Past, Present, and Potential Future Landscapes of Wisconsin, with Emphasis on Amphibian and Reptile Distributions

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The geological history of Wisconsin, particularly glacial and permafrost cycles (Clayton et al. 2001, Syverson and Colgan 2004), shaped the current topography of the state. Bedrock and soil types, rivers and natural lakes, hills and valleys are all products of past environments (e.g., Rawling et al. 2008, Lytwyn 2010, Jacobs et al. 2011, Schaetzl and Attig 2013). These geological legacies, along with climatic gradients, strongly influence the modern plant and animal diversity in Wisconsin (Albert 1995, Schulte et al. 2002, Cutright et al. 2006). Furthermore, plant communities, which are a major component of amphibian and reptile habitats, are constantly changing through natural processes. Plant communities change in the short term due to natural disturbances, weather variability, and biotic interactions (e.g., competition, predation, and facilitation). In the long term, plant communities respond to direct and indirect impacts of climate change, resulting in distributional shifts (Stohlgren et al. 2005, Yurkonis and Meiners 2006, Brooker et al. 2008, Iverson et al. 2008, Crookston et al. 2010). Humans have also strongly affected Wisconsin's vegetative communities over the past two centuries as a result of land-use change (e.g., conversion of savannas and prairies to farmland) and management actions (e.g., wildfire suppression; Radeloff et al. 1999, Grossmann and Mladenoff 2008, Rhemtulla et al. 2009). These anthropogenic landscape changes have affected local abundance and occupancy of amphibians and reptiles, in some cases resulting in steep declines (e.g., Blanchard's Cricket Frog [*Acris blanchardi*]; Hay 1998, Gray and Brown 2005).

Like all organisms, amphibians and reptiles have abiotic and biotic requirements, tolerance levels, and preferences. These factors, coupled with biological interactions and anthropogenic effects, bound the ecological niche of each species. The niche of a species can be defined as "the environmental conditions that allow a species to satisfy its minimum requirements so that birth rate of a local population is equal to or greater than its death rate along with the set of per capita impacts of that species on these environmental conditions" (Chase and Leibold 2003). Short-term, small-scale habitat changes can temporarily impact local abundance and occupancy, sometimes resulting in local extirpation, while long-term climate and landscape-scale habitat changes can impact the geographic distribution of a species (Thomas 2010, Lawing and Polly 2011). Furthermore, because each species occupies a unique ecological niche, it is not unusual for habitat change to positively impact some amphibian and reptile species while negatively impacting others (Russell et al. 1999, Adams et al. 2003, Brown et al. 2012b). Understanding the relationships between habitat condition and occurrence/abundance of amphibian and reptile species helps us to effectively manage current populations, as well as understand past and project future geographic distributions.

In this chapter we discuss past, present, and potential future landscapes of Wisconsin. We broadly discuss amphibian and reptile assemblages within these landscapes, but with the exception of potential climate change impacts, we intentionally leave the detailed species-level information to individual species accounts. Our goal is to provide a framework to understand past, present, and potential future amphibian and reptile distributions in Wisconsin.

PAST LANDSCAPES

Although many glacial-interglacial cycles have occurred in the Midwest over the last 2.5 million years, our knowledge of amphibian and reptile distributions is generally limited to the period following the Wisconsin glaciation, which occurred between ca. 75,000 and 9,500 ybp (Syverson and Colgan 2004). During this period, environmental conditions throughout most of the state were likely unsuitable for amphibians and reptiles (Holman 1992a). However, a nonglaciated refugium for more cold-tolerant species existed in southwestern Wisconsin. This refugium covered ca. 25% of the land area in the state and is known today as the Driftless Area (see Figure 12; Syverson and Colgan 2004). Species such as the Common Gartersnake (*Thamnophis sirtalis*), Prairie Skink (*Plestiodon septentrionalis*), and American Toad (*Anaxyrus americanus*) might have survived the last glacial period in this refugium (Holman 1992a, Fuerst and Austin 2004, Placyk et al. 2007), and evidence suggests that the Wood Frog (*Lithobates sylvaticus*) almost certainly used the area as a glacial refuge (Lee-Yaw et al. 2008).

Following the glacial retreat, boreal forest, dominated by spruce (*Picea* spp.), covered most of Wisconsin (Webb 1987, Panyushkina and Leavitt 2013). By 7,000 to 5,000 ybp, mesic hardwood forests were prominent in eastern and southern portions of the state (Webb 1987, Long et al. 2011). Southwestern Wisconsin transitioned to primarily oak (*Quercus* spp.) savanna and prairie ca. 5,500 ybp and then to more closed-canopy oak and birch (*Betula* spp.) forests beginning ca. 3,500 ybp (Baker et al. 1992, Wright 1992, Williams et al. 2009a). Northern Wisconsin at this time shifted to a pine-dominated (*Pinus* spp.) forest due to climate warming (Yu 2000). Birch (*Betula* spp.) and Eastern Hemlock (*Tsuga canadensis*) also became well established in northern Wisconsin ca. 3,500 ybp (Webb 1974). Today, northern Wisconsin is a transition zone between southern boreal forest to the north and northern hardwood forest to the south (Pastor and Mladenoff 1992).

The majority of amphibian and reptile species currently in Wisconsin likely colonized the state within the last 10,000 years, and fossil evidence indicates that the modern amphibian and reptile community in the central Great Lakes region was mostly present by 6,000–4,000 ybp (Holman 1992a). West and Dallman (1980) reported fossil remains of amphibians and reptiles in the Driftless Area that ranged from 17,000 to 2,400 ybp. Cleland (1966) analyzed fossils from a bog in Sauk County (southwestern Wisconsin in the Driftless Area refugium) and found amphibians from the lowest level (ca. 9,500 ybp) and reptiles from 4,500 to 3,000 ybp. Theler (2000) studied fossil remains from Native American archaeological sites in western Wisconsin and identified 19 amphibian and reptile species, including 4 species of turtles dated between 11,000 and 2,000 ybp and an additional 8 amphibian and reptile species dated between 2,000 and 800 ybp. Holman (2001) identified fossils from Iowa County that date from ca. 17,000 ybp, which included the American Toad, Northern Leopard Frog (*Lithobates pipiens*), Common Gartersnake, Eastern Foxsnake (*Pantherophis vulpinus*), and Eastern Milksnake (*Lampropeltis triangulum*).

Most species colonized Wisconsin from the south (Smith 1957, Holman 1992a, Church et al. 2003, Starkey et al. 2003, Moriarty Lemmon et al. 2007a), but recent genetic studies have shown that there are exceptions to this generalization. For example, Wood Turtles (*Glyptemys insculpta*) likely colonized from the east, moving across the Upper Peninsula of Michigan (Amato et al. 2008). Similarly, it appears that Spring Peepers (*Pseudacris crucifer*) dispersed into the Upper Midwest from eastern North America. The species moved north of the Great Lakes and then south into Minnesota and northwestern Wisconsin; meanwhile, a separate clade colonized from the south (Austin et al. 2002). These examples illustrate the often complex biogeographic histories of Wisconsin's amphibian and reptile species.

RECENT HISTORICAL AND PRESENT LANDSCAPE

The modern distribution of amphibian and reptile species in Wisconsin is influenced by both historical and current habitat conditions. In this section, we first summarize major recent changes to the Wisconsin landscape by comparing pre-European settlement land cover classes (mid-1800s) to recent land cover classes (2006). We then discuss the current status of amphibians and reptiles in the state, focusing primarily on species that have noticeably declined since European settlement. We follow this discussion with a summary of the present landscape of Wisconsin based on natural ecological units, including information on amphibian and reptile species richness, and briefly discuss assemblage differences among the ecological units. We conclude this section by projecting statewide patterns in amphibian and reptile species richness based on county-level data, which provide finer-scale information than ecological units.

Recent Changes to the Wisconsin Landscape

Several studies have attempted to create detailed reconstructions of the Wisconsin landscape prior to major European settlement in the mid- to late 1800s using information from Public Land Surveys conducted by the US General Land Office between 1832 and 1866 (e.g., Schulte et al. 2002, Bolliger and Mladenoff 2005, Liu et al. 2011). Here, we compare the pre-European settlement and current landscape based on six general land use categories: developed land, forest, grassland/shrubby, open water, wetland, and working land (i.e., farmland and pastures). We used Finley (1976) as a basis for categorizing and quantifying the historic landscape, which was based on the General Land Office records. We used the 2006 National Land Cover Dataset (NLCD; Fry et al. 2011) for categorizing and quantifying the current landscape. Based on these sources, there was a large reduction in forest cover over the last ca. 150 years (Figure 11; Table 4), from ca. 74% in the mid-1800s to ca. 36% today. This change was primarily due to conversion of forest to farmland in southern and central Wisconsin in the 1800s (Maizel et al. 1998), much of which was oak savanna (Curtis 1959). Grassland/shrubby habitat was reduced from ca. 8% to ca. 3%. The amount of wetland habitat in the state has remained roughly the same (14%–15%), but note that Dahl (1990) estimated that 27.3% of Wisconsin was wetland in the 1780s. The two categories absent prior to European settlement, working land and developed land, currently account for ca. 37% and ca. 7% of the landscape, respectively.

The structure and composition of Wisconsin's forests have also changed since European settlement, primarily due to changes in land use (e.g., logging and farming) and land management (e.g., fire suppression; Rhemtulla et al. 2007). After the mid-1800s, hemlock and White Pine (*Pinus strobus*) cover in Wisconsin decreased from ca. 22% to 1%, while the average diameter of all tree species in the state also declined (Rhemtulla et al. 2009). In addition, much of the oak savanna in southern Wisconsin that was not embedded in working lands has transitioned to mesic hardwood forest due to succession (Rhemtulla et al. 2009). White and Mladenoff (1994) studied forest change in the Border Lakes region of northern Wisconsin (Vilas County) since the 1860s and concluded that forest cover has changed from primarily old-growth hemlock/hardwoods to second-growth hardwoods/conifers. The northwestern pine barrens ecoregion has shifted from a historically open

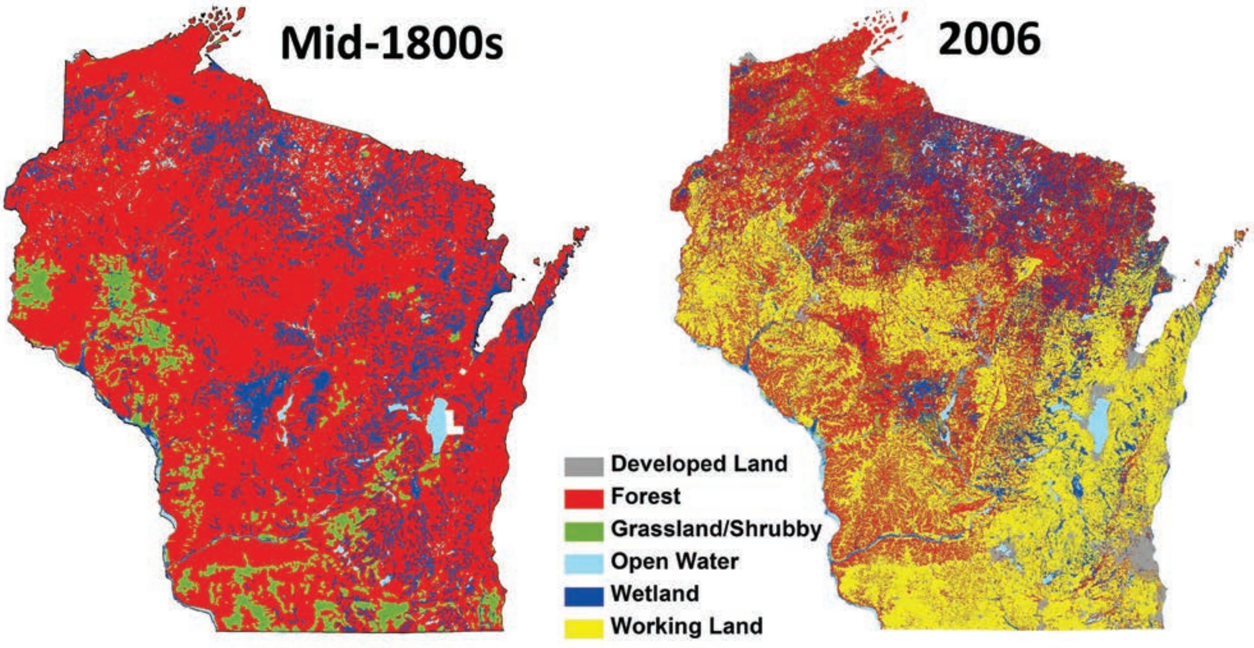

Figure 11. Comparison of recent historical and current land cover classes in Wisconsin. The historical land cover map was derived from Finley (1976), and the current land cover map was derived from the 2006 National Land Cover Dataset (NLCD; Fry et al. 2011). The comparison indicates a dramatic reduction in forest cover over the last ca. 150 years, primarily replaced by working land (farmland and pastures). Much of the forested land lost in southern and southwestern Wisconsin was oak savanna (Curtis 1959).

Table 4. Current land cover in Wisconsin based on the 2006 National Land Cover Dataset (NLCD) and pre-European settlement land cover based on Finley (1976). Included are the percentages of Wisconsin for each of the 15 NLCD classes, followed by a summary of the current and recent historic landscape using broader land cover groups. Numbers next to each NLCD class denote their broader land cover group.

Land Class	Current Land Cover (%)	Historic Land Cover (%)
Cultivated crops (1)	26.2	
Hay/pasture (1)	10.7	
Deciduous forest (2)	30.0	
Evergreen forest (2)	2.3	
Mixed forest (2)	3.6	
Emergent herbaceous wetlands (3)	2.9	
Woody wetlands (3)	10.8	
Open water (4)	3.8	
Barren land (5)	0.1	
Shrub/scrub (5)	1.3	
Herbaceous (5)	1.3	
Developed, open space (6)	4.1	
Developed, low intensity (6)	2.2	
Developed, medium intensity (6)	0.6	
Developed, high intensity (6)	0.2	
Working land (1)	36.8	0.0
Forest (2)	35.8	73.9
Wetland (3)	13.7	14.6
Open water (4)	3.8	3.3
Grassland/shrubby (5)	2.7	7.9
Developed land (6)	7.2	0.0

pine-dominated landscape to a more closed-canopy pine-oak landscape since the mid-1800s due to anthropogenic fire suppression (Radeloff et al. 1998, Radeloff et al. 1999).

Amphibians and Reptiles in the Current Wisconsin Landscape

Little information exists on the distributions of amphibians and reptiles in nineteenth-century Wisconsin. This was a key period during which the landscape was transformed by European settlers (Rhemtulla et al. 2007), and the absence of firsthand reports makes it difficult to quantify the immediate impacts of settlement on amphibians and reptiles in the state. Casper (2008c) reviewed survey records and land use changes and concluded that species richness and abundance of amphibians and reptiles have declined substantially in Milwaukee County since it was settled. Furthermore, several recent studies concluded that occupancy and relative abundance of anurans in Wisconsin were negatively associated with urbanization (Knutson et al. 1999, Woodford and Meyer 2003, Price et al. 2004). Hecnar (2004) hypothesized that 50%–90% of amphibian populations have been lost across the

Great Lakes basin since settlement, primarily due to wetland loss. While land conversion to agriculture has had a negative impact on many species, some anurans appear to be thriving in the agriculture-dominated areas of Wisconsin, potentially due to the presence of residual forest patches (Knutson et al. 1999, Paloski 2008).

Broad-scale population declines have been noted for several amphibian and reptile species in Wisconsin over the last half century. Probably the most notable of these was the decline of Blanchard's Cricket Frogs between the 1950s and 1970s (Hay 1998). Blanchard's Cricket Frogs were historically abundant throughout southern Wisconsin (Vogt 1981) but have been extirpated from a large portion of their historical distribution within the state (see Blanchard's Cricket Frog, *Acris blanchardi* species account), with concurrent declines observed throughout the Upper Midwest (Gray 2000a, 2000b, Gray and Brown 2005). Declines of several other anurans were also observed during this time period, including Northern Leopard Frogs, American Bullfrogs (*Lithobates catesbeianus*), and Pickerel Frogs (*Lithobates palustris*; Hine et al. 1975, 1981). These declines were the major impetus driving the initiation of the Wisconsin Frog and Toad Survey program in 1981 (Mossman et al. 1998).

The proposed explanations for these anuran declines vary. Northern Leopard Frog declines have been linked to redleg syndrome (a bacterial disease; Densmore and Green 2007) and atrazine (a widely used herbicide), which impacts development and survivorship (Hine et al. 1981, Casper 1998). Northern Leopard Frogs appear to be particularly susceptible to the effects of environmental contamination and degradation, which negatively impact their development and survival (see Northern Leopard Frog, *Lithobates pipiens* species account). The factor(s) that caused Blanchard's Cricket Frog declines are not fully understood (Lehtinen and Skinner 2006). Leading hypotheses include habitat degradation and the negative impacts of prolonged droughts on reproduction and winter survival (Jung 1993, Lannoo 1998, Russell et al. 2002, Gray and Brown 2005, Irwin 2005).

Notable declines have also occurred for several reptile species in the state. Venomous snakes (i.e., Timber Rattlesnake [*Crotalus horridus*] and Massasauga [*Sistrurus catenatus*]) were once common throughout the southern and western portions of the state (Pope 1923, Pope and Dickinson 1928, Schorger 1967–68) but have experienced steep declines over the last two centuries. For example, the Massasauga was historically considered abundant in southern Wisconsin (Pope 1926, Schorger 1967–68) but has declined to the point that reintroduction is now a practiced management tool (King et al. 2004). The Timber Rattlesnake was also historically reported in large numbers but has substantially declined across much of its known range over the last century (Oldfield and Keyler 1989). The reasons for these declines include habitat loss (particularly associated with suitable overwintering locations) and extensive removal by humans (Vogt 1981, Oldfield and Keyler 1989). A Timber Rattlesnake bounty existed in Wisconsin until 1975 and was nearly reinstated in 1983 (Casper 1983), while a Massasauga bounty existed in Wisconsin between 1952 and 1972 (Vogt 1981). These factors, coupled with low recruitment rates for these species, have hindered the ability of populations to recover in Wisconsin, despite legal protection.

The conversion of oak savannas and prairies to agricultural lands in southern and western Wisconsin has affected several species (Brewster 1984). Two species in particular, the Ornate Box Turtle (*Terrapene ornata*) and the Slender Glass Lizard (*Ophisaurus attenuatus*), have declined to the point of being considered Endangered in the state (WDNR 2015c). Adler (1968) reviewed archaeological evidence to conclude that the current distribution of Ornate Box Turtles in Wisconsin (and Illinois) is a small fraction of its former range. Doroff and Keith (1990) found that individual Ornate Box Turtles avoided cropland and were highly selective for remnant prairie with deep sandy soil, while Moore (1993) speculated that these turtles will likely be extirpated from Wisconsin without proactive conservation measures. Little research has been conducted on the Slender Glass Lizard in the region (Pleyte 1975), probably due to its long-standing rarity and secretive nature (Anton 1999). Yet it appears this lizard declined rapidly following European settlement and associated land use changes (Graenicher 1911, Wagner 1922). Similar to the Ornate Box Turtle, the Slender Glass Lizard requires open prairie and savanna with sandy soils (Breitenbach 2011), a habitat type that is currently rare in Wisconsin (Figure 11; Table 4).

While it is clear that many amphibian and reptile species have been affected by the landscape changes following European settlement, this problem is not unique to Wisconsin. Amphibians and reptiles are declining worldwide (Gibbons et al. 2000, Reading et al. 2010, Wake 2012a). On a positive note, there have been no verified species extirpations in the state since European settlement (see Hypothetical and Enigmatic Species of Wisconsin chapter for possible exceptions). However, populations can sometimes persist for decades or even centuries under suboptimal conditions, slowly trending toward extinction (Blaustein et al. 1994, Daszak et al. 2005, Adams et al. 2013). Continuous monitoring programs such as the Wisconsin Frog and Toad Survey (Mossman et al. 1998) are important because they provide the long-term data necessary to detect long-term population declines that would not be apparent from short-term monitoring data. The added effects of climate change will make monitoring efforts even more important in the future.

Current Natural Ecological Units

To describe the current natural ecological units of Wisconsin, we used the US Forest Service's Ecological Subregions classification system (Cleland et al. 2007). While there are other classification systems developed specifically for Wisconsin (e.g., Curtis 1959, Albert 1995), we used this classification system because it is widely employed and encompasses the entire conterminous United States. The Ecological Subregions classification system is hierarchical, with province boundaries primarily defined based on climate gradients, nested section boundaries defined based on physical geography and geology, and further nested subsection boundaries defined based on potential vegetation, soil, and hydrography (Cleland et al. 2007). The two provinces in Wisconsin are split along what is known as the ecological 'tension zone' (Anderson 2005). This zone transects several states in the Great Lakes region and occurs where two primary climatic conditions converge in Wisconsin: the cooler, moister conditions from the north, and the warmer, drier conditions from the south. The tension zone also contains an intermingling of the vegetative communities and disturbance histories associated with both northern and southern environments (Curtis 1959).

Below we provide brief descriptions of the climate, geology, and vegetation that are characteristic of the current ecological provinces ($N = 2$) and sections ($N = 11$) of Wisconsin (Figure 12). Additional information on the pre-European settlement vegetation structure specific to each section can be found in Schulte et al. (2002). The province and section descriptions were taken directly from McNab et al. (2007), with page numbers included in parentheses following description quotes. For amphibian and reptile species richness data, we used county records through December 2018 (including vouchered records and additional nonvouchered records shown in species accounts).

For each ecological unit, amphibian and reptile species richness values were obtained by overlaying county boundaries on the ecological units and determining the total number

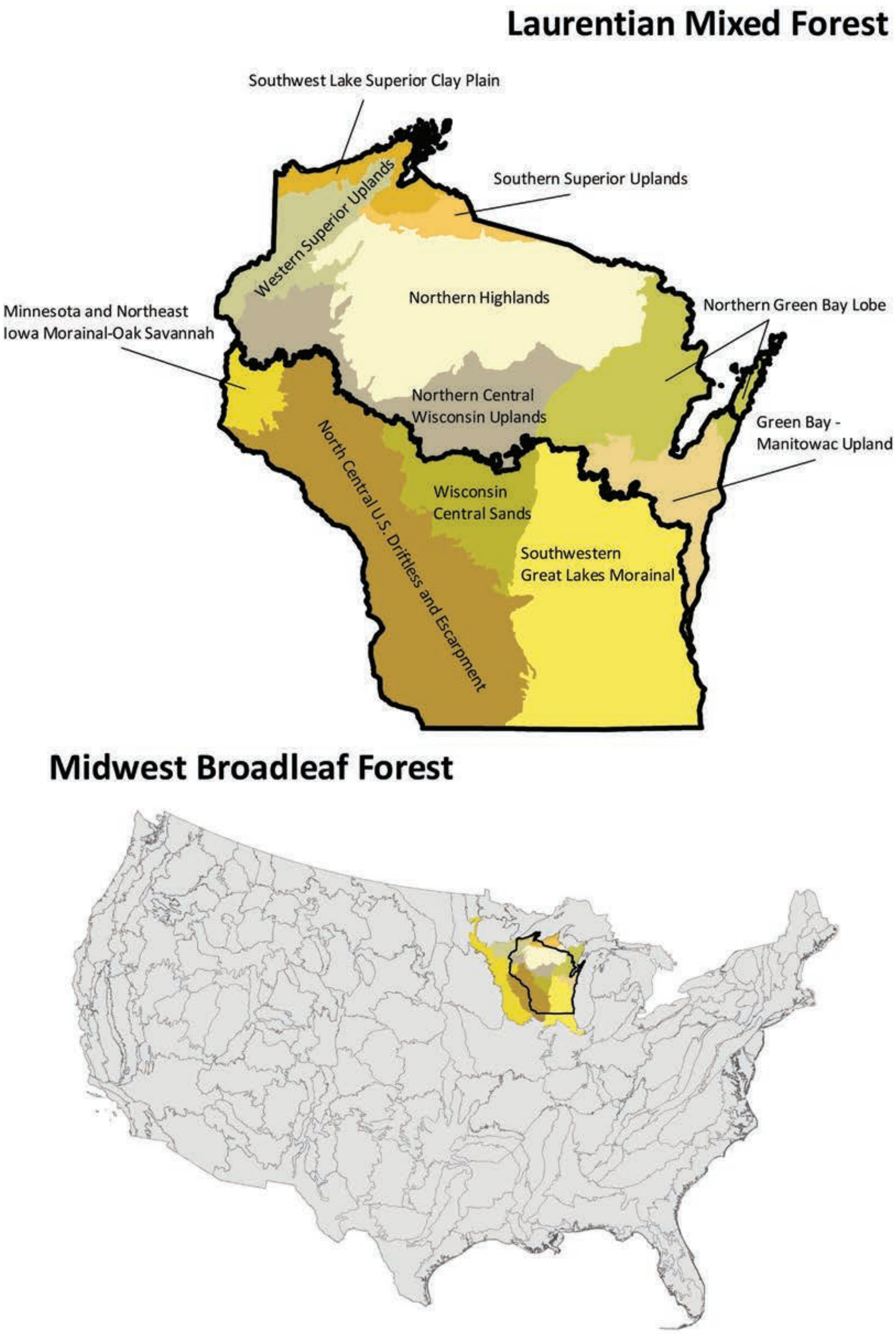

Figure 12. Natural ecological units of Wisconsin, including ecological provinces ($N = 2$) and sections ($N = 11$), based on the US Forest Service's Ecological Subregions classification system. The two provinces (i.e., Laurentian Mixed Forest and Midwest Broadleaf Forest) are separated along the 'tension zone' that crosses central Wisconsin, with a cooler/moister climate to the north and a warmer/drier climate to the south. The continental map depicts the ecological section boundaries in the US.

of documented native amphibians and reptiles in all counties at least partly included in a unit. Note that records for counties bisected by adjacent ecological units were included in species richness tallies for both units, and thus species richness estimates for some ecological units may be biased high. Because of the large variation in size of ecological units in Wisconsin (i.e., sections range from 250,747 to 3,003,647 ha [619,609 to 7,422,173 ac]), we calculated total species richness for amphibians and reptiles per unit area, standardized to a 100,000 ha area (i.e., number of species / 100,000 ha [247,104 ac]). We also calculated species richness by order: Anura (frogs and toads), Caudata (salamanders), Squamata (lizards and snakes), and Testudines (turtles). The nonstandardized species counts are provided in parentheses.

Laurentian Mixed Forest Province

Description: "The province is characterized by a continental climatic regime with maritime influence along the Great Lakes. Winters moderately long with continual ground snow cover; summers warm. Most precipitation occurs during summer. Low-relief, hilly landscapes are a product of past glaciation. Vegetation consists of forests that are a transition between boreal and broadleaf deciduous" (p. 5).

Area: 7,488,543 ha (18,504,593 ac)

Total amphibian species: 0.25 (19); Anura: 0.16 (12); Caudata: 0.09 (7)

Total reptile species: 0.38 (29); Squamata: 0.27 (20); Testudines: 0.12 (9)

Green Bay–Manitowoc Upland Section

Description: "The influence of Lake Michigan results in milder temperatures and more precipitation than sections farther inland. Terrain of this unit ranges from nearly level areas of lacustrine deposits to rolling hills of ground moraines. Bedrock is mostly shales and dolomite that has weathered to form a distinctive and extensive escarpment of cliffs. Soils include clays, loams, sands, and gravels, and many are calcareous in mineral content. Forest vegetation was largely aspen-birch and white-red-jack pine cover types" (pp. 7–8).

Area: 710,191 ha (1,754,920 ac)

Total amphibian species: 2.68 (19); Anura: 1.69 (12); Caudata: 0.99 (7)

Total reptile species: 3.10 (22); Squamata: 1.97 (14); Testudines: 1.13 (8)

North-Central Wisconsin Uplands

Description: "The topography of this section is largely a glacial till plain with portions of moraines. Bedrock formations are sandstones with some gneiss. Soils are variable, ranging from sandy to silt loams that are poorly to well drained. Historic vegetation was forests consisting of maple-beech-birch, aspen-birch, and oak-hickory cover types" (p. 6).

Area: 1,469,923 ha (3,632,259 ac)

Total amphibian species: 1.30 (19); Anura: 0.82 (12); Caudata: 0.48 (7)

Total reptile species: 1.63 (24); Squamata: 1.09 (16); Testudines: 0.54 (8)

Northern Green Bay Lobe

Description: "The landscape is variable, consisting mainly of ground moraines, with lesser areas of lacustrine plains, escarpment, sand dunes, and beach ridges; glacial outwash sand plains with rock outcrops are present along the western edge of this section. Rock formations of sandstones, limestones, and dolomite (bedrock outcrops of basalt or granites along western edge) are covered by diverse soils of lacustrine sands, loamy and poorly drained sands, with well-drained to excessively drained sands to the west. Historic vegetation was mostly forests of aspen-birch, maple-beech-birch, and spruce-fir cover types" (p. 7).

Area: 1,246,550 ha (3,080,292 ac)

Total amphibian species: 1.52 (19); Anura: 0.96 (12); Caudata: 0.56 (7)

Total reptile species: 1.76 (22); Squamata: 1.04 (13); Testudines: 0.72 (9)

Northern Highlands

Description: "This section is a dissected glacial pitted outwash plain, end and ground moraines, and smaller areas of hilly terrain; kettle lakes and depressions are common in the northern part. Bedrock is mostly sandstones and shales with small areas of gneiss and metavolcanics. Soils formed in till deposits and range from sandy loam and silts to poorly or well-drained sands. Vegetation on much of the section was a combination of aspen-birch, maple-beech-birch, white-red-jack pine, and spruce-fir cover types" (p. 7).

Area: 2,745,508 ha (6,784,298 ac)

Total amphibian species: 0.65 (18); Anura: 0.40 (11); Caudata: 0.25 (7)

Total reptile species: 0.84 (23); Squamata: 0.55 (15); Testudines: 0.29 (8)

Southern Superior Uplands Section

Description: "This section has glacial landscapes of level to gently rolling lowlands and flat lacustrine plains with equal areas of hillier uplands and escarpments. Bedrock, which is complex, includes felsic and mafic igneous formations; metamorphics of slate, schist, marble, and amphibolites; and some areas of sandstones. Rock outcrops are common in upland areas. Vegetation is forests of maple-beech-birch and aspen-birch cover types" (p. 5).

Area: 250,747 ha (619,609 ac)

Total amphibian species: 5.98 (15); Anura: 3.59 (9); Caudata: 2.39 (6)

Total reptile species: 4.79 (12); Squamata: 3.19 (8); Testudines: 1.60 (4)

Southwest Lake Superior Clay Plain

Description: "Lake Superior affects the climate of this section resulting in greater precipitation and milder temperature regimes compared to areas farther inland. Landscape is variously dissected, nearly level lake plain of lacustrine clays. Bedrock is mostly sandstones and shale that is covered by water-reworked moraine that formed mostly well-drained soils; some basalts occur in the north part of this unit. Historic vegetation was a forest dominated by conifers [and] aspen-birch cover types" (p. 7).

Area: 366,555 ha (905,777 ac)

Total amphibian species: 4.64 (17); Anura: 3.00 (11); Caudata: 1.64 (6)

Total reptile species: 3.82 (14); Squamata: 2.46 (9); Testudines: 1.36 (5)

Western Superior Uplands

Description: "This section has relatively uniform, undulating, poorly drained, level to rolling landscape of glacial drift plains consisting of ground and end moraines, and local drumlins; large areas of deep sands occur along the eastern edge of the section. Loam soils formed in thick till covering most of bedrock, which consists of sandstones and shales. Forest vegetation consists of aspen-birch, maple-beech-birch, and spruce-fir cover types" (p. 6).

Area: 699,003 ha (1,727,274 ac)

Total amphibian species: 2.57 (18); Anura: 1.57 (11); Caudata: 1.00 (7)

Total reptile species: 2.72 (19); Squamata: 1.72 (12); Testudines: 1.00 (7)

Midwest Broadleaf Forest Province

Description: "The climate in this province is continental with warm to hot summers. Frequent growing season water deficits. Flat to hilly terrain with features associated with former glaciation. Vegetation consists of cold-deciduous, hardwood-dominated forests with a high proportion of species able to tolerate mild, brief, periodic drought during the late summer" (p. 10).

Area: 7,041,446 ha (17,399,792 ac)

Total amphibian species: 0.27 (19); Anura: 0.17 (12); Caudata: 0.10 (7)

Total reptile species: 0.52 (36); Squamata: 0.36 (25); Testudines: 0.16 (11)

Minnesota and Northeast Iowa Morainal and Oak Savanna

Description: "The landscape is level plains and low, rolling hills resulting from glaciation. Soils formed in glacial drift and thin, discontinuous layer of loess. Bedrock is mixture of granites, greenstones, and metasediments with equal area dolomite and sandstone. Existing cover type is primarily agricultural; historic vegetation was a mosaic of oak-hickory, prairie, maple-beech-birch, and elm-ash-cottonwood cover types" (p. 11).

Area: 282,129 ha (697,156 ac)

Total amphibian species: 6.38 (18); Anura: 3.90 (11); Caudata: 2.48 (7)

Total reptile species: 7.44 (21); Squamata: 4.96 (14); Testudines: 2.48 (7)

North-Central US Driftless and Escarpment

Description: "Parts of this section receive above average snowfall resulting from its location bordering two Great Lakes. Section is a maturely dissected unglaciated upland plateau with steep-sided bedrock ridges and mounds. Loess covers much of bedrock, which consists of sandstones, dolomite, and shales; soils are silt loams and sandy loams. Mounds and ridges are capped by resistant dolomite. Current cover types are mostly urban and agricultural; historical vegetation consisted of oak-hickory and prairie cover types; the elm-ash-cottonwood cover type was along rivers" (p. 11).

Area: 3,003,647 ha (7,422,173 ac)

Total amphibian species: 0.63 (19); Anura: 0.40 (12); Caudata: 0.23 (7)

Total reptile species: 1.20 (36); Squamata: 0.83 (25); Testudines: 0.37 (11)

Southwestern Great Lakes Morainal

Description: "This section has relatively uniform, undulating landscape of glacial drift plains consisting of ground and end moraines, and local drumlins; large areas of deep sands occur along eastern edge of the section. Loam soils formed in thick till covering most of bedrock, which consists of sandstones and shales. Current vegetation is agricultural and urban cover types; historic vegetation was oak-hickory, maple-beech-birch, and prairie cover types" (p. 11).

Area: 2,877,570 ha (7,110,630 ac)

Total amphibian species: 0.62 (18); Anura: 0.38 (11); Caudata: 0.24 (7)

Total reptile species: 1.22 (35); Squamata: 0.83 (24); Testudines: 0.38 (11)

Wisconsin Central Sands

Description: "This section is a flat to slightly rolling lake (Glacial Lake Wisconsin) plain with scattered, exposed sandstone buttes. Underlying geology is mostly erosion-resistant sandstone with localized areas of gneiss and granitic rocks. Soils formed in glacial outwash sands and are mostly excessively drained, but small areas of poorly drained swamps also occur. Historic vegetation was a mixture of aspen-birch, oak-hickory, and white-red-jack pine cover types" (pp. 11–12).

Area: 878,101 ha (2,169,835 ac)

Total amphibian species: 2.16 (19); Anura: 1.37 (12); Caudata: 0.80 (7)

Total reptile species: 3.76 (33); Squamata: 2.51 (22); Testudines: 1.25 (11)

Amphibian and reptile assemblages

All of the amphibian and reptile species assemblages present in the Laurentian Mixed Forest Province are also present in the Midwest Broadleaf Forest Province (Table 5). The Midwest Broadleaf Forest Province contains an additional seven reptiles not found in the Laurentian Mixed Forest Province, including five species in the order Squamata (Gray Ratsnake [*Pantherophis spiloides*], Lined Snake [*Tropidoclonion lineatum*], Slender Glass Lizard, Timber Rattlesnake, Western Wormsnake [*Carphophis vermis*]) and two species in the order Testudines (Ornate Box Turtle [*Terrapene ornata*], Smooth Softshell [*Apalone mutica*]).

Table 5. Amphibian and reptile species found in ecological provinces ($N = 2$) and sections ($N = 11$) of Wisconsin, based on the US Forest Service's Ecological Subregions classification system.

	Laurentian Mixed Forest							**Midwest Broadleaf Forest**			
	Green Bay—Manitowoc Upland	**North Central Wisconsin Uplands**	**Northern Green Bay Lobe**	**Northern Highlands**	**Southern Superior Uplands**	**Southwest Lake Superior Clay Plain**	**Western Superior Uplands**	**Minnesota and Northeast Iowa Morainal-Oak Savanna**	**North Central U.S. Driftless and Escarpment**	**Southwestern Great Lakes Morainal**	**Wisconsin Central Sands**
Amphibians											
Anura											
American Bullfrog, *Lithobates catesbeianus*	X	X	X	X	X	X	X	X	X	X	X
American Toad, *Anaxyrus americanus*	X	X	X	X	X	X	X	X	X	X	X
Blanchard's Cricket Frog, *Acris blanchardi*	X	X	X	—	—	—	—	—	X	X	X
Boreal Chorus Frog, *Pseudacris maculata*	X	X	X	X	X	X	X	X	X	X	X
Cope's Treefrog, *Hyla chrysoscelis*	X	X	X	X	—	X	X	X	X	X	X
Gray Treefrog, *Hyla versicolor*	X	X	X	X	X	X	X	X	X	X	X
Green Frog, *Lithobates clamitans*	X	X	X	X	X	X	X	X	X	X	X
Mink Frog, *Lithobates septentrionalis*	X	X	X	X	X	X	X	X	X	—	X
Northern Leopard Frog, *Lithobates pipiens*	X	X	X	X	X	X	X	X	X	X	X
Pickerel Frog, *Lithobates palustris*	X	X	X	X	—	X	X	X	X	X	X
Spring Peeper, *Pseudacris crucifer*	X	X	X	X	X	X	X	X	X	X	X
Wood Frog, *Lithobates sylvaticus*	X	X	X	X	X	X	X	X	X	X	X
Caudata											
Blue-spotted Salamander, *Ambystoma laterale*	X	X	X	X	X	X	X	X	X	X	X
Eastern Newt, *Notophthalmus viridescens*	X	X	X	X	X	X	X	X	X	X	X
Eastern Red-backed Salamander, *Plethodon cinereus*	X	X	X	X	X	X	X	X	X	X	X
Eastern Tiger Salamander, *Ambystoma tigrinum*	X	X	X	X	—	—	X	X	X	X	X

Continued

Table 5. (*Continued*)

	Laurentian Mixed Forest							Midwest Broadleaf Forest			
	Green Bay—Manitowoc Upland	**North Central Wisconsin Uplands**	**Northern Green Bay Lobe**	**Northern Highlands**	**Southern Superior Uplands**	**Southwest Lake Superior Clay Plain**	**Western Superior Uplands**	**Minnesota and Northeast Iowa Morainal-Oak Savanna**	**North Central U.S. Driftless and Escarpment**	**Southwestern Great Lakes Morainal**	**Wisconsin Central Sands**
Four-toed Salamander, *Hemidactylium scutatum*	X	X	X	X	X	X	X	X	X	X	X
Mudpuppy, *Necturus maculosus*	X	X	X	X	X	X	X	X	X	X	X
Spotted Salamander, *Ambystoma maculatum*	X	X	X	X	X	X	X	X	X	X	X
Total amphibian species	**19**	**19**	**19**	**18**	**15**	**17**	**18**	**18**	**19**	**18**	**19**
Reptiles											
Squamata											
Gophersnake, *Pituophis catenifer*	—	X	—	—	—	—	X	X	X	X	X
Butler's Gartersnake, *Thamnophis butleri*	X	—	—	—	—	—	—	—	X	X	X
Common Five-lined Skink, *Plestiodon fasciatus*	X	X	X	X	—	—	X	X	X	X	X
Common Gartersnake, *Thamnophis sirtalis*	X	X	X	X	X	X	X	X	X	X	X
Dekay's Brownsnake, *Storeria dekayi*	X	X	X	X	—	X	X	X	X	X	X
Eastern Foxsnake, *Pantherophis vulpinus*	X	X	X	X	X	X	X	X	X	X	X
Eastern Hog-nosed Snake, *Heterodon platirhinos*	X	X	X	X	X	X	X	X	X	X	X
Eastern Ribbonsnake, *Thamnophis saurita*	X	—	X	X	—	—	—	—	X	X	X
Gray Ratsnake, *Pantherophis spiloides*	—	—	—	—	—	—	—	—	X	X	X
Lined Snake, *Tropidoclonion lineatum*	—	—	—	—	—	—	—	—	X	X	—
Massasauga, *Sistrurus catenatus*	—	X	X	X	—	—	—	—	X	X	X
Eastern Milksnake, *Lampropeltis triangulum*	X	X	X	X	—	—	X	X	X	X	X
North American Racer, *Coluber constrictor*	—	X	—	X	—	—	—	X	X	X	X

Common Watersnake, *Nerodia sipedon*	X	X	X	X	X	X	X	X	X	X	X
Plains Gartersnake, *Thamnophis radix*	X	—	—	—	—	—	—	X	X	X	X
Prairie Skink, *Plestiodon septentrionalis*	—	X	X	X	X	X	X	X	X	X	X
Queensnake, *Regina septemvittata*	X	—	—	—	—	—	—	—	X	X	—
Red-bellied Snake, *Storeria occipitomaculata*	X	X	X	X	X	X	X	X	X	X	X
Ring-necked Snake, *Diadophis punctatus*	X	X	X	X	X	X	X	—	X	X	X
Six-lined Racerunner, *Aspidoscelis sexlineata*	—	X	—	—	—	—	—	X	X	X	X
Slender Glass Lizard, *Ophisaurus attenuatus*	—	—	—	—	—	—	—	—	X	X	X
Smooth Greensnake, *Opheodrys vernalis*	X	X	X	X	X	X	X	—	X	X	X
Timber Rattlesnake, *Crotalus horridus*	—	—	—	—	—	—	—	X	X	X	X
Western Ribbonsnake, *Thamnophis proximus*	—	X	—	X	—	—	—	—	X	X	X
Western Wormsnake, *Carphophis vermis*	—	—	—	—	—	—	—	—	X	—	—
Testudines											
Blanding's Turtle, *Emydoidea blandingii*	X	X	X	X	—	X	X	X	X	X	X
Eastern Musk Turtle, *Sternotherus odoratus*	X	—	X	X	—	—	—	—	X	X	X
False Map Turtle, *Graptemys pseudogeographica*	X	X	X	X	—	—	X	X	X	X	X
Northern Map Turtle, *Graptemys geographica*	X	X	X	X	—	—	X	X	X	X	X
Ornate Box Turtle, *Terrapene ornata*	—	—	—	—	—	—	—	—	X	X	X
Ouachita Map Turtle, *Graptemys ouachitensis*	—	X	X	—	—	—	—	—	X	X	X
Painted Turtle, *Chrysemys picta*	X	X	X	X	X	X	X	X	X	X	X
Smooth Softshell, *Apalone mutica*	—	—	—	—	—	—	—	—	X	X	X
Snapping Turtle, *Chelydra serpentina*	X	X	X	X	X	X	X	X	X	X	X
Spiny Softshell, *Apalone spinifera*	X	X	X	X	X	X	X	X	X	X	X
Wood Turtle, *Glyptemys insculpta*	X	X	X	X	X	X	X	X	X	X	X
Total reptile species	**22**	**24**	**22**	**23**	**12**	**14**	**19**	**21**	**36**	**35**	**33**

Statewide Patterns in Amphibian and Reptile Species Richness

To visualize statewide patterns in species richness, we used county-level species richness data. We created a net of regularly spaced points (10 × 10 km [6.2 × 6.2 mi]) across the state and computed the total number of documented native species at each point per class and order based on county records (including vouchered records and additional nonvouchered records shown in species accounts). We modeled statewide species richness patterns using kriging. This approach uses semivariograms to estimate spatial autocorrelation relationships for point data and creates prediction surface maps based on the modeled relationships (Brunsdon and Comber 2015). We used a Gaussian semivariance model, with a search radius of 50 km (31 mi) and an output cell size of 10 km^2 (6.2 mi^2) to project broad species richness patterns for each class and order. We performed these analyses using ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, California).

Projected amphibian species richness was highest in the west-central region and lowest in the east-central and southwestern regions (Figure 13). Anura and Caudata showed different species richness patterns. Anuran richness was generally highest in the western and southern portions of the state, whereas salamander richness was generally highest in the northern and eastern portions of the state (Figure 13). Projected reptile species richness was highest in the western and south-central regions (Figure 14). Squamata and Testudines showed similar species richness patterns. Richness was highest in the south-central portion of the state and generally lowest in the northern and eastern portions of the state (Figure 14).

THE POTENTIAL FUTURE FOR WISCONSIN'S LANDSCAPES

It is widely recognized that rapid climate changes are occurring globally, and measurable changes will continue to occur for the foreseeable future (IPCC 2013). Understanding climate change at the state level is the focus of the Wisconsin Initiative on Climate Change Impacts (WICCI). Specifically, WICCI was formed in 2007 to promote information exchange, proactive planning, and adaptation to climate change in the state (https://wicci.wisc.edu/). In this section, we summarize observed recent climate changes and future climate projections for Wisconsin, potential concomitant changes to aquatic and terrestrial habitats, and how these changes could affect Wisconsin's amphibian and reptiles.

Between 1950 and 2006, the annual average temperature in Wisconsin increased by ca. 0.6°C (1.1°F), with the highest average warming in northwestern Wisconsin (+1.4°C [2.5°F]; WICCI 2011). Temperature is projected to continue increasing throughout the state, with annual average temperature increases of 2.2°C–5°C (4°F–9°F) and average winter temperature increases of 2.8°C–6.1°C (5°F–11°F) by around 2050, which will likely result in earlier annual first-bloom dates and longer growing seasons for native plants (Bradley et al. 1999, Zhao and Schwartz 2003, WICCI 2011). Between 1950 and 2006, annual average precipitation in Wisconsin increased by ca. 10% (7.9 cm [3.1 in]; WICCI 2011). Increases were primarily in southern and western portions of the state and during the autumn; annual precipitation decreased in the north (WICCI 2011). Annual average precipitation is also projected to increase in Wisconsin, primarily during the spring and autumn, but models vary substantially in projected precipitation levels (WICCI 2011). Schuster et al. (2012) projected that extreme rainfall events will increase in the state, particularly in the Northeast.

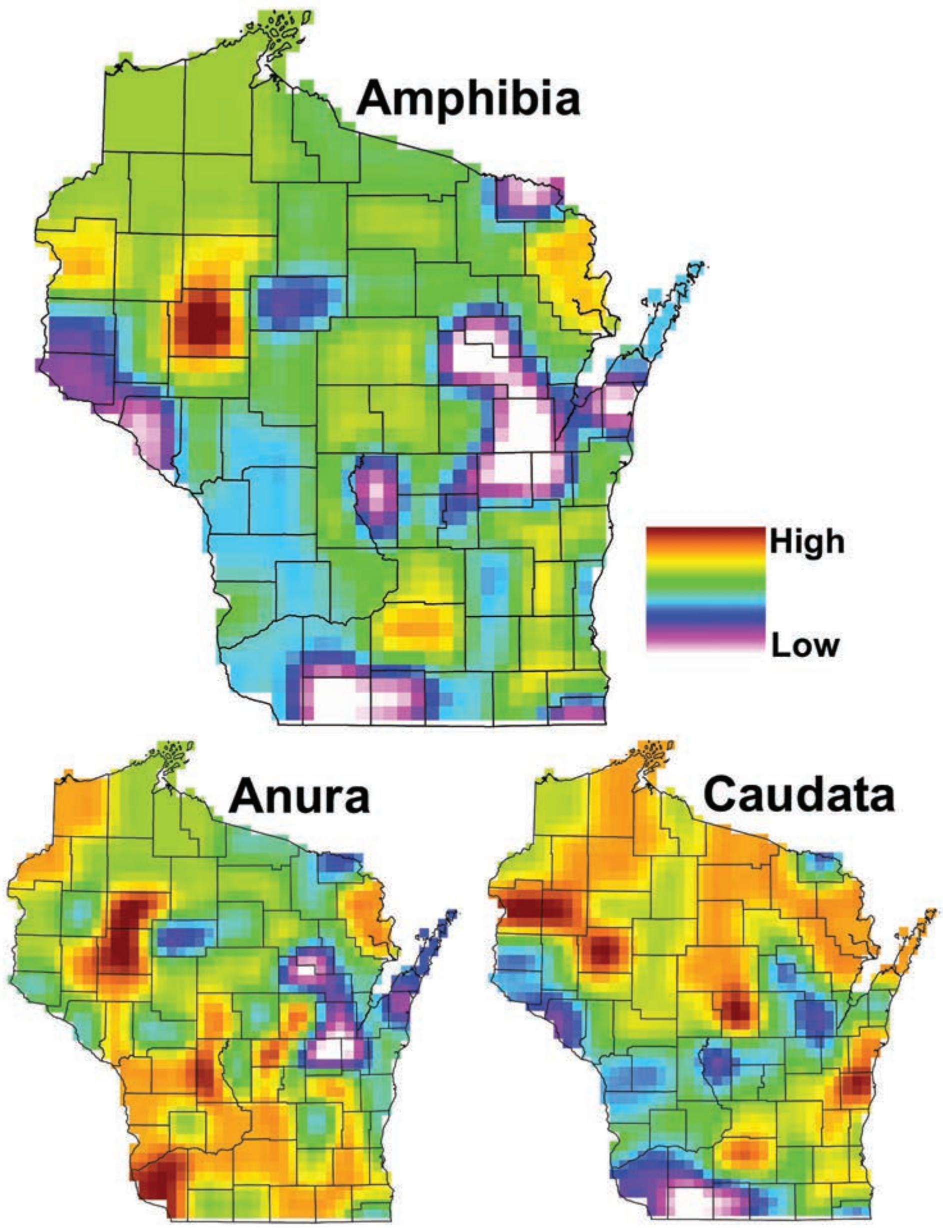

Figure 13. Projected species richness patterns for the class Amphibia and the orders Anura (frogs and toads) and Caudata (salamanders) in Wisconsin. For each map, we used county-level occurrence data and kriging to project statewide richness patterns (see main text for details). We emphasize that counties represented the finest level of data resolution for the analyses; thus, the prediction surface maps are useful only to infer broad spatial patterns.

Climate change may affect the availability and dynamics of the aquatic habitats on which most of the state's amphibians and aquatic/semiaquatic reptiles rely. Magnuson et al. (1997) completed an extensive modeling exercise of potential aquatic changes in the Great Lakes region and concluded that many lakes that traditionally experience complete ice cover during the winter could be ice-free more often. They also surmised that the duration of iced-over conditions on many lakes will be reduced. Magnuson et al. (1997) further

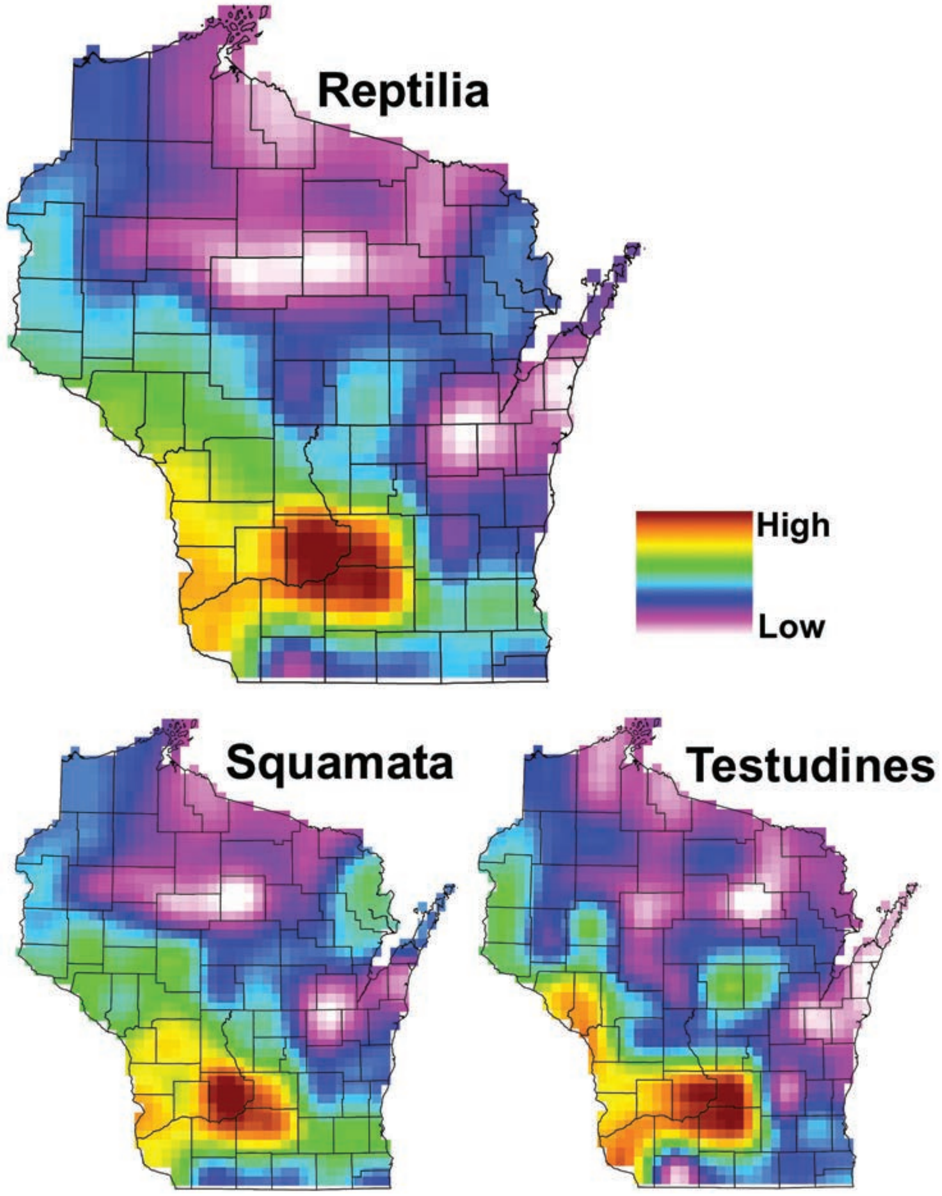

Figure 14. Projected species richness patterns for the class Reptilia and the orders Squamata (lizards and snakes) and Testudines (turtles) in Wisconsin. For each map, we used county-level occurrence data and kriging to project statewide richness patterns (see main text for details). We emphasize that counties represented the finest level of data resolution for the analyses; thus, the prediction surface maps are useful only to infer broad spatial patterns.

estimated that spatial and temporal wetland coverage will experience future declines due to increased summer evaporation. Anticipated hydrologic changes to ephemeral ponds include shifts to wetter, deeper types, increased flood duration in low-lying areas, and higher initial water levels. Such shifts could also result in these systems being connected to other, more permanent waterbodies (WICCI 2011).

As annual temperature and precipitation continue to increase in northern Wisconsin, the climate will likely become suitable for more cold-intolerant and mesic tree species, such as Black Oak (*Quercus velutina*; Iverson et al. 2008, 2013). Based on the Climate Change Tree Atlas (Swanston et al. 2011), habitat suitability in northern Wisconsin will likely decrease substantially for 12 tree species: Balsam Fir (*Abies balsamea*), Bigtooth Aspen (*Populus grandidentata*), Black Ash (*Fraxinus nigra*), Black Spruce (*Picea mariana*), Eastern Hemlock (*Tsuga canadensis*), Northern White-cedar (*Thuja occidentalis*), Paper Birch (*Betula papyrifera*), Quaking Aspen (*Populus tremuloides*), Sugar Maple (*Acer saccharum*), Tamarack (*Larix laricina*), White Spruce (*Picea glauca*), and Yellow Birch (*Betula alleghaniensis*). In contrast, 17 species are projected to have large increases in habitat suitability, all of which are deciduous trees, with the exception of Eastern Red Cedar (*Juniperus virginiana*; Swanston et al. 2011). Forest change modeling that included climate change, logging and wind disturbances, and forest fragmentation impacts on seed dispersal in northern Wisconsin concluded that five species could severely decline (Balsam Fir, White Spruce, Jack Pine [*Pinus banksiana*], Red Pine [*Pinus resinosa*], and Paper Birch), with a likely decline of five other species (Northern White-cedar, Quaking Aspen, Yellow Birch, Red Maple [*Acer rubrum*], and Red Oak [*Quercus rubra*]; Scheller and Mladenoff 2005, Swanston et al. 2011). Future vegetation projections by Williams et al. (2012a) indicated a decline in evergreen tree cover and an increase in deciduous tree cover in northern Wisconsin. Thus, current forest change models are in agreement that the prevalence of northern and boreal tree species in northern Wisconsin will decline in the future, replaced by southern and more mesic hardwoods. Vegetation projections in southern and western Wisconsin indicated that forests could be replaced by grassland prairie due to increased soil desiccation (Notaro et al. 2012).

Potential Climate Change Impacts on Amphibians and Reptiles

The wildlife subcommittee of WICCI assessed the vulnerability of Wisconsin's amphibians and reptiles to climate change as part of a project to prioritize actions for Wisconsin's wildlife (LeDee and Ribic 2015). Based on an extensive literature review, all vertebrates were scored for potential sensitivity to climate change using seven traits: specialized habitat and/or microhabitat requirements, narrow environmental thresholds likely to be exceeded, dependence on an abiotic cue to prompt physiological or behavioral response, dependence on interspecific interaction likely to be altered by changing climate, poor dispersal ability, susceptibility to infectious agents, and behavioral traits unsuited for future climate conditions (maladaptive behavior; LeDee and Ribic 2015). At the class level, amphibians and reptiles showed similar overall vulnerability to climate change based on the seven traits ($\chi^2_6 = 7.2$, $P = 0.27$); this was also found when species were categorized by order ($\chi^2_{18} = 23.7$, $P = 0.14$). Amphibians and reptiles were sensitive to climate change via specialized habitat/microhabitat requirements (94.7% of amphibians and 51.4% of reptiles), dependence on an abiotic cue (63.1% of amphibians and 40% of reptiles), and susceptibility to infectious agents (57.8% of amphibians and 17.1% of reptiles; Table 6). In terms of individual species, amphibians had more climate-sensitive traits than reptiles ($\chi^2_5 = 19.4$, $P < 0.001$). All amphibians were sensitive for either three (31.6%) or four (15.8% of amphibian species) traits, while only 8.6% of reptiles were sensitive for three traits and none for four. For reptiles, squamates were not sensitive (29.2%) or were sensitive for only one trait (41.1% of species), while 73% of Testudines were sensitive for one or two traits (Table 6). In terms of priority actions, the WICCI wildlife subcommittee recommended more research for reptiles, with targeted action or monitoring recommended for amphibians (LeDee and

Table 6. Species-specific results from an assessment of Wisconsin amphibian and reptile vulnerability to climate change based on species traits derived from the scientific literature, which were collated into seven trait groups. A summary of these results can be found in LeDee and Ribic (2015).

	Specialized Habitat and/or Microhabitat Requirements	**Narrow Environmental Thresholds Likely to Be Exceeded**	**Dependence on Environmental Cue**	**Dependence on Interspecific Interaction Likely to Be Altered**	**Poor Dispersal Ability**	**Disease/Parasitism**	**Maladaptive Behavior**	***Total***
Amphibians								
Anura								
American Bullfrog, *Lithobates catesbeianus*	1	0	1	0	0	0	0	2
American Toad, *Anaxyrus americanus*	1	0	1	0	0	1	0	3
Blanchard's Cricket Frog, *Acris blanchardi*	1	0	1	0	0	0	0	2
Boreal Chorus Frog, *Pseudacris maculata*	1	1	1	0	0	0	0	3
Cope's Treefrog, *Hyla chrysoscelis*	1	0	0	0	0	1	0	2
Gray Treefrog, *Hyla versicolor*	1	0	0	0	0	1	0	2
Green Frog, *Lithobates clamitans*	1	0	0	0	0	1	0	2
Mink Frog, *Lithobates septentrionalis*	1	1	1	0	0	1	0	4
Northern Leopard Frog, *Lithobates pipiens*	0	1	0	0	0	1	0	2
Pickerel Frog, *Lithobates palustris*	1	0	1	0	0	1	0	3
Spring Peeper, *Pseudacris crucifer*	1	0	1	0	0	1	0	3
Wood Frog, *Lithobates sylvaticus*	1	1	1	0	0	1	0	4
Caudata								
Blue-spotted Salamander, *Ambystoma laterale*	1	0	1	0	0	0	0	2
Eastern Newt, *Notophthalmus viridescens*	1	0	0	0	0	0	0	1
Eastern Red-backed Salamander, *Plethodon cinereus*	1	1	1	0	0	0	0	3
Eastern Tiger Salamander, *Ambystoma tigrinum*	1	0	1	0	0	1	0	3
Four-toed Salamander, *Hemidactylium scutatum*	1	0	0	0	1	0	0	2

Mudpuppy, *Necturus maculosus*	1	0	0	0	0	1	0	2
Spotted Salamander, *Ambystoma maculatum*	1	1	1	1	0	0	0	4
Total amphibian species	**18**	**6**	**12**	**1**	**1**	**11**	**0**	**49**
Reptiles								
Squamata								
Gophersnake, *Pituophis catenifer*	1	0	0	0	0	0	1	2
Butler's Gartersnake, *Thamnophis butleri*	0	0	0	1	0	0	0	1
Common Five-lined Skink, *Plestiodon fasciatus*	0	0	1	0	0	0	0	1
Common Gartersnake, *Thamnophis sirtalis*	0	0	0	0	0	1	0	1
Dekay's Brownsnake, *Storeria dekayi*	0	0	0	0	0	0	0	0
Eastern Foxsnake, *Pantherophis vulpinus*	0	0	0	0	0	0	0	0
Eastern Hog-nosed Snake, *Heterodon platirhinos*	1	0	0	1	0	0	0	2
Eastern Ribbonsnake, *Thamnophis saurita*	1	0	0	0	0	0	0	1
Gray Ratsnake, *Pantherophis spiloides*	0	0	1	0	0	0	0	1
Massasauga, *Sistrurus catenatus*	0	1	1	1	1	1	0	5
Eastern Milksnake, *Lampropeltis triangulum*	0	0	0	0	0	1	0	1
North American Racer, *Coluber constrictor*	0	0	0	0	0	0	0	0
Common Watersnake, *Nerodia sipedon*	1	0	1	0	0	0	0	2
Plains Gartersnake, *Thamnophis radix*	0	0	0	0	0	0	0	0
Prairie Skink, *Plestiodon septentrionalis*	1	0	0	0	0	0	0	1
Queensnake, *Regina septemvittata*	1	0	0	1	0	0	0	2
Red-bellied Snake, *Storeria occipitomaculata*	1	0	1	0	0	0	0	2
Ring-necked Snake, *Diadophis punctatus*	0	0	1	0	0	0	0	1
Six-lined Racerunner, *Aspidoscelis sexlineata*	1	0	1	0	0	0	0	2
Slender Glass Lizard, *Ophisaurus attenuatus*	0	0	0	0	0	0	0	0
Smooth Greensnake, *Opheodrys vernalis*	0	0	0	0	0	0	0	0
Timber Rattlesnake, *Crotalus horridus*	0	0	0	0	0	0	0	0
Western Ribbonsnake, *Thamnophis proximus*	0	0	0	1	0	0	0	1
Western Wormsnake, *Carphophis vermis*	0	0	0	1	0	0	0	1

Continued

Table 6. (*Continued*)

	Specialized Habitat and/or Microhabitat Requirements	Narrow Environmental Thresholds Likely to Be Exceeded	Dependence on Environmental Cue	Dependence on Interspecific Interaction Likely to Be Altered	Poor Dispersal Ability	Disease/Parasitism	Maladaptive Behavior	*Total*
Testudines								
Blanding's Turtle, *Emydoidea blandingii*	1	1	1	0	0	0	0	3
Eastern Musk Turtle, *Sternotherus odoratus*	1	0	0	0	0	1	0	2
False Map Turtle, *Graptemys pseudogeographica*	0	0	1	0	0	0	0	1
Northern Map Turtle, *Graptemys geographica*	1	0	1	0	0	0	0	2
Ornate Box Turtle, *Terrapene ornata*	1	0	0	0	0	0	0	1
Ouachita Map Turtle, *Graptemys ouachitensis*	1	0	1	0	0	0	0	2
Painted Turtle, *Chrysemys picta*	1	1	1	0	0	0	0	3
Smooth Softshell, *Apalone mutica*	1	0	1	0	0	0	0	2
Snapping Turtle, *Chelydra serpentina*	1	0	1	0	0	1	0	3
Spiny Softshell, *Apalone spinifera*	1	0	0	0	0	1	0	2
Wood Turtle, *Glyptemys insculpta*	1	0	0	0	0	0	0	1
Total reptile species	**18**	**3**	**14**	**6**	**1**	**6**	**1**	**49**

Ribic 2015). These recommendations were likely due to the lack of information about reptiles; there were fewer papers addressing climate-sensitive traits found per reptile species ($\bar{x} = 24$ papers/species, SD = 37, $n = 35$) compared to amphibian species ($\bar{x} = 70$ papers/species, SD = 73, $n = 19$).

The WICCI wildlife subcommittee also developed an overview of climate change and Wisconsin's wildlife (LeDee et al. 2013); the report used the Eastern Red-backed Salamander (*Plethodon cinereus*) and Wood Frog as examples of how different aspects of climate change might affect species distributions. LeDee et al. (2013) concluded that the Eastern Red-backed Salamander could decline in Wisconsin due to stress associated with the projected increase in summer temperature and decrease in summer precipitation. Furthermore, the Wood Frog was projected to decline in northern Wisconsin due to potential increases in frequency and severity of extreme droughts (LeDee et al. 2013).

For reptiles, Pomara et al. (2014) assessed vulnerability of Massasaugas to climate change across the species' distribution (including Wisconsin) and found that they are vulnerable to winter climate extremes (i.e., drought and flood events, which are projected to increase in the Upper Midwest) because of narrow thermal and hydration requirements in winter hibernacula. King and Niiro (2013) investigated potential distributional shifts for reptiles of conservation concern in the Great Lakes region, including seven species found in Wisconsin (Butler's Gartersnake [*Thamnophis butleri*], foxsnakes [*Pantherophis* spp.], Massasauga [*Sistrurus catenatus*], Queensnake [*Regina septemvittata*], Blanding's Turtle [*Emydoidea blandingii*], Northern Map Turtle [*Graptemys geographica*], and Wood Turtle [*Glyptemys insculpta*]). King and Niiro (2013) found that annual mean temperature was a key predictor for all of the Wisconsin species and that the optimal temperature relationship was unimodal (i.e., temperature had an optimal value, and habitat suitability decreased when conditions were higher or lower than optimal). Specifically in Wisconsin, habitat suitability for the Queen Snake and the Northern Map Turtle could increase, but habitat suitability for the Butler's Gartersnake, foxsnakes, Massasauga, Blanding's Turtle, and Wood Turtle could decrease. In addition, King and Niiro (2013) reported that Wisconsin could become more suitable for colonization by the Spotted Turtle (*Clemmys guttata*; see Hypothetical and Enigmatic Species of Wisconsin chapter for additional information on the Spotted Turtle).

In addition to potential distributional shifts, climate change will likely affect many biological processes, individual behaviors, and biotic interactions for amphibians and reptiles (see Corn [2005] and Li et al. [2013] for amphibian literature syntheses). Because amphibians and reptiles are ectothermic vertebrates, their biological and behavioral processes are strongly affected by temperature. Several studies have found changes in anuran breeding phenology in response to warming climate (Gibbs and Breisch 2001, Beebee 2002, Todd et al. 2011), and Byer et al. (2020) found that inter-year variation in median nesting date for Blanding's Turtles in Wisconsin was linked to heating degree-days in March. Donner et al. (2015) found that Blue-spotted Salamanders (*Ambystoma laterale*) and Spotted Salamanders (*A. maculatum*) moved into northern Wisconsin breeding ponds 12 and 10 days earlier, respectively, when mean April temperatures were warmer. Leach (2012) studied correlations between weather variables and Wood Frog breeding in northern Minnesota and found that average March temperature had the strongest influence on predicting when males begin to call. Thus, she predicted that Wood Frogs will spawn earlier as temperatures increase in the region. Similarly, Blaustein et al. (2001) noted a significant negative relationship between temperature and breeding for Spring Peepers (*Pseudacris crucifer*) in Michigan, indicating they might breed earlier as temperatures increase. Many aquatic and semiaquatic turtles in Wisconsin have temperature-dependent sex determination (Bull and Vogt 1979, 1981), and climate warming could potentially create female-biased populations (Ihlow et al. 2012). The warming of Wisconsin's climate could also lead to reductions in average amphibian and reptile body size (adhering to Bergmann's Rule). Daufresne et al. (2009) obtained evidence of this impact for fishes in the Baltic Sea and proposed that it be considered a "universal ecological response to global warming." In accordance, Caruso et al. (2014) reported an 8% reduction in average *Plethodon* salamander body size in the eastern United States over a 55-year period, with low-altitude sites with increasing temperature and decreasing precipitation trends showing the greatest body size reductions.

In conclusion, climate change will likely result in novel biological communities, with associated shifts in species assemblages and trophic (i.e., food chain) interactions (Lawler et al. 2010, 2013, Lurgi et al. 2012, LeDee et al. 2013). Amphibians and reptiles are highly influential in top-down and bottom-up ecosystem processes, serving as major predators (e.g., American Bullfrogs [*Lithobates catesbeianus*], Snapping Turtles [*Chelydra serpentina*]), major biomass components, and nutrient links between aquatic and terrestrial systems. Thus, the direct and indirect impacts of climate change on amphibian and reptile communities will have far-reaching effects on community composition and interactions at all trophic levels. We expect there will be a proliferation of future studies focused on how climate change affects amphibians and reptiles in the Midwest. These studies will be important for guiding proactive conservation and management of amphibians, reptiles, and their habitats in Wisconsin.