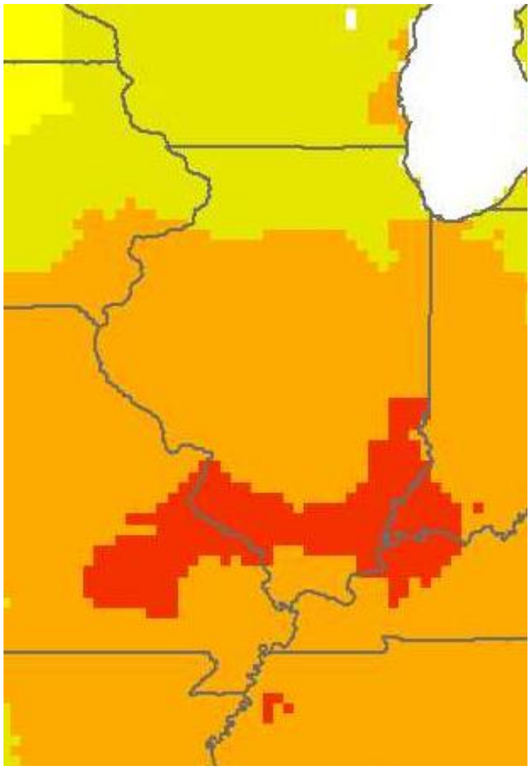
Adapting Conservation to a Changing Climate:
An Update to the Illinois Wildlife Action Plan



Partial map of projected net-drying conditions in Illinois by mid-century; www.climatewizard.org

Report to the Illinois Department of Natural Resources

Contract TNC10WAP

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EXECUTIVE SUMMARY

Since the first iteration of the Illinois Wildlife Action was developed in 2005 (Illinois Department of Natural Resources 2005), considerably more information on the potential threat of global climate change to natural and human systems has become available (e.g., International Panel on Climate Change 2007). In Illinois, the most profound effects of climate change are likely to be dangerous summer heat, a longer growing season, more flooding due to increased winter and spring rainfall in events >2 inches/day, increased summer drought, and lowered water levels in Lake Michigan (Union of Concerned Scientists 2009).

Over the same period, strategies to increase resilience, increase adaptive capacity, and mitigate the effects of climate change have emerged, and continue to evolve rapidly (Game et al. 2010, Groves et al. 2010, Hansen et al. 2010, Heller and Zavaleta 2009). In 2009, the Illinois Department of Natural Resources initiated a process to incorporate climate change considerations into the Illinois Wildlife Action Plan. This project had four explicit objectives:

1. Conduct a climate vulnerability assessment of Species in Greatest Need of Conservation and major habitat types.
2. Identify conservation strategies that increase resilience or adaptive capacity, or mitigate the effects of climate change.
3. Outline an adaptive management approach for informing management decisions.
4. Recommend changes to existing monitoring programs and identify research needs.

This report is presented in a format corresponding to the Illinois Wildlife Action Plan to facilitate cross-walking information, and facilitate integration of climate change considerations into the Wildlife Action Plan during a formal update and revision process.

We employed the NatureServe *Climate Change Vulnerability Index*, Version 2.01 (Young et al. 2010) to evaluate a subset of Species in Greatest Need of Conservation. This index accepts input on up to 29 factors relating to the exposure, sensitivity, and adaptive capacity of species and returns a rating of the relative vulnerability of a species in the assessment area. By grouping species by their relative risk and sensitivity factors, the index helps to identify adaptation strategies most likely to benefit several species.

A critical caveat to using the NatureServe *Climate Change Vulnerability Index* is that the results **ONLY** consider the specific threat of climate change to a particular species in a geographic area, and are not a complete assessment of *all* the threats affecting that species in that area. In reality, climate change is best thought of as a “threat multiplier” (CNA Corporation 2007): a population threatened by habitat loss will be further stressed by inability to disperse and track suitable conditions. A population with low genetic diversity is less likely to successfully experience microevolutionary adaptation to changing conditions. Climate change will have complex interactions with hydrology, fire, water chemistry, toxicity and other abiotic factors, and may disrupt predator/prey, disease/host, competition, mutualisms, and other interspecific interactions.

Increased temperature and more variable precipitation probably will negatively affect some native species while favoring other non-native invasive species. Higher elevation or poleward range shifts have been forecast for many groups, including trees (Iverson et al. 2005) and birds (Matthews et al. 2004). In Illinois, fragmented habitat conditions and the long distances that must be crossed to track relatively small changes in climate envelopes will further threaten many populations.

We assessed the climate change vulnerability of 162 Species in Greatest Need of Conservation. Because many species were assessed for >1 natural division or watershed, 584 assessments were completed. High proportions of mollusks and fishes were rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change. Intermediate numbers of insects and amphibians were rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change. Few birds and mammals were rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change. However, we evaluated climate change vulnerability only for conditions within Illinois, and long-distance migratory species (e.g., many birds and bats)likely face additional, complex vulnerabilities along their migratory routes.

Climate change poses several specific challenges to the major habitat types of Illinois. The Union of Concerned Scientists (2009) outlined a number of changes likely to affect Illinois by the middle and end of the 21st century, including dangerous summer heat, more flooding and drought, lower water levels in lakes and reservoirs, and a growing season up to 6 weeks longer. In addition to these changes, the Midwestern United States will become more fire-prone under all scenarios considered. All of these changes will favor species that can quickly adapt to changes in local conditions. "Climate winners" will likely have the characteristics of short generation times, high fecundity and rapid dispersal – also characteristics of many species labeled "invasive" by conservationists. By contrast, species with long generation times, low fecundity and low dispersal will be most challenged by climate change, and these challenges will be amplified by habitat fragmentation/isolation and small population size/lack of genetic diversity.

Because of the scope, potential severity, and high uncertainty of global climate change, it may be tempting to ignore the threat until clarity emerges on actions or outcomes. In reality, coping with climate change is not fundamentally different from traditional conservation biology: a 'crisis discipline,' where decisions must be made and actions taken with incomplete information, and adaptive management is especially important for refining actions as knowledge is acquired and circumstances change.

Climate change is underway, generally proceeding faster than projected, and global emissions are equal or greater than 'high emissions scenarios' used in models. This reality challenges us to move into a new conservation paradigm. The old model – spatial, static and status quo – needs to be reinvented into temporal, kinetic and forward-thinking conservation and resource management (Hansen and Hoffman 2011). Range shifts of species will complicate traditional place-based strategies like protected reserves, and managing for historical reference conditions or ranges of variation may not be, or soon will not be, practical or possible.

Hansen et al. (2010) devised four basic tenets for "climate-smart conservation":

1) Protect adequate and appropriate space;
2) Reduce non-climate stresses;
3) Use adaptive management to implement and test climate-change adaptation strategies; and
4) Reduce the rate and extent of climate change to reduce overall risk.

The first two tenets reflect resilience-building, "no regrets" actions based on the precautionary principle and already part of ongoing conservation actions: increasing the size and genetic diversity of small populations, protecting large core areas for viable populations, restoring and enhancing ecological connectivity, maintaining restoring natural patterns of ecological drivers like fire and hydrology, and reducing invasive species, pollutants, and unsustainable harvests. Other resilience strategies are more informed by climate change expectations, such as ensuring a variety of slopes, aspects, soil types and abiotic features are included within protected areas so that species are more likely to find suitable microclimates. Transformation strategies that support system changes to an altered state based on predicted future conditions are considerably more controversial. “Pre-adapting” restorations to expected future conditions by selecting seed sources or species located south of the area to be restored and assisted migration are examples of more risk-tolerant transformation actions.

Most climate scientists agree that there is sufficient carbon dioxide in the atmosphere that some climate change over the next century or longer is assured (International Panel on Climate Change 2007), thus adaptation is essential. By contrast, if emissions continue at high levels for extended periods, resilience strategies will be overwhelmed by the degree of climate change, and system transformations will be unavoidable. Emissions reductions will primarily be achieved through policy changes. In Illinois, renewable energy standards are aimed at least in part towards reducing greenhouse gas emissions, and have contributed towards expansions of wind energy developments and biofuels, with some adverse effects on wildlife and natural resources. If a market is established for carbon dioxide or other greenhouse gases, not only would an economic cost be associated with emissions, but an economic benefit could be accrued by removing carbon dioxide from the atmosphere and sequestering it soils and biomass. Some voluntary markets and standards are already in existence, and assign credits to restoration of grassland and forest (e.g., Voluntary Carbon Standard 2008).

Climate change also creates a number of different research and monitoring needs. Our use of the NatureServe *Climate Change Vulnerability Index* appeared to show sensitivity to factors related to species dispersal, and increasing ‘connectivity’ is the most frequently advised climate-adaptation strategy (Hanson and Hoffman 2011, Heller and Zavaleta 2009, Hodgson et al. 2009). Research is necessary to better understand the dispersal abilities and constraints of terrestrial and aquatic species in fragmented systems, and to understand when corridors are necessary and might be successful.

Range shifts, altered conditions, and changing community composition will set the stage for invasive species to be even more problematic in the future. Distinguishing between native species that are expanding their ranges and changes in community composition will challenge managers to identify “invasive” species.

Baseline data on water flows, withdrawal and discharge, and models of flows necessary to sustain aquatic communities are needed to anticipate changes and manage lakes and streams as climate change alters precipitation patterns and increases human demand for water (including municipal, agricultural and industrial uses). Water quality standards to protect aquatic life should be re-evaluated in the context of anticipated conditions. Increased temperature, lower dissolved oxygen, and lower pH may interact in complex ways to change the toxicity of various pollutants.

Current models of changes in species distributions are relatively simplistic, based on current and projected climate conditions. Tools that help managers better understand potential changes in native on nonnative species distributions based on factors including current and anticipated land use, soil types, and geophysical conditions as well as current and projected climate conditions may be particularly helpful for targeting conservation efforts.

While recommended strategies to adapt to and mitigate for climate change have proliferated in recent years, many of these strategies are still being (or are not yet) deployed, and to date there is very little data evaluating their costs, benefits, and relative effectiveness. As such, an adaptive management approach that treats natural resource management with an experimental design will be necessary to ensure actions are working towards reaching measureable objectives.

In the interest of balancing effort devoted to monitoring versus acting, an audit of monitoring programs and their relevance to an adaptive management framework is warranted. Monitoring activities that do not inform management decisions and data that are not analyzed and utilized are wasted effort. Similarly, actions that are undertaken without monitoring component may or may not be effective in reaching the objective. The Critical Trends Assessment Program (CTAP) is the most widespread, comprehensive natural resource monitoring program underway in Illinois, with a moderate historical baseline and scalable protocol. The CTAP has tremendous potential to provide evaluation data to inform management decisions, including climate change adaptation actions.

A few key patterns are apparent among the natural divisions and watersheds of Illinois, in the context of climate change vulnerabilities and opportunities. Northern Illinois tends to host a number of Species in Greatest Need of Conservation at the southern edge of their range in the Great Lakes, in both recently glaciated and unglaciated sections, whereas far southern Illinois has a number of Species in Greatest Need of Conservation at the northern edges of their ranges in the Ozarks, Shawnee Hills, and Coastal Plain natural divisions. As such, relatively more losses in northern Illinois and range expansions in southern Illinois of Species in Greatest Need of Conservation may be expected from climate change.

Among natural divisions, the Wisconsin Driftless, Ozarks and Shawnee Hills have the greatest proportions of natural land cover and greater topographic diversity, so these will be the most likely ‘climate refugia’ in the state. Similarly, the large rivers – the Mississippi, Ohio, Wabash and Illinois – are more likely to be buffered from the larger changes in temperature and variations in flows experienced in smaller tributaries and headwater streams.

The large rivers of Illinois, and the natural divisions lying along them, are staged to be important corridors for species migrations. As such, minimizing additional barriers in these regions has high importance. Navigation locks on the large rivers – with the Wabash being the biologically richest and a noteworthy exception – probably are partial barriers to some species, and rivers and larger streams are laterally isolated from side channels, backwaters and floodplains by levees in many areas.

Other natural divisions and watersheds are more heavily altered. As examples, the large dams and reservoirs on the Kaskaskia River at Carlyle and Shelbyville, and expanses of ‘corn-soybean desert’ in the Grand Prairie natural division are probably formidable barriers to dispersal of many species. Other changes in land use, such as perennial biomass crops in floodplains and on marginal soils and changes in development patterns, may provide unexpected opportunities for wildlife conservation in response to climate change.

ACKNOWLEDGEMENTS

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INTRODUCTION

Since the first iteration of the Illinois Wildlife Action Plan was developed in 2005 (Illinois Department of Natural Resources 2005), considerably more information on potential threat of global climate change to natural and human systems has become available (e.g., International Panel on Climate Change 2007). These developments include further refinement to global climate change models, climate projections downscaled to regions, and likely effects of climate change on agriculture, human communities, ecosystems and biodiversity. In Illinois, the most profound effects of climate change are likely to be dangerous summer heat, a longer growing season, more flooding due to increased winter and spring rainfall in events >2 inches/day, increased summer drought, and lowered water levels in Lake Michigan (Union of Concerned Scientists 2009).

Over the same period, strategies to increase resilience, increase adaptive capacity, and mitigate the effects of climate change have emerged, and continue to evolve rapidly (Game et al. 2010, Groves et al. 2010, Hansen et al. 2010, Heller and Zavaleta 2009). Climate change adaptation and mitigation strategies have recently been incorporated into the work of Chicago Wilderness though a *Climate Action Plan for Nature* (Chicago Wilderness Climate Change Task Force 2010a) and an ongoing *Climate Change Update to the Biodiversity Recovery Plan* (Chicago Wilderness Change Task Force 2010b; A. Derby-Lewis, pers. comm.).

In 2009, the Illinois Department of Natural Resources initiated a process to incorporate climate change considerations into the Illinois Wildlife Action Plan. Based in part on the Association of Fish & Wildlife Agencies' *Voluntary Guidance for States to Incorporate Climate Change into State Wildlife Action Plans & Other Management Plans* (Association of Fish & Wildlife Agencies 2009), this project had four explicit objectives:

1. **Conduct a climate vulnerability assessment of Species in Greatest Need of Conservation and major habitat types.** We assessed the vulnerability of a subset of Species in Greatest Need of Conservation by employing the NatureServe *Climate Change Vulnerability Index*. This index was based on direct exposure to local climate change, downscaled from climate models; indirect exposure to climate change such as anthropogenic barriers to dispersal; sensitivity to climate, such as species' tolerance

of climate variability over time or across geographic areas; and adaptive capacity including dispersal ability and genetic variation. The vulnerability of major habitat types was qualitatively evaluated based on projected changes in temperature, precipitation, drought, fire frequency, and flood frequency/intensity. Evaluating the factors anticipated to cause climate stress to species and habitats across Illinois informs adaptation strategies likely to have the broadest benefits.

2. **Identify conservation strategies that increase resilience or adaptive capacity, or mitigate the effects of climate change.** The seven campaigns of the Wildlife Action Plan were revisited to identify strategies that are particularly important given the realities of climate change, strategies that may need to be modified or reconsidered, and additional actions that were not included in Version 1.0 of the Illinois Wildlife Action Plan. We focused on strategies that are likely to be effective under both current and future climates (such as restoring connectivity and managing for ecological function), and considered the current and likely future conditions of natural divisions and watersheds to select regionally-appropriate strategies.

3. **Outline an adaptive management approach for informing management decisions.** Because of the large and unavoidable uncertainties of global, regional and local effects of climate change, and the complexity of potential biological and human responses to climate change, conservationists will need to employ adaptive management approaches. Unlike the typical, watered-down, 'we will make changes along the way' usage, adaptive management is a rigorous, iterative process of setting goal-based objectives, deploying strategies as experiments or learning actions, and a data-driven evaluation of results compared to objectives and effectiveness of alternate strategies.

4. **Recommend changes to existing monitoring programs and identify research needs.** Illinois has many monitoring programs in place, including the Critical Trends Assessment Program which monitors the status and trends of the state's forests, grasslands, wetlands, and streams. An effective adaptive management framework

will require implementation and effectiveness monitoring: a way of answering, "*did we undertake the actions at the scale prescribed in the Illinois Wildlife Action Plan, and did those actions have the intended effects?*"

This report is intended to function as a stand-alone document that addresses the four objectives described above, but is also presented in a format that corresponds to the Illinois Wildlife Action Plan. We hope this format will facilitate cross-walking information from this document and the Wildlife Action Plan, and facilitate integration of climate change considerations into the Wildlife Action Plan during a formal update and revision process.

METHODS FOR ASSESSING CLIMATE CHANGE VULNERABILITY

It is generally accepted that vulnerability to climate change, as with most stressors, has three components: exposure, sensitivity and adaptive capacity (Hansen and Hoffman 2011). *Exposure* refers the gross change an organism or system will encounter at a particular location and time (e.g., the amount of increased temperature). Individuals and species will vary in their *sensitivity* to the changes to which they are exposed. For example, fish species in a stream will have different physiological tolerances of the same increase in water temperature. *Adaptive capacity* includes the behavioral, phenotypic, genetic and other changes that might occur to allow individuals, populations or species to cope with climate change. The ability to disperse (by individuals or across generations) to tolerable microclimates and regional climates is an important component of adaptive capacity.

We employed the NatureServe *Climate Change Vulnerability Index,* Version 2.01 (Young et al. 2010) to evaluate a subset of Species in Greatest Need of Conservation. This index is an Excel-based workbook that accepts input on up to 29 factors relating to the exposure, sensitivity, and adaptive capacity of species. The index requires downscaled climate data for the geographic area being considered, and distribution and life history information of the species being assessed. The index returns a rating of the relative vulnerability of a species in the assessment area (Box 1), and identifies factors associated with vulnerability. By grouping species by their relative risk and sensitivity factors, the index helps to identify adaptation strategies most likely to benefit several species. To account for the absence of some life history information for some species, as well as uncertainty about future conditions and species responses, the index accepts multiple rankings of many individual factors as well as a subset of unknown rankings, and runs a background Monte Carlo simulation that considers various input combinations and produces a confidence rating to each overall vulnerability assessment.

<u>Selecting Species in Greatest Need of Conservation and Geographic Areas for Assessment:</u> We selected a subset of Species in Greatest Need of Conservation for climate change vulnerability assessment, with approximately equal representation among the major taxonomic groups. Several species were excluded from consideration, including species presumed extirpated in Illinois, mollusks and insects with inadequate life history information,

insects with unknown distributions, fishes with <20 records in the Illinois Department of Natural Resources Fisheries Analysis System database or Illinois Natural History Survey collections, and birds present in Illinois only as migrants or winter residents. All remaining crustacean, amphibian, reptile, and mammal Species in Greatest Need of Conservation were assessed. We randomly selected 20-30 species of mollusks, insects, fishes and birds among the remaining candidate species until a similar number of assessments would be conducted among taxonomic groups (approximately 100; see below).

Box 1. Definitions of *Climate Change Vulnerability Index* Rankings (from Young et al. 2010)

Extremely Vulnerable: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Not Vulnerable/Presumed Stable: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Not Vulnerable/Increase Likely: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence: Available information about a species' vulnerability is inadequate to calculate an Index score.

We considered the 14 natural divisions of Illinois (Fig. 1A) for terrestrial species, including mammals, birds, reptiles, amphibians, insects, cave-dwelling crustaceans, and a terrestrial snail. For aquatic species, we divided the state into 19 major watersheds (Fig. 1B) for assessments of fishes, mussels, stream-dwelling crustaceans. Each species was eligible for evaluation in >1 geographic area. To determine the watershed(s) or natural division(s) in which to assess a particular species, we considered several sources of information, including the Illinois GAP Analysis Project (Illinois Natural History Survey 2005), The Illinois Natural History

Survey's amphibian and reptile collection (Phillips et al. 2009), Illinois Department of Natural Resources Fisheries Analysis System (L. Hinz, pers. comm.), Illinois Natural History Survey fish collection (Page et al. 2009), Illinois Natural History Survey mussel collections (Cummings et al. 2009), Nyboer et al. (2006) for Illinois-endangered or -threatened species, and professional experience (R. Panzer and K. Gnaedinger, pers. comm.) for some insects.

A B

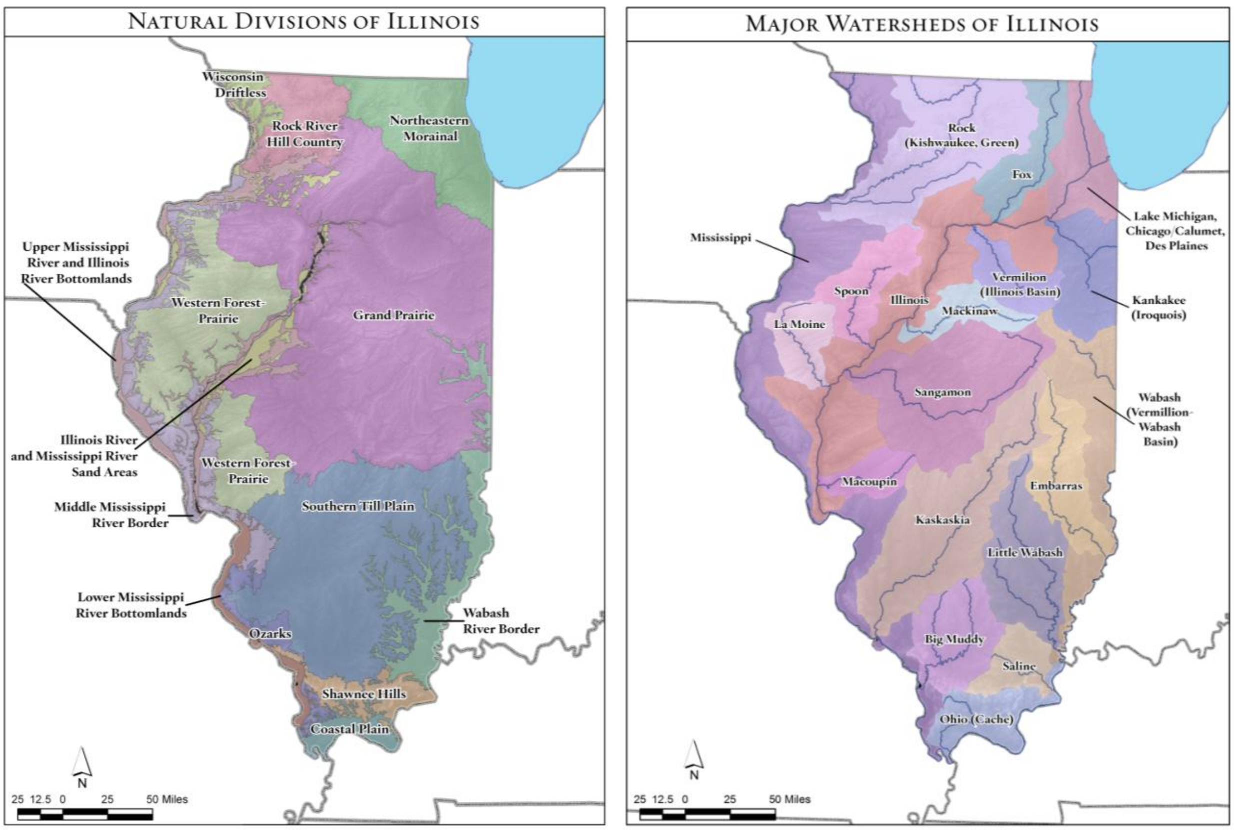


Figure 1. The Natural Divisions (A) and Major Watersheds (B) of Illinois.

<u>Direct and Indirect Exposure to Climate Change in Geographic Areas:</u> We obtained climate change projections for all natural divisions and watersheds from Climate Wizard (Zganjar et al. 2009), including change in average annual temperature and change in the Hamon AET:PET Moisture Metric (Figs. 2, 3). The Hamon AET:PET Moisture Metric is a relative comparison of actual evapotranspiration to potential evapotranspiration, and thus represents the

net drying (or wetting) effect of changes in the amount and seasonality of precipitation. For all climate variables, we used projections for mid-century (2040-2069), and the ensemble-average of general circulation models based on the A1B medium-emissions scenario.

A B

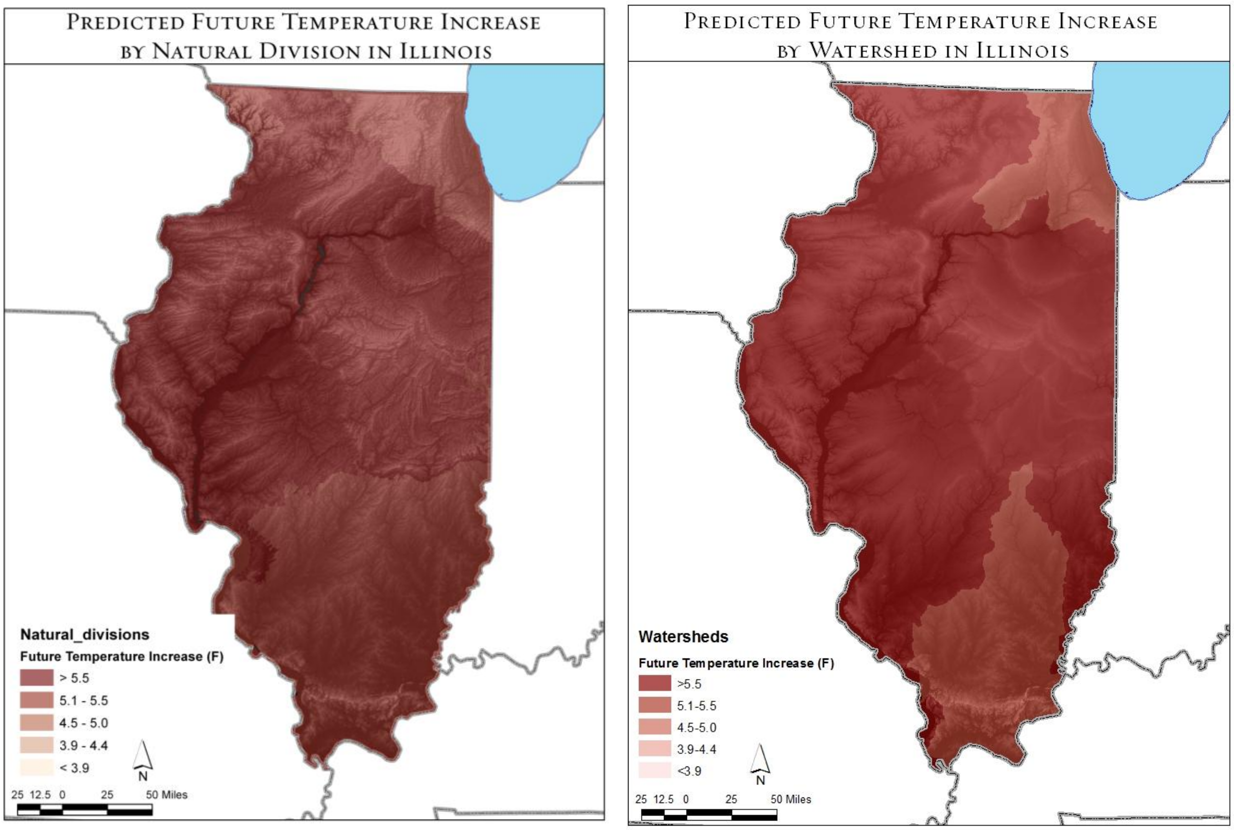


Figure 2. Projected change in average annual temperature for Illinois natural divisions (A) and watersheds (B) by mid-century.

Indirect exposure to climate change in the NatureServe *Climate Change Vulnerability Index* is scored by sea/lake level change, natural and anthropogenic barriers, and land use changes directly as a result of climate change. The index provides specific guidance on proportions of natural land cover types to consider for anthropogenic barriers, which we calculated for all natural divisions with a Geographic Information System (GIS) using the 1999-2000 Land Cover of Illinois (Fig. 4). For watersheds, we qualified anthropogenic barriers based on the presence/prevalence of navigation locks, levees, channelization, small-medium dams (impoundments), and large dams (major reservoirs; Fig. 4B).

A B

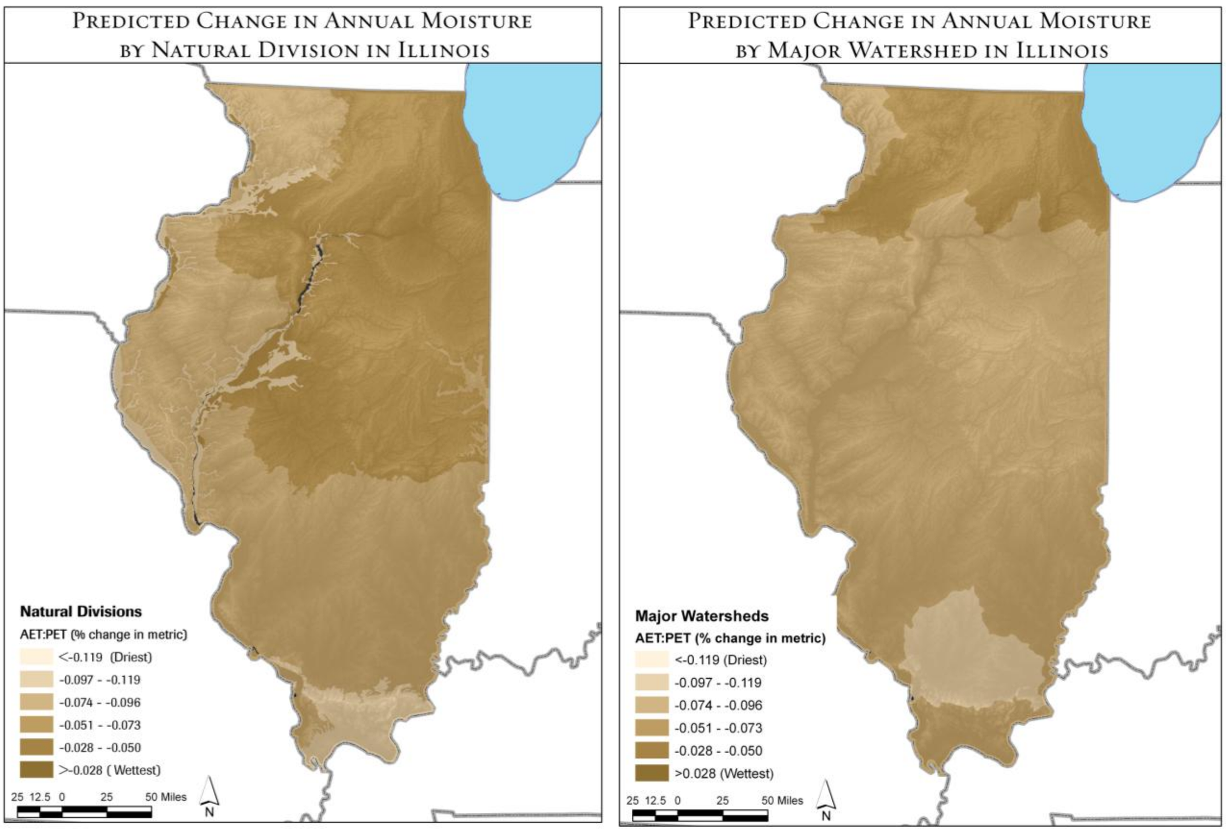


Figure 3. Projected change in Hamon AET:PET Moisture Metric for Illinois natural divisions (A) and watersheds (B) by mid-century.

Species Sensitivity & Adaptive Capacity: For all species, we obtained global and state conservation ranks, range-wide distribution (including relative position of the assessment area within the species range, e.g., northern or southern edge of range), and most of the life history information required to assess sensitivity and adaptive capacity from NatureServe *Explorer* (NatureServe 2010). Historical thermal and hydrological niches were evaluated by comparing geographic assessment areas and species' ranges to continental maps of seasonal temperature variation and average annual precipitation (Fig. 5).

A B

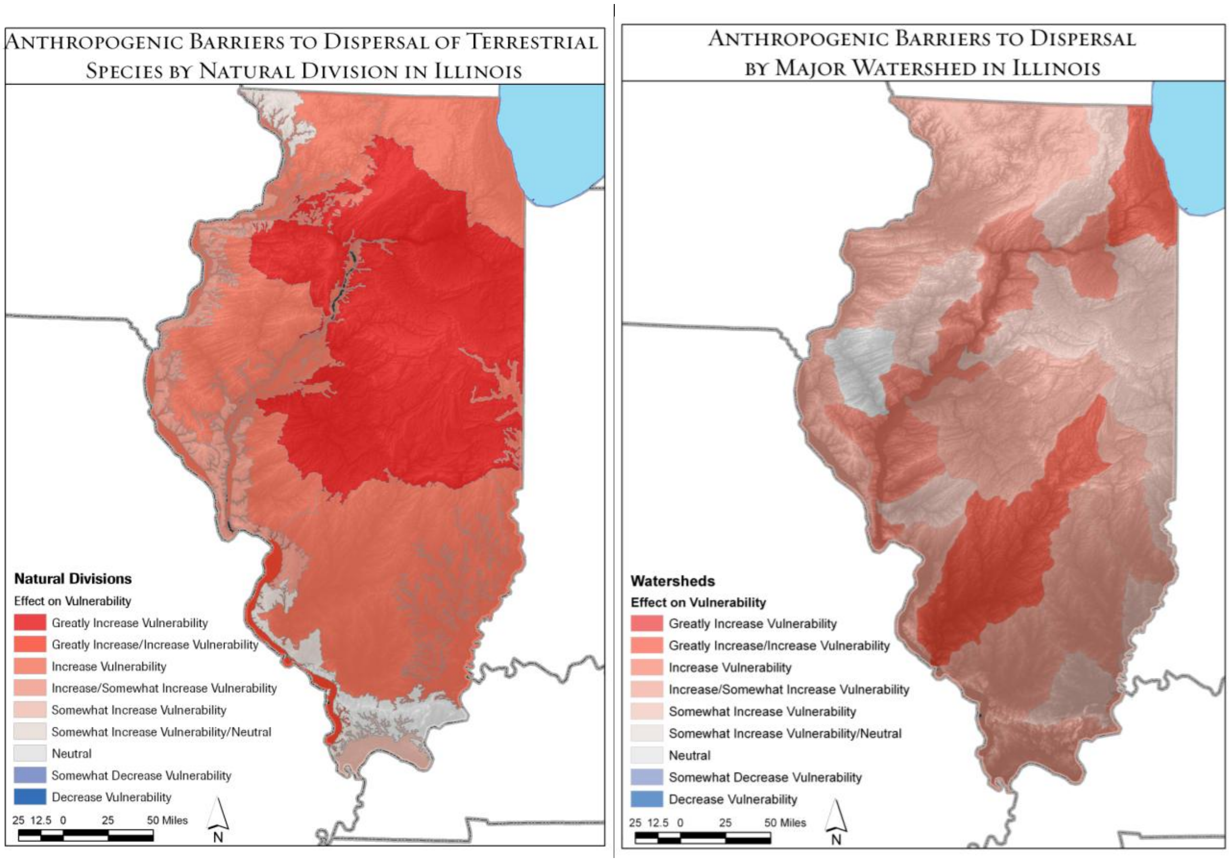
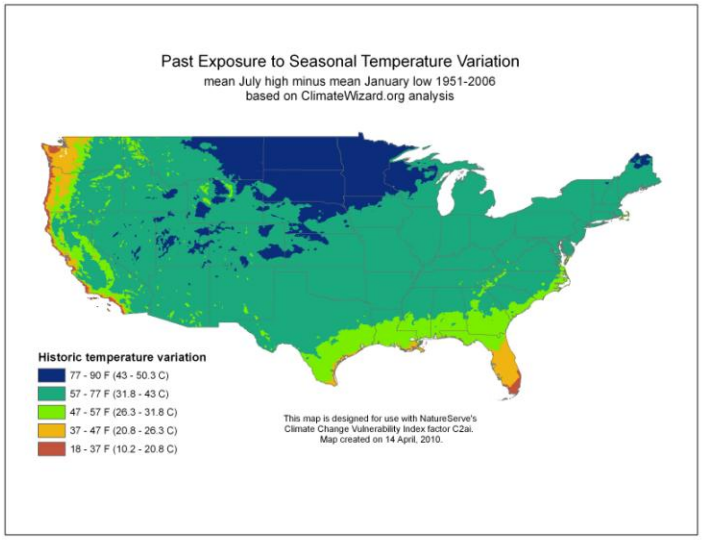


Figure 4. Anthropogenic barrier rankings for Illinois natural divisions (A) and watersheds (B).

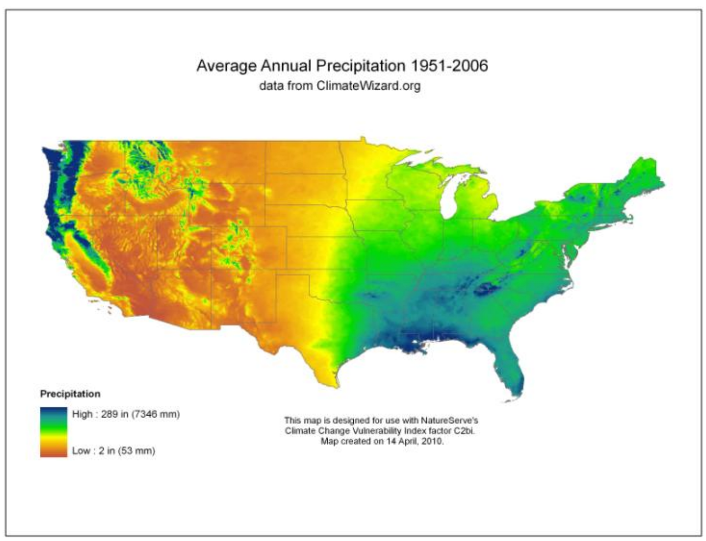
Since mussels are dependent on host fish species for development and dispersal of glochidia, we assessed the number of known host fish species for each species of mussel in the Ohio State University mussel host database (Cummings and Watters 2002). Dependence on host species was ranked as "increasing" vulnerability for mussels with a single (or unknown) host, "somewhat increasing" vulnerability for mussels with 2-5 known host fishes, and "neutral" for mussels with 6 or more host species.

<u>Repeatability of Species Vulnerability Assessments:</u> We took several steps to ensure consistent use of and repeatable outputs from the *Climate Change Vulnerability Index* among our team of users. We limited our input of sensitivity and adaptive capacity factors to information available from NatureServe *Explorer*. Prior to completing assessments for each taxonomic group, we discussed and agreed upon ratings for the dispersal abilities of species or guilds. Additionally, we selected about 25% of species to be assessed by all team members, so that we

could compare results among team members at regular intervals and identify differences in approach and input errors.



A.



B.

Figure 5. Continental maps used to rate past exposure to seasonal temperature variation (A) and average annual precipitation (B). Both maps are based on data and analyses from Climate Wizard.

CLIMATE-RELATED CHALLENGES TO WILDLIFE & HABITAT RESOURCES

A critical caveat to using the NatureServe *Climate Change Vulnerability Index* is that the results **ONLY** consider the specific threat of climate change to a particular species in a geographic area, and are not a complete assessment of *all* the threats affecting that species in that area. For example, species that were not rated as particularly vulnerable to climate change may in fact be gravely threatened by habitat loss or overharvest. In reality, climate change is best thought of as a "threat multiplier" (CNA Corporation 2007): a population threatened by habitat loss will be further stressed by inability to disperse and track suitable conditions. A population with low genetic diversity is less likely to successfully experience microevolutionary adaptation to changing conditions. Climate change will have complex interactions with hydrology, fire, water chemistry, toxicity and other abiotic factors, and may disrupt predator/prey, disease/host, competition, mutualism, and other interspecific interactions.

Increased temperature and more variable precipitation probably will negatively affect some native species while favoring other non-native invasive species. Some native species are likely to begin exhibiting invasive behavior, such as Canada goldenrod (*Solidago canadensis*) has in many locations in recent years. Higher elevation or poleward range shifts have been forecast for many groups, including trees (Iverson et al. 2005) and birds (Matthews et al. 2004). In Illinois, fragmented habitat conditions and the long distances that must be crossed to track relatively small changes in climate envelopes will further threaten many populations.

Hall and Root (*in press*) generalized the observed responses of wild animals and plants to climate change in five non-exclusive ways:

1) Spatial shifts in ranges and boundaries (e.g., moving north in the Northern Hemisphere);

2) Spatial shifts in the density of individual animals and plants within various sections of a species' range;

3) Changes in phenology (the timing of events), such as when leaves emerge in spring or when birds lay their eggs;

4) Mismatches in the phenology of interacting species; and

5) Changes in genetics.

Species in Greatest Need of Conservation: We assessed the climate change vulnerability of 162 Species in Greatest Need of Conservation. Because many species were assessed for >1 natural division or watershed, 584 assessments were completed. On average, about 27 assessments were completed for each natural division (range 18-51) and about 11 assessments for each watershed (range 4-19). For each of the 8 major taxonomic groups considered, we completed an average of 73 assessments, ranging from 11 (crustaceans) to 111 (fishes; Table 1). There was substantial variation in climate vulnerability ratings among taxonomic groups (Fig. 6). A list of species assessed is provided in Appendix I at the end of this document, and the complete input and results tables of all vulnerability assessments are provided in an accompanying Excel file (Appendix II.xls).

Table 1. Summary of climate change vulnerability assessments completed by geographic areas and taxonomic groups.

Taxa (# species)	Coastal Plain	Grand Prairie	Illinois/Mississippi River Sand Areas	Lower Mississippi River bottoms	Middle Mississippi Border	Northeastern Morainal	Ozarks	Rock River Hill Country	Shawnee Hills	Southern Till Plain	Upper Mississippi/Illinois River Bottomlands	Wabash Border	Western Forest-Prairie	Wisconsin Driftless	Big Muddy	Embarras	Fox	Illinois	Kankakee (Iroquois)	Kaskaskia	Lake Michigan, Chicago-Calumet, Desplaines	LaMoine	Little Wabash	Mackinaw	Macoupin	Mississippi	Ohio (Cache)	Rock (Kishwaukee & Green)	Saline	Sangamon	Spoon	Vermillion (Illinois)	Wabash (Vermillion)	Sum
Amphibians (14)	8	1	2	6	2	3	2	2	4	2	1	7	1	3																				44
Birds (20)	9	6	6	6	6	15	6	6	6	7	7	7	6	9																				102
Fishes (24)															5	3	14	13	12	3	6	1	3	3		10	4	12	1	5	2	3	11	111
Insects (30)	2	19	8		3	19	2	7	3	5	1		10	2																				81
Crustaceans (10)							2		2						1												5		1					11
Mammals (19)	10	6	5	6	7	9	8	6	10	6	7	4	7	6																				97
Reptiles (21)	7	9	2	7	2	5	3	3	2	3	2	5	3	1																				54
Mollusks (24)														1	2	6	4	4	5	3		3	3	5	2	6	10	4	2	4	3	3	14	84
Sum	36	41	23	25	20	51	23	24	27	23	18	23	27	22	8	9	18	17	17	6	6	4	6	8	2	16	19	16	4	9	5	6	25	584

We achieved about 98% repeatability of results from the *Climate Change Vulnerability Index* by our team. Of the 128 assessments completed by all members of the team, the *Climate Change Vulnerability Index* returned the same rating in 59.4% of cases, and in an additional 38.3% of cases, the index returned two agreeing ratings and one rating a single rank higher or lower. Examination of the Index's confidence rating suggested convergence towards the same score in 40 of 49 cases. In only three instances (2.3%) did users generate three different ratings from the index, or a rating that differed by 2 or more ranks from two agreeing ratings.

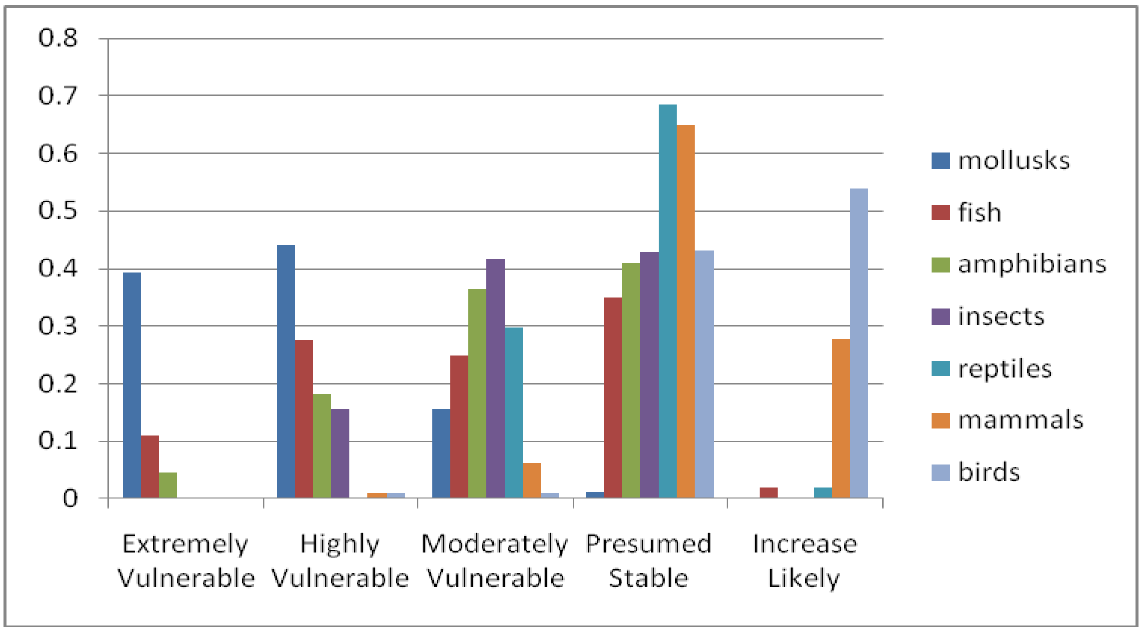


Figure 6. Proportions of Species in Greatest Need of Conservation within seven major taxonomic groups assigned different climate change vulnerability ratings.

Mollusks – Most of the species assessed were freshwater mussels. The Iowa Pleistocene Snail (*Discus macclintocki*), a glacial relict species, was rated as *Extremely Vulnerable* in the Wisconsin Driftless natural division. Of the 83 assessments for freshwater mussels, 69 were rated *Extremely Vulnerable* or *Highly Vulnerable*; only one species was assessed as *Presumed Stable* for a single watershed, and no assessments indicated *Increase Likely* (Fig. 6). Limited dispersal ability of adults, dependence on one or few host species for dispersal of the glochidia, natural restrictions to dispersal pathways (dendritic patterns of streams), and anthropogenic barriers to dispersal (e.g., dams) were common factors that contributed to the high vulnerability ratings of most species.

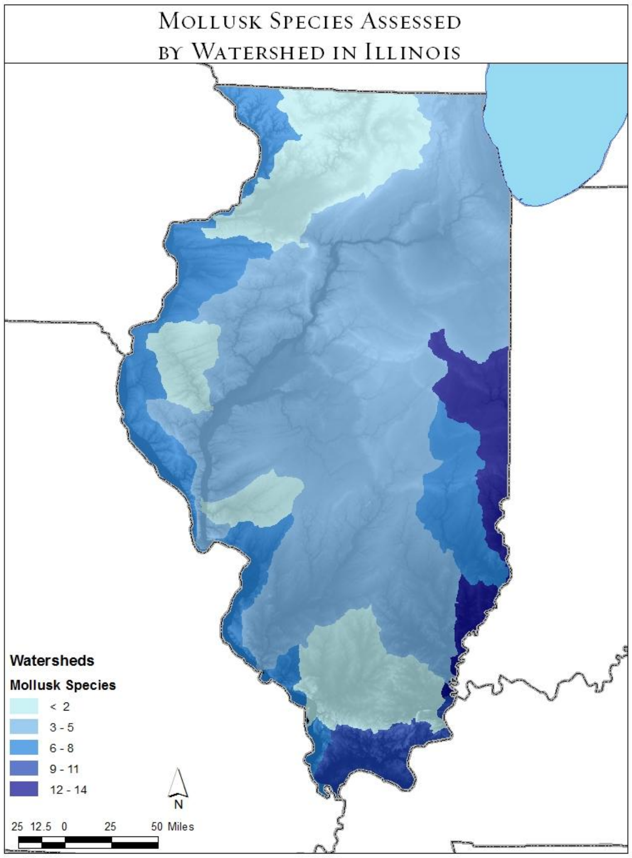


Figure 7. Distribution of mollusks assessed for climate change vulnerability by watershed.

Insects – Given that many insects were considered Species in Greatest Need of Conservation in the Illinois Wildlife Action Plan in part due to inadequate information on their status (Illinois Department of Natural Resources 2005), we were not surprised that too little distribution and/or ecological information was available to assess many species. Consequently, the insect Species in Greatest Need of Conservation that were assessed were predominantly larger insects and butterflies and moths (Lepidoptera) that have good dispersal abilities. Most assessments rated insects as *Moderately Vulnerable* or *Presumed Stable* (65 of 77 assessments; Fig. 6). Of the 12 species-natural division assessments rated as *Highly Vulnerable,* 7 were in the highly-fragmented Grand Prairie natural division. The Karner Blue Butterfly (*Lycaeides melissa* *samuelis*), Rattlesnake Masker Borer Moth (*Papaipema eryngii*), and Regal Fritillary (*Speyeria idalia*) – all species with narrow host plant requirements – were rated as *Highly Vulnerable* to climate change in other natural divisions.

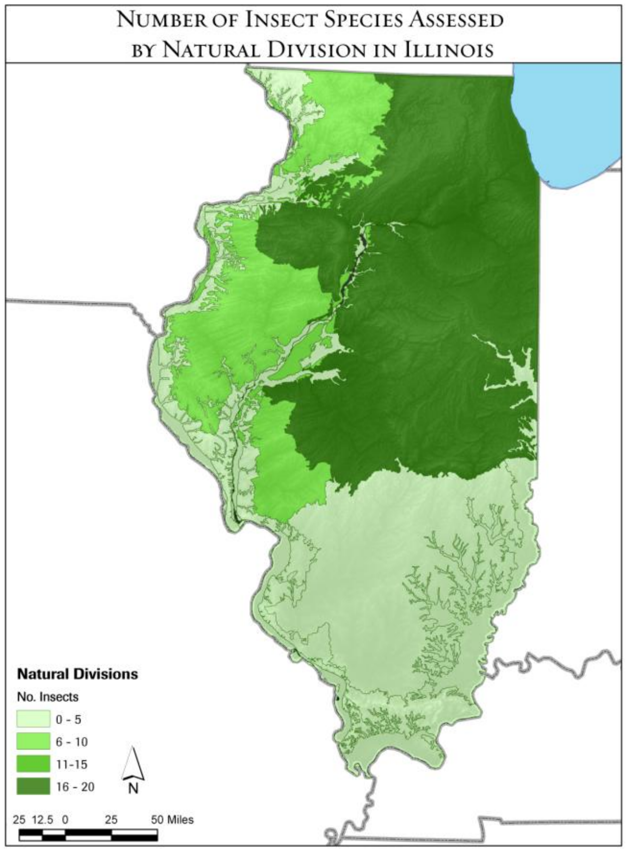


Figure 8. Distribution of insects assessed for climate change vulnerability by natural division.

Crustaceans – Only 11 assessments of 10 species of crustaceans were completed, including 5 species of stream-dwelling crayfish and 5 species of cave-dwelling amphipods and isopods. The index generated climate vulnerability ratings of *Moderately Vulnerable* and *Highly Vulnerable* for most species (Fig. 6). Although the cave-dwelling species are expected to experience low exposure to climate change, we also expect them to have high sensitivity to any changes (including groundwater flows), and low adaptive capacity due to the isolation of suitable habitat, low dispersal capability among cave systems, and small population size of species known from one or few cave systems.

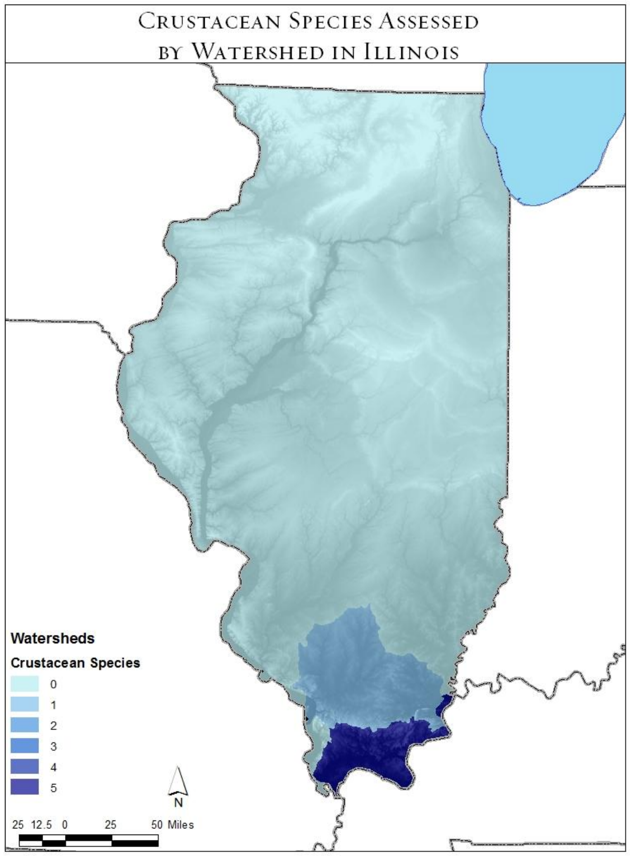


Figure 9. Distribution of crustaceans assessed for climate change vulnerability by watershed.

Fishes – Among taxonomic groups, the *Climate Change Vulnerability Index* returned a broader distribution of ratings for fishes than other groups (Fig. 6). Fishes associated with cooler water temperatures and headwater streams were rated as more vulnerable to the effects of climate change than were fishes associated with larger, warm-water rivers. This result was related to greater exposure to the effects of climate change in headwater streams compared to large rivers (increased water temperature and hydrologic variability), the sensitivity of coolwater-adapted species, and the limited capacity for fishes in headwater streams to disperse among systems. Of the 42 *Extremely Vulnerable* or *Highly Vulnerable* ratings, 34 were assessments of candidate coolwater species (L. Hinz, pers. comm.).

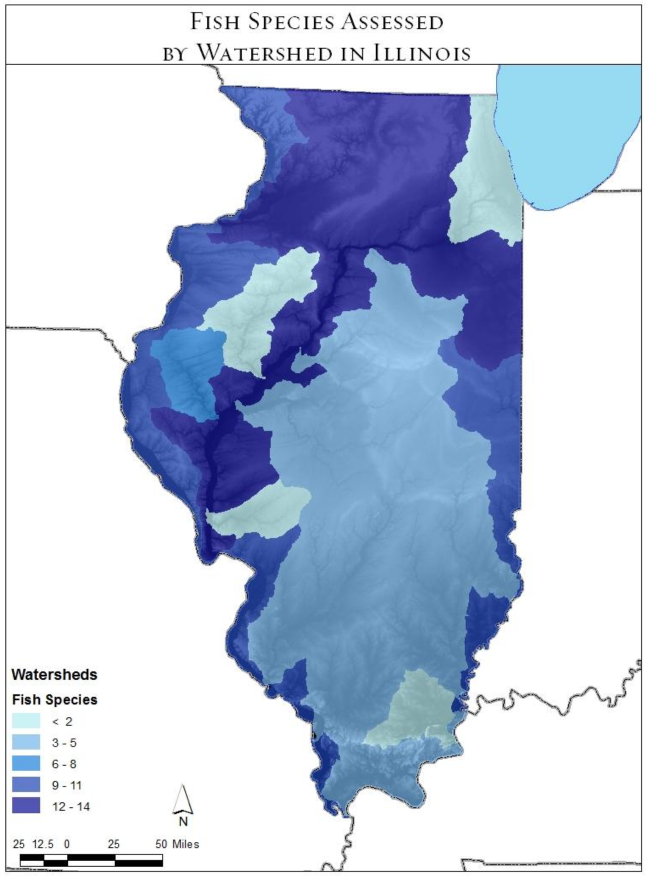


Figure 10. Distribution of fishes assessed for climate change vulnerability by watershed.

Amphibians – Many of the amphibians assessed for climate change vulnerability were rated as *Presumed Stable* or *Moderately Vulnerable* (34 of 44 assessments; Fig. 6). We assessed many species in the Wabash Border, Coastal Plain, Shawnee Hills and Lower Mississippi River Bottomlands natural divisions in southern Illinois, so expected northward range expansion may have moderated vulnerability rankings of species dependent on moister conditions and anticipated to face drier conditions. The species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change included amphibians dependent on ephemeral wetlands and associated with cooler microclimates. The hellbender (*Cryptobranchus alleganiensis*) is dependent on cooler water temperatures and has curiously short dispersal distances (typically <100 m, very rarely >500 m) for an animal its size, and pickerel frogs (*Rana palustris*) are most often found in cooler cave entrance zones. Potential drying of ephemeral pools, exacerbated by fragmented landscapes and increased water demand for irrigation, contributed to the ratings of Illinois chorus frogs (*Pseudacris streckeri illinoensis*), wood frogs (*R. sylvatica*), Jefferson's salamanders (*Ambystoma jeffersonianum*), mole salamanders (*A. talpoideum*), and silvery salamanders (*A. platineum*).

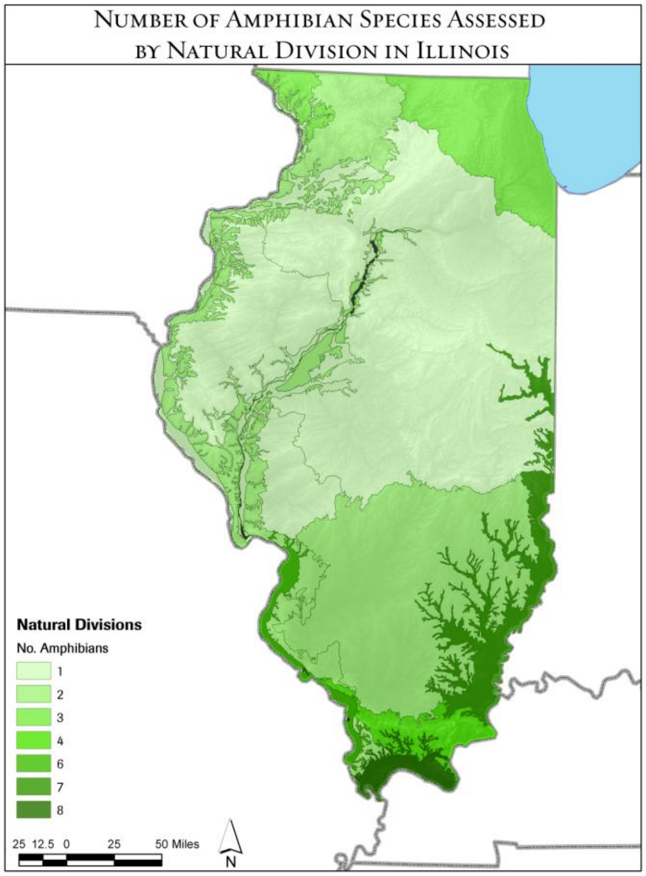


Figure 11. Distribution of amphibians assessed for climate change vulnerability by natural division.

Reptiles – Most reptiles were rated as *Presumed Stable* or *Moderately Vulnerable* (53 of 54 assessments) to climate change (Fig. 6). Anthropogenic barriers to dispersal were a contributing factor to vulnerability for many species in most natural divisions. Several species of reptiles were also constrained by their reliance on uncommon physical or geologic features, such as western hognose snakes (*Heterodon nasicus*) on sandy soils and timber rattlesnakes (*Crotalus horridus*) on rocky outcrops for hibernacula. Dispersal abilities and dietary flexibility were factors slightly decreasing the vulnerability of many reptiles. No one species was rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change.

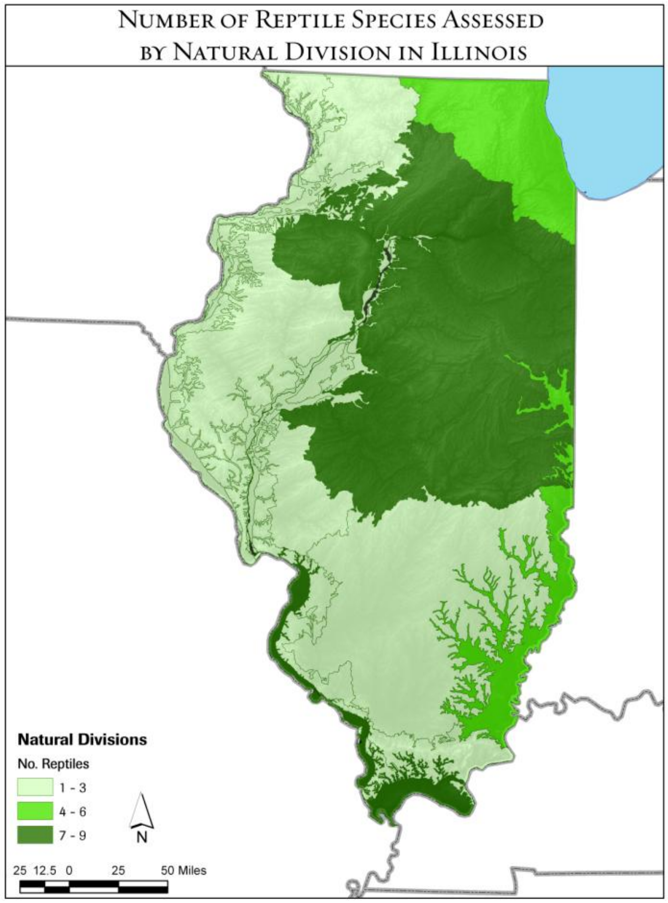


Figure 12. Distribution of reptiles assessed for climate change vulnerability by natural division.

Birds – A critical caveat to the climate vulnerability ratings of birds is that we only assessed birds during the nesting season in Illinois, and many species are likely to face additional, complex vulnerabilities along their migratory routes. Especially for Neotropical migratory birds that initiate long-distance movements based primarily on changes in photoperiod, timing mismatches between arrival and resource availability (e.g., leaf out and insect emergence) are likely along migratory pathways, and may have profound adverse effects on populations (Marra et al. 2005, Visser et al. 2006).

Virtually all the nesting-season bird assessments (100 of 102) were rated as *Presumed Stable* or *Increase Likely* (Fig. 6). Only Black Rails (*Laterallus jamaicensis*) in the Mississippi River and Illinois River Sand Areas natural division were rated as *Highly Vulnerable* to climate change, in part because drier conditions and increased water demand for irrigation may reduce availability of shallow marsh habitats. With of their high dispersal capabilities, lack of dependence on specific physical/geologic features, and dietary flexibility, birds are expected to have high adaptive capacity to climate change during the nesting season in Illinois.

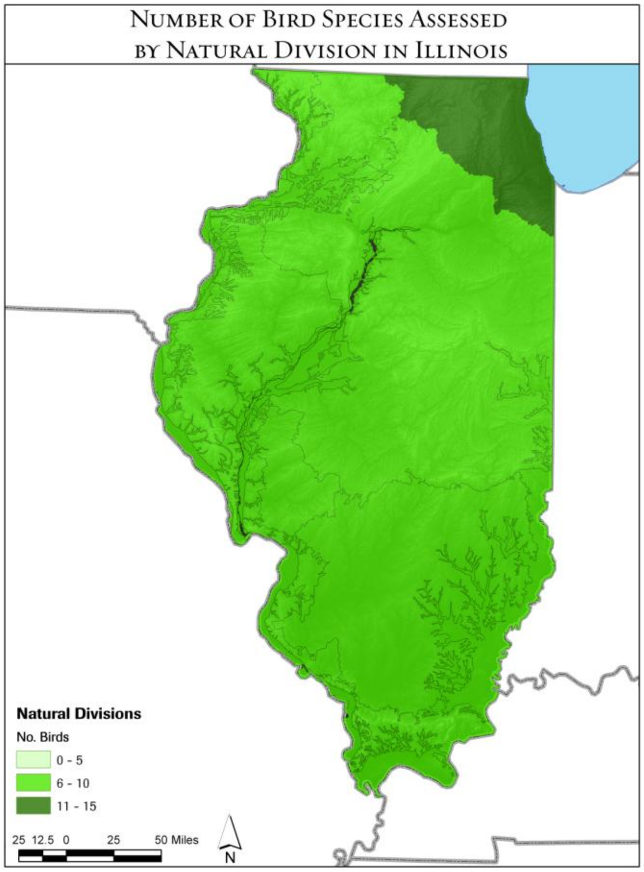


Figure 13. Distribution of birds assessed for climate change vulnerability by natural division.

Mammals – All of the 97 assessments of mammals were rated as *Presumed Stable* or *Increase Likely* (Fig. 6). Many of the mammals in Greatest Need of Conservation are widespread, wide-ranging species adaptable to a variety of habitats and food sources (River Otters [*Lontra canadensis*], American Badgers [*Taxidea taxus*], Bobcats [*Lynx rufus*]) with low sensitivity and high adaptive capacity to climate change. As with birds, migratory bats may face additional, complex vulnerabilities along their migratory routes.

Major Habitat Types: The Union of Concerned Scientists (2009) outlined a number of changes likely to affect Illinois by the middle and end of the 21st century, primarily focused on human health and agriculture, but with direct effects on natural systems as well.

- *Summer Heat*: Even under a low-emissions scenario, by mid-century about 75% of Illinois summer will be hotter than 1983 and 1988, the hottest summers on record. By the end of the century under a high-emissions scenario, Chicago could experience about 30 days >100F (compared to an historical average of about 2 days/year).

- *Flooding & Drought*: A significant increase in heavy rainfall events (>2 inches in 1 day) has already occurred over the past half-century (Trenberth et al. 2007), and 20% more of precipitation will fall in large events by mid-century. Winter and spring precipitation is projected to increase by one-third, increasing the risk of flooding, whereas summer precipitation is projected to decline 15%, leading to more droughts.

- *Lower Water Levels*: Water levels in Lake Michigan may drop 1-2 feet by mid-century (Angel and Kunkel 2009). If demand for groundwater increases for municipal needs and irrigation, base flows in rivers and streams during summer droughts may be especially troubling to aquatic life.

- *Longer Growing Seasons*: The growing season in Illinois could be as much as six weeks longer by the end of the 21st century. Warmer winter conditions will allow overwinter survival of a variety of plants, insects, and other species currently limited in Illinois by cold temperatures.

In addition to these changes, Krawchuk et al. (2009) modeled that the Midwestern United States will become more fire-prone under all scenarios considered, but it is unclear whether fire frequency will actually increase much in areas like Illinois that are highly fragmented. There is a high degree of uncertainty around many of these projections, and how natural systems will subsequently change.

All of these changes will favor species that can quickly adapt to changes in local conditions. "Climate winners" will likely have the characteristics of short generation times, high fecundity and rapid dispersal – also characteristics of many species labeled "invasive" by conservationists. By contrast, species with long generation times, low fecundity and low dispersal will be most challenged by climate change, and these challenges will be amplified by habitat fragmentation/isolation and small population size/lack of genetic diversity. At the community or ecosystem level, late-successional stages will be most vulnerable to climate change.

Forest – Warmer-biome plants are more likely to thrive in Illinois forests in the future than cooler biome species. In the recent past, upland forests in Illinois have become increasingly dominated by mesophytic tree species, especially sugar maple (*Acer saccharum*), at the expense of oaks (*Quercus spp*.; Bretthauer and Edgington 2002). By contrast, conditions are expected to become more xeric in future decades, and Iverson et al. (2005) predict conditions will not support sugar maples in Illinois. It is plausible that wildfires that do occur will have greater intensity and destructive effects. Longer growing seasons and warmer winters may increase the prevalence of tree pathogens, insect outbreaks, and invasive species. A cascading effect of physiologically-stressed mesophytic trees experiencing massive die-offs from pests or pathogens and contributing to wildfire risk, is possible. Flooding is expected to become more severe and erratic in the future, so floodplain forests are likely to be even more dominated by early successional tree species (silver maple [*A. saccharinum*], willow [*Salix spp*.], cottonwood [*Populus deltoides*]), and establishing hard mast species (e.g., pecan [*Carya illinoensis*] and oaks) will be more difficult.

Indirect effects of climate change on forests may include increased use of forests for biomass production and for carbon sequestration. In upland forests, biomass harvest could take several forms, ranging from clear-cutting to collection of slash material accompanying typical timber harvest practices. If flooding becomes too erratic and markets/incentives develop, floodplains currently in rowcrop agriculture production may be converted to forests for long-term carbon sequestration or short-rotation woody crops for biomass production.

Open Woodland/Savanna/Barren – These habitats were historically common in Illinois (e.g., Nuzzo 1985), but are currently scarce and in degraded conditions. Projections of a dryer, more fire-prone future suggest conditions may become more favorable to the restoration or establishment of open woodlands, savanna, and barrens. In the Chicago Wilderness region, wet-mesic fine-textured-soil savannas are considered at highest risk because the hydrology in this community it is difficult to restore if lost (Chicago Wilderness Change Task Force 2010b).

Grassland – Version 1.0 of the Illinois Wildlife Action Plan suggested tallgrass prairie may become more difficult to maintain due to a shift from a savanna-woodland to a temperate woodland and southeastern mixed forest climate and due to atmospheric enrichment of CO_2 that places C4 photosynthesis plants (like most native warm-season prairie grasses) at a competitive disadvantage (Inkley et al. 2004). By contrast climate projections, accounting for seasonal variability in precipitation, suggest in the future Illinois may have a climate more similar to present day eastern Oklahoma and eastern Texas than to Georgia, reflecting an expectation of increased summer droughts (Union of Concerned Scientists 2009). As in forests, warmer biome plants are more likely to maintain or expand their dominance at the expense of cooler biome species. Wet and wet-mesic prairies, and the Species in Greatest Need of Conservation dependent upon them, will be challenged by changes in precipitation patterns and increased drought frequency and severity.

Grasslands used for biomass/biofuels (including polycultures of native prairie plants and monocultures of switchgrass, Miscanthus, or other species) are a plausible indirect effect of climate change. If these markets/incentives develop, dedicated biomass crops are likely to occur on highly-erodible and poorer soils, and thus replace Conservation Reserve Program grasslands rather than displace areas currently in rowcrops (America's Energy Future Panel on Alternative Liquid Transportation Fuels 2009, Tillman et al. 2006).

Shrub/Successional – Shrublands are currently scarce in Illinois, and many are dominated by nonnative species. As indicated for forested habitats above, an indirect effect of climate change might be the expansion of shrub or early successional woody habitat for use as short-rotation biomass crops (e.g., willows [*Salix spp*.]).

Wetlands – Climate projections suggest that a greater proportion of precipitation will fall during the non-growing season, and during high rainfall events (Union of Concerned Scientists 2009). Demands for groundwater are likely to increase to augment surface water supplies and meet demand for irrigation. As a result, wetland hydrology may become more irregular, with pulses of more intense flooding that deposit sediments and other pollutants, and more frequent low water periods. These conditions would be conducive to invasive and early successional species, and will challenge water level control for moist soil management. Irregular precipitation and net drying effects will reduce the availability of ephemeral wetlands, with profound effects on the amphibians dependent on these pools for reproduction. So-called "hemi-marsh" conditions, especially important to many wetland Species in Greatest Need of Conservation found primarily in the Northeastern Morainal natural division are expected to become more difficult to reach or maintain in the Chicago Wilderness region (Chicago Wilderness Change Task Force 2010b). In response to a changing climate, society may place a greater importance on creating or restoring wetlands for water storage, flood attenuation, and water quality improvement. The value of such created wetlands for native species is highly variable (Phillips and Brown 2004).

Lake & Pond – While models suggest water levels in Lake Michigan by mid-century may increase as much as 0.42 m or decrease as much as 0.94 m, median estimates are roughly a 0.2 m decline in water levels (Angel and Kunkel 2009), suggesting an expansion of shoreline habitat. A net increase and more episodic precipitation, coupled with the potential for greater groundwater withdrawal, give a mixed picture of what may happen to water levels in lakes, ponds and reservoirs in the future. Heavy rainfall events may degrade water quality by introducing heavy sediment, untreated sewage, and pollutant loads into lakes, ponds, and reservoirs. Increasing water temperature will lengthen the stratified period in deeper lakes and favor algal blooms, resulting in more areas of low dissolved oxygen (International Panel on Climate Change 2002).

Streams – With increases in precipitation (particularly during the non-growing season) and heavy precipitation events forecast, streams are likely to become increasingly flashy, flooding will be more frequent and severe, and stream banks will come less stable. Water quality may suffer from greater periodic inputs of sediment, pollutants, and untreated sewage from heavy rainfall events (Union of Concerned Scientists 2009). Seasonal flood-pulses, already altered by levees, channelization, navigation locks, drainage alterations and other activities in many watersheds, are likely to become more irregular. With less precipitation during the growing season and higher air temperatures, periods of low flow, high water temperature and low dissolved oxygen will affect aquatic species. If groundwater contributions decline as a result of withdrawals for municipal water supplies or irrigation, the effects will be further amplified. Smaller headwater streams are likely to experience greater change and more variability than large rivers. Invasive species, altered hydrology, and loss of vegetation are common threats to terrestrial and aquatic systems, but sedimentation, pollutants, and excess nutrients have much more profound effects on aquatic communities (Brönmark and Hansson 2002).

Caves – Below-ground temperatures affecting cave life will probably change far less than surface temperatures over the next several decades. For cave-dwelling species, the larger climate-related threats are alterations in the quantity and quality of ground water caused directly by changes in precipitation amount or frequency, or indirectly with groundwater extraction.

PRIORITY CONSERVATION ACTIONS FOR ADAPTATION & MITIGATION OF THE EFFECTS OF CLIMATE CHANGE ON ILLINOIS WILLDIFE & HABITAT RESOURCES

Because of the scope, potential severity, and high uncertainty of global climate change, it may be tempting to 'give up' or ignore the threat until clarity emerges on actions or outcomes. In reality, coping with climate change is not fundamentally different from traditional conservation biology – a 'crisis discipline,' where decisions must be made and actions taken with incomplete information, and adaptive management is especially important for refining actions as knowledge is acquired and circumstances change. Given the considerable uncertainties about greenhouse gas emissions, global and regional climate model projections, the varied responses of species, the human response to climate change, and the very long-term processes being managed, it is wise to take actions conducive to a range of acceptable conservation outcomes, rather than working towards one particular view of the future.

Climate change is underway, generally proceeding faster than projected, and global emissions are equal or greater than 'high emissions scenarios' used in models. This reality challenges us to move into a new conservation paradigm. The old model – spatial, static and status quo – needs to be reinvented into temporal, kinetic and forward-thinking conservation and resource management (Hansen and Hoffman 2011). Range shifts of species will complicate traditional place-based strategies like protected reserves, and managing for historical reference conditions or ranges of variation may not be, or soon will not be, practical or possible.

Hansen et al. (2010) devised four basic tenets for "climate-smart conservation":

1) Protect adequate and appropriate space;
2) Reduce non-climate stresses;
3) Use adaptive management to implement and test climate-change adaptation strategies; and
4) Reduce the rate and extent of climate change to reduce overall risk.

These tenets reflect a range of activities to both *adapt* to and *mitigate* for climate change. *Adaptation*, as used herein, refers to activities that intend to reduce the negative effects or respond to climate change. In addition to human adaptation activities, other species will adapt through genetic, phenotypic and behavioral changes. Heller and Zavaleta (2009) describe a continuum of climate change adaptation strategies that have been proposed over the past two decades, from resistance, to resilience, to transformation. *Resistance* seeks to avoid exposure to a stressor and minimize variation, and is the least risk-tolerant stance. *Resilience* practices intend to allow a system to absorb a disturbance and return to or remain within an acceptable range of variation. Most resilience strategies are "no regrets" actions based on the precautionary principle and already part of ongoing conservation actions: increasing the size and genetic diversity of small populations, protecting large core areas for viable populations, restoring and enhancing ecological connectivity, maintaining and restoring natural patters of ecological drivers like fire and hydrology, and reducing non-climate stressors like invasive species, pollutants, and unsustainable harvest. Other resilience strategies are more informed by climate change expectations, such as ensuring a variety of slopes, aspects, soil types and abiotic features are included within protected areas so that species are more likely to find suitable microclimates. However, the International Panel on Climate Change (2007) warns that resilience strategies may only be effective under lower levels of climate change – to roughly 5F, or the amount of warming expected for Illinois by mid-century.

Transformation strategies – actions that support system changes to an altered state based on predicted future conditions – are considerably more controversial and the most risk-tolerant. Some restoration ecologists are "pre-adapting" restorations to expected future conditions by selecting seed sources located south of the area to be restored, selecting species that are more tolerant of heat and drought, and in some cases planting species that do not yet occur in the restored area. Assisted migration – intentionally moving species into new areas thought to be suitable, but where natural dispersal is unlikely or distant in the future (Shirey and Lamberti 2009, Vitt et al. 2010) – is considered especially risky, in that introduced species may compete with or displace other desirable species, or even become invasive. However, very few problematic invasive species (~7%) are the result of intra-continental species introductions (Mueller and Hellmann 2008, Vitt et al. 2010). In the fragmented landscape of Illinois, translocations of plants and animals among isolated populations is a relatively common practice to simulate natural dispersal and increase the size and genetic diversity of populations of threatened and endangered species. In the future, managers likely will be faced with more situations where translocations are necessary and even cases where individuals must be salvaged from areas that are becoming unsuitable and moved to areas offering better chances for population survival. Frameworks are available to help determine whether, and how, to best carry out assisted migration (Vitt et al. 2010).

The quotable Will Rogers is credited with saying, “If you find yourself in a hole, stop digging.” Such is the impetus for climate change *mitigation*, or reducing the amount of climate change that does occur by limiting greenhouse gas emissions and removing greenhouse gasses from the atmosphere. Most climate scientists agree that there is sufficient carbon dioxide in the atmosphere that some climate change over the next century or more is unavoidable (International Panel on Climate Change 2007), thus adaptation is essential. If emissions are quickly and significantly curtailed, the catastrophic effects of climate change will be avoided and adaptation strategies are more likely to prove successful. Reducing emissions of greenhouse gases is complimentary to climate change adaptation. By contrast, if emissions continue at high levels for extended periods, resilience strategies will be overwhelmed by the degree of climate change, and system transformations will be unavoidable. Emissions reductions will primarily be achieved through policy changes. In Illinois, renewable energy standards are aimed at least in part towards reducing greenhouse gas emissions, and have contributed towards expansions of wind energy developments and biofuels, with some adverse effects on wildlife and natural resources.

If a market is established for carbon dioxide or other greenhouse gases, not only would an economic cost be associated with emissions, but an economic benefit could be accrued by removing carbon dioxide from the atmosphere and sequestering it in soils and biomass. Some voluntary markets and standards are already in existence and assign credits to restoration of grassland and forest (e.g., Voluntary Carbon Standard 2008). Especially in the tropics where large-scale forest clearing for development and agriculture are ongoing, ‘Reduced Emissions from Destruction and Deforestation’ (REDD) projects have the potential to greatly reduce the land clearing practices that contribute about 20% of the planet’s greenhouse gas emissions (World Resource Institute 2005).

All ecosystem-based mitigation practices are subject to intense scrutiny, particularly because of concerns about additionality, leakage, and permanence. *Additionality* means that a carbon-sequestering practice is above and beyond ‘business as usual.’ For example, a timber company could not claim planting trees is a mitigation strategy because they customarily plant trees with the intent of someday harvesting them. *Leakage* is a particularly vexing problem: if an acre of forest is protected from conversion to agriculture (or an acre of cropland is restored to forest) most of that conversion is likely to happen anyway and has just been displaced. In the United States, leakage of the Conservation Reserve Program has been estimated at about 20% (Taheripour 2006), meaning that for every 5 acres enrolled in the program about 1 acre of non-cropland, such as native prairie, is converted to cropland. To be effective, ecosystem-based mitigation must hold carbon indefinitely (*permanence*). Insect outbreaks, illegal logging and stand-destroying fires are all threats to the carbon stored in forests. Soil carbon (the primary repository of carbon in grasslands) is more stable, but nonetheless vulnerable to future conversion.

For each of the *campaigns* in the Illinois Wildlife Action plan, we have paired first-tier actions with specific considerations for adaptation to or mitigation for climate change. As discussed below (Research & Monitoring), most climate adaptation/mitigation strategies remain hypothetical and untested. We encourage creative thinking for other climate-adaptation actions, and approaching implementation as experiments to assess efficacy of alternative actions.

Streams Campaign

Action	Climate Change Considerations
1. Develop and promote upland agricultural practices that decrease the energy, sediment load, temperature, and pollutant load of drainage waters	Reduces non-climate stressors to streams; Increasingly important as more precipitation falls in high rainfall events; Practice standards should account for more frequent heavy rainfall events during the non-growing season; No-tillage practices, grass waterways, riparian buffers, constructed/restored wetlands, terracing, dry-dams, and drainage water management all contribute towards this objective
2. Develop and promote practices that decrease the energy, sediment load, temperature, and pollutant load of drainage waters from developed (urban, suburban) lands	Reduces non-climate stressors to streams; wetlands and other green infrastructure help moderate flooding and improve water quality; As more precipitation falls in high rainfall events, retention basins and wastewater treatment facilities should expect greater peak flows; As water temperature rises, reduced dissolved oxygen, increased algal blooms, and increased toxicity of pollutants may require revision of water quality standards
3. Protect, restore and enhance near-stream and in-stream habitats and processes	Reduces non-climate stressors to streams; Riparian vegetation can minimize increases in water temperature; restoring stream habitat and a variety of depth creates microclimate refugia
4. Restore populations of imperiled and extirpated aquatic animals	Improves resilience of populations; streams with high groundwater contributions likely have the best chance of sustaining coolwater fish communities; Not all currently- or

	historically-occupied locations may remain appropriate; consider maintaining populations based on sustainable, viable population networks and long-term monitoring/stewardship capacity
5. Prevent and control invasions of detrimental exotic species	Reduces non-climate stressors to streams
6. Restore and manage high-quality examples of all river, stream, lake, and pond communities, including all Grade A and B Illinois Natural Areas Inventory sites, in all natural divisions within which they occur	Improves or maintains resilience of populations; Changes in species composition and relative abundance are likely over time and historic conditions should not be the only benchmark of community quality
7. Fill information gaps and develop conservation actions to address stresses	Key step to adaptive management
8. Coordinate stream and watershed conservation actions with other agencies, organizations and upstream and downstream states to meet system-wide objectives	Reduces non-climate stressors to streams and is a key step to adaptive management; Coordinated monitoring activities for baseline information such as flows and water quality to improve cross-jurisdictional management; Partners will need to define and work towards managing environmental flows necessary to sustain systems
9. Increase water quality education efforts in areas under high development pressure and/or within fragile geographic zones (i.e. karst terrain)	Reduce non-climate stressors to aquatic and troglobitic species
10. Marketing and technical assistance will be required for adoption and appropriate implementation of the streams campaign.	Reduce non-climate stressors to aquatic systems; Demand will increase as more erratic precipitation causes flood damage, stream bank destabilization and other issues

Forests Campaign

Actions	**Climate Change Considerations**
1. Maintain and enhance the composition of Illinois' forested habitats	Improves or maintains resilience of populations; Efforts to re-establish trees tolerant of more xeric conditions (e.g., oaks and hickories) are especially important considering the mesophytic species that have increased in recent decades (e.g., sugar maple) may not be able to tolerate conditions in Illinois by mid-century; Not all currently- or historically-occupied locations may remain appropriate for imperiled or extirpated species - consider maintaining populations based on sustainable, viable population networks and long-term monitoring/stewardship capacity
2. Expected increases in statewide forest acreage (the continuation of an 80-year trend) should emphasize restoring floodplains and riparian corridors, ecological connectivity among forests and other habitat patches, and reducing fragmentation.	Increased flooding frequency and severity may create an opportunity for floodplain forest restoration; identifying key forest gaps, especially in floodplain and riparian areas along streams, will be important for maintaining dispersal corridors
3. Develop and expand programs to assist private forest owners in managing forest resources	Improves or maintains resilience of forests; With rapidly changing forest composition, invasive species, and potential die-offs from insects and diseases, the demand for forest management expertise will increase
4. Promoting the increased use of prescribed fire and sustainable forestry practices will require a campaign of marketing, demonstration areas on public and private	Improves or maintains resilience of forests

forests, technical assistance, professional training, access to fire equipment, cooperation with fire protection districts, and reform or clarification of liability issues.	
5. Local and state authorities, citizens and stakeholders need to cooperate to develop zoning criteria and local greenway plans that protect important habitats and ensure "smart growth."	Reduces non-climate stressors to forests; Zoning and greenway planning should also consider ecosystem-based benefits to humans in light of climate change including cooler climate refugia (not dependent on carbon-intensive air conditioning), moderating the urban heat island effect, and floodplain green space that minimizes needs for engineered drainage and flood-prevention infrastructure
6. Fill information gaps and develop conservation actions to address stresses.	Key step to adaptive management
7. Restore and manage high-quality examples of all forest, savanna and barrens communities, including all Grade A and B Illinois Natural Areas Inventory sites, in all natural divisions within which they occur.	Improves or maintains resilience of populations; Changes in species composition and relative abundance are likely over time and historic conditions should not be the only benchmark of community quality; drier, fire-prone future conditions may be predisposed to management of savanna and barren communities; protecting or restoring hydrology of wetter habitats (e.g., flatwoods) is critical to their persistence

Farmland & Prairie Campaign

Actions	Climate Change Considerations
1. Through incentives-based programs and technical assistance, establish or restore grassland, early successional/shrub, wetland, and riparian habitat.	Improves or maintains resilience of populations; Unlike forests and wetlands that are spatially static for long periods, farm conservation programs provide the opportunity for a dynamic distribution of grassland over time and enabling grassland species to disperse across heavily altered landscapes; Field borders, riparian buffers, intercropping, shelterbelts, and short-term land-idling are all examples of practices for supporting the diversity, abundance, and dispersal of wildlife in an agricultural matrix
2. Through incentives-based programs and technical assistance, moderate disturbance regimes and enhance the condition of farmland habitats.	Improves or maintains resilience of populations and reduces non-climate stressors
3. Restore and manage native prairie communities and populations of imperiled and extirpated prairie wildlife.	Improves or maintains resilience of populations; Maintaining or restoring hydrology of wetter prairie types will be essential for their persistence; Changes in species composition and relative abundance are likely over time and historic conditions should not be the only benchmark of community quality; Not all currently- or historically-occupied locations may remain appropriate for imperiled or extirpated species - consider maintaining populations based on sustainable, viable population networks and long-term

	monitoring/stewardship capacity
4. Emphasize multiple-resource benefits of conservation in agricultural landscapes.	Reduces non-climate stressors to other systems (e.g., sediment, nutrients, and altered hydrology in streams and wetlands); Evaluate mitigation scenarios, and promote actions that sequester atmospheric carbon
5. Interagency cooperation and coordination to ensure agricultural programs do not have conflicting objectives.	Reduces non-climate stressors to farmland and other systems, and a key step to adaptive management; Drainage systems, nutrient management, and perennial biomass/biofuel crops are examples of issues influenced by climate change where agricultural, environmental and social objectives should be considered in program development
6. Fill information gaps and develop conservation actions to address stresses.	Key step to adaptive management
7. At local, county and regional scales, involve stakeholders in discussions of long-term land use planning to meet agricultural, conservation, economic, residential and recreational needs.	Reduces non-climate stressors to farmlands and other systems, and is a key step to adaptive management; Partners will need to define and work towards managing landscapes that balance agricultural, environmental and social objectives
8. Clarification or change in liability statutes to promote private land access for wildlife associated recreation.	

Wetlands Campaign

Actions	Climate Change Considerations
1. Improve the condition of existing natural and artificial wetlands.	Improves or maintains resilience of populations and reduces non-climate stressors; Additional structures to manage water levels and/or divert flow and sediments may be necessary to maintain wetlands (though sustainability of structures and maintenance must be considered); Changes in species composition and relative abundance are likely over time and historic conditions should not be the only benchmark of community quality; Not all currently- or historically-occupied locations may remain appropriate for imperiled or extirpated species - consider maintaining populations based on sustainable, viable population networks and long-term monitoring/stewardship capacity
2. Develop and manage additional wetland habitat.	Improves or maintains resilience of populations; Increasingly important as more precipitation falls in high rainfall events to attenuate flooding and maintain water quality
3. Fill information gaps and develop conservation actions to address stresses.	Key step to adaptive management
4. Inter-agency cooperation and coordination to ensure wetland programs do not have conflicting objectives.	Reduces non-climate stressors to wetlands and stream systems, and is a key step to adaptive management; Partners will need to define and work towards managing wetlands and aquatic resources that balance environmental and social objectives; Coordinated monitoring

	activities for baseline information such as hydrology and water quality will improve cross-jurisdictional management
5. Emphasize multiple-resource benefits of wetland conservation.	Reduce non-climate stressors to other systems (e.g., sediment, nutrients, and altered hydrology in streams, lakes); Evaluate mitigation scenarios, and promote actions that sequester atmospheric carbon; Determine the economic value of flood reduction, and improvement in quality and availability of drinking water provided by natural and created wetlands
6. Increase water quality education efforts in areas under high development pressure and/or within fragile geographic zones (i.e. karst terrain)	Reduce non-climate stressors to aquatic and troglobitic species

Invasive Species Campaign

Actions	Climate Change Considerations
1. A comprehensive, integrated approach is essential to effectively addressing invasive species.	Reduce non-climate stressors to all other systems; Methods for early detection of invasive species, a filter for prioritizing species for control, and determination of "invasive" behavior compared to changes in species ranges and dominance are particularly important
2. Fill information gaps and develop conservation actions to address stresses.	A key step to adaptive management; Managers will need considerable advice on determining which species are "invasive" in light of range shifts and changes in community composition; Actions that are sustainable and scalable are especially critical
3. Prioritize high-quality natural areas, large habitat patches, and other key locations for invasive species control.	Reduces non-climate stressor to these systems; Changes in species composition and relative abundance are likely over time and historic conditions should not be the only benchmark of community quality; Emphasize management of natural processes that are sustainable and scalable
4. Marketing, education, technical assistance, incentives and cost-sharing to prevent invasions, control invasive species (mechanical, chemical and biological), and restore natural disturbance regimes (e.g., fire) on private lands	A key action for scaling up efforts to reduce critical non-climate stressors to natural systems; Demand for information and assistance will increase as climate change creates rapid turnover in systems favoring invasive species

Land & Water Stewardship Campaign

Actions	Climate Change Considerations
1. Improve the stewardship of private land and water resources.	Increases resilience and reduces non-climate stressors to natural systems; Emphasize management of natural processes (e.g., fire, hydrology) that are sustainable and scalable
2. Improve the stewardship of public land and water resources.	Increases resilience and reduces non-climate stressors to natural systems; Emphasize management of natural processes (e.g., fire, hydrology) that are sustainable and scalable
3. Ecological and environmental education efforts for Illinois' citizens need to be re-doubled, and must be coupled with access to natural resources.	A key action for scaling up efforts to reduce climate and non-climate stressors to natural systems, and mitigate for climate change; Climate change is an opportunity to re-engage citizens by linking nature's benefits to people
4. Market land stewardship, demonstrated on private and public properties, to the citizens of Illinois to develop their understanding and support.	A key action for scaling up efforts to reduce non-climate stressors to natural systems; Demand for information and assistance will increase as climate change creates rapid turnover in systems
5. Clarification or change in liability statutes and property tax codes to promote private land stewardship and access for outdoor recreation.	
6. Continued removal and control (chemical, mechanical and biological) of invasive species, especially within high quality natural areas, on public and private lands	Reduces non-climate stressor to these systems; Emphasize management of natural processes that are sustainable and scalable

Green Cities Campaign

Actions	**Climate Change Considerations**
1. Minimize the adverse effects associated with development on wildlife and habitats.	Reduce non-climate stressor to wildlife populations and habitats within developed landscapes; Green infrastructure that preserves ecological connectivity enabling species to track migrating climates, and designed to accommodate more frequent high-rainfall events will be increasingly important
2. Integrate wildlife and habitat conservation in developed areas, as possible or appropriate.	Urban residents are likely to experience the most lethal effects of climate change during dangerous heat waves, and urban forests are critical ecosystem-based component of moderating urban temperatures; Wetlands and floodplain green spaces will be more important to minimizing dangerous flooding as more precipitation falls in heavy events
3. Increase water quality education efforts in areas under high development pressure and/or within fragile geographic zones (i.e. karst terrain).	Reduce non-climate stressors to aquatic species
4. Make natural areas conservation, ecology and environmental education a mandatory part of school curricula.	A key action for scaling up efforts to reduce climate and non-climate stressors to natural systems, and mitigate for climate change; Climate change is an opportunity to re-engage citizens by linking nature's benefits to people
5. Fill information gaps and develop conservation actions to address stresses.	A key step to adaptive management
6. Increase access to open lands and waters within and near urban areas for wildlife-related	

recreation.	
PROPOSED: *Mitigate against the threat of climate change with policy changes to reduce emissions of greenhouse gases and encourage ecosystem-based practices which absorb and sequester atmospheric carbon dioxide.*	

RESEARCH & MONITORING

Connectivity. Our use of the NatureServe *Climate Change Vulnerability Index* appeared to show sensitivity to factors related to species dispersal, and increasing 'connectivity' is the most frequently advised climate-adaptation strategy (Hanson and Hoffman 2011, Heller and Zavaleta 2009, Hodgson et al. 2009). We urge caution in assuming that restoring or establishing corridors is the most important adaptation strategy to deploy for species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change. The assumptions built into this tool require careful consideration when interpreting our results and deliberating conservation strategies. This tool rates anthropogenic barriers to dispersal based on the proportion of an assessment area in natural land cover types, and not actual patters of connectivity or isolation. Not all natural land cover types are equally conducive to dispersal of all species. A forest-dwelling species may be unable or unwilling to disperse across a grassland area, and a grassland species may avoid crossing a forested area, for example. Agricultural and low-density developed areas are readily utilized for dispersal by some species. For species like amphibians and reptiles, significant developed barriers (such as multi-lane highways), can be very effective barriers to dispersal even if a small proportion of the landscape.

In many circumstances, corridors may not be the critical limiting factor for isolated populations. Actions that improve local habitat quality and increase population size to alleviate demographic and genetic stresses may achieve far greater success. Hodgson et al. (2009) argue that connectivity is over-emphasized and the benefits highly uncertain, whereas habitat area and habitat quality metrics tend to deliver more reliable, concrete benefits while coincidentally increasing connectivity. Corridors have been widely attempted with mixed results. In many cases, competing, predatory or invasive species benefit from corridors.

Critically, dispersal has a temporal as well as spatial dynamic that must be considered, and the land cover of Illinois has been quite dynamic over the past 200 years and likely will be into the future (Walk et al. 2010). Research is necessary to better understand the dispersal abilities and constraints of terrestrial and aquatic species in fragmented systems, and to understand when corridors are necessary and might be successful.

Invasive Species. Range shifts, altered conditions, and changing community composition will set the stage for invasive species to be even more problematic in the future. Distinguishing between native species that are expanding their ranges and changes in community composition will challenge managers to identify "invasive" species. These determinations are as likely to be subjective and value-based as quantifiable. Tools for prioritizing invasive species for control will be essential, as will be strategies that are sustainable and scalable. Some invasions might be anticipated by tracking northward movement of invasive species in states south of Illinois or by climate envelope models of future conditions in Illinois compared to current distributions of species in North America and other temperate regions. An early invasive species watch program to support the Plants of Concern and similar programs will be crucial for mounting effective responses to new invasions.

Water Quality and Quantity. Baseline data on water flows, withdrawal and discharge, and models of flows necessary to sustain aquatic communities are needed to anticipate changes and manage lakes and streams as climate change alters precipitation patterns and increases human demand for water (including municipal, agricultural and industrial uses). Coolwater refugia that might be maintained as air temperature and surface runoff temperature increases need to be identified. Groundwater effects on stream water temperature and flows need to be better understood to avoid depletion of these resources and adverse effects on streams. Water quality standards to protect aquatic life should be re-evaluated in the context of anticipated conditions. Increased temperature, lower dissolved oxygen, and lower pH may interact in complex ways to change the toxicity of various pollutants.

Community and Species Responses to Climate Change. Current models of changes in species distributions are relatively simplistic, based on current and projected climate conditions. Tools that help managers better understand potential changes in native and nonnative species distributions based on additional factors, including current and anticipated land use, soil types, and geophysical conditions may be particularly helpful for targeting conservation efforts. Longitudinal monitoring to record changes in phenology and species associations can inform conservationists about community shifts such as plant-pollinator relationships and mismatches in flowering phenology with bird migration, although it is less clear what actions might be taken as a response to such data.

Evaluation of Climate Change Adaptation and Mitigation Strategies. While recommended strategies to adapt to and mitigate for climate change have proliferated in recent years, many of these strategies are still being (or are not yet) deployed, and to date there is very little data evaluating their costs, benefits, and relative effectiveness. As such, an adaptive management approach that treats natural resource management with an experimental design will be necessary to ensure actions are working towards reaching measureable objectives. Experiments should be initiated to assess underlying assumptions of climate adaptation strategies, such as reducing non-climate stressors to increase the resilience of populations or communities. Are woodlands treated with prescribed fire (restoring a missing process) more resilient to climate change (more stable composition) than unburned woodlands? There are likely hundreds of such questions that can be addressed.

Other interventionist strategies need rigorous testing as well. Translocations and assisted migrations should be carefully studied to help reveal factors that enhance the establishment of translocated species and minimize adverse effects on the recipient community. Is translocation of a suite of species more or less effective?

"Pre-adapted" restorations must be tested against restorations relying on local-source seeds. Local-source seeds are often acquired from small remnant populations that may have low genetic diversity, low vigor, and low adaptive potential to changing conditions. And while local-ecotype seeds are valued as adapted to local conditions, they may be mal-adapted to future conditions. Field experiments comparing the success of restorations using local, southerly, and mixed seed sources will help resolve these issues and inform best-practices for dynamic seed transfer zones, reciprocal transplants, and assisted migration.

Changes to Existing Monitoring Programs. In the interest of balancing effort devoted to monitoring versus acting, an audit of monitoring programs and their relevance to an adaptive management framework is warranted. Various models of adaptive management exist (e.g., Fig. 14), but the key elements are (1) an explicit, measurable objective, (2) an action plan that acknowledges assumptions and uncertainties, and (3) a feedback mechanism that evaluates action effectiveness, tests assumptions, reduces uncertainties and leads to a revision of objectives and actions. Monitoring activities that do not inform management decisions and data that are not analyzed and utilized are wasted effort. Similarly, actions that are undertaken without monitoring component may or may not be effective in reaching the objective.

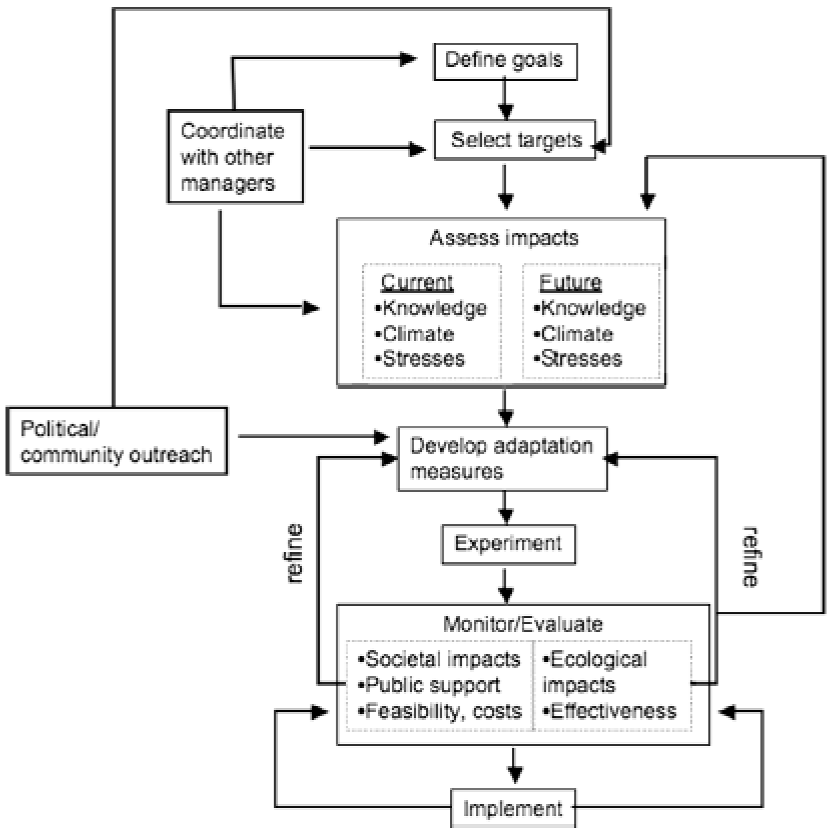


Figure 14. A model of adaptive management in the face of climate change, from Heller and Zavaleta (2009).

The Critical Trends Assessment Program (CTAP) is the most widespread, comprehensive natural resource monitoring program underway in Illinois, with a moderate historical baseline and scalable protocol. The CTAP has tremendous potential to provide evaluation data to inform management decisions, including climate change adaptation actions. As examples, repeated visits within a season may be warranted for a subset of sites along a longitudinal gradient if phenology data is considered important for decision-making. CTAP data can be analyzed for range shifts, changes in species association, and for trends in community composition. Already, CTAP data have been modeled to show range shifts of invasive species. Perhaps most powerfully, the CTAP can begin to tease out the effectiveness of various conservation strategies. By recording stewardship histories of sites in the program, and re-deployed or expanding the CTAP protocol to additional sites, and assigning various treatment scenarios to each site (e.g., prescribed fire, invasive species control, restored hydrology), the CTAP can quantify the most effective and cost-effective interventions that enhance resilience and function of natural systems.

NATURAL DIVISION & WATERSHED ASSESSMENTS

Some patterns are emerging among the natural divisions and watersheds of Illinois, with respect to climate change vulnerabilities and opportunities. Northern Illinois tends to host a number of Species in Greatest Need of Conservation occurring at the southern edge of their ranges whereas far southern Illinois has a number of Species in Greatest Need of Conservation at the northern edges of their ranges. As such, relatively more s losses in northern Illinois and range expansions in southern Illinois of Species in Greatest Need of Conservation may be expected from climate change.

Among natural divisions, the Wisconsin Driftless, Ozarks and Shawnee Hills have the greatest proportions of natural land cover and greater topographic diversity, so these will be the most likely ‘climate refugia’ in the state. Similarly, the large rivers – the Mississippi, Ohio, Wabash and Illinois – are more likely to be buffered from the larger changes in temperature and variations in flows experienced in smaller tributaries and headwater streams.

The large rivers of Illinois, and the natural divisions lying along them, are staged to be important corridors for species migrations. As such, minimizing additional barriers in these regions has high importance. Navigation locks on the large rivers – with the Wabash being the biologically richest and anoteworthy exception – are probably partial barriers to some species, and rivers and larger streams are laterally isolated from side channels, backwaters and floodplains by levees in many areas.

Other natural divisions and watersheds are more heavily altered. As examples, the large dams and reservoirs on the Kaskaskia River at Carlyle and Shelbyville, and expanses of ‘corn-soybean desert’ in the Grand Prairie natural division are probably formidable barriers to dispersal of many species. Other changes in land use, such as perennial biomass crops in floodplains and on marginal soils and changes in development patterns, may provide unexpected opportunities for wildlife conservation in response to climate change.

For all natural divisions and watersheds, we present the parameters utilized in applying the NatureServe *Climate Change Vulnerability Index* to Species in Greatest Need of Conservation. Additionally, we report those species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change in each natural division or watershed.

Coastal Plain

The Coastal Plain natural division in far southern Illinois represents the northernmost extent of the Gulf Coastal Plain and several communities (e.g., cypress-tupelo swamps, canebrakes) and species (e.g., bird-voiced treefrog, swamp rabbit, Swainson's warbler) characteristic of that ecoregion. Combined with extensive conservation holdings and ongoing floodplain restoration work, the biota of the Coastal Plain would seem to be somewhat less vulnerable to moderate warming than those in other natural divisions of Illinois. Changes in precipitation patterns, and a net drying effect, pose a greater risk to wetlands of the natural division. Restoration of once-extensive glade and barrens communities may pre-adapt these communities for conditions that will favor them in future decades.

Parameters considered in the *Climate Change Vulnerability Index* for the Coastal Plain natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barriers	Not significant
Anthropogenic barriers	49% natural, 99-00 Land Cover of Illinois
Land use change as climate mitigation	
Forest	little change (but extensive conservation reforestation)
Cropland	short-rotation woody crops on floodplain soils possible
Stream	flood storage within levee districts (Cache River reconnection likely)
Grassland	little change (but see reversion to forest via conservation)
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	likely to be infrequent in floodplains, system fragmented
Flooding	increased frequency, severity; disruption of seasonality

Drought	possible increased frequency, severity

Species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Coastal Plain natural division:

Cryptobranchus alleganiensis	hellbender

Grand Prairie

The largest of Illinois' natural divisions, the Grand Prairie is also the most heavily altered and fragmented. Restoring spatial connectivity of prairies and wetlands in this region likely is not practical and a network of suitably-sized managed areas may provide the best chance for species to persist in the natural division. Given that many native prairie species already rely on nonnative grasslands, the Grand Prairie may be an appropriate region for creative 'transformation' strategies that emphasize providing an evolutionary stage and ecosystem functions more than particular species composition. The several medium to large rivers crossing the natural division, and their accompanying riparian vegetation, are likely to be important dispersal pathways for species of streams and wooded habitats. Extensive wind energy development is underway in the Grand Prairie.

Parameters considered in the *Climate Change Vulnerability Index* for the Grand Prairie natural division:

Temperature	>5F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	Not significant
Anthropogenic barrier	15% natural, greatly increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	inputs/yield likely to remain high, harvest may include residue for biomass, new biofuel crop may emerge (see grassland biofuels below)
Stream	increase in impoundments, irrigation in response to irregular precipitation
Grassland	little change in extent, some conversion to biomass crops, but unlikely to displace cropland or forest

Developed, Infrastructure	extensive wind energy development
Disturbance Regimes	
Fire	likely to be infrequent system fragmented, though predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Grand Prairie natural division:

Euphyes dion	Dion Skipper
Lycaena xanthoides	great copper
Poanes viator	Broad-winged skipper
Problema byssus	Byssus skipper
Schinia jaguarina	jaguar flower moth
Schinia lucens	leadplant flower moth
Papaipema speciosissima	Osmunda Borer Moth

Illinois River and Mississippi River Sand Areas

Many of the characteristic species found in the Sand Areas natural division (e.g., western hognose snake) are disjunct from other populations farther west. While warming and drying conditions may provide opportunity for maintaining some local populations, reliance on sandy soils forms an additional form of isolation beyond extensive habitat loss in the natural division. An increased reliance on groundwater for irrigation could increase the vulnerability of Illinois chorus frogs (*Pseudacris streckeri illinoensis*) and other species dependent on shallow wetlands.

Parameters considered in the *Climate Change Vulnerability Index* for the Illinois River and Mississippi River Sand Areas natural division:

Temperature	>5F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	species restricted to sandy soils are essentially on "islands"
Anthropogenic barrier	33% natural, increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	inputs/yield likely to remain high, harvest may include residue for biomass, new biofuel crop may emerge (see grassland bioefuels below)
Stream	increase in irrigation in response to irregular precipitation
Grassland	some conversion to biomass crops, may displace cropland if irrigation costs high
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	likely increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Illinois River and Mississippi River Sand Areas natural division:

Laterallus jamaicensis	black rail
Speyeria idalia	regal fritillary
Pseudacris streckeri illinoensis	Illinois chorus frog

Lower Mississippi River Bottomlands

As in the Coastal Plain natural division, several of the Species in Greatest Need of Conservation assessed for climate change vulnerability in the Lower Mississippi River Bottomlands natural division were at the northern edge of their range, and further northward expansion is predicted. However, this natural division is also one of the most heavily altered divisions. The north-south corridor of the Mississippi River, and the possibility of changing floodplain land use from annual row cropping to perennial crops and/or flood storage in response to more severe and erratic flooding of the Mississippi River may provide an opportunity for wildlife to benefit.

Parameters considered in the *Climate Change Vulnerability Index* for the Lower Mississippi River Bottomlands natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.097 - -0.119
Natural topographic/geographic barrier	Not significant
Anthropogenic barrier	21% natural land cover, greatly increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	short-rotation woody crops on floodplain soils possible
Stream	flood storage within levee areas possible
Grassland	little change
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	infrequent in fragmented system, though predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Lower Mississippi River Bottomlands natural division:

Pseudacris streckeri illinoensis	Illinois chorus frog
Ambystoma talpoideum	mole salamander
Rana sylvatica	wood frog

Middle Mississippi River Border

The north-south oriented Middle Mississippi River Border is one of the less-altered natural divisions in Illinois. This region is likely to be a key dispersal corridor for plants and animals.

Parameters considered in the *Climate Change Vulnerability Index* for the Middle Mississippi River Border natural division:

Temperature	>5F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	Not significant
Anthropogenic barrier	40% natural land cover, Increase/somewhat increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	short-rotation woody crops on floodplain soils possible
Stream	flood storage within levee areas possible
Grassland	little change
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated as *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Middle Mississippi River Border natural division:

Rana palustris	pickerel frog

Northeastern Morainal

The Northeastern Morainal natural division is the most developed region of Illinois, and represents the southernmost extent of several glacial relict communities (bogs, glacial lakes). The Northeastern Morainal natural division is also at or near the southern edge of many wetland species' ranges (e.g., Blanding's turtle, black tern). While warming and drying are expected to be somewhat less severe in this region than other parts of the state, many species and communities may not be able to withstand future conditions and dispersal across an urban matrix will not be practical for others. Assisted migration, already widely practiced as translocations and restorations in the region, may become increasingly important. As in the Grand Prairie, a network of suitably-sized managed reserves may be the best option for conserving many species and sustaining ecosystem functions. Ecosystem-based adaptation strategies (e.g., the Chicago Wilderness Green Infrastructure Vision), a relatively robust network of existing greenspace, and an availability of conservation resources far greater than in other regions of the state will help to abate the threat of climate change.

Parameters considered in the *Climate Change Vulnerability Index* for the Northeastern Morainal natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.051 - -0.073
Natural topographic/geographic barrier	Not significant; If lake level declines (as most models suggest), additional shoreline-dune habitat may be available
Anthropogenic barrier	25% natural land cover, increase vulnerability
Land use change as climate mitigation	
Forest	increase w/in buffers, green space
Cropland	little change (but extensive loss to development expected)
Stream	increase in impoundments, flood storage basins in response to irregular precipitation
Grassland	little change (but extensive loss to development expected)

Developed, Infrastructure	already intense, extensive…
Disturbance Regimes	
Fire	tightly controlled, likely similar or less frequency than present
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Northeastern Morainal natural division:

Plebejus melissa samuelis	Karner blue butterfly
Papaipema eryngii	rattlesnake master borer moth

Ozarks

The Illinois portion of the Ozarks natural division is disjunct from the rest of the Ozark Plateau, but it is unclear how many species are narrowly restricted to this land form or are isolated by the Mississippi River. The Ozarks is among the lesser-altered natural divisions in Illinois. Coupled with considerably more topographic variety than most other natural divisions, many species may be able to locate suitable microhabitat refugia in this region. This region in Illinois is expected to experience the most drying effects, so future conditions may better support barren, glade, and hill prairie habitats.

Parameters considered in the *Climate Change Vulnerability Index* for the Ozarks natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.097 - -0.119
Natural topographic/geographic barrier	Karst-dependent and other species may be isolated from remainder of Ozark Plateau by Mississippi River
Anthropogenic barrier	60% natural land cover, neutral effect on vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	little change
Stream	little change
Grassland	little change
Developed, Infrastructure	little climate-related, but exurban expected from St. Louis metro region
Disturbance Regimes	
Fire	increased frequency predicted
Flooding	increased frequency, severity; disruption of seasonality
Drought	likely increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Ozarks natural division:

Rana palustris	pickerel frog

Rock River Hill Country

The Rock River Hill Country has moderate topographic variety and natural land cover compared to other natural divisions. As in the Northeastern Morainal natural division, several of the Species in Greatest Need of Conservation characteristic of the Rock River Hill Country are at the southern edge of their range. Extensive wind energy development is underway in the Rock River Hill Country.

Parameters considered in the *Climate Change Vulnerability Index* for the Rock River Hill Country natural division:

Temperature	>5F warmer
Hamon AET:PET Moisture Metric	-0.051 - -0.073
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	27% natural land cover, increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	inputs/yield likely to remain high, harvest may include residue for biomass, new biofuel crop may emerge (see grassland bioefuels below)
Stream	little change
Grassland	some conversion to biomass crops, little displacement of crop or forest
Developed, Infrastructure	extensive wind energy development
Disturbance Regimes	
Fire	infrequent in fragmented system, though predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Rock River Hill Country natural division:

Rana palustris	pickerel frog

Shawnee Hills

The Shawnee Hills are the least altered natural division in Illinois. A trait shared with the adjacent Ozarks and the Wisconsin Driftless natural divisions, the Shawnee Hills have more topographic variety than most other natural divisions, and many species may be able to locate suitable microhabitat refugia in this region. This region in Illinois is expected to experience the most drying effects, so future conditions may better support barren, glade, and open woodland habitats.

Parameters considered in the *Climate Change Vulnerability Index* for the Shawnee Hills natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.097 - -0.119
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	80% natural land cover, neutral effect on vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	little change
Stream	little change
Grassland	some conversion to biomass crops, little displacement of crop or forest
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Shawnee Hills natural division:

Crangonyx anomalus	anomolous spring amphipod

Southern Till Plain

The Southern Till Plain natural division is second in size to the Grand Prairie, and approaches that division in the degree of landscape alteration and fragmentation. Given that many native prairie species already rely on nonnative grasslands, the Southern Till Plain may be an appropriate region for creative 'transformation' strategies that emphasize providing an evolutionary stage and ecosystem functions more than particular species composition. With somewhat less productive and more erodible soils than the Grand Prairie, the Southern Till Plain has more idle cropland (Conservation Reserve Program grassland) that may be more compatible with perennial biomass/biofuel cropping if technologies and markets develop. The several medium-large rivers crossing the natural division, and their accompanying riparian vegetation, are likely to be important dispersal pathways for species of wooded habitats.

Parameters considered in the *Climate Change Vulnerability Index* for the Southern Till Plain natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	32% natural land cover, increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	inputs/yield likely to remain high, harvest may include residue for biomass, new biofuel crop may emerge (see grassland biofuels below)
Stream	increase in impoundments, irrigation in response to irregular precipitation
Grassland	little change in extent, some conversion to biomass crops, but unlikely to displace cropland or forest

Developed, Infrastructure	little change
Disturbance Regimes	
Fire	likely to be infrequent system fragmented, though predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Southern Till Plain natural division:

Papaipema eryngii	rattlesnake master borer moth

Upper Mississippi River and Illinois River Bottomlands

As in the Lower Mississippi River Bottomlands, this natural division is one of the most heavily altered. Several large floodplain areas are in conservation management, and the possibility of changing floodplain land use from annual row cropping to perennial crops and/or flood storage in response to more severe and erratic flooding of the Mississippi and Illinois rivers may provide an opportunity for wildlife to benefit.

Parameters considered in the *Climate Change Vulnerability Index* for the Upper Mississippi River and Illinois River Bottomlands natural division:

Temperature	>5F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	24% natural land cover, increase vulnerability
Land use change as climate mitigation	
Forest	little change (though increasing on conservation lands)
Cropland	short-rotation woody crops on floodplain soils possible
Stream	flood storage within levee areas possible
Grassland	little change
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	likely to be infrequent in floodplains, system fragmented
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

No species were rated Extremely or Highly Vulnerable to climate change in the Upper Mississippi River and Illinois River Bottomlands natural division.

Wabash Border

The north-south oriented Wabash Border natural division may experience northward expansion of species and communities typically found farther south in the Ohio River valley today, such as cane, cypress and tupelo. Like the Lower Mississippi River Bottomlands and Upper Mississippi River and Illinois River Bottomlands natural divisions, the Wabash Border landscape is heavily altered, but floodplain land use seems to moving towards reforested and wetland conditions as flooding makes row cropping less viable.

Parameters considered in the *Climate Change Vulnerability Index* for the Wabash Border natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	27% natural land cover, increase vulnerability
Land use change as climate mitigation	
Forest	little change (though increasing on conservation lands)
Cropland	short-rotation woody crops on floodplain soils possible
Stream	flood storage within levee areas possible
Grassland	little change
Developed, Infrastructure	little change
Disturbance Regimes	
Fire	likely to be infrequent in floodplains, system fragmented
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Wabash Border natural division:

Cryptobranchus alleganiensis	hellbender
Ambystoma jeffersonianum	Jefferson's salamander
Ambystoma platineum	silvery salamander

Western Forest-Prairie Border

The Western Forest-Prairie Border natural division has moderate topographic variety and natural land cover compared to other natural divisions. As in the Southern Till Plain, marginal cropland will be a likely location for perennial biomass/biofuel crops as technologies and markets develop.

Parameters considered in the *Climate Change Vulnerability Index* for the Western Forest-Prairie Border natural division:

Temperature	>5F warmer
Hamon AET:PET Moisture Metric	-0.074 - -0.096
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	32% natural land cover, increase vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	inputs/yield likely to remain high, harvest may include residue for biomass, new biofuel crop may emerge (see grassland biofuels below)
Stream	increase in impoundments, irrigation in response to irregular precipitation
Grassland	little change in extent, some conversion to biomass crops, but unlikely to displace cropland or forest
Developed, Infrastructure	moderate wind energy development
Disturbance Regimes	
Fire	likely to be infrequent system fragmented, though predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Western Forest-Prairie Border natural division:

Speyeria idalia	regal fritillary

Wisconsin Driftless

A trait shared with the Shawnee Hills and Ozarks natural divisions, the Wisconsin Driftless natural division has more topographic variety and more natural land cover than most other natural divisions, and many species may be able to locate suitable microhabitat refugia in this region. Incontrast to the Shawnee Hills and Ozarks divisions, the Wisconsin Driftless natural division includes several glacial relict species, notably the Iowa Pleistocene snail, which will be gravely challenged by warming and drying conditions.

Parameters considered in the *Climate Change Vulnerability Index* for the Wisconsin Driftless natural division:

Temperature	5.1-5.5° F warmer
Hamon AET:PET Moisture Metric	-0.051 - -0.073
Natural topographic/geographic barrier	not significant
Anthropogenic barrier	60% natural land cover, neutral effect on vulnerability
Land use change as climate mitigation	
Forest	little change
Cropland	inputs/yield likely to remain high, harvest may include residue for biomass, new biofuel crop may emerge (see grassland bioefuels below)
Stream	little change
Grassland	little change in extent, some conversion to biomass crops, but unlikely to displace cropland or forest
Developed, Infrastructure	moderate-extensive wind energy development
Disturbance Regimes	
Fire	predicted to increase
Flooding	increased frequency, severity; disruption of seasonality
Drought	possible increased frequency, severity

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Wisconsin Driftless natural division:

Discus macclintocki	Iowa pleistocene snail

Big Muddy

Parameters considered in the *Climate Change Vulnerability Index* for the Big Muddy watershed:

Temperature	5.40F warmer
Hamon AET:PET Moisture Metric	-0.097
Anthropogenic barriers	Increase Vulnerability
Navigation locks (mostly passable)	no
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	one
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Big Muddy watershed:

Arcidens confragosus	rock pocketbook
Umbra limi	central mudminnow
Quadrula metanevra	monkeyface

Embarras

Parameters considered in the *Climate Change Vulnerability Index* for the Embarras watershed:

Temperature	5.57F warmer
Hamon AET:PET Moisture Metric	-0.096
Anthropogenic barriers	Increase/Somewhat Increase Vulnerability
Navigation locks (mostly passable)	no
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	no
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Embarras watershed:

Ammocrypta pellucida	eastern sand darter
Lampetra appendix	American brook lamprey
Ptychobranchus fasciolaris	kidneyshell mussel
Villosa lienosa	little spectacle case mussel
Arcidens confragosus	rock pocketbook
Quadrula metanevra	monkeyface
Epioblasma triquetra	snuffbox mussel
Elliptio dilatata	spike

Fox

Parameters considered in the *Climate Change Vulnerability Index* for the Fox watershed:

Temperature	5.49F Warmer
Hamon AET:PET Moisture Metric	-0.071
Anthropogenic barriers	Increase/Somewhat Increase Vulnerability
Navigation locks (mostly passable)	no
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	no
Land use change as climate mitigation	Increased water use for municipal supplies likely; increased use of riparian/floodplain buffers associated with development; flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Fox watershed:

Cottus bairdi	mottled sculpin
Phoxinus erythrogaster	southern redbelly dace
Alasmidonta viridis	slippershell mussel
Culaea inconstans	brook stickleback
Rhinichthys obtusus	Western blacknose dace
Venustaconcha ellipsiformis	ellipse
Simpsonaias ambigua	salamander mussel

Illinois

Parameters considered in the *Climate Change Vulnerability Index* for the Illinois watershed:

Temperature	5.68F warmer
Hamon AET:PET Moisture Metric	-0.084
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	yes
Impoundments with small-medium dams (sometimes passable)	few
Reservoirs with major dams (mostly impassable)	no
Land use change as climate mitigation	short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Illinois watershed:

Arcidens confragosus	rock pocketbook
Umbra limi	central mudminnow
Phoxinus erythrogaster	southern redbelly dace
Rhinichthys obtusus	Western blacknose dace
Fusconaia ebena	ebonyshell
Quadrula metanevra	monkeyface

Kankakee (+ Iroquois)

Parameters considered in the *Climate Change Vulnerability Index* for the Kankakee watershed:

Temperature	5.60F warmer
Hamon AET:PET Moisture Metric	-0.078
Anthropogenic barriers	Increase/Somewhat Increase Vulnerability
Navigation locks (mostly passable)	no
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	no
Land use change as climate mitigation	Increased water use for irrigation likely

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Kankakee watershed:

Notropis texanus	weed shiner
Notropis chalybaeus	ironcolor shiner
Venustaconcha ellipsiformis	ellipse
Alasmidonta viridis	slippershell mussel
Umbra limi	central mudminnow
Phoxinus erythrogaster	southern redbelly dace
Rhinichthys obtusus	Western blacknose dace
Quadrula metanevra	monkeyface
Plethobasus cyphyus	sheepnose mussel
Elliptio dilatata	spike

Kaskaskia

Parameters considered in the *Climate Change Vulnerability Index* for the Kaskaskia watershed:

Temperature	5.54F warmer
Hamon AET:PET Moisture Metric	-0.094
Anthropogenic barriers	Greatly Increase Vulnerability
Navigation locks (mostly passable)	one
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	two
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Kaskaskia watershed:

Phoxinus erythrogaster	southern redbelly dace
Quadrula metanevra	monkeyface
Arcidens confragosus	rock pocketbook
Elliptio dilatata	spike
Centrarchus macropterus	flier

Lake Michigan, Chicago-Calumet, Des Plaines

Parameters considered in the *Climate Change Vulnerability Index* for the Lake Michigan, Chicago-Calumet, Des Plaines watershed:

Temperature	5.43F warmer
Hamon AET:PET Moisture Metric	-0.073
Anthropogenic barriers	Greatly Increase/Increase Vulnerability
Navigation locks (mostly passable)	yes (also electronic barrier)
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Little Change – Extensively Developed

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Lake Michigan, Chicago-Calumet, Des Plaines watershed:

Umbra limi	central mudminnow
Cottus bairdi	mottled sculpin
Umbra limi	central mudminnow
Etheostoma exile	Iowa darter
Culaea inconstans	brook stickleback

LaMoine

Parameters considered in the *Climate Change Vulnerability Index* for the LaMoine watershed:

Temperature	5.72F warmer
Hamon AET:PET Moisture Metric	-0.086
Anthropogenic barriers	Neutral Effect on Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	few
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the LaMoine watershed:

Phoxinus erythrogaster	southern redbelly dace
Venustaconcha ellipsiformis	ellipse
Arcidens confragosus	rock pocketbook

Little Wabash

Parameters considered in the *Climate Change Vulnerability Index* for the Little Wabash watershed:

Temperature	5.49F warmer
Hamon AET:PET Moisture Metric	-0.095
Anthropogenic barriers	Increase/Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Little Wabash watershed:

Arcidens confragosus	rock pocketbook
Fusconaia ebena	ebonyshell
Quadrula metanevra	monkeyface

Mackinaw

Parameters considered in the *Climate Change Vulnerability Index* for the Mackinaw watershed:

Temperature	5.75F warmer
Hamon AET:PET Moisture Metric	-0.085
Anthropogenic barriers	Increase/Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Mackinaw watershed:

Venustaconcha ellipsiformis	ellipse
Arcidens confragosus	rock pocketbook
Alasmidonta viridis	slippershell mussel
Phoxinus erythrogaster	southern redbelly dace
Rhinichthys obtusus	Western blacknose dace
Lasmigona compressa	creek heelsplitter
Quadrula metanevra	monkeyface

Macoupin

Parameters considered in the *Climate Change Vulnerability Index* for the Macoupin watershed:

Temperature	5.58F warmer
Hamon AET:PET Moisture Metric	-0.093
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	few
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Macoupin watershed:

Arcidens confragosus	rock pocketbook
Quadrula metanevra	monkeyface

Mississippi

Parameters considered in the *Climate Change Vulnerability Index* for the Mississippi watershed:

Temperature	5.58F warmer
Hamon AET:PET Moisture Metric	-0.085
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	yes
Impoundments with small-medium dams (sometimes passable)	few
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Mississippi watershed:

Phoxinus erythrogaster	southern redbelly dace
Rhinichthys obtusus	Western blacknose dace
Fusconaia ebena	ebonyshell
Arcidens confragosus	rock pocketbook
Plethobasus cyphyus	sheepnose mussel
Cumberlandia monodonta	spectacle case mussel

Ohio (+ Cache)

Parameters considered in the *Climate Change Vulnerability Index* for the Ohio watershed:

Temperature	5.23F warmer
Hamon AET:PET Moisture Metric	-0.094
Anthropogenic barriers	Increase/Somewhat Increase Vulnerability
Navigation locks (mostly passable)	yes
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Extensive reforestation/conservation underway; managed re-connection of upper/lower Cache likely; short-rotation woody crops and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Ohio watershed:

Elliptio crassidens	elephant-ear mussel
Potamilus capax	fat pocketbook pearly mussel
Plethobasus cooperianus	orange-foot pimpleback
Toxolasma lividum	purple lilliput mussel
Arcidens confragosus	rock pocketbook
Orconectes placidus	bigclaw crayfish

Rock (+ Kishwaukee, Green)

Parameters considered in the *Climate Change Vulnerability Index* for the Rock watershed:

Temperature	5.54F warmer
Hamon AET:PET Moisture Metric	-0.069
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Rock watershed:

Cottus bairdi	mottled sculpin
Etheostoma exile	Iowa darter
Notropis texanus	weed shiner
Lampetra appendix	American brook lamprey
Arcidens confragosus	rock pocketbook
Alasmidonta viridis	slippershell mussel
Umbra limi	central mudminnow
Phoxinus erythrogaster	southern redbelly dace
Campostoma oligolepis	largescale stoneroller
Rhinichthys obtusus	Western blacknose dace
Venustaconcha ellipsiformis	ellipse
Quadrula metanevra	monkeyface

Saline

Parameters considered in the *Climate Change Vulnerability Index* for the Saline watershed:

Temperature	5.31F warmer
Hamon AET:PET Moisture Metric	-0.098
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Saline watershed:

Arcidens confragosus	rock pocketbook
Quadrula metanevra	monkeyface

Sangamon

Parameters considered in the *Climate Change Vulnerability Index* for the Sangamon watershed:

Temperature	5.66F warmer
Hamon AET:PET Moisture Metric	-0.091
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Sangamon watershed:

Lampetra appendix	American brook lamprey
Notropis chalybaeus	ironcolor shiner
Arcidens confragosus	rock pocketbook
Simpsonaias ambigua	salamander mussel
Alasmidonta viridis	slippershell mussel
Quadrula metanevra	monkeyface

Spoon

Parameters considered in the *Climate Change Vulnerability Index* for the Spoon watershed:

Temperature	5.74F warmer
Hamon AET:PET Moisture Metric	-0.083
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Spoon watershed:

Phoxinus erythrogaster	southern redbelly dace
Venustaconcha ellipsiformis	ellipse
Arcidens confragosus	rock pocketbook
Rhinichthys obtusus	Western blacknose dace
Quadrula metanevra	monkeyface

Vermilion of the Illinois

Parameters considered in the *Climate Change Vulnerability Index* for the Vermilion watershed:

Temperature	5.74F warmer
Hamon AET:PET Moisture Metric	-0.082
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	few
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Vermilion watershed:

Venustaconcha ellipsiformis	ellipse
Lasmigona compressa	creek heelsplitter
Quadrula metanevra	monkeyface

Wabash (+ Vermilion)

Parameters considered in the *Climate Change Vulnerability Index* for the Wabash watershed:

Temperature	5.58F warmer
Hamon AET:PET Moisture Metric	-0.090
Anthropogenic barriers	Somewhat Increase Vulnerability
Navigation locks (mostly passable)	none
Impoundments with small-medium dams (sometimes passable)	yes
Reservoirs with major dams (mostly impassable)	none
Land use change as climate mitigation	Increased water use for irrigation; short-rotation woody crop and flood storage possible on floodplains

Species rated *Extremely Vulnerable* or *Highly Vulnerable* to climate change in the Wabash watershed:

Etheostoma exile	Iowa darter
Phoxinus erythrogaster	southern redbelly dace
Elliptio crassidens	elephant-ear mussel
Toxolasma lividum	purple lilliput mussel
Alasmidonta viridis	slippershell mussel
Lampsilis fasciola	wavy-rayed lampmussel
Potamilus capax	fat pocketbook pearly mussel
Ptychobranchus fasciolaris	kidneyshell mussel
Villosa lienosa	little spectacle case mussel
Arcidens confragosus	rock pocketbook

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Appendix I. Species in Greatest Need of Conservation and geographic areas selected for climate change vulnerability assessment.

MOLLUSKS	Lake Michigan, Chicago-Calumet, Desplaines	Rock (Kishwaukee & Green)	Mississippi	Illinois	Kankakee (Iroquois)	Fox	Vermillion (Illinois)	Mackinaw	Spoon	Sangamon	LaMoine	Macoupin	Kaskaskia	Big Muddy	Wabash (Vermillion)	Embarras	Little Wabash	Saline	Ohio (Cache)
Alasmidonta viridis (slippershell mussel)		x			x	x		x		x					x				
Arcidens confragosus (rock pocketbook)		x	x	x				x	x	x	x	x	x	x	x	x	x	x	x
Cumberlandia monodonta (spectacle case mussel)			x																x
Cyprogenia stegaria (fanshell mussel)															x				
Discus macclintocki (Iowa Pleistocene snail)	(Wisconsin Driftless)																		
Elliptio crassidens (elephant-ear mussel)															x				x
Elliptio dilatata (spike)					x	x							x			x			
Epioblasma triquetra (snuffbox mussel)																x			
Fusconaia ebena (ebonyshell)			x	x											x		x		x
Lampsilis abrupta (pink mucket)																			x
Lampsilis fasciola (wavy-rayed lampmussel)															x				
Lampsilis higginsii (Higgins eye)			x																
Lasmigona compressa (creek heelspliter)				x			x	x							x				
Plethobasus cooperianus (orange-foot pimpleback)																			x

Plethobasus cyphyus (sheepnose mussel)			x		x														
Potamilus capax (fat pocketbook pearly mussel)															x				x
Ptychobranchus fasciolaris (kidneyshell mussel)															x	x			
Quadrula metanerva (monkeyface)		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
Simpsonaias ambigua (salamander mussel)					x					x					x				
Toxolasma lividus (purple lilliput mussel)															x				x
Venustaconcha ellipsiformis (ellipse)		x			x	x	x	x	x		x								
Villosa iris (rainbow mussel)															x				
Villosa lienosa (little spectacle case mussel)															x	x			

INSECTS	Coastal Plain	Grand Prairie	Illinois/Mississippi River Sand Areas	Lower Mississippi River bottoms	Middle Mississippi Border	Northeastern Morainal	Ozarks	Rock River Hill Country	Shawnee Hills	Southern Till Plain	Upper Mississippi/Illinois River Bottomlands	Wabash Border	Western Forest-Prairie	Wisconsin Driftless
Aflexia rubranura (redveined prairie leafhopper)						x								
Arphia pseudonietana					x			x						
Atrytone arogos (arogos skipper)		x												
Atrytonopsis hianna	x	x	x		x				x				x	
Boloria selene myrina		x				x		x						
Calephelis muticum (swamp metalmark)		x				x								
Chlosyne gorgone carlota		x			x			x					x	
Euchloe olympia		x				x		x						
Euphyes bimacula		x				x				x			x	
Euphyes dion		x				x		x			x			
Glaucopsyche lygdamus		x						x					x	
Hesperia metea (cobweb skipper)			x										x	
Hesperia ottoe (ottoe skipper)		x	x		x			x						
Hesperia sassacus		x												
Lethe appalachia	x	x				x			x	x				
Lycaeides melissa samuelis (Karner blue butterfly)						x								
Lycaena helloides		x				x		x					x	
Lycaena xanthoides		x	x			x				x			x	
Papaipema eryngii (rattlesnake-master borer moth)						x				x				

Papaipema speciosissima		x				x								
Paraphlepsius lupalus (leafhopper)						x								
Petrophora subaequaria		x				x								
Poanes viator		x				x								
Problema byssus (Byssus skipper)		x	x		x	x	x		x				x	
Satyrium edwardsii			x			x	x			x			x	
Schinia jaguarina		x												
Schinia lucens		x	x			x								
Somatochlora hineana (Hine’s emerald dragonfly)						x								
Speyeria aphrodite						x		x					x	x
Speyeria idalia (regal fritillary)			x			x		x					x	x

CRUSTACEANS	Lake Michigan, Chicago-Calumet, Desplaines	Rock (Kishwaukee & Green)	Mississippi	Illinois	Kankakee (Iroquois)	Fox	Vermillion (Illinois)	Mackinaw	Spoon	Sangamon	LaMoine	Macoupin	Kaskaskia	Big Muddy	Wabash (Vermillion)	Embarras	Little Wabash	Saline	Ohio (Cache)
Caecidotea lesliei (isopod)	(Western Forest-Prairie Border)																		
Caecidotea spatulata (a cave obligate isopod)	(Ozarks)																		
Crangonyx anomalus (anomolous spring amphipod	(Shawnee Hills)																		
Crangonyx packardi (amphipod)	(Shawnee Hills)																		
Gammarus acherondytes (Illinois cave amphipod)	(Ozarks)																		
Gammarus bousefieldi (Boufield's amphipod)																			x
Orconectes illinoisensis (Illinois crayfish)																			
Orconectes indianensis (Indiana crayfish)														x				x	
Orconectes kentuckiensis (Kentucky crayfish)																			x
Orconectes lancifer (shrimp crayfish)																			x
Orconectes placidus (bigclaw crayfish)																			x
Stygobromus iowae (Iowa amphipod)	(Wisconsin Driftless)																		

FISHES	Lake Michigan, Chicago-Calumet, Desplaines	Rock (Kishwaukee & Green)	Mississippi	Illinois	Kankakee (Iroquois)	Fox	Vermillion (Illinois)	Mackinaw	Spoon	Sangamon	LaMoine	Macoupin	Kaskaskia	Big Muddy	Wabash (Vermillion)	Embarras	Little Wabash	Saline	Ohio (Cache)
Ammocrypta pellucida (eastern sand darter)															x	x			
Anguilla rostrata (American eel)			x	x						x				x	x		x		
Campostoma oligolepis (largescale stoneroller)		x	x	x		x													
Centrarchus macropterus (flier)													x	x				x	x
Cottus bairdi (mottled sculpin)	x	x				x													
Culaea inconstans (brook stickleback)	x	x				x													
Erimyzon sucetta (lake chubsucker)				x	x	x				x									
Etheostoma exile (Iowa darter)	x	x				x									x				
Fundulus dispar (starhead topminnow)					x	x													
Hybopsis amnis (pallid shiner)			x		x					x									
Lampetra appendix (American brook lamprey)		x								x						x			
Micropterus punctulatus (spotted bass)															x	x	x		x
Moxostoma carinatum (river redhorse)					x		x								x				
Moxostoma valenciennesi (greater redhorse)				x		x	x												
Notropis chalybaeus (ironcolor shiner)					x					x									
Notropis rubellus (rosyface shiner)		x	x	x	x	x	x	x							x				
Notropis texanus (weed shiner)		x			x														
Opsopoeodus emilae (pugnose minnow)			x	x	x	x								x	x		x		x

Perca flavescens (yellow perch)	x		x	x		x													
Phoxinus erythrogaster (southern redbelly dace)		x	x	x	x	x		x	x		x		x		x				
Polyodon spathula (North American paddlefish)			x	x											x				
Rhyinichthys atratulus (blacknose dace)		x	x	x	x	x		x	x						x				
Stizostedion vitreum (walleye)		x	x	x		x									x				
Umbra limi (central mudminnow)	x	x		x	x	x								x					

AMPHIBIANS	Coastal Plain	Grand Prairie	Illinois/Mississippi River Sand Areas	Lower Mississippi River bottoms	Middle Mississippi Border	Northeastern Morainal	Ozarks	Rock River Hill Country	Shawnee Hills	Southern Till Plain	Upper Mississippi/Illinois River Bottomlands	Wabash Border	Western Forest-Prairie	Wisconsin Driftless
Ambystoma jeffersonianum (Jefferson salamander)												x		
Ambystoma laterale (blue-spotted salamander)						x								
Ambystoma platineum (silvery salamander)												x		
Ambystoma talpoideum (mole salamander)	x			x										
Cryptobranchus alleganiensis (hellbender)	x								x			x		
Desmognathus conanti (spotted dusky salamander)	x													
Gastrophryne carolinensis (eastern narrowmouth toad)	x			x										
Hemidactylium scutatum (four-toed salamander)												x		x
Hyla avivoca (bird-voiced treefrog)	x			x										
Necturus maculosus (mudpuppy)	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pseudacris streckeri illinoensis (Illinois chorus frog)			x	x										
Rana areolata (crayfish frog)	x								x	x		x		
Rana palustris (pickerel frog)					x		x	x						x
Rana sylvatica (wood frog)	x			x		x			x			x		

REPTILES	Coastal Plain	Grand Prairie	Illinois/Mississippi River Sand Areas	Lower Mississippi River bottoms	Middle Mississippi Border	Northeastern Morainal	Ozarks	Rock River Hill Country	Shawnee Hills	Southern Till Plain	Upper Mississippi/Illinois River Bottomlands	Wabash Border	Western Forest-Prairie	Wisconsin Driftless
Apalone mutica (smooth softshell turtle)	x	x		x	x			x		x	x	x		
Clemmys guttata (spotted turtle)						x								
Clonophis kirtlandii (Kirtland's snake)		x				x				x			x	
Crotalus horridus (timber rattlesnake)							x		x					x
Elaphe emoryi (great plains rat snake)							x							
Emydoidea blandingii (Blanding's turtle)		x				x								
Farancia abacura (mud snake)	x			x					x					
Heterodon nasicus (western hognose snake)		x	x					x						
Kinosternon flavescens (Illinois mud turtle)			x											
Kinosternon subrubrum (eastern mud turtle)	x			x								x		
Liochlorophis vernalis (smooth green snake)		x				x								
Macrochelys temminckii (alligator snapping turtle)	x			x										
Nerodia cyclopion (Mississippi green water snake)				x										
Nerodia erythrogaster neglecta (n. copperbelly watersnake)									x			x		
Ophisaurus attenuatus (slender glass lizard)		x			x								x	
Pseudemys concinna (river cooter)	x			x								x		

Sistrurus catenatus catenatus (eastern massasauga)		x				x				x				
Tantilla gracilis (flathead snake)							x							
Terrapene ornata (ornate box turtle)		x	x					x		x				
Thamnophis sauritus (eastern ribbon snake)	x											x		
Tropidoclonion lineatum (lined snake)		x											x	

BIRDS	Coastal Plain	Grand Prairie	Illinois/Mississippi River Sand Areas	Lower Mississippi River bottoms	Middle Mississippi Border	Northeastern Morainal	Ozarks	Rock River Hill Country	Shawnee Hills	Southern Till Plain	Upper Mississippi/Illinois River Bottomlands	Wabash Border	Western Forest-Prairie	Wisconsin Driftless
Buteo platypterus (broad-winged hawk)					x	x	x		x					x
Cistothorus palustris (marsh wren)						x					x			
Empidonax virescens (Acadian flycatcher)	x			x	x		x	x	x			x	x	x
Ictinia mississippiensis (Mississippi kite)	x			x										
Phalaropus tricolor (Wilson's phalarope)						x								
Caprimulgus vociferus (whip-poor-will)	x		x	x	x		x		x	x	x	x	x	x
Ammodramus savannarum (grasshopper sparrow)		x	x			x		x		x			x	x
Dendroica cerulea (cerulean warbler)	x				x	x	x	x	x			x	x	x
Nyctanassa violacea (yellow-crowned night-heron)	x			x							x	x		
Vermiforma pinus (blue-winged warbler)						x	x		x	x		x		
Bartramia longicauda (upland sandpiper)		x	x			x		x		x				x
Chlidonias niger (black tern)						x								
Egretta caerulea (little blue heron)	x			x								x		
Helmitheros vermiforma (worm-eating warbler)					x		x		x					x
Pandion haliaetus (osprey)	x					x					x			
Spiza americana (dickcissel)	x	x	x			x		x		x			x	x
Sterna forsteri (Forster's tern)						x								
Coccyzus erythropthalmus (black-billed cuckoo)		x	x		x	x		x			x		x	x
Gallinula chloropus (common moorhen)						x					x			
Laterallus jamaicensis (black rail)		x	x			x				x				

Rallus elegans (king rail)	x	x		x		x				x	x			
Toxostoma rufum (brown thrasher)		x	x		x	x		x		x		x	x	x

MAMMALS	Coastal Plain	Grand Prairie	Illinois/Mississippi River Sand Areas	Lower Mississippi River bottoms	Middle Mississippi Border	Northeastern Morainal	Ozarks	Rock River Hill Country	Shawnee Hills	Southern Till Plain	Upper Mississippi/Illinois River Bottomlands	Wabash Border	Western Forest-Prairie	Wisconsin Driftless
Corynorhinus rafinesquii (eastern big-eared bat)	x													
Lontra canadensis (river otter)	x			x							x	x		
Lynx rufus (bobcat)	x			x	x		x	x	x	x		x	x	x
Microtus pinetorum (woodland vole)	x					x	x		x					
Mustela nivalis (least weasel)					x	x		x						x
Myotis austroriparius (southeastern bat)	x								x					
Myotis grisescens (gray bat)					x		x				x		x	
Myotis sodalis (Indiana bat)	x			x	x				x		x		x	
Neotoma floridana (eastern woodrat)				x			x							
Ochrotomys nuttalli (golden mouse)	x								x					
Ondatra zibethicus (muskrat)		x		x		x				x		x		
Oryzomys palustris (marsh rice rat)	x						x		x					
Peromyscus gossypinus (cotton mouse)	x								x					
Sorex hoyi (pygmy shrew)						x								
Spermophilus franklinii (Franklin's ground squirrel)		x	x			x								
Sylvilagus aquaticus (swamp rabbit)	x									x		x		
Tamiasciurus hudsonicus (red squirrel)		x												
Taxidea taxus (American badger)		x	x		x	x		x		x			x	x
Urocyon cinereoargenteus (gray fox)				x	x	x	x	x	x	x	x		x	x