Effects of Climate Change on Midwestern Ecosystems: Temperate Flooded and Swamp Forest

Suggested Citation

Ratcliffe, H., Charton, K., Siddons, T., Lyons, M. and LeDee, O. 2025. Effects of Climate Change on Midwestern Ecosystems: Temperate Flooded and Swamp Forest. Midwest Climate Adaptation Science Center. (112 pages) Available: https://mwcasc.umn.edu/SWAP-support

Acknowledgements

This work was supported by the U.S. Geological Survey (USGS) Midwest Climate Adaptation Science Center and included technical contributors from the Oak Ridge Institute for Science Education and the University of Minnesota, Twin Cities. We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups for producing and making available their model output. For CMIP, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and leads development of software infrastructure in partnership with the Global Organization for Earth System Science Portals. We thank the Midwest Association of Fish and Wildlife Agencies, Wildlife Diversity Technical Working Committee for their engagement.

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Foreword

Series Overview

The following is the first chapter of a multi-part series examining the vulnerability of natural habitats in the Midwest region to the impacts of climate change. This work was conceived as part of an inter-agency effort to facilitate the inclusion of climate change considerations into 2025 revisions of State Wildlife Action Plans (SWAPs). Although tailored to the needs of state agencies within the Midwest region, these assessments focus on habitats and species found throughout North America and are thus broadly relevant to regions and considerations beyond that of the Midwest.

This work was developed as a collaboration between the U.S. Geological Survey (USGS) Midwest Climate Adaptation Science Center (MW CASC) and natural resource agencies from Minnesota, Wisconsin, Michigan, Ohio, Indiana, Illinois, Iowa, and Missouri. During discussions on the needs and challenges of the 2025 SWAP revision process, collaborators identified habitat climate vulnerability as a key area requiring further exploration and deeper understanding.

Process

To assess the impact of climate change on habitats in the Midwest, the MW CASC developed a process comprised of the following steps: 1) potential habitat identification and delineation; 2) summarizing exposure to key climate change stressors; and 3) reviewing and synthesizing relevant scientific literature into qualitative summaries of climate change impacts to habitats.

Habitat Selection

We identified and defined habitats using the U.S. National Vegetation Classification database (USNVC, 2020), which provides a common lexicon of hierarchically classified and spatially referenced vegetation communities throughout the United States. Within this hierarchy, the Group level represents the finest resolution classification tier that is coupled with spatially referenced distributions. Hereafter, discrete “habitats” are synonymous with USNVC Groups and their corresponding lower-level community classifications (Alliance and Association). To enhance relevancy for the Midwest region, the lowest-level classifications for each group (Association) not occurring within the Midwest were excluded from this assessment.

Climate Exposure

To summarize climate exposure, we utilized a combination of Level II and Level III ecoregions (U.S. Environmental Protection Agency, 2013) to identify 12 ecologically relevant subregions of the Midwest that served as the spatial basis for summarizing climate exposure (Figure i). Climate projections are derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and were statistically downscaled using the MACAv2-METDATA dataset, which applies the Multivariate Adaptive Constructed Analogs (MACA) method (Abatzoglou, 2013; van Vuuren and others, 2011). Projections are presented under two greenhouse gas concentration pathways: RCP4.5, an emissions scenario assuming global mitigation efforts that lead to greenhouse gas emissions peaking mid-century and stabilizing by 2100, and RCP8.5, a high-emissions scenario that assumes continued growth in greenhouse gas emissions with

limited mitigation. These scenarios represent a range of plausible future climate conditions and are commonly used to bracket moderate and high-end climate change trajectories. In-text references to climate projections primarily detail RCP8.5 estimates to highlight particularly severe outcomes, although all tables and figures report both RCP4.5 and RCP8.5 estimates. To capture variation across CMIP5 climate models, models with the lowest (minimum model) and highest (maximum model) projected values under the RCP8.5 scenario are presented in addition to the mean of all models. Appendix 2 includes a list of all climate models as well as the minimum and maximum model selected for each region and climate variable.

Figure i. Distribution and names of 12 ecoregions within the larger Midwest region. Ecoregions represent a mixture of Level II and Level III EPA ecoregions (U.S. Environmental Protection Agency, 2013) and have been renamed following the Midwest Conservation Blueprint Ecoregions (Wright and others, 2022).

Habitat Prioritization

Seventy-seven natural Groups (habitats) occur in states comprising the Midwest region (Minnesota, Wisconsin, Michigan, Ohio, Indiana, Illinois, Iowa, and Missouri). To focus this assessment on a subset of these habitats, representatives from each state identified two or more habitats for each ecoregion

present in their respective state. We reconciled conflicting priorities to identify two habitats per ecoregion (hereafter identified as "priority habitats") for a total of 22 habitats that served as the focus of our analysis (Table i).

Table i. Priority habitats for each ecoregion. Analogous Level III EPA ecoregion numbers (U.S. Environmental Protection Agency, 2013) and U.S. National Vegetation Classification database Group numbers (USNVC, 2020) are provided for each ecoregion and priority habitat.

Ecoregion	Priority habitat
Appalachian Forest (8.4.3)	Appalachian-Central Interior Mesic Forest (G020)
	Central Appalachian-Northeast Oak Forest and Woodland (G650)
Central Irregular Plains (9.2.4)	Central Midwest Oak Openings and Barrens (G181)
	South Central-Appalachian-Northeast Floodplain Forest Group (G673)
Central Plains (8.2.1–8.2.4)	Midwest Floodplain Forest (G652)
	Central Interior-Great Lakes Flatwoods and Swamp Forest (G917)
Driftless Area (8.1.5)	North-Central Beech- Maple- Basswood Forest (G021)
	North-Central Oak- Hickory Forest and Woodland (G649)
Erie Drift Plains (8.1.1, 8.1.10)	North-Central Beech- Maple- Basswood Forest (G021)
	Appalachian-Northeast Mesic Forest (G742)
Interior Plateau (8.3.2, 8.3.3, 8.3.6, 8.5.2)	Bald-cypress- Tupelo Floodplain Forest (G033)
	Interior Low Plateau Oak Forest, Woodland and Savanna (G950)
Mixed Wood Plains (8.1.4)	Laurentian-Acadian Alkaline Swamp (G046)
	Eastern North American Freshwater Marsh (G125)
Northern Hardwood Forest (5.2.1, 5.2.2)	Laurentian Subboreal Mesic Balsam Fir- Spruce- Hardwood Forest (G048)
	Eastern North American Boreal-Subboreal Bog and Acidic Fen (G1172)
Northern Plains (9.2.1, 9.2.2)	Northern Tallgrass Prairie (G075)
	Midwest Wet Prairie, Wet Meadow, and Shrub Swamp (G770)
Ozarks (8.4.5)	Central Midwest Oak Openings and Barrens (G178)
	Oak- Shortleaf Pine Ozark-Ouachita Forest, Woodland and Savanna (G949)
Temperate Prairie (9.2.3)	North-Central Oak-Hickory Forest and Woodland (G059)
	Interior Low Plateau Oak Woodland Forest (G333)
Great Lakes Plains (8.1.6)	Midwest Prairie Alkaline Fen (G183)

Focal Wildlife Species

We include focal wildlife species to demonstrate how habitat impacts may influence wildlife responses to climate change. For each priority habitat (Table i), we review climate change impacts on one focal wildlife species, with specific attention paid to habitat considerations. We selected focal wildlife species based on consultation with state agencies, with the aim of choosing species listed by one or more state agency as a Species of Greatest Conservation Need (SGCN).

Focal Aquatic Systems

Because the USNVC is predominantly focused on terrestrial habitat types, we also include sections summarizing the impact of climate change on select focal aquatic systems. Unlike the focal wildlife species sections, which are associated with specific priority habitats (Table i), we selected one focal aquatic system for each ecoregion (Figure i). These selections were based on consultation with state agencies, with the aim of discussing a diverse set of aquatic system types. While focused on specific geographic areas, each section includes climate change impacts that are relevant to the broader aquatic system type.

Taxonomic Conventions

Wherever possible, we follow the Integrated Taxonomic Information System database (Integrated Taxonomic Information System (ITIS), 2025) for common names, Latin names, and taxonomic authorities. Because many species have multiple common names, we defer to the PLANTS Database (USDA, NRCS, 2025) to select a single, consistent common name for each plant species. In cases where taxonomic resolution is lacking, such as for certain pests or pathogens not included in ITIS, we use the most widely accepted names from the primary scientific literature. To enhance clarity and usability, especially for readers consulting individual sections as standalone references, we define Latin names at first mention for each common name in each chapter subsection.

Literature Review

For each unique habitat, we reviewed and synthesized available scientific literature. We used USNVC habitat descriptions and lists of dominant plant species provided for each Group and relevant sub-level to characterize each habitat and focus our literature search (Appendix 1). We searched for relevant literature related to these habitat characteristics and dominant species that either explicitly mentioned climate change or indirectly discussed climate-related topics. Lastly, to narrow our focus, we identified two particularly relevant climate-related stressors for each habitat to hone our literature search.

Chapter Organization

Each chapter in this series focuses on a subset of ecologically related priority habitats (Table ii). Because climate change impacts are frequently shared between similar habitat types, we first provide an overview of climate impacts to the broader system type before summarizing climate impacts for each specific habitat. The higher-level USNVC classification that links ecologically similar habitats (typically at the Macrogroup level and hereafter referred to as “ecosystem”) determines each broader system type into which chapters are organized.

Table ii. Series chapters and priority habitats. Habitats are organized by the series chapter in which they occur, with their corresponding U.S. National Vegetation Classification database Group numbers (USNVC, 2020).

Series chapter	Priority habitat
1. Temperate Flooded and Swamp Forest	Midwest Floodplain Forest (G652)
	South Central-Appalachian-Northeast Floodplain Forest Group (G673)
	Bald-cypress- Tupelo Floodplain Forest (G033)
	Central Interior-Great Lakes Flatwoods and Swamp Forest (G917)
	Laurentian-Acadian Alkaline Swamp (G046)
2. Appalachian-Interior-Northeast Mesic Forest	Appalachian-Central Interior Mesic Forest (G020)
	Appalachian-Northeast Mesic Forest (G742)
	North-Central Beech- Maple- Basswood Forest (G021)
3. North American Bog and Fen	Midwest Prairie Alkaline Fen (G183)
	Eastern North American Boreal-Subboreal Bog and Acidic Fen (G1172)
4. Eastern North American Temperate Freshwater Marsh, Wet Meadow and Shrubland	Eastern North American Freshwater Marsh (G125)
	Midwest Wet Prairie, Wet Meadow and Shrub Swamp (G770)
5. Central and Eastern North American Grassland and Shrubland	Central Tallgrass Prairie (G333)
	Northern Tallgrass Prairie (G075)
	Central Interior Acidic Open Glade and Barrens (G178)
	Eastern North American Ruderal Meadow and Shrubland (G059)
6. Central Interior Oak Forest, Woodland and Savanna	Interior Low Plateau Oak Forest, Woodland and Savanna (G950)
	Oak- Shortleaf Pine Ozark-Ouachita Forest, Woodland and Savanna (G949)
	Central Midwest Oak Openings and Barrens (G181)
	North-Central Oak- Hickory Forest and Woodland (G649)
	Central Appalachian-Northeast Oak Forest and Woodland (G650)
7. Laurentian-Acadian Mesic Hardwood- Conifer Forest	Laurentian Subboreal Mesic Balsam Fir- Spruce- Hardwood Forest (G048)

Executive Summary

The Temperate Flooded and Swamp Forest ecosystem is experiencing profound ecological shifts due to climate-driven hydrological changes, particularly increased flooding and intensified summer drying. These stressors are reshaping habitat structure and altering community composition and species interactions. More frequent and intense flooding events, driven by rising winter and spring precipitation and streamflow, accelerate erosion, alter sediment deposition, and promote cycles of habitat loss and creation. These conditions favor flood-tolerant and pioneering species while limiting the regeneration of others, particularly those requiring stable moisture regimes. Simultaneously, summer drying, exacerbated by increasing summer temperatures and vapor pressure deficits, is creating soil moisture deficits that compromise seedling establishment, increase tree mortality, and shift competitive dynamics toward drought-tolerant species. Together, these altered hydrologic regimes may reduce habitat diversity and promote more homogeneous, stress-tolerant forest communities.

The five focal habitat groups within this ecosystem in the Midwest face distinct yet overlapping challenges. The Midwest Floodplain Forest and South Central-Appalachian-Northeast Floodplain Forest are threatened by increased flooding and sediment deposition, which favor flood-tolerant species while limiting recruitment of dominant canopy species. The Bald-cypress - Tupelo Floodplain Forest, while adapted to inundation, remains vulnerable to prolonged dry periods that hinder tree regeneration and shift forest composition toward drought-adapted species. The Central Interior-Great Lakes Flatwoods and Swamp Forest and Laurentian-Acadian Alkaline Swamp, with their highly seasonal water regimes, are experiencing intensified flood-drought cycles, reducing periods of hydrologic stability and increasing tree mortality risks.

Beyond hydrological stresses, invasive species, pests and pathogens, and herbivory further compound these challenges. Canopy gaps created by climate-driven disturbances, such as flooding and drought, facilitate the spread of invasive plants in the Temperate Flooded and Swamp Forest. Pest and pathogen outbreaks are also expected to intensify as climate change accelerates life cycles, facilitating range expansions, and increasing host susceptibility. Deer and other herbivores, also benefiting from climate-driven population increases, impose additional stress by consuming browse-preferred species, limiting natural regeneration. Thus, climate will impact this ecosystem both directly and through interactions with invasive species, pests and pathogens, and herbivory. These interactions will accelerate successional processes and drive transitions toward novel community assemblages with uncertain long-term stability.

Given these multifaceted challenges, conservation and management strategies may depend on scientific understanding to inform the protection of hydrological processes, promotion of adaptive species compositions, and mitigation of biotic stressors to sustain the ecological integrity of these important forests. Further research is needed to fully understand how these complex processes will interact and ultimately shape the Temperate Flooded and Swamp Forest ecosystem under ongoing climate change.

Temperate Flooded and Swamp Forest

Key Climate Change Stressors

The Temperate Flooded and Swamp Forest ecosystem is defined by specific hydrological conditions and is especially sensitive to changes in water availability. Although these conditions naturally fluctuate, climate change is pushing hydrological patterns beyond their normal range, especially through increased flooding and intensified summer drying.

Flooding

Floods are becoming more frequent, and both the onset of floods and peak water flows are shifting earlier in the year across the Midwest (Archfield and others, 2016; Cardona, 2023; Dhakal and Palmer, 2020; Mallakpour and Villarini, 2015; Neri and others, 2020; Wang and others, 2024). Projected increases in winter and spring rainfall, combined with reduced snowpack and earlier snowmelt due to projected warmer temperatures, suggest that these trends will persist (Byun and others, 2019; Demaria and others, 2016; Ford and others, 2021; Marvel and others, 2023; Neri and others, 2020; Wieder and others, 2022). These changes are expected to produce larger streamflows in winter and spring and reduced flows during summer and fall (Figure 1). Additionally, more extreme precipitation events may trigger floods later in the year (Dhakal and Palmer, 2020; Zhou and others, 2022). Because the frequency, timing, and duration of floods drive essential ecosystem processes, these shifts can have major ecological consequences for the Temperate Flooded and Swamp Forest ecosystem (Garssen and others, 2015; Höök and others, 2018).

Summer Drying

Higher summer temperatures coupled with decreased summer precipitation are expected to increase evaporation and decrease soil moisture (Marvel and others, 2021; Ting and others, 2021; USDA Forest Service, USA and others, 2019; Will and others, 2013a). For the Temperate Flooded and Swamp Forest ecosystem, summer drying, especially at the soil surface, will likely impose significant stress on this predominantly hydrophilic ecosystem. For example, the Central Interior-Great Lakes Flatwoods and Swamp Forest habitat, typically found in precipitation-dependent watersheds with impermeable soils that promote ponding yet restrict water access during dry periods, is particularly vulnerable to moisture deficits (Brandt and others, 2014; Faber-Langendoen and others, 2020). Vapor pressure deficit (VPD) is projected to rise across the Midwest by the end of the century (Figure 2), intensifying drying conditions (Ficklin and Novick, 2017; Vanderhoof and others, 2024).

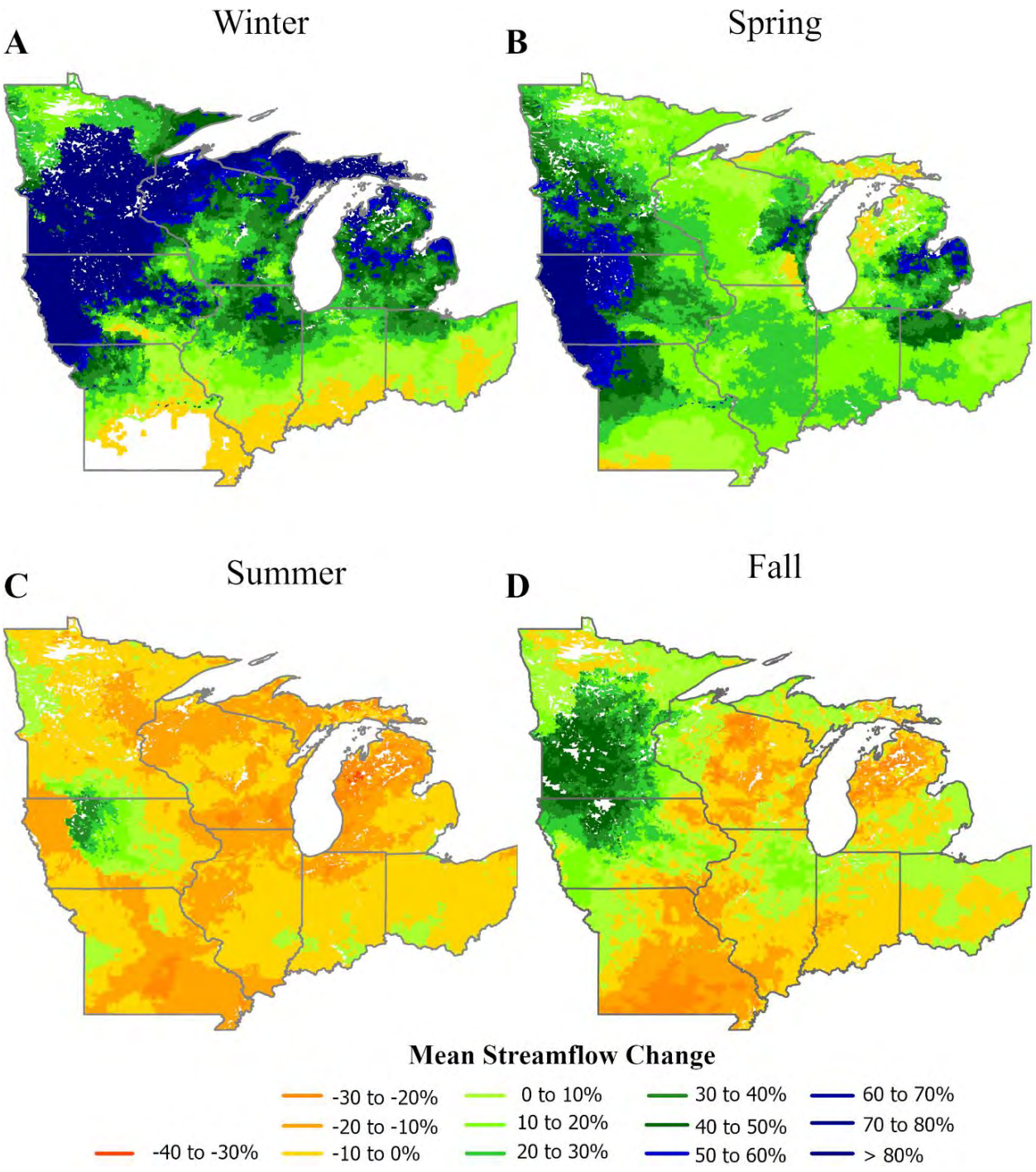

Figure 1. Projected changes in mean streamflow in the Midwest. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show the percent change in mean daily streamflow (cubic feet per second) for each season (winter, December–February; spring, March–May; summer, June–August; fall, September–November) at the end of the century (2070–2099) compared to historical data (1977–2006). Data and metric definitions are provided by the U.S. Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

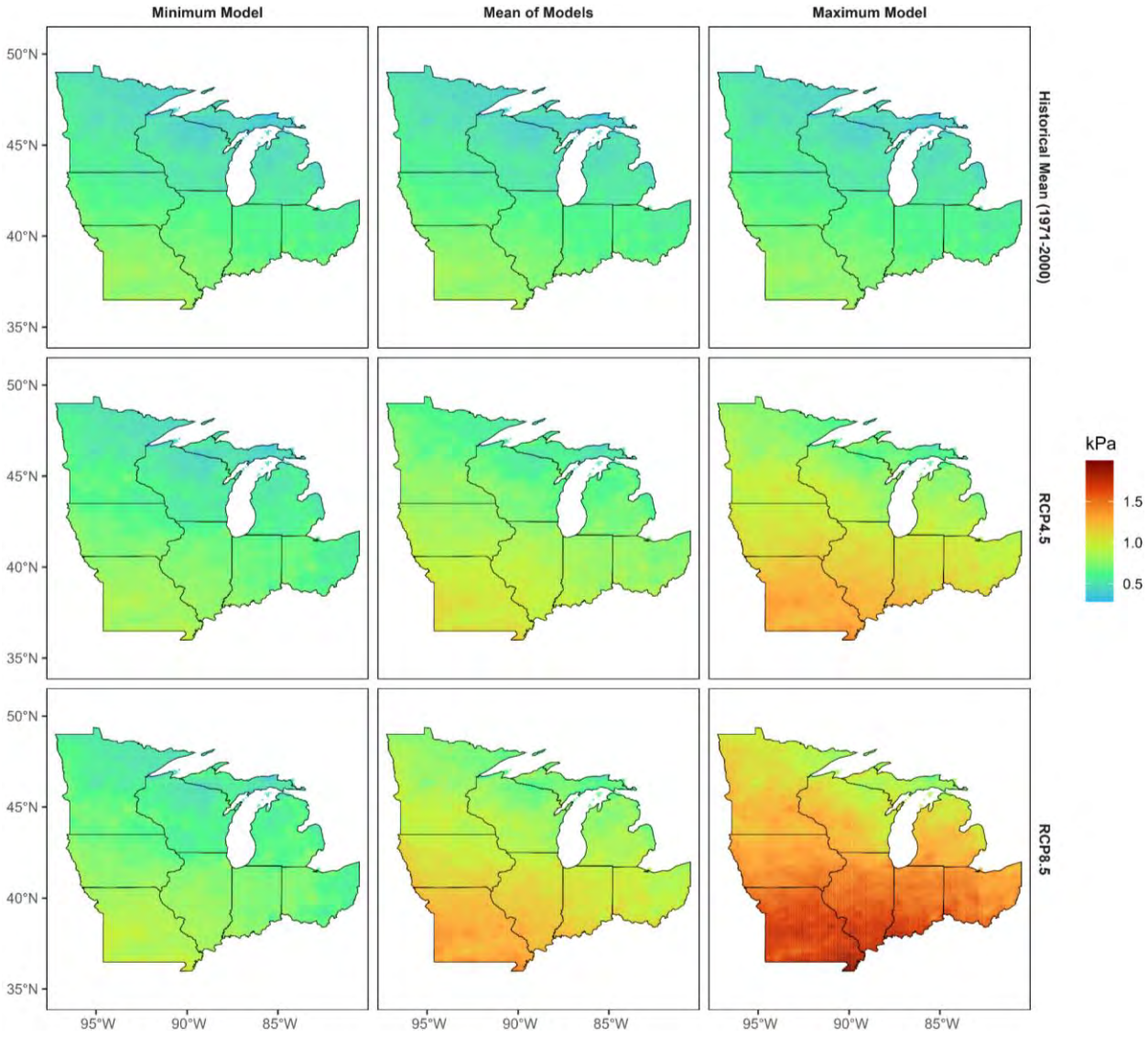

Figure 2. Projected changes in annual vapor pressure deficit in the Midwest. Projections use gridded climate data obtained via the Climate Toolbox Climate Mapper at a 4-km resolution (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971–2000, top row) and projected (2070–2099) annual vapor pressure deficit (VPD; kilopascals) for each emissions scenario (RCP 4.5, middle row; RCP 8.5, bottom row). To capture variation across climate models, models with the lowest (minimum model, left column) and highest (maximum model, right column) projected annual VPD under RCP 8.5 are presented in addition to the mean of all models (middle column).

Key Climate Change Impacts

Many species have evolved specialized strategies to thrive under the unique hydrological conditions of the Temperate Flooded and Swamp Forest ecosystem (Ulrich and others, 2002). Increased flooding and intensified summer drying are expected to impose substantial stress on this ecosystem, potentially altering habitat structure, community composition, and species interactions.

Habitat Structure

Abiotic responses to flooding. Flooding significantly alters the habitat structure of the Temperate Flooded and Swamp Forest ecosystem through erosion and deposition. High magnitude and frequent floods can increase erosion and cause habitat loss by processes such as scour, streambank and topsoil erosion, channelization, and loss of large woody debris (Novak and others, 2016). This impact is heightened in agricultural regions where erosion rates are already elevated (Juracek and Fitzpatrick, 2022). At the same time, these flooding events can also create new habitat (Fitzpatrick and others, 2016; Juracek and Fitzpatrick, 2022; Osterkamp and Hupp, 2010; Wohl and others, 2015). Increasing flooding and erosion may lead to more sediment deposition (Hudson, 2021; Nearing and others, 2004; Tong, 2007; Wang and others, 2018), filling in low-lying areas and resulting in shallower water depths during floods, seasonal drying, and even terrestrialization (Amoros and others, 2000; Faber-Langendoen and others, 2020; Junk, 2005). Additionally, floodwaters can be substantial inputs of nutrients as well as pollutants from nearby agricultural and urban areas, which influence biogeochemical functioning of the Temperate Flooded and Swamp Forest ecosystem (Cline, 2018; Staffen and others, 2019).

Biotic responses to flooding. The Temperate Flooded and Swamp Forest comprises species with varying degrees of flood tolerance (Niinemets and Valladares, 2006). While some, like bald cypress (*Taxodium distichum*) and black willow (*Salix nigra*), can withstand prolonged growing-season inundation, most species tolerate only moderate depth, short-duration floods (weeks to months) during the dormant season (Cosgriff and others, 2007; Ingvalson and others, 2020; Osterkamp and Hupp, 2010; Wilwhite and Toliver, 1990). Even species that are highly flood-tolerant as mature trees can be vulnerable as saplings (Schindler and others, 2020). For floodplain tree species, flooding disturbances represent a multi-dimensional and duration-dependent stress that both physically affects plants via water velocity and shear stress and induces biotic responses to cope with varying levels of water depth (Glenz and others, 2006; McKnight and others, 1981; Theriot, 1988). Inundation creates anoxic (i.e., low-oxygen) conditions that impair plant photosynthesis, respiration, and nutrient uptake, leading to physiological stress, reduced growth, and higher mortality (Gomes and Kozlowski, 1980; Harms, 1973; Keller and others, 2024a; Pezeshki, 2001). As such, flooding tolerance is difficult to categorize and is highly dependent on the context of a given flood. Typically, tree mortality increases with flood frequency, magnitude, and duration, especially among seedlings (Cosgriff and others, 2007; De Jager and others, 2019; Garssen and others, 2015). Although larger, older trees may better survive floods (Gill, 1970; Schindler and others, 2020; Siebel and Blom, 1998), severe and prolonged events like the Great Flood of 1993 have caused widespread mortality across species and age classes (Ulrich and others, 2002), and the lasting stress from such events can render surviving trees more susceptible to additional disturbances (Donovan and others, 1988; Férriz and others, 2024).

Biotic responses to summer drying. Increased summer drying, marked by higher vapor pressure deficits (VPD), also impairs plant photosynthesis, respiration, and nutrient uptake, again leading to physiological stress, reduced growth, and higher mortality (Choat and others, 2018; D'Orangeville and others, 2018;

Edwards, 2024; Novick and others, 2022; Perry and others, 2013; Rodgers and others, 2018; Wang and others, 2012). Approximately three out of four tree species globally have a narrow margin of safety against hydraulic failure during drought, highlighting widespread forest drought vulnerability (Choat and others, 2018; LeBlanc and others, 2020). Species commonly found in the Temperate Flooded and Swamp Forest ecosystem, such as maples (*Acer* spp.), ashes (*Fraxinus* spp.), and eastern hemlock (*Tsuga canadensis*) tend to be particularly susceptible to drought (Férriz and others, 2024; Niinemets and Valladares, 2006; Peters and others, 2015), with eastern hemlock seedlings being especially vulnerable (Godman and Lancaster, 1990).

Community Composition

Community responses to flooding. Novel flooding regimes are expected to shift community composition within the Temperate Flooded and Swamp Forest ecosystem. More frequent floods, higher inundation depths, and extended periods of inundation will favor species that are highly flood-tolerant and adapted to low-oxygen conditions, as well as those that are able to quickly establish in post-flood environments (Brandt and others, 2014; Charles and others, 2023). These changes may accelerate the current trend of declining mast-producing oaks (*Quercus* spp.) and hickories (*Carya* spp.), while promoting pioneering, flood-tolerant species like ashes (*Fraxinus* spp.), willows (*Salix* spp.), and maples (*Acer* spp.) (Brandt and others, 2014; Johnson and others, 2016; King and others, 2021; Osterkamp and Hupp, 2010; Ulrich and others, 2002). Repeated flooding can deplete or even eliminate existing seed banks and seedlings, leading to a decline in regeneration that compromises the community's ability to recover after disturbances (Cosgriff and others, 2007; De Jager and others, 2019; De Jager and others, 2024; Dixon, 2003; Herrera-Bevan and Ibáñez, 2024; Yin and others, 1993).

Community responses to summer drying. Intensified summer drying and drought conditions are expected to also alter community composition within the Temperate Flooded and Swamp Forest ecosystem by favoring species with greater drought tolerance (Batllori and others, 2020; Lee and Ibáñez, 2021; Middleton and Kleinebecker, 2012; Tracy and others, 2024). Reduced water availability can hinder the regeneration of dominant riparian species such as willows (*Salix* spp.) and cottonwoods (*Populus* spp.), while promoting drought-tolerant species, including invasive species (e.g., *Elaeagnus angustifolia*, *Tamarix* spp., *Ulmus pumila*) that are better adapted to persistent moisture deficits (Batllori and others, 2020; Edwards, 2024; Perry and others, 2013). In the Laurentian-Acadian Alkaline Swamp habitat, prolonged drying may facilitate the expansion of ericaceous shrubs and other drought-resilient species at the expense of moisture-sensitive species like tamarack (*Larix laricina*) and black spruce (*Picea mariana*), thereby altering successional patterns, seedling recruitment, and overall forest structure (Handler and others, 2020; Ireland and others, 2012; Kassahun and Renninger, 2021; Miller and Bassuk, 2022; Stelling and others, 2023). Additionally, drought stress can diminish seed banks, as has been seen in the Laurentian-Acadian Alkaline Swamp habitat, where repeated or prolonged droughts reduced the seed bank of numerous species, including bald cypress (*Taxodium distichum*) (Middleton, 2006; Middleton and Kleinebecker, 2012). This reduced regeneration can lead to more homogeneous stand-level characteristics, such as uniform age and size classes, ultimately resulting in canopies with less structural heterogeneity (Garssen and others, 2015; Havrdová and others, 2023). Over time, these changes may reduce the diversity and resilience of the Temperate Flooded and Swamp Forest ecosystem (Charles and others, 2023).

Invasive Species

Invasive species responses to flooding and summer drying. As rising temperatures cause species to move northward in search of cooler climates, the Midwest is poised to experience an influx of neo-native invasive species, organisms native to nearby regions that are likely to establish themselves locally and exhibit invasive behaviors (Allen and Bradley, 2016; Clements and DiTommaso, 2022; Evans and others, 2024). Climate-driven flooding and summer drying are likely to intensify the threat these species pose to the Temperate Flooded and Swamp Forest ecosystem. More frequent flooding may facilitate the spread of invasive species (Havrdová and others, 2023; Turbelin and Catford, 2021; Zedler and Herrick, 2023) and create openings that these species exploit to outcompete native species like willows (*Salix* spp.) and cottonwoods (*Populus* spp.) (Brandt and others, 2014; Coffman and others, 2010; Havrdová and others, 2023; Johnson and others, 2016; Juracek and Fitzpatrick, 2022). Moreover, invasive species are generally better equipped than native species to survive during frequent flooding conditions (Herrera-Bevan and Ibáñez, 2024). Changing flooding patterns may also alter the location of suitable habitat, leading to shifting distributions of invasive species, like reed canarygrass (*Phalaris arundinacea*), which is more prevalent in frequently flooded areas, but is also sensitive to extreme flooding duration and depth (Delaney and others, 2024). In contrast, summer drying and drought conditions are unlikely to immediately favor invasive species. However, if drought stress causes declines in dominant canopy species, invasive species may be able to capitalize on an increase in available space and resources (Beloiu and others, 2022; Vose and others, 2019).

Pests and Pathogens

General pest responses to climate change. A wide array of pests and pathogens currently affects key species in the Temperate Flooded and Swamp Forest ecosystem, weakening their resilience to climate change (Vose and others, 2013). Climate change is likely to intensify these threats, as pests are highly sensitive to temperature. Warmer conditions, especially during winter, accelerate pest metabolism, boost populations, and enable additional annual broods, thereby increasing their impact on plant communities (Dukes and others, 2009; Hamann and others, 2021; Lemoine and others, 2017; O'Connor and others, 2011; Pureswaran and others, 2018; Stanturf and others, 2024; Weed and others, 2013a). For example, heightened pest pressure may further reduce the landscape presence of species like American elm (*Ulmus americana*), which was previously severely impacted by Dutch elm disease (*Ophiostoma* spp.) (Bey, 1990; Potter and others, 2019; Weed and others, 2013b). Similarly, species such as black willow (*Salix nigra*) and basswood (*Tilia americana*) are vulnerable to invasive pests like the spongy moth (*Lymantria dispar*) and forest tent caterpillar (*Malacosoma disstria*), with outbreaks of these pests projected to worsen under changing climatic conditions (Haynes and others, 2014; Latifovic and Arain, 2024; Moser and others, 2020). Other pests, like emerald ash borer (*Agrilus planipennis*), which is currently devastating ash (*Fraxinus* spp.) populations throughout the Midwest region, are shifting the time of life cycle events in response to climate change, creating novel host-pest interaction dynamics (Barker and others, 2023).

Pest responses to flooding and summer drying. Flooding and summer drying can heighten vulnerability to pest infestations. After floods, some pests preferentially target trees weakened by inundation, thereby elevating the risk of tree mortality (Moraal and Hilszczanski, 2000; Ranger and others, 2019; Stanturf and others, 2024). Similarly, drought-stressed trees often exhibit reduced vigor and compromised defenses, making them more susceptible to pest attacks (Anderegg, 2015; Kolb and others, 2016; Stanturf and others, 2024; Vose and others, 2019). Drought can directly trigger or indirectly exacerbate outbreaks of pests such as the eastern larch beetle (*Dendroctonus simplex*), emerald ash borer (*Agrilus planipennis*),

forest tent caterpillar (*Malacosoma disstria*), and hickory bark beetle (*Scolytus quadrispinosus*), all of which thrive when host trees are water-stressed and less capable of mounting effective defenses (Butler and others, 2015; Chakraborty and others, 2014; Haynes and others, 2014; Moser and others, 2020; Ward and Aukema, 2019).

General pathogen responses to climate change. Pathogens such as beech bark disease (*Neonectria* spp.), Dutch elm disease (*Ophiostoma* spp.), and oak wilt (*Bretziella fagacearum*) have already caused widespread mortality and decline among North American beech (*Fagus grandifolia*), American elm (*Ulmus americana*), and oak species (*Quercus* spp.), reshaping the Temperate Flooded and Swamp Forest ecosystem. Milder winters are linked to the current and projected range expansion of these diseases, most notably the spread of beech bark disease into the Midwest, where they are expected to significantly alter habitat composition and structure (Kasson and Livingston, 2012; Kish, 2022; Stephanson and Ribarik Coe, 2017).

Pathogen responses to flooding and summer drying. Like with pests, flooding and summer drying can increase vulnerability to pathogens. Many pathogens, especially soilborne organisms, thrive in moist, humid conditions, and their spread is likely to intensify as more frequent flooding and prolonged soil saturation facilitate dispersal (Hailey and Percival, 2015; Sturrock and others, 2011). As a result, many species may become more susceptible to soilborne pathogens such as root rot (*Armillaria* spp.) and water molds (e.g., *Phytophthora* spp., *Pythium* spp.) (Contreras-Cornejo and others, 2023; Hubbart and others, 2016). Oaks (*Quercus* spp.), which are generally less flood-tolerant than many coexisting species, are particularly vulnerable to pathogens (Gustafson and others, 2022; Pijut, 2005; Tubbs and Houston, 1990). For example, evidence shows that recurrent dormant-season flooding can make pin oak (*Q. palustris*) susceptible to fungal decay organisms (McQuilkin, 1990). Drought conditions can also worsen pathogen impacts. Under water stress, pathogens like root rot and various canker diseases (e.g., *Biscogniauxia* spp., *Botryosphaeria* spp., *Diplodia* spp.) may become more detrimental (Butler and others, 2015; Dukes and others, 2009; Haavik and others, 2015; Kliejunas, 2011; Sturrock and others, 2011). Moreover, infections by these pathogens tend to reduce plant resilience, leaving species less capable of withstanding subsequent drought events (Jactel and others, 2012).

Herbivory

General herbivory responses to climate change. Climate change is expected to affect herbivore populations and their feeding patterns in complex ways. In the Midwest, white-tailed deer (*Odocoileus virginianus*) populations have surged in recent decades (Côté and others, 2004; MDNR, 2016; Patton and others, 2021) and are likely to continue rising as warmer winters boost survival rates and improve access to forage (Felton and others, 2024; Weiskopf and others, 2019). Whether increasing or remaining stable in the future, high deer populations will continue to impose significant stress on the Temperate Flooded and Swamp Forest ecosystem. Heavy browsing pressure can limit the regeneration of species deer prefer to browse, such as sugar maple (*Acer saccharum*) and eastern white cedar (*Thuja occidentalis*), preventing them from recruiting into the canopy, and subsequently driving shifts toward more uniform, less diverse vegetative communities (Champagne and others, 2021; Frerker and others, 2014; Henry and Walters, 2023; Novick and others, 2022; Patton and others, 2021; Sample and others, 2023; White, 2012). Deer browsing can also promote invasion by species like reed canarygrass (*Phalaris arundinacea*), thereby indirectly driving shifts in key soil properties (Cogger and others, 2014; De Jager and others, 2015). Consequently, deer browsing is increasingly recognized as a major barrier to effective climate adaptation (Champagne and others, 2021; Dobor and others, 2024).

Climate Change Impacts by Habitat

Midwest Floodplain Forest

The Midwest Floodplain Forest habitat is an uncommon, yet vital, habitat group found throughout the Midwest (Figure 3) and is characterized by dense stands of deciduous trees with moderately open canopies and a rich mix of herbaceous understory vegetation and shrubs (Faber-Langendoen and Menard, 2015). Primarily located along river floodplains and streambanks, these forests extend from streamside sandbars to areas bordering well-drained upland habitats. Flooding, specifically its seasonal timing, magnitude, duration, and frequency, plays a key role in shaping species composition, successional patterns, and the overall structure and function of the Midwest Floodplain Forest habitat (Baker and Wiley, 2009; Cosgriff and others, 2007; De Jager and others, 2013b; Dixon, 2003; Garssen and others, 2015; Johnson and others, 2016; Junk and others, 1989; Osterkamp and Hupp, 2010; Romano, 2006; Yin, 1998). Historically, altered flooding regimes driven by dam construction, flow regulation, and agricultural conversion resulted in more homogeneous plant communities that are less capable of sustaining essential ecological functions and ecosystem services (Faber-Langendoen and Menard, 2015; Hudson, 2021; Johnson and others, 2016; Morrison and others, 2023; Yin and others, 2009).

Intact communities are marked by vigorous tree growth, whereas degraded communities often exhibit persistent gaps in tree and shrub cover, increasing their vulnerability to pests, pathogens, and physical stresses (Wray, 1998). These forests primarily comprise 22 dominant species (Table 1), though other non-dominant species also contribute to overall habitat diversity and function. In addition to the species listed below, invasive species include common buckthorn (*Rhamnus cathartica*), European privet (*Ligustrum vulgare*), honeysuckles (*Lonicera* spp.), and reed canarygrass (*Phalaris arundinacea*).

Table 1. Plant species common to the Midwest Floodplain Forest habitat. Asterisks (*) denote species introduced to the region. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (USDA, NRCS, 2025).

Species	Common name	Growth habit
Acer saccharinum L.	Silver maple	Tree
Acer saccharum Marshall	Sugar maple	Shrub, tree
Asimina triloba (L.) Dunal	Pawpaw	Shrub, tree
Betula nigra L.	River birch	Tree
Carya cordiformis (Wangenh.) K. Koch	Bitternut hickory	Tree
Celtis occidentalis L.	Common hackberry	Shrub, tree
Fagus grandifolia Ehrh.	American beech	Tree
Fraxinus pennsylvanica Marshall	Green ash	Tree
Liriodendron tulipifera L.	Tuliptree	Tree
Platanus occidentalis L.	American sycamore	Tree
Populus deltoides W. Bartram ex Marshall	Eastern cottonwood	Tree
Quercus bicolor Willd.	Swamp white oak	Tree
Quercus macrocarpa Michx.	Bur oak	Shrub, tree

Species	Common name	Growth habit
Quercus shumardii Buckley	Shumard's oak	Shrub, tree
**Rosa multiflora* Thunb.	Multiflora rose	Shrub, vine
Salix nigra Marshall	Black willow	Tree
Tilia americana L.	American basswood	Tree
Ulmus americana L.	American elm	Tree
**Alliaria petiolata* (M. Bieb.) Cavara & Grande	Garlic mustard	Forb/herb
Elymus virginicus L.	Virginia wildrye	Graminoid
Laportea canadensis (L.) Weddell	Canadian woodnettle	Forb/herb
**Lysimachia nummularia* L.	Creeping jenny	Forb/herb

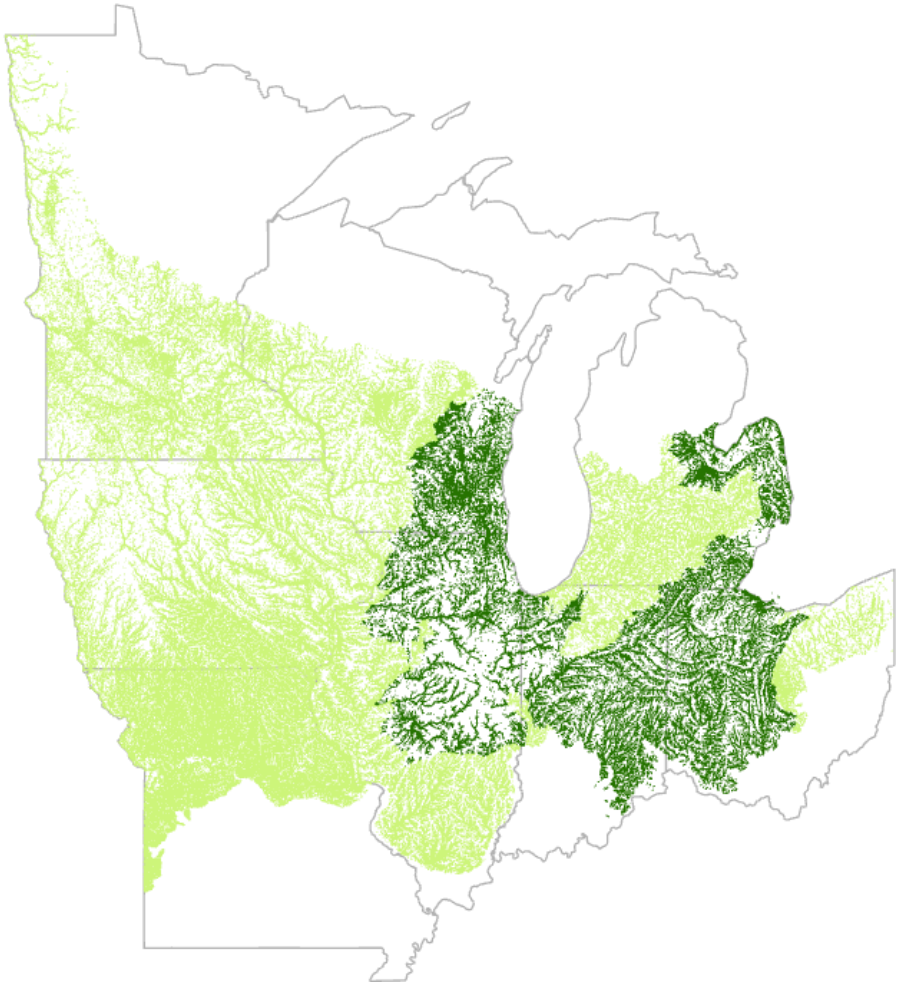

Figure 3. Midwest Floodplain Forest habitat distribution. Geographic distribution of the Midwest Floodplain Forest habitat (Group Code: G652) in the Midwest (USNVC, 2020). Dark green areas indicate Midwest Floodplain Forest habitat in the Central Plains ecoregion, while light green areas mark additional locations throughout the Midwest. Polygon boundaries have been enlarged to enhance visibility and do not reflect true proportions.

Overview of Climate Projections

The Midwest Floodplain Forest habitat is a priority within the Central Plains ecoregion. Climate projections for this ecoregion largely reflect regional trends. Both average and extreme temperatures are expected to rise throughout the coming century (Table 2) (Clarke and others, 2022; Marvel and others, 2023; Masson-Delmotte and others, 2021). Most climate models also project an increase in precipitation, although a few indicate a slight decrease (Table 3) (Marvel and others, 2023). Additionally, precipitation patterns are anticipated to shift towards more extreme events and greater seasonal variability, with notably wetter springs (Dollan and others, 2022; Marvel and others, 2023).

Table 2. Projected changes in annual temperature in the Central Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual mean temperature (°F) by mid- (2040-2069) and end of the century (2070-2099), as well as the absolute change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected temperature under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	50.1°F	52.5°F (2.5)	53.6°F (3.6)	53.2°F (3.2)	56.1°F (6.0)
Mean of models	50.2°F	54.9°F (4.7)	56.4°F (6.2)	55.9°F (5.7)	60.1°F (9.9)
Maximum model	50.0°F	56.2°F (6.2)	58.2°F (8.3)	58.4°F (8.5)	64.2°F (14.3)

Table 3. Projected changes in annual precipitation in the Central Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected precipitation under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	37.4 in	38.1 in (2%)	36.8 in (-2%)	40.2 in (7%)	36.0 in (-4%)
Mean of models	37.5 in	39.7 in (6%)	39.9 in (6%)	39.6 in (6%)	40.6 in (8%)
Maximum model	37.0 in	42.5 in (15%)	39.2 in (6%)	43.3 in (17%)	44.6 in (20%)

Key Climate Change Stressors

Flooding. Across the Central Plains ecoregion, annual streamflow is projected to rise by approximately 14% by the end of the century (Table 4). Increased seasonal variability and frequency of heavy precipitation events, however, will alter streamflow patterns, with mean flow rates rising by 20% in winter and 23% in spring, leading to approximately 5% more winter floods by the end of the century,

while summer and fall flows are expected to decrease (Figure 1; Table 4). These projections vary across the region. In northern areas bordering the Great Lakes, the frequency of winter flooding is expected to increase substantially, whereas in southern regions along the agricultural Corn Belt, it may remain steady or even decrease slightly (Figure 4). Snowfall amount and snowmelt timing are likely drivers of these spatial differences. These projections suggest that the Midwest Floodplain Forest habitat will experience more pronounced and seasonally distinct flooding dynamics, with higher peak flows during winter and spring and significant variability over both short- and long-term time scales.

Table 4. Projected changes in streamflow in the Central Plains ecoregion. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show average historical (1977-2006) and projected (2070-2099) streamflow metrics, as well as the percent change over this timeframe. Data and metric definitions are provided by the U.S Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Streamflow metric	1977–2006	2070–2099	Percent change
Mean Winter (December–February) Flow	31.07 ft^3/s	37.34 ft^3/s	20%
Mean Spring (March–May) Flow	48.03 ft^3/s	58.92 ft^3/s	23%
Mean Summer (June–August) Flow	20.3 ft^3/s	18.92 ft^3/s	-7%
Mean Fall (September–November) Flow	16.81 ft^3/s	16.81 ft^3/s	0%
Mean Annual Flow	29.08 ft^3/s	33.03 ft^3/s	14%
1.5-year Flood (33rd percentile)	187.32 ft^3/s	217.63 ft^3/s	16%
10-year Flood (90th percentile)	420.45 ft^3/s	485.27 ft^3/s	15%
25-year Flood (96th percentile)	541.3 ft^3/s	602.82 ft^3/s	11%
Number of Winter Floods	6.9	7.3	5%
Average Lowest 7-day Flow	6.31 ft^3/s	5.80 ft^3/s	-8%
Center of Flow Mass Timing	April 1	March 29	-2%

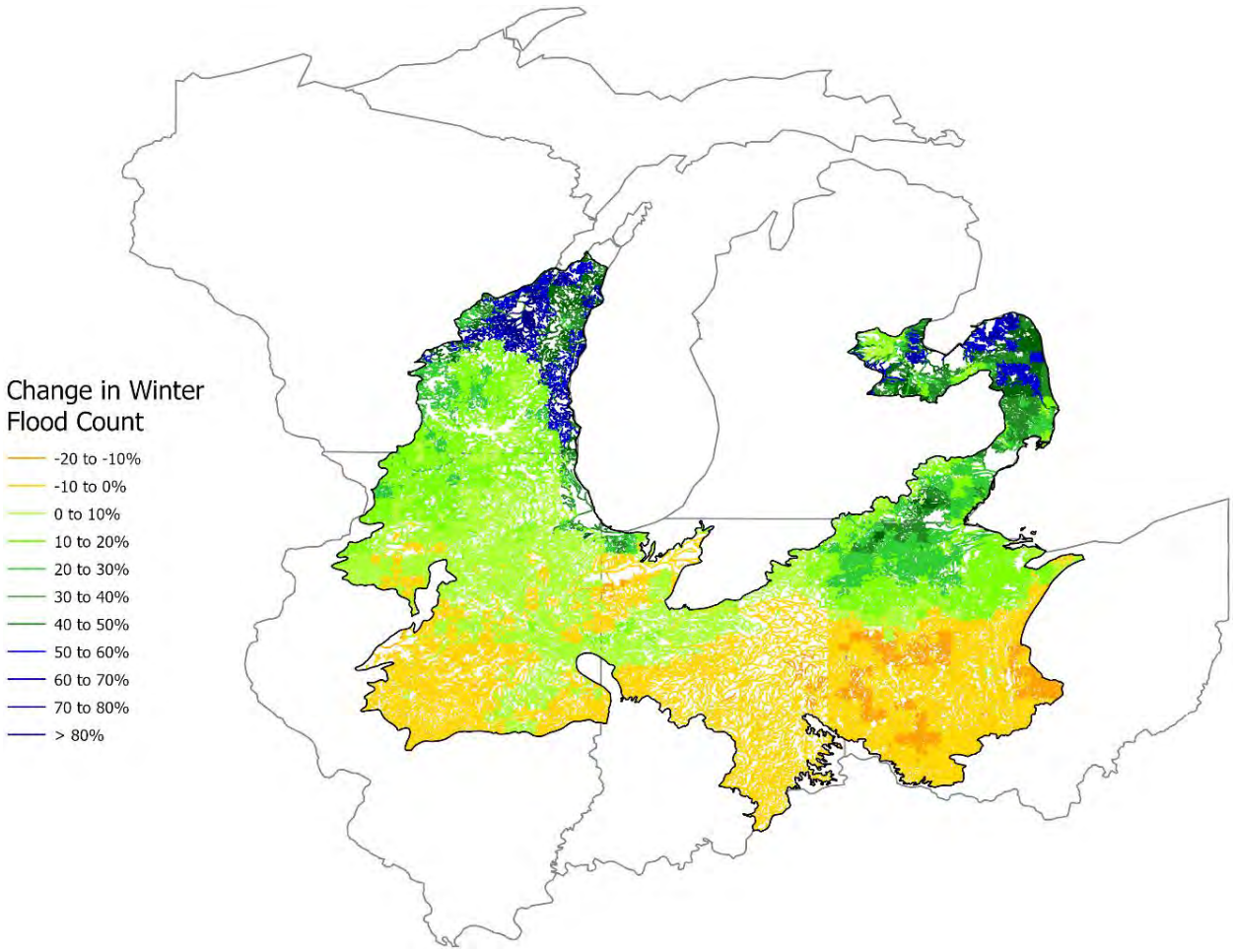

Figure 4. Projected changes in the number of winter floods in the Central Plains ecoregion. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show the percent change in number of winter floods at the end of the century (2070–2099) compared to historical data (1977–2006). Winter floods are calculated as the average number of daily flows between December 1 and March 31 that exceed the 95th percentile across the entire year. Data and metric definitions are provided by the U.S. Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Key Climate Change Impacts

This section summarizes how climate change is impacting the Midwest Floodplain Forest habitat. It covers both the overall influence on species distributions, adaptive capacity, and vulnerability (Table 5) and the specific effects of flooding and summer drying (Table 6). The bullet points below provide a concise overview of these impacts on habitat structure, community composition, invasive species, pests and pathogens, and herbivory.

Habitat structure:

- More frequent and higher magnitude floods may accelerate changes to the physical environment and create more dynamic habitats (Table 4)

- Erosion rates may rise in some areas while sediment deposition increases in others, with outcomes varying based on stream management practices (Juracek and Fitzpatrick, 2022).
- Shifts in vegetation composition, particularly along riverbanks, can alter the timing and duration of water flow in streams and affect bank erosion rates (Hupp and others, 2009; Sweeney and others, 2004).

Community composition:

- Flooding is most stressful during the growing season, yet flooding is projected to increase most in the winter and spring, potentially mitigating some of its negative impacts on the plant community if inundation periods do not persist into the growing season (Table 4) (Cosgriff and others, 2007; Ingvalson and others, 2020; Kroschel and King, 2021; Osterkamp and Hupp, 2010).
- While some key species may lose suitable habitat, many dominant species are predicted to gain suitable habitat (Table 5).
- Limited adaptive capacity and heightened vulnerability may hinder the persistence of some species (Table 5).
- Increased frequency and duration of flooding elevate the risk of mortality and regeneration failure, particularly for plants in lower floodplain areas and/or with low flooding tolerance, leading to a shift toward more flood-tolerant species (e.g., *Acer saccharinum*) and a reduction in many mast-producing species like oaks (Tables 5; 6) (Brandt and others, 2014; De Jager and others, 2013b; Ulrich and others, 2002).
- Canopy gaps created by flooding and mortality-induced turnover are likely to accelerate succession and increase the abundance of herbaceous understory species (Cosgriff and others, 2007; Garssen and others, 2015; Ulrich and others, 2002).

Invasive species:

- Flooding disturbances may promote invasive species spread by facilitating dispersal and creating empty ecological niches that these species can rapidly capitalize on (e.g., *Lysimachia nummularia*, *Microstegium vimineum*, *Phalaris arundinacea*) (Budelsky and Galatowitsch, 2004; Havrdová and others, 2023; Innes, 2011; Krahulec and others, 1980; Warren and others, 2011a; Warren and others, 2011b).
- The establishment of invasive species may further hinder native tree regeneration and promote shifts toward more open habitat (De Jager and others, 2024, p. 2; Donoso and others, 2024; Fryer, 2011; Thomsen and others, 2012).

Pests and pathogens:

- Climate change is expected to amplify pest and pathogen pressure by directly increasing pest and pathogen populations and indirectly heightening host susceptibility (Dukes and others, 2009; Stanturf and others, 2024; Sturrock and others, 2011; Teshome and others, 2020; Vose and others, 2013).
- Introduced pests and pathogens may become more prevalent as climate change facilitates their spread throughout the Midwest (e.g., emerald ash borer (*Agrilus planipennis*), beech scale (*Cryptococcus fagisuga*), and spongy moth (*Lymantria dispar*)) (Cooke and Roland, 2018; Fraver

and others, 2022; Kasson and Livingston, 2012; Liang and Fei, 2014; Tobin and others, 2014; Ward and Aukema, 2019).

- Increased heatwaves, phenological mismatches, and other climate change impacts may, however, reduce the impact of some pests and pathogens (e.g., spongy moth (*Lymantria dispar*), forest tent caterpillar (*Malacosoma disstria*)) (Banahene and others, 2018; Schwartzberg and others, 2014).
- Oak species (*Quercus* spp.) may be especially vulnerable to certain pathogens (e.g., *Biscogniauxia* spp., *Pythium spp*., *Phytophthora* spp.) as flooding promotes pathogen spread while drought weakens trees and heightens susceptibility (Balci and others, 2010; Bergot and others, 2004; Contreras-Cornejo and others, 2023; Hubbart and others, 2016; Sturrock and others, 2011; Thompson and others, 2014; Wood and others, 2018).

Herbivory:

- Warmer winters are expected to increase deer survival rates and population growth across the Midwest (Felton and others, 2024; Weiskopf and others, 2019).
- Selective deer browsing can reduce tree flood tolerance, and combined with climate-driven stressors, may disrupt tree regeneration, limiting the persistence of browse-preferred species, especially those also intolerant to flooding (e.g., *Acer saccharum*, *Carya cordiformis*, *Quercus shumardii*) (Castleberry and others, 1999; Champagne and others, 2021; Cogger and others, 2014; De Jager and others, 2013b; Frerker and others, 2014; Patton and others, 2021; White, 2012).
- The combined effects of browsing and flooding may favor species that tolerate both pressures (e.g., *Betula nigra, Fraxinus pennsylvanica*, *Salix nigra*) (Table 6), potentially altering species dominance and reinforcing long-term shifts in floodplain forest composition (Castleberry and others, 1999; Cogger and others, 2014; NRCS, 2020; Richardson, 2009; Sample and others, 2023; Wakeland and Swihart, 2009; Webster and others, 2008).

Table 5. Summary of the expected general influence of climate change on Midwest Floodplain Forest habitat species. Asterisks (*) denote species introduced to the region. Some species appear in contradictory columns (e.g., showing both negative and positive influences on distribution), reflecting conflicting findings in the literature.

Expected influence of climate change on species distributions		Hypothesized adaptive capacity and vulnerability to climate change	
Reduced extent or amount (–)	Increased extent or amount (+)	Low adaptive capacity or high vulnerability (–)	High adaptive capacity or low vulnerability (+)
Acer saccharinum[1,2]	*Acer saccharinum*[4,5,11–14]	*Acer saccharinum*[18]	*Acer saccharinum*[19]
Acer saccharum[3,4]	**Alliaria petiolata*[10]	*Acer saccharum*[19]	*Acer saccharum*[4]
Asimina triloba[5]	*Asimina triloba*[15]	*Asimina triloba*[4,18]	*Betula nigra*[18]
Carya cordiformis[6]	*Betula nigra*[4,5]	*Carya cordiformis*[18]	*Celtis occidentalis*[18]
Fagus grandifolia[7]	*Carya cordiformis*[4,5]	*Fagus grandifolia*[4]	*Fagus grandifolia*[19]
Fraxinus pennsylvanica[5]	*Celtis occidentalis*[4,5]	*Platanus occidentalis*[18]	*Fraxinus pennsylvanica*[4,18]
**Lysimachia nummularia*[8]	*Fagus grandifolia*[4]	*Quercus bicolor*[18]	*Populus deltoides*[18]
**Phalaris arundinacea*[9]	*Fraxinus pennslyvanica*[4]	*Quercus shumardii*[18]	*Quercus macrocarpa*[18,20]
**Rhamnus cathartica*[8,10]	**Ligustrum* spp.[8,10]	*Salix nigra*[4]	*Salix nigra*[18]

Expected influence of climate change on species distributions		Hypothesized adaptive capacity and vulnerability to climate change	
Reduced extent or amount (–)	Increased extent or amount (+)	Low adaptive capacity or high vulnerability (–)	High adaptive capacity or low vulnerability (+)
**Rosa multiflora*[8]	**Lonicera maackii*[8]	*Tilia americana*[18,19]	*Ulmus americana*[18]
Tilia americana[7]	*Platanus occidentalis*[4,16]		
Ulmus americana[4]	*Populus deltoides*[4,16]		
	Quercus bicolor[4]		
	Quercus macrocarpa[4,5,14]		
	Quercus shumardii[4,5,17]		
	Salix nigra[4]		
	Ulmus americana[4,5,14]		

[1]Brandt and others (2014); [2]Wang and others (2019); [3]Bapikee (2013); [4]Peters and others (2020); [5]Hanberry (2024); [6]Mambo and others (2024); [7]Philips and others (2020); [8]Evans and others (2024); [9]Kurtz (2010); [10]Bradley and others (2010); [11]Kozlowski (1997); [12]Keller and others (2023); [13]Handler and others (2014); [14]Prasad and others (2020); [15]Wyatt and others (2021); [16]Ozment and others (2024); [17]Rauschendorfer and others (2022); [18]Potter and others (2017); [19]Royer-Tardif and others (2021); [20]Etterson and others (2020)

Table 6. Summary of impacts from key climate change stressors on Midwest Floodplain Forest habitat species. Asterisks (*) denote species introduced to the region.

Stressor	Impact	Effected species
Flooding	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Carya cordiformis*[1]
		Celtis occidentalis[2]
		Fraxinus pennslyvanica[2]
		Quercus macrocarpa[3]
	When flood tolerance is high, increased abundance despite added stress	*Acer saccharinum*[1,2,4–11]
		Betula nigra[1,5–8,11]
		Celtis occidentalis[2,9,12,13]
		Elymus virginicus[14]
		Fraxinus pennslyvanica[4,6–9,15–18]
		**Lysimachia nummularia*[19]
		Populus deltoides[7,8,15,20]
		Quercus bicolor[1,6,7,11,21,22]
		Salix nigra[4,7,8,23–25]
	When flood tolerance is low, reduced growth rates and abundance and elevated mortality risk	*Acer saccharum*[1,8,11,26,27]
		Asimina triloba[8]
		Carya cordiformis[1,4,11,12]
		Fagus grandifolia[8,28,29]

Stressor	Impact	Effected species
		Laportea canadensis[30]
		Platanus occidentalis[8,11,15]
		Populus deltoides[4,5,7,31,32]
		Quercus macrocarpa[1,3,7,8]
		Quercus shumardii[8]
		**Rosa multiflora*[33]
		Tilia americana[4,8]
Summer drying	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer saccharum*[34]
		Celtis occidentalis[35]
		Populus deltoides[36]
		Quercus shumardii[37]
		Salix nigra[36,38]
	When drought tolerance is low, heightened susceptibility to disturbances, competitive exclusion, and mortality	*Acer saccharum*[8,39–43]
		**Alliaria petiolata*[44]
		Asimina triloba[8]
		Betula nigra[8,40]
		Fagus grandifolia[8,40,45–47]
		Populus deltoides[8,48]
		Salix nigra[8,40]
		Ulmus americana[40,49]

[1]Keller and others (2024a); [2]Cosgriff and others (2007); [3]Tang and Kozlowski (1982); [4]Whitlow and Harris (1979); [5]Dixon (2003); [6]Gergel and others (2002); [7]Ingvalson and others (2020); [8]Niinemets and Vallardares (2006); [9]Romano (2006); [10]Yin and others (2009); [11]Keller and others (2023); [12]De Jager (2019); [13]Krajicek and Williams (1990); [14]Sanderson and others (2010); [15]Krinard and Johnson (1981); [16]Kroschel and King (2021); [17]Schindler and others (2020); [18]Kennedy (1990); [19]Innes (2011); [20]Haverbeke (1990); [21]Palik and others (2021a); [22]De Jager (2012); [23]Donovan and others (1988); [24]McAlhaney (2018); [25]Pitcher and McKnight (1990); [26]Godman and others (1990); [27]Herrera-Bevan and Ibanez (2024); [28]Geßler and others (2007); [29]Tubbs and Houston (1990); [31]Ghanbary and others (2012); [32]De Jager and others (2013b); [33]Kurtz (2010); [34]Reich and others (2022); [35]Lei and Middleton (2018); [36]Perry and others (2013); [37]Will and others (2013a); [38]Amlin and Rood (2002); [39]Maxwell and others (2024); [40]Peters and others (2015); [41]Randall and Walters (2019); [42]Stangler and others (2016); [43]Au and others (2020); [44]Anderson and others (2021); [45]Stephanson and Ribarik Coe (2017); [46]Burns (1983); [48]Sun and others (2021); [49]Bey (1990)

Focal Wildlife Species: Red-shouldered Hawk

The red-shouldered hawk (*Buteo lineatus*) is a medium-sized raptor found throughout the eastern and central U.S. In the Midwest, these hawks typically occupy mature forests with favorable proximity to wetlands to forage for amphibians and reptiles (Balcerzak and Wood, 2003; Henneman and Andersen, 2009; Woodford and others, 2008).

While cooler temperatures combined with heavy precipitation may reduce nestling survival during the breeding season, warmer temperatures can increase prey activity, foraging efficiency, and reproductive rates, suggesting a positive effect of warming on the species (Bednarz and Dinsmore, 1982; Craighead

and others, 1969; Dykstra and others, 2021; Henneman, 2006; Jacobs and Jacobs, 2002). However, climate change-driven loss of wetlands and reductions in forests, especially coniferous forests, may adversely affect their reproductive success and survival (Dykstra and others, 2021). Despite these challenges, red-shouldered hawks demonstrate adaptive capacity through their flexible diet and habitat use, including successfully occupying suburban habitats (Dykstra and others, 2019).

Climate change may reduce suitable habitat for red-shouldered hawks in the Midwest Floodplain Forest habitat by decreasing contiguous forest cover and increasing the frequency and size of canopy gaps. These gaps are associated with increased rates of nest predation and increased competition from red-tailed hawks (*Buteo jamaicensis*) (Bednarz and Dinsmore, 1982; Craighead and others, 1969; Henneman, 2006; Jacobs and Jacobs, 2002). More frequent flooding may have mixed effects on prey populations, potentially reducing some small mammal populations while creating canopy gaps that benefit other species (Chamberlain and Leopold, 2003; Scharine and others, 2009). Moreover, key nesting trees such as American beech (*Fagus grandifolia*), oaks (*Quercus* spp.), and sugar maple (*Acer saccharum*) may be negatively impacted by increased flooding and higher pest pressure from forest tent caterpillars (*Malacosoma disstria*) and spongy moths (*Lymantria dispar*) (Cuthrell and others, 2003; Jacobs and Jacobs, 2002).

Management implications. The goals and methods of forest management in response to climate change may offer the greatest opportunity for climate adaptation for this species. Although red-shouldered hawks tolerate small patches of open habitat, intensive and even standard harvest practices that reduce forest density can produce unsuitable habitat for this species (Henneman and Andersen, 2009; Naylor and others, 2004). Active management that maintains relatively dense forests may include pest control, the establishment of fuel breaks to reduce fire risk, and the introduction of tree species suited to future conditions (Swanston and others, 2016). In addition, manage actions that increase tree species richness and diversity, increase the quantity of down woody debris, and protect forested wetlands can all foster the retention of red-shouldered hawks on the landscape (King and others, 2011).

Focal Aquatic System: Sugar River

The Sugar River originates from groundwater-fed springs near Mount Horeb, Wisconsin, and flows southeast for 91 miles before joining the Pecatonica River at the Wisconsin-Illinois border (Amrhein and Sorge, 2015). Along its course, the river undergoes distinct transitions, from a cool-warm mainstem near Belleville, to a warm mainstem starting around Albany, and finally to a large river downstream of Brodhead. The upper 20 miles support a cool-water fish community, while the entire river is designated as warmwater sport fish habitat (Amrhein and Sorge, 2015). Climate change is expected to significantly alter the Sugar River's flow patterns, increase water temperatures, and cause more frequent flooding and prolonged droughts (Table 7).

The river’s hydrological regime is likely to change significantly due to both direct and indirect impacts from climate change. The predominately agricultural land surrounding the Sugar River means that increased flooding and extreme peak flows can dramatically increase nutrient runoff (Kelly and others, 2017). This may reduce aquatic plant diversity and lower dissolved oxygen levels, factors critical for aquatic species that depend on clear, well-oxygenated waters (Höök and others, 2020). In addition, urbanization and dam construction have already fragmented habitats and obstructed natural water flows, restricting movement and connectivity (Wisconsin Department of Natural Resources, 2013). Prolonged droughts could exacerbate these issues by lowering water levels and impeding the free movement of aquatic organisms (Bouska and others, 2019).

Table 7. Projected changes in streamflow for the Sugar River. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show average historical (1977-2006) and projected (2070-2099) streamflow metrics, as well as the percent change over this timeframe. Data and metric definitions are provided by the U.S Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Streamflow metric	1977–2006	2070–2099	Percent change
Mean Winter (December–February) Flow	31.07 ft^3/s	37.34 ft^3/s	20%
Mean Spring (March–May) Flow	48.03 ft^3/s	58.92 ft^3/s	23%
Mean Summer (June–August) Flow	20.3 ft^3/s	18.92 ft^3/s	-7%
Mean Fall (September–November) Flow	16.81 ft^3/s	16.81 ft^3/s	0%
Mean Annual Flow	29.08 ft^3/s	33.03 ft^3/s	14%
1.5-year Flood (33rd percentile)	187.32 ft^3/s	217.63 ft^3/s	16%
10-year Flood (90th percentile)	420.45 ft^3/s	485.27 ft^3/s	15%
25-year Flood (96th percentile)	541.3 ft^3/s	602.82 ft^3/s	11%
Number of Winter Floods	6.93	7.3	5%
Average Lowest 7-day Flow	6.31 ft^3/s	5.8 ft^3/s	-8%
Center of Flow Mass Timing	April 1	March 29	-2%

South Central-Appalachian-Northeast Floodplain Forest

Functionally and compositionally similar to the Midwest Floodplain Forest habitat, the South Central-Appalachian-Northeast Floodplain Forest habitat is a vital yet sporadically distributed habitat group (Figure 5) characterized by diverse, dense stands of deciduous trees, along with a complex understory of shrubs and herbaceous plants (Pyne, 2015b). These forests primarily occur on level-to-gently-sloping terraces and levees along river and stream floodplains, ranging from streambanks and point bars to oxbow margins and low ridges shaped by flooding regimes (Pyne, 2015b). Species composition in these forests is highly variable, driven by a mosaic of moisture conditions, local topography, and flooding regimes that act as the primary disturbance agent (Bornette and others, 2008; Cosgriff and others, 2007; Junk and others, 1989; Ward and others, 2001). Historically, modifications to natural flooding patterns resulting from river alterations and land-use changes altered community composition (Dixon, 2003; Johnson and others, 2016; Morrison and others, 2024). Given that these forests provide critical ecosystem services and diverse wildlife habitat, any future reduction in their extent or integrity could have far-reaching ecological impacts (Mitsch and Gosselink, 2015).

Intact communities are marked by vigorous tree growth, rich shrub layers, and protective litter that support natural successional processes and forest regeneration. In contrast, degraded communities may exhibit persistent gaps in canopy and shrub cover, poor regeneration, and more uniform composition, age, and size structure (Morrison and others, 2024; Pederson and others, 2014; Pederson and others, 2015; Ulrich and others, 2002; Wray, 1998). Degraded communities are also vulnerable to transformation into alternative community types, either through increased dominance of invasive species like garlic mustard (*Alliaria petiolata*), honeysuckle (*Lonicera* spp.), and Nepalese browntop (*Microstegium vimineum*) or due to regeneration failure and compositional change (De Jager and others, 2019). These forests are primarily comprised of twenty-one key dominant species (Table 8), though other non-dominant species also contribute importantly to overall diversity and function. In addition to the species listed below, invasive species include creeping jenny (*Lysimachia nummularia*), European privet (*Ligustrum vulgare*), honeysuckles (*Lonicera* spp.), multiflora rose (*Rosa multiflora*), Nepalese browntop (*Microstegium vimineum)*, and reed canarygrass (*Phalaris arundinacea*).

Table 8. Plant species common to the South Central-Appalachian-Northeast Floodplain Forest habitat. Daggers (†) denote some species within the genus may be introduced to the region, though most are native. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (USDA, NRCS, 2025).

Species	Common name	Growth habit
Acer saccharinum L.	Silver maple	Tree
Betula nigra L.	River birch	Tree
Carya illinoinensis (Wangenh.) K. Koch	Pecan	Tree
Celtis laevigata Willd.	Sugarberry	Shrub, tree
Celtis occidentalis L.	Common hackberry	Shrub, tree
Forestiera acuminata (Michx.) Poir.	Eastern swampprivet	Shrub, tree
Fraxinus pennsylvanica Marshall	Green ash	Tree
Ilex decidua Walter	Possumhaw	Shrub, tree
Platanus occidentalis L.	American sycamore	Tree

Species	Common name	Growth habit
Quercus macrocarpa Michx.	Bur oak	Shrub, tree
Salix nigra Marshall	Black willow	Tree
Ulmus americana L.	American elm	Tree
Boehmeria cylindrica (L.) Sw.	Smallspike false nettle	Forb/herb
Carex L.†	Sedge	Forb/herb, graminoid
Galium L.†	Bedstraw	Forb/herb, shrub, vine
Impatiens capensis Meerb.	Jewelweed	Forb/herb
Impatiens pallida Nutt.	Pale touch-me-not	Forb/herb
Laportea canadensis (L.) Weddell	Canadian woodnettle	Forb/herb
Leersia Sw.	Cutgrass	Graminoid
Pilea pumila (L.) A. Gray	Canadian clearweed	Forb/herb
Viola L.†	Violet	Forb/herb, shrub

Figure 5. South Central-Appalachian-Northeast Floodplain Forest habitat distribution. Geographic distribution of the South Central-Appalachian-Northeast Floodplain Forest (Group Code: G673) in the Midwest (USNVC, 2020). Dark orange areas indicate South Central-Appalachian-Northeast Floodplain Forest habitat in the Central Irregular Plains ecoregion, while light orange areas mark additional locations throughout the Midwest. Polygon boundaries have been enlarged to enhance visibility and do not reflect true proportions.

Overview of Climate Projections

The South Central-Appalachian-Northeast Floodplain Forest habitat is a priority within the Central Irregular Plains ecoregion. Both average and extreme temperatures are expected to rise throughout the coming century (Table 9) (Clarke and others, 2022; Marvel and others, 2023; Masson-Delmotte and others, 2021). Most climate models also project an increase in precipitation, although some indicate a slight decrease (Table 10) (NCA 5 Chapter 2). Additionally, precipitation patterns are anticipated to shift

towards more extreme events and greater seasonal variability, with notably wetter springs (Dollan and others, 2022; Marvel and others, 2023).

Table 9. Projected changes in annual temperature in the Central Irregular Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual mean temperature (°F) by mid- (2040-2069) and end of the century (2070-2099), as well as the absolute change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected temperature under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	53.1°F	55.2°F (2.1)	56.2°F (3.1)	56.0°F (2.9)	58.6°F (9.8)
Mean of models	53.2°F	57.8°F (4.6)	59.3°F (6.1)	58.7°F (5.5)	63.0°F (9.8)
Maximum model	53.0°F	59.2°F (6.2)	61.1°F (8.1)	61.1°F (8.2)	66.7°F (13.7)

Table 10. Projected changes in annual precipitation in the Central Irregular Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected precipitation under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	39.4 in	38.7 in (-2%)	35.5 in (-10%)	42.4 in (8%)	34.4 in (-13%)
Mean of models	39.2 in	40.9 in (4%)	40.9 in (4%)	40.7 in (4%)	41.3 in (5%)
Maximum model	39.1 in	41.5 in (6%)	43.9 in (12%)	45.9 in (17%)	46.7 in (19%)

Key Climate Change Stressors

Flooding. Across the Central Irregular Plains ecoregion, annual streamflow is projected to rise by approximately 7% by the end of the century (Table 11). Increased seasonal variability and frequency of heavy precipitation events, however, will alter streamflow patterns, with mean flow rates rising by 5% in winter and 19% in spring (Figure 1; Table 11). Concentrated streamflow in winter and spring is expected to drive higher annual flow rates and larger flooding events by the end of the century (Table 11). For example, the magnitude of 1.5-year floods is projected to increase by 23% throughout the ecoregion, with the highest increases occurring in areas adjacent to the Missouri River lowlands, where flood magnitudes could increase up to 50% (Figure 6). This suggests that common minor flooding events will become larger, potentially increasing the overall depth and duration of flooding. Rarer, more extreme floods (e.g., 25-year floods) are projected to increase as well (Table 11).

Table 11. Projected changes in streamflow in the Central Irregular Plains ecoregion. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show average historical (1977-2006) and projected (2070-2099) streamflow metrics, as well as the percent change over this timeframe. Data and metric definitions are provided by the U.S Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Streamflow metric	1977–2006	2070–2099	Percent change
Mean Winter (December–February) Flow	16.92 ft^3/s	20.26 ft^3/s	20%
Mean Spring (March–May) Flow	31.96 ft^3/s	43.27 ft^3/s	35%
Mean Summer (June–August) Flow	22 ft^3/s	21.05 ft^3/s	-4%
Mean Fall (September–November) Flow	22.64 ft^3/s	22.03 ft^3/s	-3%
Mean Annual Flow	23.41 ft^3/s	26.7 ft^3/s	14%
1.5-year Flood (33rd percentile)	256.76 ft^3/s	324.74 ft^3/s	26%
10-year Flood (90th percentile)	817.97 ft^3/s	1117.62 ft^3/s	37%
25-year Flood (96th percentile)	1101.21 ft^3/s	1555.44 ft^3/s	41%
Number of Winter Floods	3.9	4.4	12%
Average Lowest 7-day Flow	1.47 ft^3/s	1.09 ft^3/s	-26%
Center of Flow Mass Timing	April 8	April 8	0%

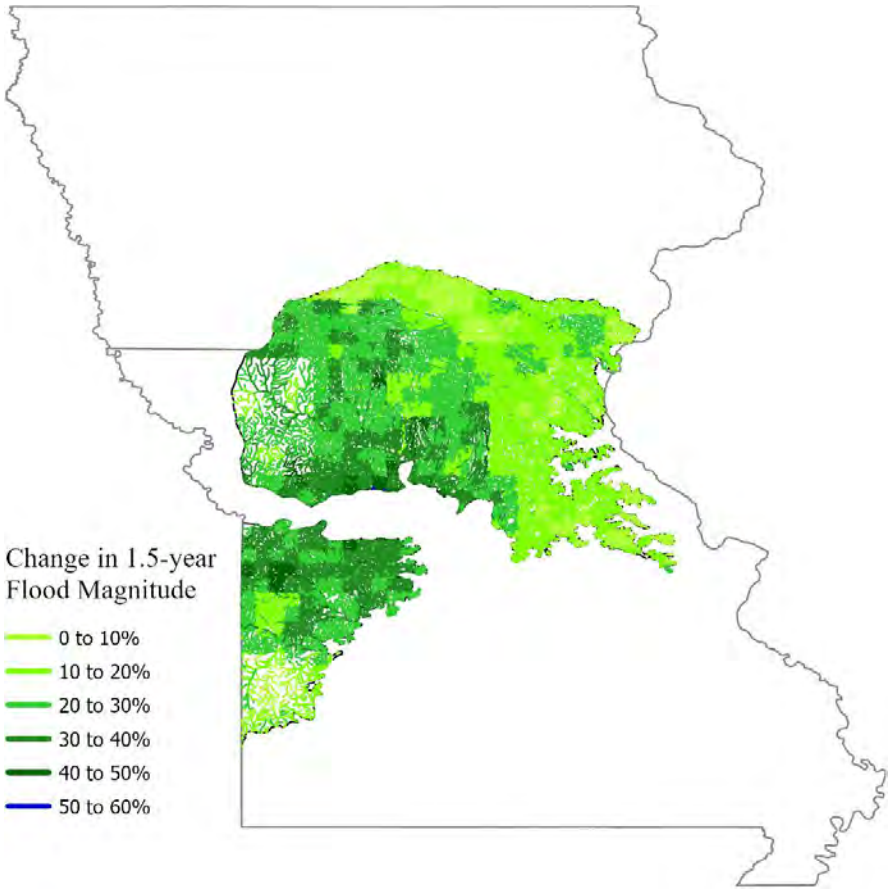

Figure 6. Projected changes in 1.5-year flood magnitude in the Central Irregular Plains ecoregion. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show the percent change in 1.5-year flood magnitude at the end of the century (2070–2099) compared to historical data (1977–2006). 1.5-year floods are determined by identifying the highest daily flow each year and calculating the 33rd percentile of the annual maximum series, representing a flow event that occurs approximately every 1.5 years on average. Data and metric definitions are provided by the U.S. Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Key Climate Change Impacts

This section summarizes how climate change is impacting the South Central-Appalachian-Northeast Floodplain Forest habitat. It covers both the overall influence on species distributions, adaptive capacity, and vulnerability (Table 12) and the specific effects of flooding and summer drying (Table 13). The bullet points below provide a concise overview of these impacts on habitat structure, community composition, invasive species, pests and pathogens, and herbivory.

Habitat structure:

- More frequent and higher magnitude floods may accelerate changes to the physical environment and create more dynamic habitats (Table 11).
  - Erosion rates may rise in some areas while sediment deposition increases in others, with outcomes varying based on stream management practices (Juracek and Fitzpatrick, 2022).

- Shifts in vegetation composition, particularly along riverbanks, can alter the timing and duration of water flow in streams and affect bank erosion rates (Hupp and others, 2009; Sweeney and others, 2004).

Community composition:

- Flooding is most stressful during the growing season, and projections indicate that increased spring flood frequency and a slight shift in the center of flow mass later in the year could extend flood events into the growing season, intensifying their impact on the plant community (Table 11) (Cosgriff and others, 2007; Guyon and Battaglia, 2018; Ingvalson and others, 2020; Kroschel and King, 2021; Osterkamp and Hupp, 2010).
- While some key species may lose suitable habitat, many dominant species are predicted to gain suitable habitat (Table 12).
- Limited adaptive capacity and heightened vulnerability may hinder the persistence of some species (Table 12).
- Increased frequency and duration of flooding elevate the risk of mortality and regeneration failure, particularly for plants in lower floodplain areas and/or with low flooding tolerance, leading to a shift toward more flood-tolerant species (e.g., *Acer saccharinum*, *Celtis* spp.) (Table 13).
- Canopy gaps created by flooding and mortality-induced turnover are likely to accelerate succession and increase the abundance of herbaceous understory species (Cosgriff and others, 2007; Garssen and others, 2015; Ulrich and others, 2002).

Invasive species:

- Flooding disturbances may promote invasive species spread by facilitating dispersal and creating empty ecological niches that these species can rapidly capitalize on (e.g., *Lysimachia nummularia*, *Microstegium vimineum*, *Phalaris arundinacea*) (Budelsky and Galatowitsch, 2004; Havrdová and others, 2023; Innes, 2011; Krahulec and others, 1980; Warren and others, 2011a; Warren and others, 2011b).
- The establishment of invasive species may further hinder native tree regeneration and promote shifts toward more open habitat (De Jager and others, 2024; Donoso and others, 2024; Fryer, 2011; Thomsen and others, 2012).

Pests and pathogens:

- Climate change is expected to amplify pest and pathogen pressure by directly increasing pest and pathogen populations and indirectly heightening host susceptibility (Dukes and others, 2009; Stanturf and others, 2024; Sturrock and others, 2011; Teshome and others, 2020; Vose and others, 2013).
- Introduced and native pests and pathogens alike may become more prevalent as climate change facilitates their spread throughout the Midwest (e.g., emerald ash borer (*Agrilus planipennis*), root rot (*Armillaria* spp.)) (Cooke and Roland, 2018; Fraver and others, 2022; Kasson and Livingston, 2012; Liang and Fei, 2014; Tobin and others, 2014; Ward and Aukema, 2019).
- Increased heatwaves, phenological mismatches, and other climate change impacts may, however, reduce the impact of some pests and pathogens (e.g., spongy moth (*Lymantria dispar*), forest tent caterpillar (*Malacosoma disstria*)) (Banahene and others, 2018; Schwartzberg and others, 2014).

- Oak species (*Quercus* spp.) may be especially vulnerable to certain pathogens (e.g., *Biscogniauxia* spp., *Pythium spp*., *Phytophthora* spp.) as flooding promotes their spread while drought weakens trees and heightens susceptibility (Balci and others, 2010; Bergot and others, 2004; Contreras-Cornejo and others, 2023; Hubbart and others, 2016; Sturrock and others, 2011; Thompson and others, 2014; Wood and others, 2018).

Herbivory:

- Warmer winters are expected to increase deer survival rates and population growth across the Midwest (Felton and others, 2024; Weiskopf and others, 2019).
- Selective deer browsing can reduce tree flood tolerance, which, when combined with climate-driven stressors, may disrupt tree regeneration, limiting the persistence of browse-preferred species, especially those also intolerant to flooding (e.g., *Quercus macrocarpa, Celtis occidentalis*) (Table 13) (Castleberry and others, 1999; Champagne and others, 2021; Cogger and others, 2014; De Jager and others, 2013b; Frerker and others, 2014; Henry and Walters, 2023; Patton and others, 2021; Sample and others, 2023; White, 2012).
- The combined effects of browsing and flooding may favor species that tolerate both pressures (e.g., *Betula nigra, Celtis laevigata, Fraxinus pennsylvanica*, *Salix nigra*) (Table 13), potentially altering species dominance and reinforcing long-term shifts in floodplain forest composition (Castleberry and others, 1999; Cogger and others, 2014; NRCS, 2020; Richardson, 2009; Sample and others, 2023; Wakeland and Swihart, 2009; Webster and others, 2008),

Table 12. Summary of the expected general influence of climate change on South Central-Appalachian-Northeast Floodplain Forest habitat species. Asterisks (*) denote species introduced to the region. Some species appear in contradictory columns (e.g., showing both negative and positive influences on distribution), reflecting conflicting findings in the literature.

Expected influence of climate change on species distributions		Hypothesized adaptive capacity and vulnerability to climate change	
Reduced extent or amount (–)	Increased extent or amount (+)	Low adaptive capacity or high vulnerability (–)	High adaptive capacity or low vulnerability (+)
Acer saccharinum[1,2]	*Acer saccharinum*[3,6–9]	*Acer saccharinum*[13]	*Acer saccharinum*[16]
Fraxinus pennslyvanica[3]	*Betula nigra*[3,6]	*Carya illinoinensis*[6,13]	*Betula nigra*[13]
**Lysimachia nummularia*[4]	*Carya illinoinensis*[3]	*Impatiens capensis*[14,15]	*Celtis laevigata*[13]
**Phalaris arundinacea*[5]	*Celtis occidentalis*[3,6]	*Platanus occidentalis*[13]	*Celtis occidentalis*[13]
**Rosa multiflora*[4]	*Fraxinus pennsylvanica*[6]	*Salix nigra*[6]	*Fraxinus pennsylvanica*[6,13]
Ulmus americana[6]	*Impatiens capensis*[10]		*Quercus macrocarpa*[13,17]
	**Ligustrum* spp.[4,11]		*Salix nigra*[13]
	**Lonicera maacki*[4]		*Ulmus americana*[13]
	Platanus occidentalis[6,12]		
	Quercus macrocarpa[3,6,8]		
	Salix nigra[6]		
	Ulmus americana[3,6,8]		

[1]Brandt and others (2014); [2]Wang and others (2019); [3]Hanberry (2024); [4]Evans and others (2024); [5]Kurtz (2010); [6]Peters and others (2020); [7]Handler and others (2014); [8]Prasad and others (2020); [9]Kozlowski (1997); [10]Rewicz and others (2022); [11]Bradley and others (2010); [12]Ozment and others (2024); [13]Potter and others (2017); [14]Environment and Climate Change Canada and U.S. Environmental Protection Agency (2021); [15]Sansom (2020); [16]Royer-Tardif and others (2021); [17]Etterson and others (2020)

Table 13. Summary of impacts from key climate change stressors on South Central-Appalachian-Northeast Floodplain Forest habitat species.

Stressor	Impact	Effected species
Flooding	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Carya illinoinensis*[1]
		Celtis laevigata[2]
		Celtis occidentalis[3]
		Fraxinus pennsylvanica[3]
		Quercus macrocarpa[4]
	When flood tolerance is high, increased abundance despite added stress	*Acer saccharinum*[3,5–13]
		Betula nigra[7–12]
		Celtis laevigata[14]
		Celtis occidentalis[3,15–17]
		Fraxinus pennsylvanica[2,6,8,9,12,14,16,18,19]
		Ilex decidua[12,20]
		Salix nigra[6,9,12,21–23]
	When flood tolerance is low, reduced growth rates and abundance and elevated mortality risk	*Laportea canadensis*[24]
		Platanus occidentalis[10,12,14]
		Quercus macrocarpa[4,9,11,12]
Summer drying	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Celtis occidentalis*[25]
		Salix nigra[26,27]
	When drought tolerance is low, heightened susceptibility to disturbances, competitive exclusion, and mortality	*Betula nigra*[12,28]
		Carya illinoinensis[12,29]
		Celtis laevigata[28]
		Ilex decidua[12]
		Salix nigra[12,28]
		Ulmus americana[28,30]

[1]Férriz and others (2024); [2]Kroschel and King (2021); [3]Cosgriff and others (2007); [4]Johnson (1990a); [5]De Jager and others (2012); [6]Whitlow and Harris (1979); [7]Dixon (2003); [8]Gergel and others (2002); [9]Ingvalson and others (2020); [10]Keller and others (2023); [11]Keller and others (2024b); [12]Niinemets and Vallardares (2006); [13]Yin and others (2009); [14]Krinard and Johnson (1981); [15]De Jager and others (2019); [16]Romano (2006); [17]Krajicek and Williams (1990); [18]Schindler and others (2020); [19]Kennedy (1990); [20]Sullivan (1993); [21]Donovan and others (1988); [22]McAlhaney (2018); [23]Pitcher and McKnight (1990); [24]Hardin and Wistendahl (1983); [25]Lei and Middleton (2018); [26]Amlin and Rood (2002); [27]Perry and others (2013); [28]Peters and others (2015); [29]King and others (2021); [30]Calvin (1990)

Focal Wildlife Species: Crawfish Frog

The crawfish frog (*Lithobates areolatus*), a secretive and difficult-to-study species, is believed to be in decline due to wetland loss from land conversion. Remaining suitable habitat is likely to be affected not only by continuing land conversion but also by changing climate. Climate-driven shifts in temperature and precipitation will influence the timing and duration of breeding season, egg production and larval survival, and the availability of breeding habitat and burrows. As the Midwest represents the northern edge of the species' range, temperature increases are unlikely to exceed crawfish frog's thermal tolerance. However, high temperatures and low rainfall could increase desiccation risk and limit surface activity (Hoffmann and others, 2021). While periods of drought do not appear to have a direct impact on adult survival (Lannoo and Stiles, 2017), increasing heavy rainfall events can drown adult frogs or drive them from burrows, increasing predation risk (Heemeyer and Lannoo, 2012). Unlike many frog species, crawfish frogs do not directly respond to temperature cues for breeding (Lannoo and Stiles, 2017). However, frogs appear to migrate during large rain events, so any changes in the timing or frequency of these events will affect breeding phenology. During drought years, breeding periods lengthen as adult frogs remain in ponds longer, potentially increasing their exposure to predators (Lannoo and Stiles, 2017). Drought conditions in Indiana have also been linked to reduced fecundity, significantly decreasing egg mass size (Lannoo and Stiles, 2017). In Indiana, drought potentially impacts fecundity, substantially decreasing egg mass size (Lannoo and Stiles, 2017).

Crawfish frogs rely on semi-permanent, fishless ponds for breeding, which may become less available due to climate change. Niche modeling indicates that temperature during the driest quarter is important for current frog distributions, likely due to the length of hydroperiod necessary for reproduction and larval survival (Boycott and others, 2024). Shortened hydroperiods will lead to dry years with less suitable water or water bodies that dry before metamorphosis (Terrell and others, 2023), and wet years will connect waterbodies, potentially decreasing availability of fishless breeding areas (Engbrecht and Lannoo, 2012).

Adult crawfish frogs also rely on burrows to avoid extreme temperatures and disturbances (e.g., fires) (Engbrecht and Lannoo, 2012). Adult crawfish frogs utilize a single crayfish burrow for their entire non-breeding season, up to 11 months of the year. The availability of these burrows depends on the presence of burrowing crayfish, and although all crayfish produce burrows, only a subset of species create burrows that extend to the groundwater, which is critical for crawfish frogs (Florey and Moore, 2019). Native freshwater crayfish (e.g., *Procambarus gracilis*) are highly vulnerable to climate change due to their small ranges, narrow environmental tolerances, and sensitivity to changes in flow and sediment (Hossain and Beierkuhnlein, 2018). Additionally, climate change may facilitate the movement and establishment of non-native crayfish, which pose a large threat to native crayfish species (Koch, 2017). However, if non-native crayfish create similar burrows to native species, crawfish frogs will likely adapt.

To conserve crawfish frogs in the face of climate change, conservation efforts may prioritize maintaining and enhancing habitat. Protecting and restoring native grasslands will benefit adult survival and immigration (Engbrecht and Lannoo, 2012), both of which are critically important shifting precipitation regimes increase episodic larval failure. Population models have identified tadpole survival as an important stage for management (Terrell and others, 2023), suggesting that conservation efforts should focus on wetland restoration and the maintenance of predator-free habitat (Terrell and others, 2023). Wetlands created for crawfish frogs should be placed in areas that minimize flood connections to fish-inhabited waters. In some cases, it may be necessary to captive-rear and head-start crawfish frogs to bypass climate-sensitive early life stages (Boycott and others, 2024; Terrell and others, 2023).

Bald-cypress- Tupelo Floodplain Forest

The Bald-cypress - Tupelo Floodplain Forest habitat is primarily located along the Atlantic and Gulf Coastal Plains, with portions stretching up the Mississippi River Alluvial Plain into the Midwest region in southern Illinois and southeastern Missouri (Figure 7) (Pyne, 2015a). These forests are dominated by flood-tolerant tree species and are found on hydric soils along streams, rivers, oxbow ponds, natural lakes, and backwater sloughs (Pyne, 2015a). The low-lying topographic position of these forests makes flooding a defining ecological characteristic (Pyne, 2015a). Inundation events can range from shallow to deep and persist for weeks to months, sometimes extending well into the growing season depending on location (Pyne, 2015a). This prolonged inundation period limits the establishment and growth of flood-intolerant species and often results in a sparse herbaceous understory (Fredrickson, 1979; Pyne, 2015a; Robertson and others, 1984). Other key factors shaping community composition include drought, beaver activity, wetland impoundments, windthrow, and, less frequently, fire (Conner and Buford, 2019; Fredrickson, 1979; Pyne, 2015a).

Like many floodplain forests in North America, the Bald-cypress - Tupelo Floodplain Forest habitat has been significantly altered by human activities, including changes to hydrological regimes, the introduction of invasive species, and increased sedimentation from adjacent land conversion. In the Midwest, intact habitats primarily comprise twenty key dominant species (Table 14), though other non-dominant species also contribute to overall habitat diversity and function. In addition to the species listed below, invasive species include alligatorweed (*Alternanthera philoxeroides*), Chinese privet (*Ligustrum sinense*), and honeysuckles (*Lonicera* spp.).

Table 14. Common plant species found in Bald-cypress- Tupelo Floodplain Forest habitat. Asterisks (*) denote species introduced to the region, while daggers (†) denote some species within the genus may be introduced to the region, though most are native. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (U.S. Department of Agriculture, Natural Resources Conservation Service).

Species	Common name	Growth habit
Acer rubrum L.	Red maple	Tree
Cornus foemina Mill.	Stiff dogwood	Shrub, tree
Fraxinus profunda (bush) Bush	Pumpkin ash	Tree
Itea virginica L.	Virginia sweetspire	Shrub
Liquidambar styraciflua L.	Sweetgum	Tree
Nyssa aquatica L.	Water tupelo	Tree
Populus heterophylla L.	Swamp cottonwood	Tree
Quercus palustris Münchh.	Pin oak	Tree
Salix nigra Marshall	Black willow	Tree
Taxodium distichum (L.) Rich.	Bald cypress	Tree
Arthraxon hispidus (Thunb.) Makino*	Small carpetgrass	Graminoid
Carex L.†	Sedge	Forb/herb, graminoid
Eichhornia crassipes (Mart.) Solms*	Common water hyacinth	Forb/herb
Glyceria R. Br.†	Mannagrass	Graminoid
Impatiens capensis Meerb.	Jewelweed	Forb/herb

Species	Common name	Growth habit
Leersia oryzoides (L.) Sw.	Rice cutgrass	Graminoid
Leersia Sw.	Cutgrass	Graminoid
Microstegium vimineum (Trin.) A. Camus *	Nepalese browntop	Graminoid
Polygonum punctatum Elliott	Dotted smartweed	Forb/herb
Polygonum sagittatum L.	Arrowleaf tearthumb	Forb/herb, vine

Figure 7. Bald-cypress- Tupelo Floodplain Forest habitat distribution. Geographic distribution of the Bald-cypress-Tupelo Floodplain Forest habitat (Group Code: G033) in the Midwest (USNVC, 2020). Dark purple areas indicate Bald-cypress- Tupelo Floodplain Forest habitat in the Interior Plateau ecoregion (all portions of the habitat within the Midwest are located within this ecoregion). Polygon boundaries have been enlarged to enhance visibility and do not reflect true proportions.

Overview of Climate Projections

The Bald-cypress - Tupelo Floodplain Forest habitat is a priority within the Interior Plateau ecoregion, and climate projections for this area largely reflect regional trends. Both average and extreme temperatures are expected to rise throughout the coming century (Table 15) (Clarke and others, 2022; Marvel and others, 2023; Masson-Delmotte and others, 2021). Most models also project an increase in precipitation, although a few indicate a slight decrease (Table 16) (Marvel and others, 2023). Additionally, precipitation patterns are anticipated to shift towards more extreme events and greater seasonal variability, with notably wetter springs (Dollan and others, 2022; Marvel and others, 2023).

Table 15. Projected changes in annual temperature in the Interior Plateau ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual mean temperature (°F) by mid- (2040-2069) and end of the century (2070-2099), as well as the absolute change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected temperature under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	54.5°F	56.7°F (2.2)	57.8°F (3.3)	57.3°F (2.8)	60.0°F (5.4)
Mean of models	54.6°F	59.1°F (4.5)	60.6°F (6.0)	60.0°F (5.4)	64.2°F (9.6)
Maximum model	54.4°F	60.6°F (6.1)	62.5°F (8.0)	62.6°F (8.2)	68.1°F (13.6)

Table 16. Projected changes in annual precipitation in the Interior Plateau ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected precipitation under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	42.1 in	43.7 in (4%)	39.7 in (-6%)	45.6 in (8%)	39.4 in (-6%)
Mean of models	42.6 in	44.7 in (5%)	44.8 in (5%)	44.3 in (4%)	45.4 in (7%)
Maximum model	42.5 in	44.3 in (4%)	46.3 in (9%)	47.4 in (11%)	48.9 in (15%)

Key Climate Change Stressors

Flooding. Across the Interior Plateau ecoregion, annual streamflow is projected to increase by approximately 14% by the end of the century (Table 17). Increased seasonal variability and frequency of heavy precipitation events, however, will alter streamflow patterns, with mean flow rates rising by 20% in winter and 35% in spring, leading to approximately 12% more winter floods by the end of the century, while summer and fall flows are expected to decrease (Figure 1; Table 17). Concentrated streamflow in winter and spring is expected to drive higher annual flow rates and larger flooding events by the end of the century (Table 17). For example, the magnitude of 1.5-year floods is projected to increase by approximately 26% throughout the ecoregion, with the highest increases occurring in the southern reaches of Illinois and Indiana, where flood magnitudes could increase by as much as 80% (Figure 8). This suggests that common minor flooding events will become larger, potentially increasing the overall depth and duration of flooding. Rarer, more extreme floods (e.g., 25-year floods) are projected to increase substantially as well (Table 17).

Summer drying. Additionally, summer vapor pressure deficit (VPD) is projected to increase across the Interior Plateau ecoregion by approximately 80% by the end of the century (Table 18). Projected

increases remain relatively constant throughout the ecoregion, with slightly higher summer VPD occurring in the southern portion (Figure 9). Despite overall precipitation increases (Table 16), heightened precipitation variability, combined with rising temperatures (Table 15), will likely lead to more extreme fluctuations between wet and dry periods. This variability, along with higher VPD, is expected to prolong periods of drying, intensifying soil moisture deficits and increasing physiological stress for plants during summer months.

Table 17. Projected changes in streamflow in the Interior Plateau ecoregion. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show average historical (1977-2006) and projected (2070-2099) streamflow metrics, as well as the percent change over this timeframe. Data and metric definitions are provided by the U.S Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Streamflow metric	1977–2006	2070–2099	Percent change
Mean Winter (December–February) Flow	48.03 ft^3/s	50.58 ft^3/s	5%
Mean Spring (March–May) Flow	60.16 ft^3/s	71.75 ft^3/s	19%
Mean Summer (June–August) Flow	22.59 ft^3/s	21.35 ft^3/s	-5%
Mean Fall (September–November) Flow	22.12 ft^3/s	20.54 ft^3/s	-7%
Mean Annual Flow	38.22 ft^3/s	41.07 ft^3/s	7%
1.5-year Flood (33rd percentile)	240.57 ft^3/s	296.6 ft^3/s	23%
10-year Flood (90th percentile)	667.36 ft^3/s	797.2 ft^3/s	19%
25-year Flood (96th percentile)	894.69 ft^3/s	1055.08 ft^3/s	18%
Number of Winter Floods	8.49	8.13	-4%
Average Lowest 7-day Flow	6.86 ft^3/s	6.26 ft^3/s	-9%
Center of Flow Mass Timing	March 25	March 26	1%

Table 18. Projected changes in summer vapor pressure deficit in the Interior Plateau ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected summer vapor pressure deficit (VPD; kilopascals) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected VPD under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	1.18 kPa	1.21 kPa (3%)	1.32 kPa (11%)	1.29 kPa (9%)	1.39 kPa (17%)
Mean of models	1.18 kPa	1.56 kPa (30%)	1.75 kPa (45%)	1.66 kPa (38%)	2.19 kPa (80%)
Maximum model	1.19 kPa	1.85 kPa (53%)	2.07 kPa (70%)	2.27 kPa (86%)	3.42 kPa (177%)

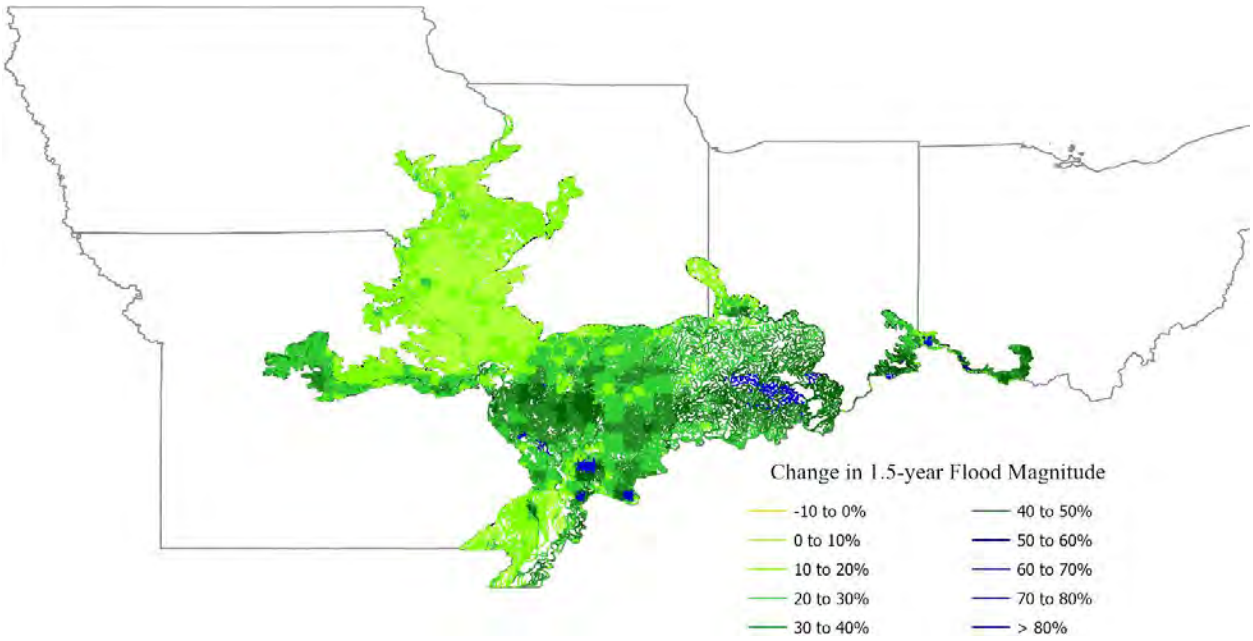

Figure 8. Projected changes in 1.5-year flood magnitude in the Interior Plateau ecoregion. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show the percent change in 1.5-year flood magnitude at the end of the century (2070–2099) compared to historical data (1977–2006). 1.5-year floods are determined by identifying the highest daily flow each year and calculating the 33rd percentile of the annual maximum series, representing a flow event that occurs approximately every 1.5 years on average. Data and metric definitions are provided by the U.S. Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Figure 9. Projected changes in summer vapor pressure deficit in the Interior Plateau ecoregion. Projections gridded climate data obtained via the Climate Toolbox Climate Mapper at a 4-km resolution (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971–2000, top row) and projected (2070–2099) summer vapor pressure deficit (VPD; kilopascals) for each emissions scenario (RCP 4.5, middle row; RCP 8.5, bottom row). To capture variation across climate models, models with the lowest (minimum model, left column) and highest (maximum model, right column) projected VPD under RCP 8.5 are presented in addition to the mean of all models (middle column).

Key Climate Change Impacts

This section summarizes how climate change is impacting the Bald-cypress - Tupelo Floodplain Forest habitat. It covers both the overall influence on species distributions, adaptive capacity, and vulnerability (Table 19) and the specific effects of flooding and summer drying (Table 20). The bullet points below provide a concise overview of these impacts on habitat structure, community composition, invasive species, pests and pathogens, and herbivory.

Habitat structure:

- More frequent and higher magnitude floods may accelerate changes to the physical environment and create more dynamic habitats (Table 11).
  - Erosion rates may rise in some areas while sediment deposition increases in others, with outcomes varying based on stream management practices (Juracek and Fitzpatrick, 2022).
  - Shifts in vegetation composition, particularly along riverbanks, can alter the timing and duration of water flow in streams and affect bank erosion rates (Hupp and others, 2009; Sweeney and others, 2004).

Community composition:

- Increasing VPD is expected to be most stressful during the growing season, and projections indicate that rising VPD alongside decreasing streamflow in summer could prolong periods of summer drying, intensifying its impact on the plant community (Table 17; 18).
- While some key species may lose suitable habitat, many dominant species are predicted to gain suitable habitat (Table 19).
- Limited adaptive capacity and heightened vulnerability may hinder the persistence of some species (Table 19).
- Despite the flooding tolerance of many species, increasing moisture variability from both flooding and summer drying, potentially elevates the risk of forest regeneration failure, particularly for species that are sensitive to both extremes (Table 20).
- More frequent flooding may further reduce the already limited abundance of herbaceous understory species (Anderson and others, 2009; Conner and Buford, 1998; Guyon and Battaglia, 2018).

Invasive species:

- Flooding disturbances may promote invasive species spread by facilitating dispersal and creating empty ecological niches that these species can rapidly capitalize on (e.g., *Alternanthera philoxeroides*, *Eichhornia crassipes*, *Microstegium vimineum*) (Beloiu and others, 2022; Havrdová and others, 2023; Kriticos and Brunel, 2016; Orbán and others, 2021; Ren and others, 2023; Warren and others, 2011a; Webster and others, 2008)
- Summer drying is expected to negatively influence most invasive species in this habitat, such as honeysuckles (*Lonicera* spp.), whose distribution is thought to be drought limited (Peterson and others, 2024).
- The establishment of invasive species may further hinder native tree regeneration and promote shifts toward more open habitat, as some invasives, such as Amur honeysuckle (*Lonicera maackii*), intensify moisture stress for adjacent native seedlings (De Jager and others, 2024; Donoso and others, 2024; Fryer, 2011; Pfeiffer and Gorchov, 2015; Thomsen and others, 2012).

Pests and pathogens:

- Climate change is expected to amplify pest and pathogen pressure by directly increasing pest and pathogen populations and indirectly by heightening host susceptibility (Dukes and others, 2009;

Stanturf and others, 2024; Sturrock and others, 2011; Teshome and others, 2020; Vose and others, 2013).

- Introduced pests and pathogens may become more prevalent as climate change facilitates their spread throughout the Midwest (e.g., emerald ash borer (*Agrilus planipennis*), spongy moth (*Lymantria dispar*), and fungal pathogens) (Dukes and others, 2009; Stanturf and others, 2024; Sturrock and others, 2011; Teshome and others, 2020; Vose and others, 2013).
- Increased heatwaves, phenological mismatches, and other climate change impacts may, however, reduce the impact of some pests and pathogens (e.g., spongy moth (*Lymantria dispar*), forest tent caterpillar (*Malacosoma disstria*)) (Banahene and others, 2018; Schwartzberg and others, 2014).
- Rapid and compounding transitions between flood and drought stress may favor some pest and pathogen species by weakening tree resistance to infestation and infection (Gandhi and others, 2007; Huberty and Denno, 2004; Vogt and others, 2020; Vose and others, 2016).
- Oak species (*Quercus spp.*), in particular pin oak (*Quercus palustris*), may be especially vulnerable to pests (e.g., *Agrilus planipennis*) and pathogens (e.g., *Pythium* spp., *Phytophthora* spp.) as flooding promotes their spread, while drought heightens tree susceptibility (Balci and others, 2010; Bergot and others, 2004; Contreras-Cornejo and others, 2023; Hubbart and others, 2016; Sturrock and others, 2011; Thompson and others, 2014; Wood and others, 2018).

Herbivory:

- Warmer winters are expected to increase deer survival rates and population growth across the Midwest (Felton and others, 2024; Weiskopf and others, 2019).
- Selective deer browsing, combined with climate change-driven stressors, may disrupt plant regeneration and shift community composition, particularly by limiting the persistence of browse-preferred species in floodplain habitats (e.g., red maple (*Acer rubrum*), jewelweeds (*Impatiens spp.*), and pin oak (*Quercus palustris*)) (Champagne and others, 2021; Frerker and others, 2014; Henry and Walters, 2023; Novick and others, 2022; Patton and others, 2021).
- Regeneration failure due to browsing and summer drying may favor browse-resistant species (e.g., green ash *Fraxinus pennsylvanica*, *Itea virginica*, *Liquidambar styraciflua*, *Lonicera* spp., *Microstegium vimineum*) and reduce the presence of species intolerant to both browsing and drought (e.g., *Acer rubrum*) (Table 20) (Castleberry and others, 1999; Cogger and others, 2014; NRCS, 2020; Richardson, 2009; Sample and others, 2023; Wakeland and Swihart, 2009; Webster and others, 2008)

Table 19. Summary of the expected general influence of climate change on Bald-cypress- Tupelo Floodplain Forest habitat species. Asterisks (*) denote species introduced to the region. Some species appear in contradictory columns (e.g., showing both negative and positive influences on distribution), reflecting conflicting findings in the literature.

Expected influence of climate change on species distributions		Hypothesized adaptive capacity and vulnerability to climate change	
Reduced extent or amount (–)	Increased extent or amount (+)	Low adaptive capacity or high vulnerability (–)	High adaptive capacity or low vulnerability (+)
Acer rubrum[1]	*Acer rubrum*[2]	*Fraxinus profunda*[12]	*Acer rubrum*[15]
Liquidambar styraciflua[1]	**Alternanthera philoxeroides*[3]	*Impatiens capensis*[13,14]	*Liquidambar styraciflua*[12]
	**Eichhornia crassipes*[3–5]	*Liquidambar styraciflua*[1]	*Salix nigra*[12]
	Impatiens capensis[6]	*Nyssa aquatica*[1,12]	
	**Ligustrum* spp.[3,7]	*Populus heterophylla*[12]	
	Liquidambar styraciflua[1,8]	*Quercus palustris*[1,12]	
	**Lonicera maackii*[3]	*Salix nigra*[1]	
	Quercus palustris[9,10]	*Taxodium distichum*[12]	
	Salix nigra[1]		
	Taxodium distichum[11]		

[1]Peters and others (2020); [2]Prasad and others (2020); [3]Evans and others (2024); [4]Kriticos and Brunel (2016); [5]Coredeiro and others (2020); [6]Rewicz and others (2022); [7]Bradley and others (2010); [8]Ozment and others (2024); [9]Hanberry (2024); [10]Rauschendorfer and others (2022); [11]Wang and others (2019); [12]Potter and others (2017); [13]Environment and Climate Change Canada and U.S. Environmental Protection Agency (2021); [14]Sansom (2020); [15]Royer-Tardif and others (2021)

Table 20. Summary of impacts from key climate change stressors on Bald-cypress- Tupelo Floodplain Forest habitat species. Asterisks (*) denote species introduced to the region.

Stressor	Impact	Effected species
Flooding	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer rubrum*[1,2]
		Itea virginica[3]
		Leersia oryzoides[4]
		Liquidambar styraciflua[5]
		Quercus palustris[6,7]
		Taxodium distichum[8,9]
	When flood tolerance is high, increased abundance despite added stress	*Acer rubrum*[10–13]
		Fraxinus profunda[11,14]
		Leersia oryzoides[4]
		Liquidambar styraciflua[11,15]
		**Microstegium vimineum*[16–18]
		Nyssa aquatica[11,19,20]
		Populus heterophylla[11,21]

Stressor	Impact	Effected species
		Quercus palustris[11,22]
		Salix nigra[11,19,23–26]
		Taxodium distichum[11,27]
Summer drying	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer rubrum*[28–30]
		Liquidambar styraciflua[29,31]
		Salix nigra[32,33]
		Taxodium distichum[34]
	When drought tolerance is low, heightened susceptibility to disturbances, competitive exclusion, and mortality	*Acer rubrum*[11]
		Fraxinus profunda[11,14]
		Liquidambar styraciflua[11,35]
		Nyssa aquatica[11,35,36]
		Populus heterophylla[11]
		Salix nigra[11,35]

[1]Ehrenfeld (2012); [2]Herrera-Bevan and Ibáñez (2024); [3]Anderson and others (2009); [4]Darris and Bartow (2004); [5]Krinard and Johnson (1981); [6]Cline (2018); [7]Cosgriff and others (2007); [8]Middleton and Johnson (2021); [9]Middleton (2009); [10]Keller and others (2023); [11]Niinemets and Vallardares (2006); [12]Palik and others (2021b); [13]Carpenter and Mitchell (1979); [14]Harms (1990); [15]Evans and others (2022); [16]Barden (1991); [17]European and Mediterranean Plant Protection Organization [EPPO] (2025); [18]Warren and others (2011a); [19]Donovan and others (1988); [20]Johnson (1990c); [21]Johnson (1990b); [22]McQuilkin (1990); [23]Whitlow and Harris (1979); [24]Ingvalson and others (2020); [25]McAlhaney (2018); [26]McKnight (1965); [27]Fredrickson (1979); [28]Ibanez and others (2017); [29]Ramage and others (2023); [30]Reich and others (2022); [31]Kormanik (1990); [32]Amlin and Rood (2002); [33]Perry and others (2013); [34]Middleton and others (2023); [35]Peters and others (2015); [36]Tracy and others (2024)

Focal Wildlife Species: Prothonotary Warbler

The prothonotary warbler (*Protonotaria citrea*) is a small cavity-nesting songbird that breeds in riparian and floodplain forests in the central Midwest and winters in mangrove forests in Central and South America. Climate-driven hydrological changes and sea-level rise threaten both its breeding and non-breeding habitats. The species has been documented expanding its breeding range northward, including into the Mississippi River Valley, and its population remains relatively stable (NatureServe, 2008).

Prothonotary warblers nest in tree cavities over standing water, making them highly sensitive to hydrological extremes (Cooper and others, 2009). High magnitude flooding with high water levels can directly impact reproductive success (Flaspohler, 1996; Graber and others, 1983). Prolonged floodplain inundation can also alter predator foraging behavior by limiting non-arboreal options, increasing warbler nest depredation by predators like raccoons (Cooper and others, 2009). However, partial flooding appears to provide optimal protection against predation (Cooper and others, 2009; Hoover, 2006; Hoover, 2009). Conversely, drier conditions expose dense ground cover, thus removing the protective influence of standing water and increasing rates of nest depredation (Cooper and others, 2009; Kirsch, 2009). Despite these direct influences of hydrology, altered hydrological regimes appear unlikely, except in the most severe instances of flooding, to reduce the abundance of most preferred nesting tree species, which include red maple (*Acer rubrum*), sugarberry (*Celtis laevigata*), and silver maple (*Acer saccharinum*) (Table 20) (Gabbe and others, 2002; Kirsch and Wellik, 2017; Wuebbles and others, 2021).

Brood parasitism by brown-headed cowbirds (*Molothrus ater*) is another major threat to the prothonotary warbler, affecting up to 50% of nests— reducing clutch size, hatching success, and nesting survival (Hoover, 2003b). Although brown-headed cowbird abundance has been in decline (Cox and others, 2012; Forrester and others, 2023), parasitism rates remain high, and climate-driven increases in precipitation could boost cowbird numbers, further threatening warbler populations (Forrester and others, 2023; Rosamond and others, 2020). Moreover, as native bird populations decline due to higher precipitation, parasitism pressure may increase on small host populations (Rosamond and others, 2020). Prothonotary warblers show limited ability to adapt to brood parasitism, making them particularly vulnerable (Hoover, 2003a).

As forested wetlands face increasing climate stress, climate-informed restoration may be a key adaptation strategy for this species. For example, in the Cache River watershed, habitat restoration increased protonotary warbler density and nesting success (Hoover, 2009). Additionally, artificial nesting structures offer a promising conservation strategy, as warblers readily use nest boxes, which have shown no recorded depredation (Mueller and others, 2019).

Focal Aquatic System: Lusk Creek

Lusk Creek originates near Delwood, Illinois, and flows through northeastern Pope County, draining a 228-square-kilometer watershed before joining the Ohio River in Golconda, Illinois. The 40-kilometer-long creek, averaging 7 meters in width, flows through the Shawnee National Forest for nearly half its course, carving a canyon through thick sandstone and creating cliffs that range from a few meters to nearly 30 meters high (Carmody and Phillippi, 1991). Its character shifts along its course, with shallow, fast-moving stretches punctuated by rocky riffles in some areas, while deeper sections form calm, quiet pools that support aquatic wildlife (Page and others, 1992; Smith, 1971). Recognized for its natural beauty and ecological value, Lusk Creek is considered one of Illinois' most scenic and pristine streams, making it a critical focus for conservation efforts.

Projected increases in temperature and shifting precipitation patterns are expected to reduce soil moisture, groundwater recharge, and streamflow, especially during summer and fall months (Table 21) (Dierauer and Zhu, 2020). Unlike snowmelt-dominated watersheds in northern latitudes, southern-temperate streams experience variable spring flooding patterns driven by heavy precipitation and elevated cool-season soil moisture (Byun and others, 2019). In warmer watersheds, including those in southern Illinois, flooding is expected to become more frequent during the cold season, with localized trends influenced by slope and land use (Byun and others, 2019; Khan and others, 2021). Despite the relative stability of its forested watershed (Khan and others, 2021), Lusk Creek remains vulnerable to climate change impacts, particularly from extreme events. Increased precipitation intensity is expected to elevate peak flows, which can erode streambeds, elevate sediment loads, and destabilize substrates, altering critical flow regimes (Byun and others, 2019; Wuebbles and others, 2021). These changes, combined with drought-driven low flows, may fragment habitats and reduce water availability during ecologically sensitive periods (Birnie-Gauvin and others, 2021).

Table 21. Projected changes in streamflow for Lusk Creek. Projections use gridded simulations of daily runoff based on CMIP5 climate models under the high-emissions (RCP 8.5) scenario. Values show average historical 1977-2006) and projected (2070–2099) streamflow metrics, as well as the percent change over this timeframe. Data and metric definitions are provided by the U.S Stream Flow Metric Dataset (Luce and others, 2025; U.S. Department of the Interior, Bureau of Reclamation, 2014; USDA Forest Service Office of Sustainability and Climate, 2022; Wenger and others, 2010).

Streamflow metric	1977–2006	2070–2099	Percent change
Mean Winter (December–February) Flow	87.5 ft^3/s	83.5 ft^3/s	-5%
Mean Spring (March–May) Flow	80.4 ft^3/s	90.1 ft^3/s	12%
Mean Summer (June–August) Flow	22.9 ft^3/s	19.7 ft^3/s	-14%
Mean Fall (September–November) Flow	24.5 ft^3/s	22.5 ft^3/s	-8%
Mean Annual Flow	53.8 ft^3/s	53.9 ft^3/s	0%
1.5-year Flood (33rd percentile)	308.5 ft^3/s	431.1 ft^3/s	40%
10-year Flood (90th percentile)	1339.5 ft^3/s	1757.0 ft^3/s	31%
25-year Flood (96th percentile)	1856.4 ft^3/s	2173.8 ft^3/s	17%
Number of Winter Floods	11.9	12.4	5%
Average Lowest 7-day Flow	10.2 ft^3/s	9.4 ft^3/s	-8%
Center of Flow Mass Timing	March 15	March 14	-1%

Central Interior-Great Lakes Flatwoods and Swamp Forest

The Central Interior-Great Lakes Flatwoods and Swamp Forest habitat is a regionally rare and locally important wooded wetland habitat found in flat depressions that may be adjacent to or disconnected from floodplain systems and are located throughout Ohio, Indiana, Illinois, southern Michigan, and parts of southern Wisconsin (Figure 10) (Faber-Langendoen and others, 2020; Taft and others, 2009). These bottomland forests are defined by a semi-to completely impermeable claypan subsoil layer, leading to seasonally fluctuating water levels, predominantly driven by precipitation patterns (Faber-Langendoen and others, 2020). Winter and spring bring wet and waterlogged conditions due to ponding and a suspended water table, whereas poor soil water retention results in rapid drying and drought conditions during summer due to evapotranspiration (Faber-Langendoen and others, 2020; Kassahun and Renninger, 2021; Slaughter and others, 2010; Taft and others, 1995; Taft and others, 2009). This extreme flood-drought cycle favors species adapted to both conditions (Faber-Langendoen and others, 2020; Slaughter and others, 2010; Taft and others, 1995). Additionally, fire following dry periods and windthrow events play major roles in disturbance dynamics and community composition (Faber-Langendoen and others, 2020; Slaughter and others, 2010).

These forested wetlands provide important habitat for a wide variety of wildlife and often support ecologically significant vernal pools (Slaughter and others, 2010). However, the Central Interior-Great Lakes Flatwoods and Swamp Forest habitat is becoming increasingly isolated and fragmented throughout the Midwest, with conservation efforts challenged by hydrological alterations to drainage networks, invasive species pressure, and high deer browsing rates (Brandt and others, 2014; Faber-Langendoen and others, 2020; Nelson and others, 2009; Slaughter and others, 2010; Taft and others, 1995). As transitional habitats, situated between aquatic and upland systems, these forested wetlands are highly sensitive to precipitation patterns and hydrologic shifts, making them particularly vulnerable to changing environmental conditions. Intact forests are primarily comprised of thirteen dominant species (Table 22), though other non-dominant species also contribute to overall habitat diversity and function. In addition to the species listed below, invasive species include common buckthorn (*Rhamnus cathartica*), creeping jenny (*Lysimachia nummularia*), garlic mustard (*Alliaria petiolata*), honeysuckles (*Lonicera spp.*), purple loosestrife (*Lythrum salicaria*), and reed canarygrass (*Phalaris arundinacea*).

Table 22. Plant species common to the Central Interior-Great Lakes Flatwoods and Swamp Forest habitat. Asterisks (*) denote species introduced to the region. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (USDA, NRCS, 2025).

Species	Common name	Growth habit
Acer rubrum L.	Red maple	Tree
Acer saccharum Marshall	Sugar maple	Shrub, tree
Fagus grandifolia Ehrh.	American beech	Tree
Nyssa sylvatica Walter	Swamp tupelo	Tree
Quercus alba L.	White oak	Tree
Quercus bicolor Willd.	Swamp white oak	Tree
Quercus ellipsoidalis E.J. Hill	Northern pin oak	Tree
Quercus macrocarpa Michx.	Bur oak	Shrub, tree
Quercus michauxii Nutt.	Swamp chestnut oak	Tree

Species	Common name	Growth habit
Quercus palustris Münchh.	Pin oak	Tree
Quercus shumardii Buckley	Shumard's oak	Shrub, tree
Salix nigra Marshall	Black willow	Tree
Ulmus rubra Muhl.	Slippery elm	Tree
Vitis labrusca L.	Fox grape	Vine

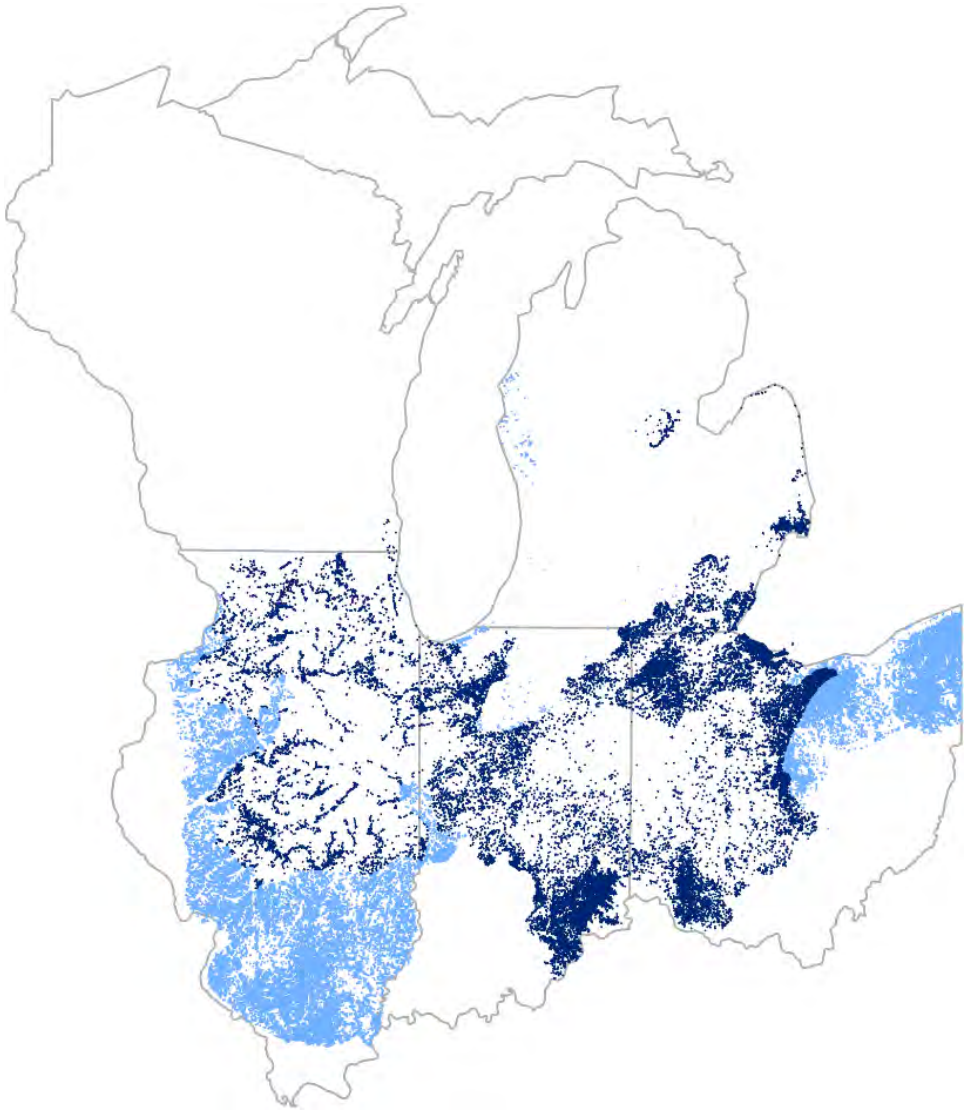

Figure 10. Central Interior-Great Lakes Flatwoods and Swamp Forest habitat distribution. Geographic distribution of the Central Interior-Great Lakes Flatwoods and Swamp Forest (Group Code: G917) in the Midwest (USNVC, 2020). Dark blue areas indicate Central Interior-Great Lakes Flatwoods and Swamp Forest habitat in the Central Plains ecoregion, while light blue areas mark additional locations throughout the Midwest. Polygon boundaries have been enlarged to enhance visibility and do not reflect true proportions.

Overview of Climate Projections

The Central Interior-Great Lakes Flatwoods and Swamp Forest habitat is prioritized for the Central Plains ecoregion, and climate projections for this area largely reflect regional trends. Both average and extreme temperatures are expected to rise throughout the coming century (Table 23) (Clarke and others, 2022; Marvel and others, 2023; Masson-Delmotte and others, 2021). Most models also project an increase in precipitation, although a few indicate a slight decrease (Table 24) (Marvel and others, 2023). Additionally, precipitation patterns are anticipated to shift towards more extreme events and greater seasonal variability, with notably wetter springs (Dollan and others, 2022; Marvel and others, 2023).

Table 23. Projected changes in annual temperature in the Central Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual mean temperature (°F) by mid- (2040-2069) and end of the century (2070-2099), as well as the absolute change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected temperature under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	50.1°F	52.5°F (2.5)	53.6°F (3.6)	53.2°F (3.2)	56.1°F (6.0)
Mean of models	50.2°F	54.9°F (4.7)	56.4°F (6.2)	55.9°F (5.7)	60.1°F (9.9)
Maximum model	50.0°F	56.2°F (6.2)	58.2°F (8.3)	58.4°F (8.5)	64.2°F (14.3)

Table 24. Projected changes in annual precipitation in the Central Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected precipitation under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	37.4 in	38.1 in (2%)	36.8 in (-2%)	40.2 in (7%)	36.0 in (-4%)
Mean of models	37.5 in	39.7 in (6%)	39.9 in (6%)	39.6 in (6%)	40.6 in (8%)
Maximum model	37.0 in	42.5 in (15%)	39.2 in (6%)	43.3 in (17%)	44.6 in (20%)

Key Climate Change Stressor

Summer drying. Across the Central Plains ecoregion, summer vapor pressure deficit (VPD) is projected to increase by approximately 82% by the end of the century (Table 25), with projected values relatively consistent throughout the region and slightly higher in the southern portion (Figure 11). Spring

precipitation is expected to increase by approximately 20% (Table 26), with areas projected to have the highest summer VPD also receiving the most precipitation during spring (Figure 12). Despite overall precipitation increases, heightened precipitation variability, combined with rising temperatures and VPD, is expected to drive more extreme swings between wet and dry periods, such as above-average spring precipitation followed by prolonged summer drying. These shifts will likely exacerbate flood-drought cycles, intensify soil moisture deficits, and increase physiological stress for plants during summer months.

Table 25. Projected changes in summer vapor pressure deficit in the Central Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected summer vapor pressure deficit (VPD; kilopascals) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected VPD under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	1.25 kPa	1.29 kPa (3%)	1.40 kPa (12%)	1.38 kPa (10%)	1.50 kPa (20%)
Mean of models	1.26 kPa	1.64 kPa (30%)	1.81 kPa (44%)	1.75 kPa (39%)	2.29 kPa (82%)
Maximum model	1.26 kPa	1.86 kPa (48%)	2.06 kPa (64%)	2.26 kPa (79%)	3.24 kPa (158%)

Table 26. Projected changes in spring precipitation in the Central Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected spring precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected VPD under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	10.3 in	10.9 in (5%)	10.3 in (0%)	10.4 in (1%)	10.8 in (5%)
Mean of models	10.3 in	11.6 in (12%)	11.8 in (14%)	11.6 in (12%)	12.4 in (20%)
Maximum model	10.3 in	13.4 in (31%)	11.8 in (14%)	13.6 in (33%)	14.0 in (36%)

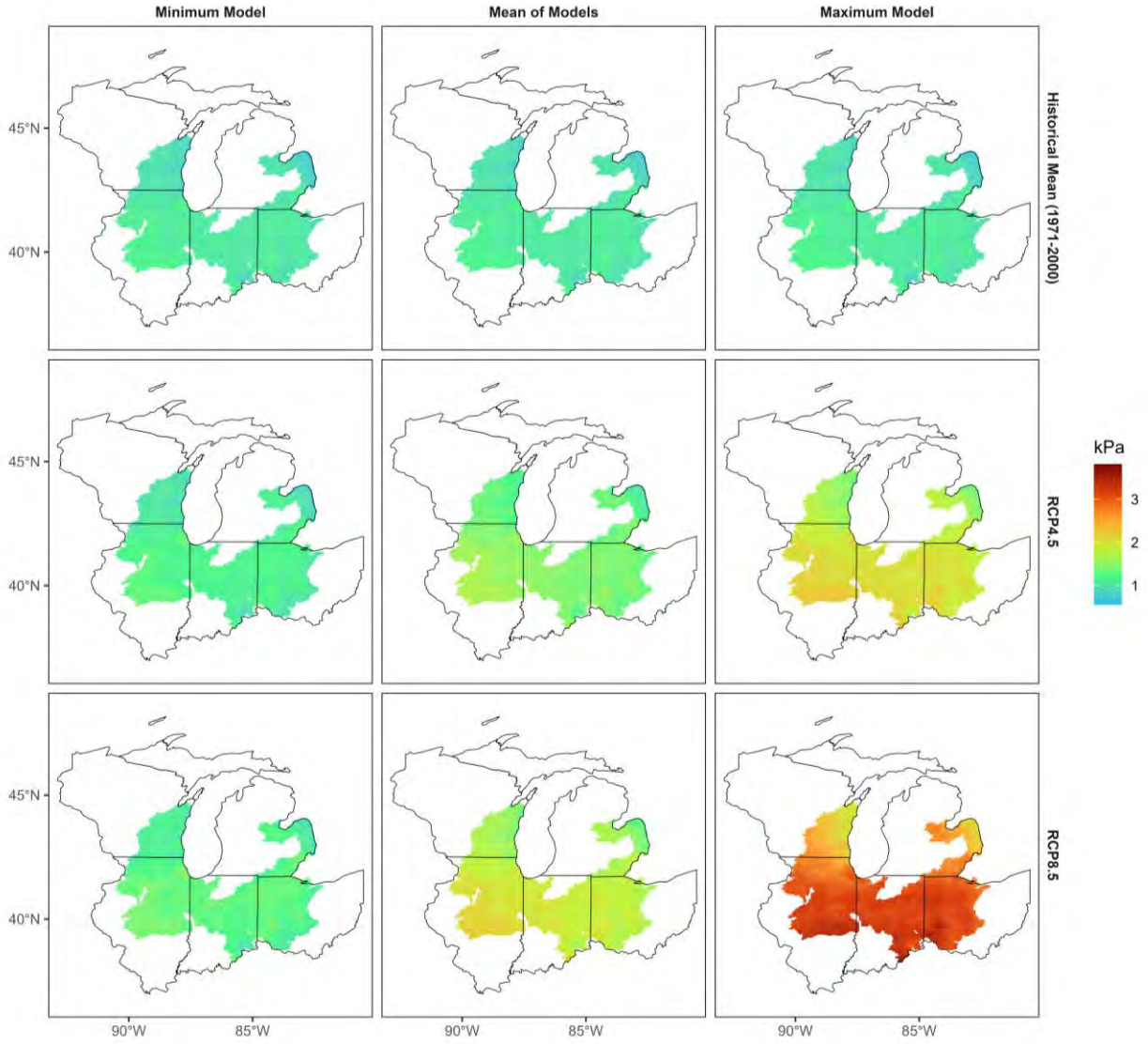

Figure 11. Projected changes in summer vapor pressure deficit in the Central Plains ecoregion. Projections gridded climate data obtained via the Climate Toolbox Climate Mapper at a 4-km resolution (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971–2000, top row) and projected (2070–2099) summer vapor pressure deficit (VPD; kilopascals) for each emissions scenario (RCP 4.5, middle row; RCP 8.5, bottom row). To capture variation across climate models, models with the lowest (minimum model, left column) and highest (maximum model, right column) projected VPD under RCP 8.5 are presented in addition to the mean of all models (middle column).

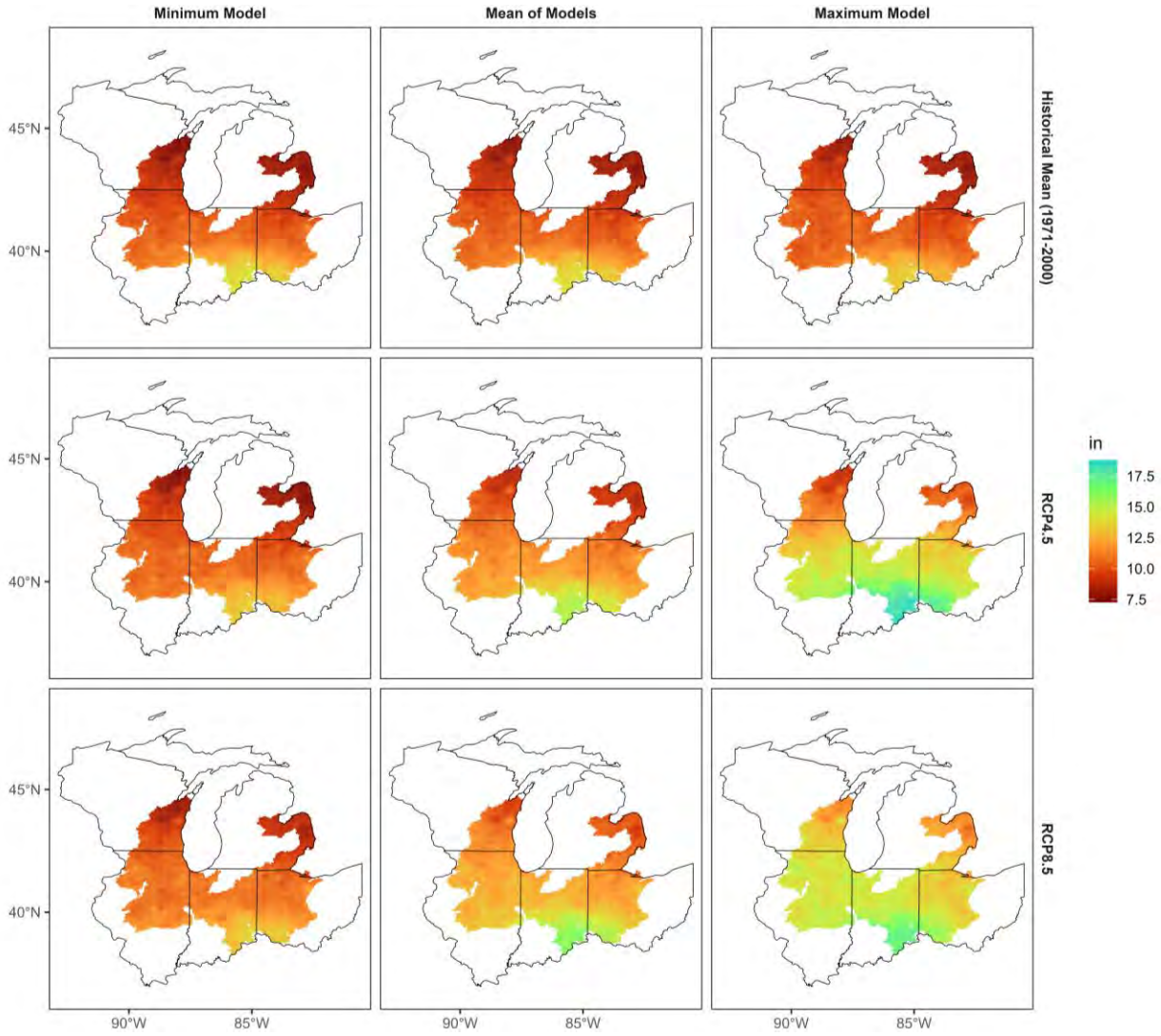

Figure 12. Projected changes in spring precipitation in the Central Plateau ecoregion. Projections use gridded climate data obtained via the Climate Toolbox Climate Mapper at a 4-km resolution (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971–2000, top) and projected (2070–2099) spring precipitation (inches) for each emissions scenario (RCP 4.5, middle row; RCP 8.5, bottom row). To capture variation across climate models, models with the lowest (minimum model, left column) and highest (maximum model, right column) projected VPD under RCP 8.5 are presented in addition to the mean of all models (middle column).

Key Climate Change Impacts

This section summarizes how climate change is impacting the Central Interior-Great Lakes Flatwoods and Swamp Forest habitat. It covers both the overall influence on species distributions, adaptive capacity, and vulnerability (Table 27) and the specific effects of flooding and summer drying (Table 28). The bullet points below provide a concise overview of these impacts on habitat structure, community composition, invasive species, pests and pathogens, and herbivory.

Habitat structure:

- More frequent and higher magnitude floods may accelerate erosion in some areas adjacent to floodplain systems or along slope bottoms while increasing sediment deposition in others, leading to infilling of low-lying features, reduced water depth, increased seasonal drying, and eventual terrestrialization (Amoros and others, 2000; Junk, 2005; Pyne, 2014; Slaughter and others, 2010) .
- More frequent flood-drought cycles may alter biogeochemical, microbial, decomposition, and nutrient cycling processes, negatively impacting wetland plants, invertebrates, and other species adapted to specific habitat conditions (Mortsch and others, 2003; Staffen and others, 2019; Trettin and others, 2019).

Community composition:

- Projections indicate that rising spring precipitation, followed by increased summer VPD, could intensify flood-drought cycles, leading to considerable impacts to the plant community (Tables 25; 26).
- While some key species may lose suitable habitat, many dominant species are predicted to gain suitable habitat (Table 27).
- Limited adaptive capacity and heightened vulnerability may hinder the persistence of some species, particularly oaks (*Quercus* spp.) (Table 27).
- Increasing summer VPD may heighten the risk of mortality and regeneration failure, particularly for seeds, seedlings, saplings, and juvenile trees, potentially shifting species composition toward more flood-tolerant species and resulting in more homogeneous age and size-class stands (Table 28).
- Intensified flood-drought cycles, driven by rising spring precipitation and increased summer VPD, may favor species tolerant of both flooding and drought (e.g., *Quercus bicolor*, *Quercus michauxii*, *Quercus palustris*) (Table 28).

Invasive species:

- Flooding disturbances may promote invasive species spread by facilitating dispersal and creating empty ecological niches that these species can rapidly capitalize on (e.g., *Lysimachia nummularia*, *Lythrum salicaria*, *Phalaris arundinacea*) (Budelsky and Galatowitsch, 2004; Innes, 2011; Munger, 2002).
- While summer drying and moisture stress may not directly benefit most invasive species, higher summer VPD can create canopy gaps, reduce community resistance, and promote the encroachment of upland species, facilitating invasion (Middleton and Kleinebecker, 2012; Ponzio and others, 2019; Sanders and others, 2024; Tiner, 2003).

Pests and pathogens:

- Climate change is expected to amplify pest and pathogen pressure by directly increasing pest and pathogen populations and by indirectly heightening host susceptibility (Dukes and others, 2009; Stanturf and others, 2024; Sturrock and others, 2011; Teshome and others, 2020; Vose and others, 2013).

- Introduced and native pests and pathogens alike may become more prevalent as climate change facilitates their spread throughout the Midwest (e.g., red oak borer (*Enaphalodes rufulus*)) (Cooke and Roland, 2018; Duan and others, 2022; Tobin and others, 2014; Ward and Aukema, 2019).
- Increased heatwaves, phenological mismatches, and other climate change impacts may reduce the impact of some pests and pathogens (e.g., spongy moth (*Lymantria dispar*), forest tent caterpillar (*Malacosoma disstria*)) (Banahene and others, 2018; Schwartzberg and others, 2014).
- Oak species (*Quercus* spp.) may be especially vulnerable to certain pathogens (e.g., *Biscogniauxia* spp., *Pythium* spp., *Phytophthora* spp.) as flooding promotes their spread while drought weakens trees and heightens susceptibility (Bergot et al. 2004; Balci et al. 2010; Sturrock et al. 2011; Corcobado 2014; Thompson et al. 2014; Haavik et al. 2015; Hubbart et al. 2016; Wood et al. 2018; Contreras-Cornejo et al. 2023).

Herbivory:

- Warmer winters are expected to increase deer survival rates and population growth across the Midwest (Felton and others, 2024; Weiskopf and others, 2019).
- Selective deer browsing, combined with climate change-driven stressors, may disrupt tree regeneration and shift community composition, particularly by limiting the persistence of browse-preferred species in floodplain forests (Champagne and others, 2021; Frerker and others, 2014; Henry and Walters, 2023; Novick and others, 2022; Patton and others, 2021).
- Regeneration failure due to browsing and summer drying may favor browse-resistant species (e.g., *Fagus grandifolia, Lonicera* spp*., Rhamnus cathartica, Vitis* spp.) and reduce the presence of species intolerant to both browsing and drought (e.g., *Acer saccharum*, *Nyssa sylvatica*) (Table 28) (Champagne and others, 2021; Frerker and others, 2014; Henry and Walters, 2023; Novick and others, 2022; Patton and others, 2021).

Table 27. Summary of the expected general influence of climate change on Central Interior-Great Lakes Flatwoods and Swamp Forest habitat species. Asterisks (*) denote species introduced to the region. Some species appear in contradictory columns (e.g., showing both negative and positive influences on distribution), reflecting conflicting findings in the literature.

Expected influence of climate change on species distributions		Hypothesized adaptive capacity and vulnerability to climate change	
Reduced extent or amount (–)	Increased extent or amount (+)	Low adaptive capacity or high vulnerability (–)	High adaptive capacity or low vulnerability (+)
Acer rubrum[1]	*Acer rubrum*[9]	*Acer saccharum*[12]	*Acer rubrum*[12]
Acer saccharum[1,2]	**Alliaria petiolata*[4]	*Fagus grandifolia*[1]	*Acer saccharum*[1]
Fagus grandifolia[3]	*Fagus grandifolia*[1]	*Quercus bicolor*[13]	*Fagus grandifolia*[12]
**Lysimachia nummularia*[4]	**Lonicera maackii*[4]	*Quercus ellipsoidalis*[13]	*Nyssa sylvatica*[1,13]
**Lythrum salicaria*[4]	*Nyssa sylvatica*[1]	*Quercus michauxii*[13]	*Quercus alba*[13]
**Phalaris arundinacea*[5]	*Quercus bicolor*[1]	*Quercus palustris*[1,13]	*Quercus macrocarpa*[13,14]
**Rhamnus cathartica*[4,6]	*Quercus ellipsoidalis*[1,10]	*Quercus shumardii*[13]	
Quercus alba[7,8]	*Quercus macrocarpa*[1,7,9]		
	Quercus michauxii[1]		
	Quercus palustris[7,10]		
	Quercus shumardii[1,7,10]		
	Ulmus rubra[7]		
	Vitis labrusca[11]		

[1]Peters and others (2020); [2]Bapikee (2013); [3]Philips and others (2020); [4]Evans and others (2024); [5]Kurtz (2010); [6]Bradley and others (2010); [7]Hanberry (2024); [8]Wang and others (2019); [9]Prasad and others (2020); [10]Rauschendorfer and others (2022); [11]Zhang and others (2024); [12]Royer-Tardif and others (2021); [13]Potter and others (2017); [14]Etterson and others (2020)

Table 28. Summary of impacts from key climate change stressors on Central Interior-Great Lakes Flatwoods and Swamp Forest habitat species.

Stressor	Impact	Effected species
Flooding	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer rubrum*[1,2]
		Nyssa sylvatica[3]
		Quercus macrocarpa[4]
		Quercus michauxii[5,6]
		Quercus palustris[7,8]
	When flood tolerance is high, increased abundance despite added stress	*Acer rubrum*[9–12]
		Quercus bicolor[9,11,13–16]
		Quercus michauxii[17]
		Quercus palustris[10,18]

Stressor	Impact	Effected species
	When flood tolerance is low, reduced growth rates and abundance and elevated mortality risk	*Acer saccharum*[2,9,10,16,19]
		Fagus grandifolia[10,20,21]
		Nyssa sylvatica[10]
		Quercus alba[10,22]
		Quercus ellipsoidalis[14,15]
		Quercus macrocarpa[4,10,15,16]
		Quercus shumardii[10]
		Ulmus rubra[10,23]
Summer drying	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer rubrum*[24–26]
		Acer saccharum[26]
		Nyssa sylvatica[25]
		Quercus shumardii[27]
	When drought tolerance is low, heightened susceptibility to disturbances, competitive exclusion, and mortality	*Acer rubrum*[10]
		Acer saccharum[10,28–32]
		Fagus grandifolia[10,30,33–35]
		Nyssa sylvatica[10,30]

[1]Ehrenfeld (2012); [2]Herrera-Bevan and Ibáñez (2024); [3]McCarron and others (1998); [4]Tang and Kozlowski (1982); [5]Angelov and others (1996); [6]Krinard and Johnson (1981); [7]Cline (2018); [8]Cosgriff and others (2007); [9]Keller and others (2023); [10]Niinemets and Vallardares (2006); [11]Palik and others (2021b); [12]Carpenter and Mitchell (1979); [13]De Jager and others (2012); [14]Gergel and others (2002); [15]Ingvalson and others (2020); [16]Keller and others (2024b); [17]Shankman and others (2012); [18]McQuilkin (1990); [19]Godman and Yawney (1990); [20]Geßler and others (2007); [21]Tubbs and Houston (1990) ; [22]Bell (1975); [23]Cooley and Van Sambeek (1990); [24]Ibanez and others (2017); [25]Ramage and others (2023); [26]Reich and others (2022); [27]Will and others (2013b); [28]Au and others (2020); [29]Maxwell (2024); [30]Peters and others (2015); [31]Randall and Walters (2019); [32]Stangler and others (2016); [33]Booth and others (2012); [34]Stephanson and Ribarik Coe (2017); [35]Burns (1990)

Focal Wildlife Species: Wood Frog

Wood frogs (*Lithobates sylvaticus*), like all amphibians, are extremely sensitive to climate change. Wood frogs have the northernmost range of any amphibian or reptile in North America, with populations in the upper Midwest representing the southern, non-mountainous edge of their distribution. Warmer winters are expected to shift breeding earlier (Sheridan and others, 2018), while potentially decreasing fecundity (Benard, 2015). If breeding occurs earlier due to warmer environmental cues, but bodies of water remain cold, larval development may slow (Benard, 2015), increasing depredation risk for larvae. Furthermore, variable and decreasing snowpack associated with warmer winters may decrease winter survival for this freeze-tolerant species (O'Connor and Rittenhouse, 2016). Shorter winters may lower winter energy expenditure in parts of its range, such as southern Wisconsin, while increasing it in Minnesota and northern Wisconsin, ultimately reducing survival and reproductive success in northern areas (Fitzpatrick and others, 2020).

Vernal pools within the Central Interior-Great Lakes Flatwoods and Swamp Forest habitat provide important habitats for wood frogs throughout the upper Midwest. These ephemeral wetlands, which

rely on precipitation, are particularly vulnerable to hydroperiod variability. Wood frogs require specific hydroperiods for reproducing – long enough for egg and larval development, but not so long as to sustain predatory fish or other frog species. While prolonged hydroperiods can increase tadpole survival by allowing more time for metamorphosis (Nagel and others, 2021), they may also support overwintering green frog larvae, which prey on wood frog eggs and larvae (Crump and Houlahan, 2017; Lent and Babbitt, 2020). Conversely, shorter hydroperiods punctuated by summer soil drying can cause reproductive failure, larval mortality, or reduced larval fitness due to early metamorphosis (Green and others, 2013; Nagel and others, 2021). These hydroperiod fluctuations may drive year-to-year population oscillations in wood frogs (Green and others, 2013).

Habitat management may prioritize identifying and maintaining pools with longer hydroperiods (Baldwin and others, 2006; Green and others, 2013). Management strategies may also include removal of invasive plant species like common buckthorn (*Rhamnus cathartica*), which can negatively impact wood frog persistence (Sacerdote, 2009).

Laurentian-Acadian Alkaline Swamp

The Laurentian-Acadian Alkaline Swamp habitat is a narrowly defined and ecologically distinct forested wetland habitat found across northern New England, southern Ontario and Quebec, and the upper Midwest, including northern Minnesota, Michigan, and Wisconsin (Figure 13) (Gawler and Drake, 2014). These wetlands are characterized by nutrient-rich, alkaline groundwater seepage and mineral soils, along with organic muck, and peat substrate. They occur along floodplains, shorelines, and topographical depressions, forming a complex and sensitive habitat with diverse species composition (Gawler and Drake, 2014; Slaughter and others, 2007). Hydrologic regimes play a critical role in these habitats, with groundwater seepage and seasonal inundation maintaining essential conditions for the characteristic vegetation (Gawler and Drake, 2014; Kost, 2001; Schwintzer and Tomberlin, 1982). Although flooding events and saturated soils are common, prolonged growing-season flooding can cause significant stress for many species in this habitat. While drought exposure is less frequent, it remains a significant stress. Dominant tree species reflect these hydrological requirements, favoring those tolerant of periodic inundation and soil moisture that fluctuates between wet and dry extremes.

Other natural disturbances also shape Laurentian-Acadian Alkaline Swamp habitat communities. Minor windthrow events are common due to shallow-rooting tree species and contribute to habitat heterogeneity and forest regeneration (Slaughter and others, 2007; Slaughter, 2009). Occasionally, catastrophic windthrow can cause near-complete canopy loss (Minnesota Department of Natural Resources, 2009b; Minnesota Department of Natural Resources, 2009a). Fire is infrequent but may occur during very dry periods (Gawler and Drake, 2014). The complex structure of these forested wetlands, including hummocks, hollows, and diverse vegetation layers**,** creates a mosaic of microhabitats that support a variety of wildlife species with high conservation value (Gawler and Drake, 2014; Slaughter, 2009). Today, these systems increasingly face threats from habitat fragmentation, altered hydrology, deer browse, and various pests and pathogens, including emerald ash borer (*Agrilus planipennis*) and eastern larch beetle (*Dendroctonus simplex*). Intact forests are primarily comprised of nine key dominant species (Table 29), though other non-dominant species also contribute to overall habitat diversity and function. In addition to the species listed below, invasive species include cattails (*Typha spp.*), common reed (*Phragmites australis*), glossy buckthorn (*Frangula alnus*), purple loosestrife (*Lythrum salicaria*), and reed canarygrass (*Phalaris arundinacea*).

Table 29. Plant species common to the Laurentian-Acadian Alkaline Swamp habitat. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (USDA, NRCS, 2025).

Species	Common name	Growth habit
Acer rubrum L.	Red maple	Tree
Betula alleghaniensis Britton	Yellow birch	Tree
Betula papyrifera Marshall	Paper birch	Tree
Fraxinus nigra Marshall	Black ash	Tree
Fraxinus pennsylvanica Marshall	Green ash	Tree
Larix laricina (Du Roi) K. Koch	Tamarack	Tree
Picea mariana (Mill.) Britton, Sterns & Poggenb.	Black spruce	Tree
Thuja occidentalis L.	Arborvitae	Tree
Tsuga canadensis (L.) Carrière	Eastern hemlock	Tree

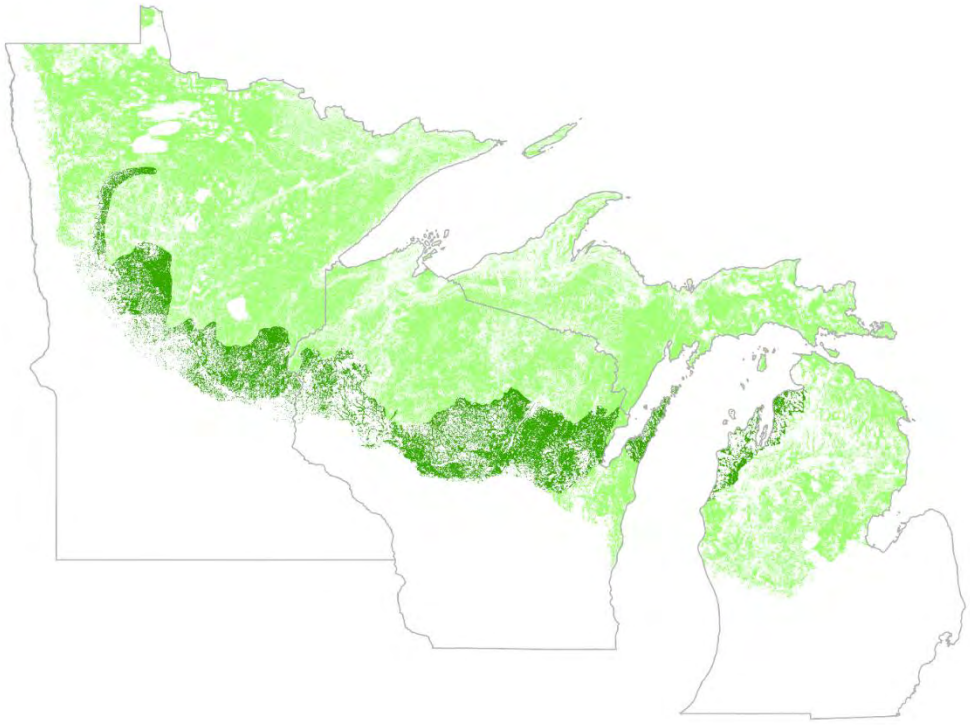

Figure 13. Laurentian-Acadian Alkaline Swamp habitat distribution. Geographic distribution of the Laurentian-Acadian Alkaline Swamp habitat (Group Code: G046) in the Midwest (USNVC, 2020). Dark green areas indicate Laurentian-Acadian Alkaline Swamp habitat in the Mixed Wood Plains ecoregion, while light green areas mark additional locations throughout the Midwest. Polygon boundaries have been enlarged to enhance visibility and do not reflect true proportions.

Overview of Climate Projections

The Laurentian-Acadian Alkaline Swamp habitat is prioritized for the Mixed Wood Plains ecoregion, and climate projections for this area largely reflect regional trends. Both average and extreme temperatures are expected to rise throughout the coming century (Table 30) (Clarke and others, 2022; Marvel and others, 2023; Masson-Delmotte and others, 2021). Most models also project an increase in precipitation, although a few indicate a slight decrease (Table 31) (Marvel and others, 2023). Additionally, precipitation patterns are anticipated to shift towards more extreme events and greater seasonal variability, with notably wetter springs (Dollan and others, 2022; Marvel and others, 2023).

Table 30. Projected changes in annual temperature in the Mixed Wood Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual mean temperature (°F) by mid- (2040-2069) and end of the century (2070-2099), as well as the absolute change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected temperature under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	43.7 °F	46.4 °F (2.7)	47.4 °F (3.7)	47.3 °F (3.6)	50.1 °F (6.5)
Mean of models	43.7 °F	48.9 °F (5.2)	50.5 °F (6.8)	50.0 °F (6.3)	54.6 °F (10.9)
Maximum model	43.9 °F	51.9 °F (8.0)	53.4 °F (9.5)	53.6 °F (9.7)	59.1 °F (15.2)

Table 31. Projected changes in annual precipitation in the Mixed Wood Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected annual precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected precipitation under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	30.3 in	30.7 in (1%)	29.7 in (-2%)	32.2 in (6%)	28.8 in (-5%)
Mean of models	30.1 in	32.0 in (6%)	32.1 in (7%)	31.9 in (6%)	32.7 in (9%)
Maximum model	30.2 in	33.7 in (11%)	33.5 in (11%)	33.1 in (9%)	36.0 in (19%)

Key Climate Change Stressors

Summer drying. Across the Mixed Wood Plains ecoregion, summer vapor pressure deficit (VPD) is projected to increase by approximately 72% by the end of the century (Table 32), with values remaining relatively consistent throughout the region and slightly higher in the southern portion, especially around the Minnesota-Wisconsin border (Figure 14). Spring precipitation is expected to increase by approximately 25% (Table 33), with areas projected to have the highest summer VPD also receiving the most precipitation during spring (Figure 15). Despite overall precipitation increases, heightened precipitation variability, combined with rising temperatures and VPD, is expected to drive more extreme swings between wet and dry periods, such as above-average spring precipitation followed by prolonged summer drying. These shifts will likely exacerbate flood-drought cycles, intensify soil moisture deficits, and increase physiological stress for plants during summer months.

Table 32. Projected changes in summer vapor pressure deficit in the Mixed Wood Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected summer vapor pressure deficit (VPD; kilopascals) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected VPD under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	0.91 kPa	0.88 kPa (-3%)	0.91 kPa (0%)	1.00 kPa (9%)	1.07 kPa (18%)
Mean of models	0.95 kPa	1.20 kPa (26%)	1.32 kPa (38%)	1.30 kPa (36%)	1.64 kPa (72%)
Maximum model	0.98 kPa	1.42 kPa (45%)	1.62 kPa (65%)	1.73 kPa (77%)	2.42 kPa (147%)

Table 33. Projected changes in spring precipitation in the Mixed Wood Plains ecoregion. Projections use data obtained via the Climate Toolbox Climate Mapper (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971-2000) and projected spring precipitation (inches) by mid- (2040-2069) and end of the century (2070-2099), as well as the percent change relative to the historical value (in parentheses), for each emissions scenario. To capture variation across climate models, models with the lowest (minimum model) and highest (maximum model) projected VPD under RCP 8.5 are presented in addition to the mean of all models.

	1971–2000	2040–2069		2070–2099	
	Historical	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Minimum model	7.3 in	8.0 in (10%)	8.2 in (13%)	8.9 in (22%)	8.1 in (11%)
Mean of models	7.7 in	8.6 in (12%)	9.0 in (16%)	8.8 in (14%)	9.7 in (25%)
Maximum model	7.7 in	9.7 in (26%)	9.2 in (20%)	9.4 in (22%)	11.3 in (47%)

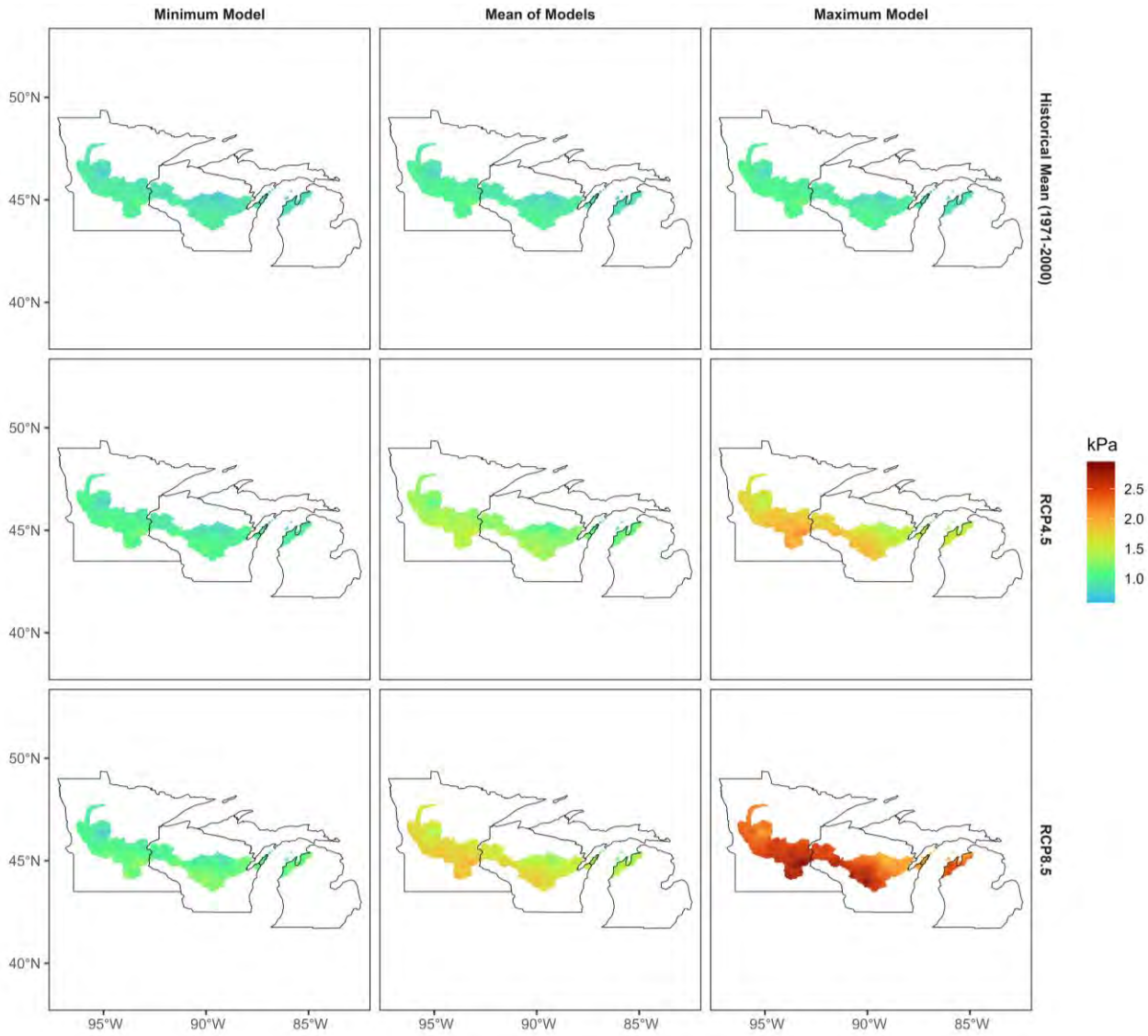

Figure 14. Projected changes in summer vapor pressure deficit in the Mixed Wood Plains ecoregion. Projections gridded climate data obtained via the Climate Toolbox Climate Mapper at a 4-km resolution (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971–2000, top row) and projected (2070–2099) summer vapor pressure deficit (VPD; kilopascals) for each emissions scenario (RCP 4.5, middle row; RCP 8.5, bottom row). To capture variation across climate models, models with the lowest (minimum model, left column) and highest (maximum model, right column) projected VPD under RCP 8.5 are presented in addition to the mean of all models (middle column).

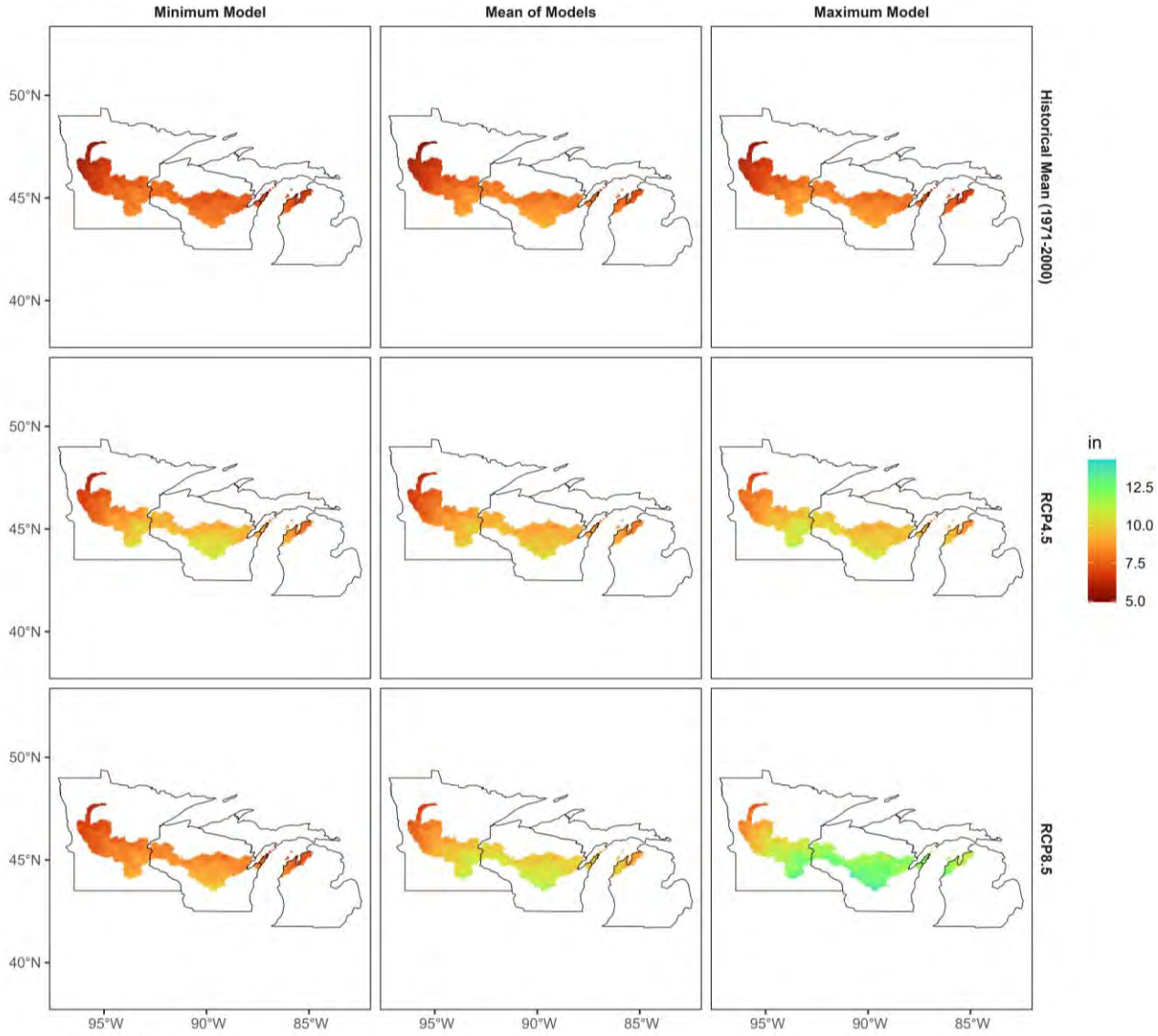

Figure 15. Projected changes in spring precipitation in the Mixed Wood Plains ecoregion. Projections gridded climate data obtained via the Climate Toolbox Climate Mapper at a 4-km resolution (Hegewisch and Abatzoglou, 2024) based on 20 CMIP5 climate models downscaled using MACAv2-METDATA for moderate- and high-emissions (RCP 4.5 and 8.5) scenarios (Abatzoglou, 2013; Abatzoglou and Brown, 2012). Values show average historical (1971–2000, top row) and projected (2070–2099) spring precipitation (inches) for each emissions scenario (RCP 4.5, middle row; RCP 8.5, bottom row). To capture variation across climate models, models with the lowest (minimum model, left column) and highest (maximum model, right column) projected VPD under RCP 8.5 are presented in addition to the mean of all models (middle column).

Key Climate Change Impacts

This section summarizes how climate change is impacting the Central Interior-Great Lakes Flatwoods and Swamp Forest habitat. It covers both the overall influence on species distributions, adaptive capacity, and vulnerability (Table 34) and the specific effects of flooding and summer drying (Table 35). The bullet points below provide a concise overview of these impacts on habitat structure, community composition, invasive species, pests and pathogens, and herbivory.

Habitat structure:

- More frequent flood-drought cycles may alter biogeochemical, microbial, decomposition, and nutrient cycling processes, negatively impacting wetland plants, invertebrates, and other species adapted to specific habitat conditions (Mortsch and others, 2003; Staffen and others, 2019; Trettin and others, 2019).
- Rising wildfire intensity and frequency, driven by climate change and increased fuel loads, may elevate fire risk, particularly as higher summer VPD lowers water tables and dries sphagnum peat layers, increasing flammability and fire severity (Apfelbaum and others, 2023; Galatowitsch and others, 2009; Staffen and others, 2019; Sutheimer and others, 2023; USDA Forest Service, USA and others, 2019).
- Windthrow events, while contributing to habitat heterogeneity, may become more frequent and severe as frozen-soil periods shorten, increased flooding stress, and as heightened pathogen and pest pressure collectively weaken trees and elevate their vulnerability to windthrow (Poling and others, 2016; Roberts, 2004; Stanturf and others, 2024; Vogt and others, 2020).

Community composition:

- Projections indicate that rising spring precipitation, followed by increased summer VPD, could intensify flood-drought cycles, leading to considerable impacts to the plant community (Table 31; 32).
- Many key species may lose suitable habitat, as they are already near the southern extent of their range and have heightened vulnerability and limited adaptive capacity, making them especially at risk from climate change (e.g., *Larix laricina*, *Picea mariana*) (Table 34).
- Increasing summer VPD may heighten the risk of mortality and regeneration failure, particularly for seeds, seedlings, saplings, and juvenile trees, potentially shifting species composition toward more flood-tolerant species and resulting in more homogeneous age and size-class stands (Table 35).
- Intensified flood-drought cycles, driven by rising spring precipitation and increased summer VPD, may favor species tolerant of both flooding and drought, potentially accelerating ecological transformation due to the limited availability of such species currently in this system (Table 35).

Invasive species:

- Flooding disturbances may promote invasive species spread by facilitating dispersal and creating empty ecological niches that these species can rapidly capitalize on (e.g., *Lythrum salicaria*, *Phalaris arundinacea*, *Phragmites australis*, *Typha* spp.) (Budelsky and Galatowitsch, 2004; Havrdová and others, 2023; Munger, 2002; O'Briain and others, 2023; Reinartz and Kroeger, 1982; Youngquist and others, 2020).

Pests and pathogens:

- Climate change is expected to amplify pest and pathogen pressure by directly increasing pest and pathogen populations and indirectly by heightening host susceptibility (Dukes and others, 2009; Stanturf and others, 2024; Sturrock and others, 2011; Teshome and others, 2020; Vose and others, 2013).

- Introduced and native pests and pathogens alike may become more prevalent as climate change facilitates their spread into the Midwest (e.g., eastern larch beetle (*Dendroctonus simplex*), eastern spruce budworm (*Choristoneura fumiferana*), hemlock woolly adelgid (*Adelges tsugae*), root rot (*Armillaria* spp., *Pythium* spp.)) (Cheah, 2017; Ellison and others, 2018; Hepting, 1971; Johnston, 1990b; McKee and others, 2022; Palik and others, 2021a; Ren and others, 2020).
- Increased heatwaves, phenological mismatches, and other climate change impacts may reduce the impact of some pests and pathogens (e.g., spongy moth (*Lymantria dispar*), forest tent caterpillar (*Malacosoma disstria*)) (Banahene and others, 2018; Schwartzberg and others, 2014).

Herbivory:

- Warmer winters are expected to increase deer survival rates and population growth across the Midwest (Felton and others, 2024; Weiskopf and others, 2019).
- Selective deer browsing, combined with climate change-driven stressors, may disrupt tree regeneration and shift community composition, particularly by limiting the persistence of browse-preferred species in floodplain habitats (Champagne and others, 2021; Frerker and others, 2014; Henry and Walters, 2023; Novick and others, 2022; Patton and others, 2021).
- Regeneration failure due to browsing and summer drying may favor browse-resistant species (e.g., *Fraxinus pennsylvanica*, *Picea mariana*) and reduce the presence of species intolerant to both browsing and drought (e.g., *Acer rubrum*, *Tsuga canadensis*) (Table 34) (Bradshaw and Waller, 2016; Cogger and others, 2014; De Jager and others, 2013a; Henry and Walters, 2023; Patton and others, 2021; Pike, 2022; Pike and Haase, 2024; White, 2012).

Table 34. Summary of the expected general influence of climate change on Laurentian-Acadian Alkaline Swamp habitat species. Asterisks (*) denote species introduced to the region. Some species appear in contradictory columns (e.g., showing both negative and positive influences on distribution), reflecting conflicting findings in the literature.

Expected influence of climate change on species distributions		Hypothesized adaptive capacity and vulnerability to climate change	
Reduced extent or amount (–)	Increased extent or amount (+)	Low adaptive capacity or high vulnerability (–)	High adaptive capacity or low vulnerability (+)
Acer rubrum[1]	*Acer rubrum*[2]	*Betula alleghaniensis*[1]	*Acer rubrum*[10]
Betula alleghaniensis[2]	*Betula alleghaniensis*[4]	*Betula papyrifera*[1]	*Betula alleghaniensis*[9,10]
Betula papyrifera[1,2]	*Betula papyrifera*[4]	*Fraxinus nigra*[9]	*Betula papyrifera*[9,10]
**Frangula alnus*[3]	*Fraxinus pennslyvanica*[1]	*Larix laricina*[1,9]	*Fraxinus pennsylvanica*[1,9]
Fraxinus nigra[4]	**Phalaris arundinacea*[8]	*Picea mariana*[9,10]	*Thuja occidentalis*[9]
Fraxinus pennslyvanica[4]	*Thuja occidentalis*[4]	*Thuja occidentalis*[10]	*Tsuga canadensis*[9]
**Lythrum salicaria*[5]		*Tsuga canadensis*[10]	
Picea mariana[1,2,6,7]			
Thuja occidentalis[1,2]			
Tsuga canadensis[1,2]			

[1]Peters and others (2020); [2]Prasad and others (2020); [3]Reinhardt and others (2020); [4]Hanberry (2024); [5]Evans and others (2024); [6]Boisvert-Marsh and Blois (2022); [7]Joyce and Rehfeldt (2017); [8]Kurtz (2010); [9]Potter and others (2017); [10]Royer-Tardif and others (2021)

Table 35. Summary of impacts from key climate change stressors on Laurentian-Acadian Alkaline Swamp habitat species.

Stressor	Impact	Effected Species
Flooding	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer rubrum*[1,2]
		Fraxinus pennsylvanica[3]
		Larix laricina[4]
	When flood tolerance is high, increased abundance despite added stress	*Acer rubrum*[5–8]
		Fraxinus nigra[6,9]
		Fraxinus pennsylvanica[6,10–17]
		Picea mariana[5,6,18]
		Tsuga canadensis[6]
	When flood tolerance is low, reduced growth rates and abundance and elevated mortality risk	*Betula alleghaniensis*[6,18]
		Larix laricina[18–23]
		Thuja occidentalis[6,22–24]
Summer drying	Loss of seed bank, germination failure, and/or sapling mortality impede regeneration	*Acer rubrum*[25–27]
		Betula alleghaniensis[28]
		Betula papyrifera[27]
		Larix laricina[4]
		Thuja occidentalis[29]
		Tsuga canadensis[30,31]
	When drought tolerance is low, heightened susceptibility to disturbances, competitive exclusion, and mortality	*Acer rubrum*[6]
		Betula papyrifera[6,32,33]
		Fraxinus nigra[6,33]
		Larix laricina[6,20,34]
		Picea mariana[6,33]
		Tsuga canadensis[6,33,35]

[1]Ehrenfeld (2012); [2]Herrera-Bevan and Ibáñez (2024); [3]Cosgriff and others (2007); [4]Johnston (1990b); [5]Keller and others (2023); [6]Niinemets and Vallardares (2006); [7]Palik and others (2021b); [8]Carpenter and Mitchell (1979); [9]Wright and Rauscher (1990); [10]Whitlow and Harris (1979); [11]Gergel and others (2002); [12]Ingvalson and others (2020); [13]Krinard and Johnson (1981); [14]Kroschel and King (2021); [15]Romano (2006); [16]Schindler and others (2020); [17]Kennedy (1990); [18]Keller and others (2024b); [19]Janowiak and others (2014); [20]Olson and others (2021); [21]Stelling and others (2023); [22]Denyer and Riley (1964); [23]Walters and others (2023); [24]Peters and others (2020); [25]Ibanez and others (2017); [26]Ramage and others (2023); [27]Reich and others (2022); [28]Erdmann (1990); [29]Johnston (1990a) ; [30]Goerlich and Nyland (1980); [31]Godman and Lancaster (1990); [32]Perillo (2017); [33]Peters and others (2015); [34]Mamet and others (2019); [35]Shuman and others (2019)

Focal Wildlife Species: Zigzag Darner

The zigzag darner (*Aeshna sitchensis*) is a boreal species of Odonata (dragonflies and damselflies) found in northern Minnesota, Wisconsin, and Michigan (DuBois and others, 2004). While little is known about

the direct effects of climate change on zigzag darners, research on other Odonata species has documented climate-driven changes such as advanced phenology, altered development time, pigmentation changes, behavioral adjustments in time spent basking and other activities, and shifts in geographic distribution (Hassall and Thompson, 2008; Zeuss and others, 2014). Additionally, higher temperatures may increase Odonata sensitivity to environmental stressors, including insecticides and other pollutants (Ishiwaka and others, 2024; Sirois-Delisle and Kerr, 2022). As generalist aquatic predators, larval Odonata are unlikely to be directly affected by changes in prey phenology (Hassall and Thompson, 2008). However, rising temperatures may alter their ability to capture prey. One study found that at higher temperatures, zigzag darner larvae showed decreased activity, while their prey, wood frog (*Lithobates sylvaticus*) tadpoles, became more active (Hayden and others, 2015).

Zigzag darners breed in cool-water bogs and fens with little to no emergent vegetation. In the Great Lakes region, these habitats are vulnerable to climate-driven changes in water temperature, ice-cover, and water-level fluctuations (DuBois and others, 2004; DuBois and others, 2018; Magee and others, 2021). This species prefers small pools that often dry during summer (DuBois and others, 2004). However, increasing rainfall variability, with cycles of drought and deluge, may lead to more frequent early drying or pool connections to larger water bodies, reducing suitable breeding habitat. Maintaining and restoring boreal, cool-water bogs and fens will be essential to zigzag darner persistence under warming temperatures and variable precipitation patterns. Additionally, because warming temperatures often amplify other environmental stressors, management strategies may include reducing exposure to toxins, such as insecticides (Ishiwaka and others, 2024) and copper (Hayden and others, 2015).

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Appendix 1

Table ii. Tree species common to the Temperate Flooded and Swamp Forest ecosystem ecosystem. Key species were identified using USNVC floristic descriptions (USNVC, 2020), filtered by associations occurring within the Midwest that collectively comprise the Temperate Flooded and Swamp Forest ecosystem. Asterisks (*) denote species introduced to the region. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (USDA, NRCS, 2025).

Species	Common name	Growth habit	Midwest Floodplain Forest	South Central-Appalachian-Northeast Floodplain Forest	Bald-cypress-Tupelo Floodplain Forest	Central Interior-Great Lakes Flatwoods and Swamp Forest	Laurentian-Acadian Alkaline Swamp
Acer rubrum L.	Red maple	Tree			×	×	×
Acer saccharinum L.	Silver maple	Tree	×	×		×	
Acer saccharum Marshall	Sugar maple	Shrub, tree	×				
Asimina triloba (L.) Dunal	Pawpaw	Shrub, tree	×				
Betula alleghaniensis Britton	Yellow birch	Tree					×
Betula nigra L.	River birch	Tree	×	×			
Betula papyrifera Marshall	Paper birch	Tree					×
Carya cordiformis (Wangenh.) K. Koch	Bitternut hickory	Tree	×				
Carya illinoinensis (Wangenh.) K. Koch	Pecan	Tree		×			
Celtis laevigata Willd.	Sugarberry	Shrub, tree		×			
Celtis occidentalis L.	Common hackberry	Shrub, tree	×	×			
Cornus foemina Mill.	Stiff dogwood	Shrub, tree			×		
Fagus grandifolia Ehrh.	American beech	Tree	×			×	
Forestiera acuminata (Michx.) Poir.	Eastern swampprivet	Shrub, tree		×			
Fraxinus nigra Marshall	Black ash	Tree					×
Fraxinus pennsylvanica Marshall	Green ash	Tree	×	×			×

Species	Common name	Growth habit	Midwest Floodplain Forest	South Central-Appalachian-Northeast Floodplain Forest	Bald-cypress-Tupelo Floodplain Forest	Central Interior-Great Lakes Flatwoods and Swamp Forest	Laurentian-Acadian Alkaline Swamp
Fraxinus profunda (bush) Bush	Pumpkin ash	Tree			×		
Itea virginica L.	Virginia sweetspire	Shrub			×		
Ilex decidua Walter	Possumhaw	Shrub, tree		×			
Larix laricina (Du Roi) K. Koch	Tamarack	Tree					×
Liquidambar styraciflua L.	Sweetgum	Tree			×		
Liriodendron tulipifera L.	Tuliptree	Tree	×				
Nyssa aquatica L.	Water tupelo	Tree			×	×	
Picea mariana (Mill.) Britton, Sterns & Poggenb.	Black spruce	Tree					×
Platanus occidentalis L.	American sycamore	Tree	×	×			
Populus deltoides W. Bartram ex Marshall	Eastern cottonwood	Tree	×				
Populus heterophylla L.	Swamp cottonwood	Tree			×		
Quercus alba L.	White oak	Tree				×	
Quercus bicolor Willd.	Swamp white oak	Tree	×			×	
Quercus ellipsoidalis E.J. Hill	Northern pin oak	Tree				×	
Quercus macrocarpa Michx.	Bur oak	Shrub, tree	×	×		×	
Quercus michauxii Nutt.	Swamp chestnut oak	Tree				×	
Quercus palustris Münchh.	Pin oak	Tree			×	×	
Quercus shumardii Buckley	Shumard's oak	Shrub, tree	×			×	
**Rosa multiflora* Thunb.	Multiflora rose	Shrub, vine	×				
Salix nigra Marshall	Black willow	Tree	×	×	×	×	
Taxodium distichum (L.) Rich.	Bald cypress	Tree			×		

Species	Common name	Growth habit	Midwest Floodplain Forest	South Central-Appalachian-Northeast Floodplain Forest	Bald-cypress-Tupelo Floodplain Forest	Central Interior-Great Lakes Flatwoods and Swamp Forest	Laurentian-Acadian Alkaline Swamp
Thuja occidentalis L.	Arborvitae	Tree					×
Tilia americana L.	American basswood	Tree	×				
Tsuga canadensis (L.) Carrière	Eastern hemlock	Tree					×
Ulmus americana L.	American elm	Tree	×	×		×	

Table iii. Non-tree species common to the Temperate Flooded and Swamp Forest ecosystem. Key species were identified using USNVC floristic descriptions (USNVC, 2020), filtered by associations occurring within the Midwest that collectively comprise the Temperate Flooded and Swamp Forest ecosystem. Asterisks (*) denote species introduced to the region. Taxonomic authority, common name, growth habit, and native status are determined according to the PLANTS Database (USDA, NRCS, 2025).

Species	Common name	Growth habit	Midwest Floodplain Forest	South Central-Appalachian-Northeast Floodplain Forest	Bald-cypress-Tupelo Floodplain Forest	Central Interior-Great Lakes Flatwoods and Swamp Forest	Laurentian-Acadian Alkaline Swamp
**Alliaria petiolata* (M. Bieb.) Cavara & Grande	Garlic mustard	Forb/herb	×				
Arthraxon hispidus (Thunb.) Makino*	Small carpetgrass	Graminoid			×		
Boehmeria cylindrica (L.) Sw.	Smallspike false nettle	Forb/herb		×			
Carex L.†	Sedge	Forb/herb, graminoid		×	×		
Eichhornia crassipes (Mart.) Solms*	Common water hyacinth	Forb/herb			×		
Elymus virginicus L.	Virginia wildrye	Graminoid	×				
Galium L.†	Bedstraw	Forb/herb, shrub, vine		×			
Glyceria R. Br.†	Mannagrass	Graminoid			×		
Impatiens capensis Meerb.	Jewelweed	Forb/herb		×	×		
Impatiens pallida Nutt.	Pale touch-me-not	Forb/herb		×			
Laportea canadensis (L.) Weddell	Canadian woodnettle	Forb/herb	×	×			
Leersia oryzoides (L.) Sw.	Rice cutgrass	Graminoid			×		
Leersia Sw.	Cutgrass	Graminoid		×	×		
**Lysimachia nummularia* L.	Creeping jenny	Forb/herb	×				
Microstegium vimineum (Trin.) A. Camus *	Nepalese browntop	Graminoid			×		
Pilea pumila (L.) A. Gray	Canadian clearweed	Forb/herb		×			

Species	Common name	Growth habit	Midwest Floodplain Forest	South Central-Appalachian-Northeast Floodplain Forest	Bald-cypress-Tupelo Floodplain Forest	Central Interior-Great Lakes Flatwoods and Swamp Forest	Laurentian-Acadian Alkaline Swamp
Polygonum punctatum Elliott	Dotted smartweed	Forb/herb			×		
Polygonum sagittatum L.	Arrowleaf tearthumb	Forb/herb, vine			×		
Viola L.†	Violet	Forb/herb, shrub		×			
Vitis labrusca L.	Fox grape	Vine				×	

Appendix 2

Climate projections are derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and include model outputs from 20 unique models.

CMIP5 Models:

- bcc-csm1-1
- bcc-csm1-1-m
- CNRM-CM5
- CSIRO-Mk3-6-0
- GFDL-ESM2M
- HadGEM2-CC365
- HadGEM2-ES365
- inmcm4
- IPSL-CM5A-LR
- PSL-CM5A-MR
- MIROC5
- MIROC-ESM
- MIROC-ESM-CHEM
- MRI-CGCM3
- NorESM1-M
- IPSL-CM5B-LR
- CanESM2
- CCSM4
- GFDL-ESM2G
- BNU-ESM

To capture variation across CMIP5 climate models, models with the lowest (minimum model) and highest (maximum model) projected values under the RCP8.5 scenario are presented in addition to the mean of all models. Table vi includes a list of all minimum and maximum models selected for each region and climate variable.

Table vi. Climate Projection Minimum and Maximum Models. For each region and climate variable, minimum and maximum models were determined by averaging the each climate variable projection for RCP8.5 end of the century (2070–2099) scenario across each region.

Ecoregion	Climate Variable	Season	Minimum Model	Maximum Model
Central Plains	Precipitation	Annual	IPSL-CM5A-MR	CSIRO-Mk3-6-0
Mixed Wood Plains	Precipitation	Annual	IPSL-CM5A-MR	GFDL-ESM2M
Interior Plateau	Precipitation	Annual	IPSL-CM5A-MR	IPSL-CM5B-LR
Central Plains	Precipitation	Spring	IPSL-CM5A-LR	CSIRO-Mk3-6-0
Mixed Wood Plains	Precipitation	Spring	IPSL-CM5B-LR	MIROC-ESM
Central Plains	Mean Temperature	Annual	MRI-CGCM3	HadGEM2-CC365
Interior Plateau	Mean Temperature	Annual	MRI-CGCM3	HadGEM2-CC365
Mixed Wood Plains	Mean Temperature	Annual	MRI-CGCM3	MIROC-ESM-CHEM
Midwest Region	Vapor Pressure Deficit	Annual	MRI-CGCM3	HadGEM2-CC365
Mixed Wood Plains	Vapor Pressure Deficit	Summer	GFDL-ESM2G	HadGEM2-CC365
Central Plains	Vapor Pressure Deficit	Summer	MRI-CGCM3	HadGEM2-CC365
Interior Plateau	Vapor Pressure Deficit	Summer	MRI-CGCM3	HadGEM2-CC365
Central Plains	Mean Temperature	Annual	MRI-CGCM3	HadGEM2-CC365