of the benefits humans derive from forests is a diverse supply of wood products. Although the importance of forest industry to the overall economy varies throughout the Midwest Region, the sector accounts for between 0.5-2.1% of total employment in a given state and 0.9% of employment across the region (Table 1). Beyond direct employment, the Midwest is an important component of the nation's forest products industry. Wisconsin is the top-ranking paper producer in the country, and Indiana is a national leader in the production of wood office furniture, kitchen cabinets, and other products (Indiana Department of Natural Resources 2010; Wisconsin Department of Natural Resources 2010). The forest products industry is the 4th largest manufacturing industry in the state of Minnesota (Minnesota Department of Natural Resources 2010).

While employment related to direct growth and harvest operations has remained more or less consistent, employment in processing mills and manufacturing facilities has been declining steadily over the past decade (Figure 5).

The ecological changes that occur as a consequence of climate change could have cascading effects throughout the forest products industry, from altered timber supply to the management practices that may be employed (Irland et al. 2001). These effects depend not only on ecological responses to the changing climate, but also on socioeconomic factors that will undoubtedly continue to change over the coming century. Major socioeconomic factors include national and regional economic policies, demand for wood products, and competing values for forestland (Irland et al. 2001). It is possible that the net effect of climate change to the forest products industry in the Midwest will be positive, if the industry can adapt effectively.

An example of how climate change may influence the forest products industry throughout the Midwest can be seen in white oak, which occurs across the grassland and broadleaf forest ecoregions. White oak is an important tree species, economically and ecologically. As recently as 2005, oak species accounted for 36% of annual harvest in Illinois, and white oak in particular was a favored harvest species (Illinios Department of Natural Resources 2010). Oak species are also the primary harvest species in the Ohio portion of the Oceanic Eastern Broadleaf ecoregion (Ohio Department of Natural Resources 2010). The ongoing decrease in oak species is likely a result of several factors, ranging from fire suppression to drought to pests and diseases, as mentioned above. Climate change may amplify the rate of this decrease. The species does show variation in sensitivity to climate parameters across its entire range, highlighting the fact that relationships may differ geographically for widely distributed species (Goldblum 2010).

Future models considering climate change also project that other commercial species like aspen, sugar maple, black cherry, and hickory may see substantial changes in distribution and abundance (Iverson et al. 2008). Large potential shifts in commercial species availability may pose risks for the forest products sector if the shifts are rapid and the industry is unprepared. These trends will be important to examine for other economically important species, and the forest industry will benefit from awareness of regional differences as well as potential opportunities as new merchantable species gain suitable habitat in the region.

	Total Private Employment	Timber Employment	Economic Output of Forest Industry
Midwest	*23,830,646*	*215,526*	*$55.8 billion*
Illinois	5,120,970	26,416	$2.5 billion
Indiana	2,449,980	28,069	$7.5 billion
Iowa	1,283,769	14,031	$3 billion
Michigan	3,383,615	23,478	$8 billion
Minnesota	2,417,174	25,505	$6 billion
Missouri	2,358,706	16,356	$5.7 billion
Ohio	4,460,553	31,527	$2.6 billion
Wisconsin	2,355,879	50,144	$20.5 billion

Table 1*: Total employment, timber-related employment, and economic output for the forestry sector for the entire Midwest Region and the individual states. Employment figures are from Headwaters Economics (2011). Economic output figures are from the 2010 State Forest Resources Assessments (Flickinger 2010; Illinios Department of Natural Resources 2010; Indiana Department of Natural Resources 2010; Minnesota Department of Natural Resources 2010; Ohio Department of Natural Resources 2010; Price 2008; Raeker et al. 2010; Wisconsin Department of Natural Resources 2010).*

Water Resources

6. ***Key Vulnerability*: *Climate change impacts on forests will impair the ability of many forested watersheds to produce reliable supplies of clean water (possible).***

Forested watersheds play a vital role in providing clean water supplies. Forests reduce surface runoff, soil erosion, water temperatures, and pollutant levels as water moves through the ecosystem (Furniss et al. 2010). For these reasons, maintaining forest cover can be a key aspect of "source water protection" for municipal watersheds. Drinking water often arises from forested landscapes, and the proportion of forest cover in source watersheds is inversely related to the cost of water treatment (Ernst, Hopper, and Summers 2004). Protecting drinking water sources from contamination remains a much cheaper and effective option than disinfection and filtration of water supplies. As noted in the Indiana Statewide Forest Assessment, forest cover alone cannot ensure water quality, because other factors like storm water management, point-source pollution, and agricultural practices often have large influences (Indiana Department of Natural Resources 2010). Responsible stewardship of forest land is still a critical determinant of overall watershed health, however.

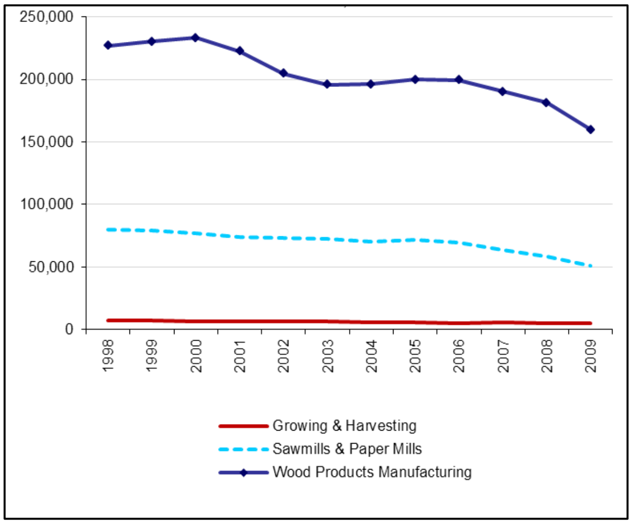

Figure 5*: Employment in Timber-related fields, from recent census data compiled across all 8 states in the Midwest NCA region (Headwaters Economics 2011).*

All eight states in the Midwest Region have experienced sharp declines in the ratio of forest acres per person over the past century, with Illinois, Indiana, Iowa and Ohio all having less than one forest acre per person (Barnes et al. 2009). Public surface water supplies are common in all states throughout the Midwest, with the exception of Wisconsin. In Iowa, forests account for only 14% of the land cover in surface water protection zones for municipalities that rely on surface drinking water supplies (Flickinger 2010). The Missouri Department of Natural Resources estimates only 55% of the potentially forested riparian buffers are currently forested across the state (Raeker et al. 2010). If these rates continue to decline, municipal water supplies will be further stressed to provide clean water.

Barnes et al. (2009) developed an index to characterize a watershed's ability to produce clean water by combining six layers of spatial data: road density; soil erodibility; housing density; and the percentages of forest land, agricultural land, and riparian forest cover. Much of the Laurentian Forest Province scored very high according to this assessment, while other ecoregions within the Midwest had low to mid-range scores (Figure 6).

As outlined above, interacting effects of climate change, habitat fragmentation, disturbance, and forest stressors may result in reduced forest cover throughout the Midwest Region. This could occur through a variety of pathways, including ecosystem shifts and migration of the prairie-forest border, or situations where existing forest species experience declines and new migrants are unable to fully colonize the available habitat. The impacts of climate change on the extent and condition of forest ecosystems across the Midwest Region will alter the ability of these watersheds to produce clean water, which in turn will dictate how municipalities across the region provide water to the human population.

Regional changes in precipitation patterns will further alter the quality and supply of water delivered from forest ecosystems. Across the central United States, the ratio of wintertime snowfall to precipitation has been declining over the past half century (Feng and Hu 2007). This trend has implications for the hydrologic cycle, meaning that a greater percentage of water is delivered through immediate surface runoff rather than through gradual release from snow packs. Cherkauer and Sinha (2010) project that this trend will continue, with increasing surface flows in spring and summer months by the late 21st century in the 4 states surrounding Lake Michigan. Additionally, observed trends over the 20th century indicate that a larger proportion of annual rainfall in the central United States is occurring in high-intensity events, and that intense rainfall events are becoming more frequent (Andresen, Hilberg, and Kunkel 2012; Kunkel et al. 2008; Saunders et al. 2012). The Midwest Region in particular stands out as experiencing substantial increases in the frequency of large precipitation events (Kunkel, Andsager, and Easterling 1999). Over the past 50 years, the frequency of rainfall events of greater than 3 in./day has increased by 103% across the region (Saunders et al. 2012). Forest ecosystems may be less able to absorb and filter large pulses of rainfall, rain-on-snow events, or rapid snowmelt. This substantial shift in precipitation patterns will make it more difficult for forested watersheds to deliver clean water supplies, regardless of changes in the extent or condition of forest ecosystems in the Midwest Region.

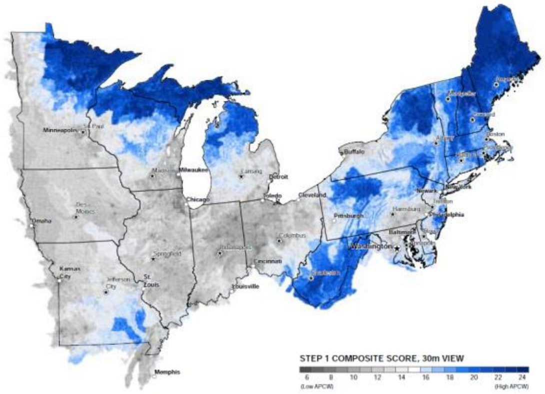

Figure 6: *Index of the Ability to Produce Clean Water, from Barnes et al. (2009). Dark blue areas have higher scores and a greater ability to produce clean water.*

Water provisioning is among the most critical ecosystem services provided by forest ecosystems for human well-being. Therefore, this vulnerability may warrant special attention and monitoring over the next several years.

Carbon Storage

7. ***Key Vulnerability*: *Climate change will result in a widespread decline in carbon storage in forest ecosystems across the region (very unlikely).***

Forest ecosystems and urban forests play a valuable role as a carbon sink across the Midwest Region (Flickinger 2010; Minnesota Department of Natural Resources 2010; Nowak and Crane 2002; Ohio Department of Natural Resources 2010; Price 2008; Raeker et al. 2010; Wisconsin Department of Natural Resources 2010). Carbon sequestration and storage in forest ecosystems depends on the health and function of those ecosystems in addition to human management, episodic disturbances, and forest stressors. All of these factors will interact with climate change, but the effect on carbon storage will vary from place to place. It is possible that forest carbon stocks in localized areas will experience decreases over time under future climate change, but it is also possible that carbon stocks in some areas will increase under climate change. A large-scale decline in carbon stocks across the entire Midwest Region is very unlikely.

Each year, forests and forest products nationwide remove greenhouse gases from the atmosphere that are equivalent to more than ten percent of annual US fossil fuel emissions (Birdsey, Pregitzer, and Lucier 2006; McKinley et al. 2011; Ryan and America 2010; Smith et al. 2006). The accumulated terrestrial carbon pool within forest soils, belowground biomass, dead wood, aboveground live biomass, and litter represents an enormous store of carbon (Birdsey, Pregitzer, and Lucier 2006). Widespread land-use change in the Midwest has dramatically reduced above-ground carbon storage and re-arranged the distribution of carbon pools on the landscape (Rhemtulla, Mladenoff, and Clayton 2009). Terrestrial carbon stocks in the region have generally been increasing for the past few decades, and there is increased attention on the potential to manage forests to maximize and maintain this carbon pool (Flickinger 2010; Malmsheimer et al. 2011; Minnesota Department of Natural Resources 2010). The amount of carbon stored in future forests in the Midwest will be determined in large part by their extent and composition, which already varies considerably across the region. For example, in Wisconsin maple/beech/birch forests sequester an average of 224 metric tons C/acre, while spruce/fir forests sequester an average of 87 metric tons C/acre (Wisconsin Department of Natural Resources 2010). Similarly, the average carbon density in urban forests is about half that of forested ecosystems (Nowak and Crane 2002). Climate change and management are very likely to continue to influence the distribution and composition of forests throughout the region.

Episodic disturbances
Interactions of climate change with wildfires, wind storms, and insect outbreaks may result in net gains or losses of ecosystem carbon. An ecosystem model study by Lenihan et al. (2008), found that more frequent wildfires and ecosystem conversions resulted in average carbon losses of 11% across the eastern US. Continued fire suppression reduced the average carbon loss to 6%. Some studies have shown that repeated disturbances (clear-cut harvesting and fire) reduced annual carbon storage and forest productivity, and have projected that these trends may be amplified by climate change (Gough et al. 2008). Other studies have projected that aboveground live biomass will increase under high and low climate future scenarios, regardless of whether harvesting and wind disturbance are included in the simulations (Scheller and Mladenoff 2005). The trend of increased total biomass projected by Scheller and Mladenoff (2005) occurred despite the fact that many boreal species were extirpated from the study area in their model simulations.

Additionally, insect pests and diseases can determine whether forest ecosystems are net sinks or sources of carbon (Hicke et al. 2011). Forest ecosystems can take decades to recover from widespread pest attacks. If climate change increases the prevalence or activity of these or other disturbance agents, forests in the Midwest could suffer localized declines in growth or increased mortality.

Effects on productivity
Several studies have projected the outcome of climate change on forest growth and productivity, which could have positive and negative consequences for forest carbon sequestration. Free-Air CO_2 enrichment (FACE) experiments in forest stands across several regions have found a consistent increase in net primary production, and suggest that forests may be more responsive to elevated CO_2 than other ecosystem types (Ainsworth and Long 2005; Norby and Zak 2011; Norby et al. 2005). Ainsworth and Long (2005) estimated a 28% increase in dry matter production in four forest types in response to elevated CO_2, including aspen in northern Wisconsin. It also appears that forests in the Midwest may not face N-limitation that could otherwise dampen the response to elevated CO_2, and that ozone-resistant genotypes and species, if present, could help forests overcome the potentially detrimental effects of elevated ozone (Norby and Zak 2011; Zak et al. 2011).

Considering species range shifts due to climate change, Chiang et al. (2008) estimated an increase in net primary production (NPP) in northern Wisconsin, with minimal changes in Ohio. Increased NPP in northern areas of the Midwest may result from greater growth from oak and cherry (*Prunus spp.*) species, which could offset reduced growth in aspen and birch.

Retrospective studies that measure the influences of temperature and precipitation on NPP are rare. Bradford (2011) examined the strength and seasonality of this relationship across the entire Laurentian Forest Province, using two decades of gathered data. The findings from this study indicate that there are multi-year and seasonal controls that govern growth in a given growing season. The weather conditions of a given year are often not directly correlated with the growth during that growing season.

Recreational Opportunities

8. ***Key Vulnerability*: *Many contemporary and iconic forms of recreation within forest ecosystems will change in extent and timing due to climate change (very likely).***

Forest ecosystems are one of the centerpieces of recreation in the Midwest Region. People throughout this region enjoy hunting; fishing; camping; wildlife watching; and exploring trails on foot, bicycles, skis, snowshoes, horseback, and off-highway vehicles (OHVs), among many other recreational pursuits. The vulnerabilities associated with climate change in forest ecosystems will very likely result in shifted timing or participation opportunities for forest-based recreation.

Estimates of actual participation in these activities rely on varying methods and are often limited to fee-based recreation areas, but the popularity of these types of activities reinforces the notion that forests are an important setting for enjoyment of nature. There are 10 National Forests, 3 National Parks, 4 National Lakeshores, 64 National Wildlife Refuges, and hundreds of state and county parks within the Midwest Region, all of which are hotspots of forest-based recreation and tourism. For the 10 National Forests in the Midwest Region, over 55% of visitors reported travelling more than 50 miles to visit, reflecting the potential of these locations to draw visitors from a wide area (US Forest Service 2011). According to data from 2005-2009, there are approximately 10.6 million visits to the National Forests each year (data reported for different Forests in different years). Total spending associated with these visits was over $700 million per year.

The state of Wisconsin estimated that forest-based recreationists spend approximately $2.5 billion within Wisconsin communities (Marcouiller and Mace 1999). Surveys in Wisconsin also show that most types of recreation show stable or increasing demand in future projections (Wisconsin Department of Natural Resources 2010). The state of Ohio found that 62% of the state's recreational sites were located within or nearby forests (Ohio Department of Natural Resources 2010).

Forest-based recreation and tourism are strongly seasonal. Observations support the idea that seasons have shifted measurably over the previous 100 years, and projections indicate that seasonal shifts will continue toward shorter, milder winters and longer, hotter summers in the future (Andresen, Hilberg, and Kunkel 2012; Winkler, Arritt, and Pryor 2012). Climate change generally stands to reduce opportunities for winter recreation in the Midwest, while warm-weather forms of nature-based recreation may benefit (Dawson and Scott 2010; Jones and Scott 2006; Mcboyle, Scott, and Jones 2007). For example, opportunities for winter-based recreation activities such as cross-country skiing, snowmobiling, and ice fishing may be reduced due to shorter winter snowfall seasons (Notaro et al. 2011) and decreasing periods of lake-ice (Kling et al. 2003; Magnuson et al. 2000; Mishra et al. 2011). Conversely, warm-weather recreation activities such as mountain biking, OHV riding, and fishing may benefit from extended seasons in the Midwest.

Scientific literature assessing the impacts of these changes on forest-based recreation is lacking, with the majority of published studies focused on the downhill skiing industry or international tourism (Nickerson, Becerra, and Zumstein 2011). Irland et al. (2001) describes the difficulties associated with projecting the impacts of climate change on the recreation industry. In many cases, it is unclear if there are particular thresholds for change that will reduce enjoyment of a given activity.

Saunders et al. (2011) provide a case study for the Midwest Region, focusing on four National Lakeshores and one National Park surrounding the Great Lakes. Total visitor attendance at these five sites is over 4 million people per year, with visitor spending over $200 million. The more immediate impacts of climate change - projected ecosystem disruption, loss of wildlife and fish, changing temperatures, disease outbreaks, and wildfire – could lead to a loss of visitor enjoyment and a drop in visitation at the region's parks.

In the National Visitor Use Monitoring program for National Forests, survey respondents were asked to choose among a few general "substitute behavior" choices, which might serve as general indicators of what the typical response might be to a situation when visiting a given recreational location at a given time was undesirable (US Forest Service 2011). Fewer than half reported their preference would be to travel elsewhere for the same activity, while nearly 20% would have stayed at home or gone to work. Only 35% of visitors reported that they would be willing to travel more than 100 miles to an alternate location. If visitors are seeking a particular type of recreational experience that is shaped in large part by the well-being of the surrounding ecosystem or certain climatic factors, this extent of travel might be more necessary in the future.

The loss of visitor enjoyment, uncertainty about ideal timing of visitation, and increased travel distances could lead to reduced public interaction with a wide range of natural areas, from county parks to National Forests. Such reductions would likely be associated with a decrease in visitor spending. New opportunities could offset decreases on a regional basis, though localized areas may experience decreases in traditional recreational enjoyment and spending.

Cultural Values

9. ***Key Vulnerability*: *Climate change will alter many traditional and modern cultural connections to forest ecosystems (likely).***

Some of humankind's fundamental and yet intangible connections with the environment are the relationships we hold with particular plant and animal species, modes of interaction with the landscape, and special places. These relationships help define culture, and they are not always straightforward to assess or interpret. However subtle these cultural relationships to forest ecosystems may be, they are likely to be transformed by climate change. Below, we present some of these potential cultural connections that may be at risk due to climate change.

Forest species
Particular species can hold unique cultural importance, often based on established uses. Changes in forest composition and extent may alter the presence or availability of culturally important species throughout the Midwest Region. For example, Dickmann and Leefers

(2003) compiled a list of over 50 tree species from Michigan that were used by several Native American tribes in the region. Among these, white cedar and paper birch stand out as having particular importance for defining a culture and way of life. Unfortunately, due to climate change these two species are expected to experience large declines in suitable habitat over the next century (Iverson et al. 2008).

Non-Timber Forest Products
Non-timber forest products (NTFPs) are important cultural features and sources of income throughout the Midwest. Some of these include mushrooms, berries, maple syrup, wild ginseng, balsam fir boughs, and Christmas trees. In some cases, NTFPs support regionally important industries based on the harvest and sale of these goods. Collection of balsam fir boughs in northern Minnesota resulted in $23 million in sales for Christmas wreaths (Minnesota Department of Natural Resources 2010). Balsam bough collection on National Forest and State-owned lands drives a $50 million per year industry in Wisconsin (Wisconsin Department of Natural Resources 2010). From 1992 to 2010, the maple syrup industry produced an average of $2.4 million in Ohio, $2.6 million in Michigan, and $2.9 million in Wisconsin (USDA Economic Research Service 2012). Data were unavailable for Minnesota, which is also a large syrup-producing state. Collection of these NTFPs may be influenced by future changes in climate if focal species experience declines or life-cycle alterations.

Special Places
It may be one of the more difficult cultural connections to firmly document, but association with particular places on the landscape is an important aspect of humankind's relationship with forests. Saunders et al. (2011) provide a few useful examples of how climate change may physically alter the places that we hold dear. Erosion from rising lake levels and storm surges in the Great Lakes has already begun to wash away cultural sites within the Grand Portage National Monument and Apostle Islands National Lakeshore.

Adaptation

Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Parry, Canziani, and Palutikof 2007). Numerous actions can be taken to enhance the ability of ecosystems to adapt to climate change and its effects. People will have a key role in dictating these responses, which might focus on avoiding loss of forest cover, or maintaining forest productivity, or preserving ecosystem processes. Importantly, adaptation measures can also be targeted to address the environmental benefits that forests provide to people, such as water, recreation, and wood products. There is no single "silver bullet" approach to climate change adaptation, but rather a broad array of strategies and approaches that can be tailored to specific ecosystems and management goals. In many instances, targeted policy measures will be necessary to implement adaptation efforts. This section presents general adaptation measures that may be appropriate for the topic areas mentioned earlier, summarized for the entire Midwest Region.

Box 1 from Swanston and Janowiak (2012)

The concepts of resistance, resilience, and response serve as the fundamental options for managers to consider when responding to climate change (Millar, Stephenson, and Stephens 2007):

- ***Resistance*** actions improve the forest's defenses against anticipated changes or directly defend the forest against disturbance in order to maintain relatively unchanged conditions. Although this option may be effective in the short term, it is likely that resistance options will require greater resources and effort in resisting change over the long term as the climate shifts further from historical norms. Additionally, as the ecosystem persists into an unsuitable climate, the risk that the ecosystem will undergo irreversible change (such as through a severe disturbance) increases over time.

- ***Resilience*** actions accommodate some degree of change, but encourage a return to prior conditions after a disturbance, either naturally or through management. Resilience actions may also be best suited to short-term efforts, high-value resources, or areas that are well buffered from climate change impacts. Like the resistance option, this option may engender an increasing level of risk over time if an ecosystem becomes increasingly ill-suited to the altered climate.

- ***Response*** actions intentionally accommodate change and enable ecosystems to adaptively respond to changing and new conditions. A wide range of actions exists under this option, all working to influence the ways in which ecosystems adapt to future conditions, instead of being caught off-guard by rapid and catastrophic changes.

Forest Ecosystems

There is a growing library of tools and resources pertinent to climate change adaptation in forest ecosystems (Glick, Stein, and Edelson 2011; Heller and Zavaleta 2009; Millar, Stephenson, and Stephens 2007; Ogden and Innes 2008; Swanston and Janowiak 2012). Published studies evaluating adaptation methods are lacking, as is long-term monitoring on pilot projects. Nevertheless, this body of knowledge provides a framework for integrating knowledge of projected climate change impacts into natural resource planning and management. There has been an early focus on "no regrets" decision-making and adopting a triage mentality to prioritizing climate change adaptation (Millar, Stephenson, and Stephens 2007). Millar and others also frame the three fundamental options for adapting to climate change as "resistance, resilience, or response"(Box 1).

Particular land owners or forest management entities may prefer one mode of adaptation over another, or they may be required to favor a particular course of action. For example, National Wildlife Refuges and other management units with particular mandates to preserve habitat for endangered species might automatically favor "resistance" or "resilience" options for climate change adaptation. Many other landowners, including private landowners, will be able to consider a variety of options and design specific management tactics that are suited for their individual goals.

Forest Adaptation Resources: Climate change tools and approaches for land managers describes a framework for responding to climate change and is broadly applicable for forest managers across the Midwest Region (Swanston and Janowiak 2012). This system creates and gathers scientific information, establishes cross-ownership partnerships, and fosters collaboration between scientists and land managers. The document provides a wide-ranging "menu" of adaptation strategies and approaches and a workbook process to help land managers consider ecosystem vulnerabilities, select adaptation approaches that meet their needs, and devise tactics for implementation. Table 2 highlights the overarching adaptation strategies, which are subsequently tailored to more specific local approaches and tactics.

It is important to note the role that forest management can play in the context of climate change adaptation. LANDIS simulations have shown that harvesting can create opportunities to encourage diversity and maintain vulnerable tree species over time, but harvesting can also reduce seed sources and limit regrowth (Scheller and Mladenoff 2005). Studies in Minnesota reveal similar patterns (Ravenscroft et al. 2010). Many aspects of contemporary sustainable forest management are compatible with the need for climate change adaptation, and the adaptive management paradigm can be tailored to incorporate climate change considerations for forest management (Seppälä, Buck, and Katila 2009; Swanston and Janowiak 2012).

Urban Forests

A case study from Philadelphia, while outside the region, provides an example that illustrates how cities are evaluating the potential impacts of climate change on urban forests in order to develop appropriate adaptation strategies (Yang 2009). Urban forest managers found that the combination of climate-induced stress, pests, and diseases reduced the future suitability of 10 tree species commonly planted in the city. Conversely, they were also able to identify a few species that would be expected to thrive under future climate conditions. Similar assessments have also occurred to identify potential climate-adapted trees for parks and cities across Central Europe (Roloff, Korn, and Gillner 2009). Conducting these sorts of analyses will be helpful for urban forest managers and city planners to effectively plan for change. Chicago's Climate Change

Strategy	Resistance	Resilience	Response
1. Sustain fundamental ecological functions.	X	X	X
2. Reduce the impact of existing biological stressors.	X	X	X
3. Protect forests from severe fire and wind disturbance.	X	X	
4. Maintain or create refugia.	X		
5. Maintain and enhance species and structural diversity.	X	X	
6. Increase ecosystem redundancy across the landscape.		X	X
7. Promote landscape connectivity.		X	X
8. Enhance genetic diversity.		X	X
9. Facilitate community adjustments through species transitions.			X
10. Plan for and respond to disturbance.			X

Table 2: Climate change adaptation strategies for forest management (Butler et al. 2012).

Action Plan also includes a section on Adaptation, which covers strategies for maintaining and enhancing green spaces and urban forests in the city (Coffee et al. 2010). The Arbor Day Foundation's Tree City USA program, or similar national assistance programs, may offer an effective platform for engaging municipalities across the Midwest Region and sharing best practices for adaptation. As of July 2011, over 1,000 cities and towns across the 8-state region are already participating members in the Tree City USA program (www.arborday.org/programs/treeCityUSA/index.cfm).

Forest Products

The forest products industry has undergone a great deal of change over the past century – technology is continually improving, markets are global, and the policy environment has become more complex. The forest resource base upon which the industry has depended has also been dramatically altered - first as a result of early forest industry practices and subsequent disturbance, and more recently as forests have matured and the landscape has become more fragmented.

Climate change may result in new unpredictable changes for forest ecosystems in the Midwest Region, and the forest industry will benefit most strongly as an economic sector if it continues to respond proactively to landscape changes. The entire industry – from harvest operations to manufacturing – can be actively engaged in an adaptation mindset. This will involve continually incorporating new information on climate change impacts and making calculated responses to manage risk. Species declines or migrations will affect market supplies in different regions of the country, as will climate-induced disturbance events. The timing of harvest and transport operations may also be influenced by temperature and precipitation patterns, which could have cascading impacts throughout the supply chain. New opportunities may appear if climate change has favorable influences on growth rates or results in increased habitat suitability for southern merchantable species.

A critical consideration is that the forest industry will have a vital role in sustaining healthy forest ecosystems (Seppälä, Buck, and Katila 2009). A planned, measured approach to climate change adaptation might ultimately depend on having a vibrant forest industry, because it will require considerable management intervention to actively influence the course of ecosystem adaptation and avoid catastrophic, unplanned outcomes. A key point is that climate change adaptation will be best pursued as a proactive, rather than reactive, course of action (Seppälä, Buck, and Katila 2009). Forest managers will need to be prepared to encourage resilience or facilitate ecosystem transitions through management operations, and an agile industry can take advantage of these management opportunities to produce desired goods and services.

Collaborate to protect and restore watersheds
- Connect water users and watersheds
- Link to research and adaptive management
- Engage the community
  (including stakeholder groups – tribes, municipalities, etc.)
- Link water from healthy watersheds to water quality markets
- Employ new methods that facilitate collaboration
- Collaborate globally to support sustainable forests

Implement practices that protect and maintain watershed processes and services

Restore watershed processes
- Restore streams and valley bottoms
- Restore riparian areas and bottomlands
- Restore upslope water conditions
- Reconnect flood plains and habitats

Table 3: Highlighted recommendations on Collaboration and Action from the Water, Climate Change, and Forests report (Furniss et al. 2010).

Water Resources

Adaptation of forest ecosystems to global climate change will be essential for preserving the quality of water supplies throughout the Midwest. In a review of the relationship between climate change impacts, forests, and water resources, Furniss and colleagues outline several adaptation guidelines to enhance watershed resilience (Furniss et al. 2010). Table 3 summarizes some of these key ideas, and we encourage readers to refer to this publication for complete explanations.

Improving the state of knowledge and sharing information widely will help reduce the uncertainty surrounding future projections of water resources. Integrating an understanding of climate change and forest ecosystems into watershed and source water protection planning will also be essential for systematically addressing these challenges. The authors also advocate a "collaborative, participatory approach to adaptation based on connecting people, their lifestyles, and land-use decisions to their effects on critical watershed services," and outline several strategies for achieving this comprehensive goal. Land management actions across several domains – fire and fuels, wildlife habitat, timber harvest, infrastructure, and habitat restoration – can be implemented with an eye toward maintaining or enhancing watershed function.

Carbon Storage

The past few years have witnessed an increased focus on maintaining and expanding forest carbon stocks, both globally and within the US. While it is evident that forests in the Midwest must be managed to provide a full spectrum of ecosystem services, climate change adaptation decisions will also likely incorporate the desire to prevent forest carbon from being lost to the atmosphere. Indeed, this is one sector of activity where climate change adaptation and mitigation strategies can operate in concert.

Malmsheimer et al. (2011) offer several guiding principles for land managers and policy makers to consider when pursuing effective forest carbon management. They focus on maintaining forests as forests, which may take considerable management intervention and public support if wide-scale climate change results in localized or widespread ecosystem transitions. This is especially true for the Midwest Region, which contains a mobile prairie-forest border and competing land-use opportunities for agriculture. In addition, they advocate for market incentives to recognize the climate change mitigation benefits of carbon sequestration in long-lived wood products, product substitution for wood-based materials over carbon-intensive materials, and fuel substitution for biomass over fossil fuels.

Hennigar, MacLean, and Amos-Binks (2008) created an optimization model to evaluate strategies for maximizing forest carbon sequestration over several hundred years. Their approach highlights the different approaches to carbon management that can result, based on whether wood products are counted as a short to medium-term carbon sink. This is a policy decision that will certainly influence carbon management and forest adaptation efforts, and cost-benefit models such as those employed in this study will be valuable tools to explore tradeoffs.

Recreational Opportunities

It will be imperative for municipalities, recreation areas, and the associated recreation and tourism industries to acknowledge likely outcomes of climate change and begin preparing for the future. In the Midwest Region, winter sports that depend on snow cover or lake ice offer a clear illustration of the need to adapt our modes of recreation. It may be possible to shift the dates and locations of particular events to take advantage of more favorable conditions. In some cases, areas may become unsuitable for particular forms of recreation. This may cause economic and cultural hardship for cities and towns that have deep-rooted investments in particular forms of recreation, such as cross-country skiing, snowmobiling, or ice fishing. It is important that organizers and participants alike do not take unnecessary safety risks by continuing to operate solely according to tradition.

Conversely, climate change may also offer new opportunities for expanded recreation in forested areas. Spring and fall seasons may be extended for many forms of outdoor recreation, and planning for change sooner rather than later will ease the transition.

Cultural Values

Cultural connections to forest landscapes throughout the Midwest Region will likely be altered by climate change. It is important to document local uses and local knowledge of forests, as a means to record incremental changes that occur over time and to preserve these sources of knowledge. Extensive knowledge of the landscape will be essential for effectively planning localized adaptation tactics for forest ecosystems, and a cultural body of understanding can assist this process. In instances where culturally important plants or animals are at risk of local extinction, people may need to prepare for accessing these species in new places. In some cases, it may be possible to actively encourage and prepare climate refugia or design resistance options to maintain particular ecosystem components in an area.

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