Wildlife Crossing Hotspot Analyses for Major Highways in Wisconsin, USA

Final Report

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16. Abstract

In this report we explore where and how to enhance road safety in Wisconsin through reducing collisions with large wild mammals on state-maintained routes, while also ensuring safe crossing opportunities for wildlife. We identified and prioritized road sections in Wisconsin along state-maintained routes that have a relatively high concentration of collisions involving large wild mammals, mostly with white-tailed deer. We used the large wild mammal crash and carcass data to conduct cost-benefit analyses to identify road sections where the implementation of mitigation measures may be less expensive than doing nothing and letting these types of collisions continue to occur. We also identified 36 species of conservation concern in Wisconsin. The species of conservation concern, as defined for this report, included 4 amphibian species (3 frog species, 1 salamander species), 20 reptile species (3 lizard species, 13 snake species, 4 turtle species), and 12 mammal species (1 insectivore species, 5 rodent species, 1 mustelid species, 1 canid species, 2 felid species, 2 ungulate species). We identified road sections, or counties, where species of conservation concern have been observed. Road sections that would need to be prioritized for reducing collisions with common large mammals (i.e., mostly white-tailed deer) are mostly in the eastern and southeastern parts of Wisconsin. Areas where a relatively high number of species occur that are of conservation concern are predominantly in the southwestern parts of Wisconsin. This illustrates that there would be benefits to having a two-track system of policy, funding mechanisms and implementation programs; one that is rooted in human safety through reducing collisions with large wild mammals that are common, and another that is rooted in biological conservation. We also identified measures for both large wild mammals and small animal species that are aimed at reducing wildlife-vehicle collisions and associated direct road mortality of the animals, and at reducing the barrier effects of roads and traffic to wildlife.

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About the Western Transportation Institute

The Western Transportation Institute (WTI) was founded in 1994 by the Montana and California Departments of Transportation, in cooperation with Montana State University. WTI concentrates on rural transportation research; as stewards and champions of rural America, WTI also has a strong interest in sustainability. WTI research groups create solutions that work for clients, sponsors, and rural transportation research partners. WTI Research Centers include the Montana Local Technical Assistance Program, the National Center for Rural Road Safety, the Small Urban, Rural and Tribal Center on Mobility, the Federal-Public Lands Transportation Institute, and the West Region Transportation Workforce Center.

Disclaimer

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- University of Wisconsin (Steven Parker).
- Wisconsin Department of Natural Resources (Anna Rossler, Stacy Rowe, Melissa Tumbleson).
- Volunteers that contributed to the Wisconsin Department of Natural Resources data and Natural Heritage Inventory (NHI) program on species observations.

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1 Summary

In this report we explore where and how to enhance road safety in Wisconsin through reducing collisions with large wild mammals on state-maintained routes, while also ensuring safe crossing opportunities for wildlife. We identified and prioritized road sections in Wisconsin along state-maintained routes that have a relatively high concentration of collisions involving large wild mammals, mostly with white-tailed deer. We used the large wild mammal crash and carcass data to conduct cost-benefit analyses to identify road sections where the implementation of mitigation measures may be less expensive than doing nothing and letting these types of collisions continue to occur. We also identified 36 species of conservation concern in Wisconsin. The species of conservation concern, as defined for this report, included 4 amphibian species (3 frog species, 1 salamander species), 20 reptile species (3 lizard species, 13 snake species, 4 turtle species), and 12 mammal species (1 insectivore species, 5 rodent species, 1 mustelid species, 1 canid species, 2 felid species, 2 ungulate species). We identified road sections, or counties, where species of conservation concern have been observed. Road sections that would need to be prioritized for reducing collisions with common large mammals (i.e., mostly white-tailed deer) are mostly in the eastern and southeastern parts of Wisconsin. Areas where a relatively high number of species occur that are of conservation concern are predominantly in the southwestern parts of Wisconsin. This illustrates that there would be benefits to having a two-track system of policy, funding mechanisms and implementation programs; one that is rooted in human safety through reducing collisions with large wild mammals that are common, and another that is rooted in biological conservation. We also identified measures for both large wild mammals and small animal species that are aimed at reducing wildlife-vehicle collisions and associated direct road mortality of the animals, and at reducing the barrier effects of roads and traffic to wildlife.

2 Introduction

2.1 Wildlife-vehicle collisions and other impacts of roads and traffic on wildlife

Wildlife-vehicle collisions are becoming increasingly common across much of North America, posing risks to both human safety and the individual animals involved (Huijser et al., 2008a; Abraham & Mumma, 2021). In the United States alone, several million collisions with large wild mammals occur annually (Huijser et al., 2009; Conover, 2019). These collisions nearly always result in vehicle damage and costly repairs, but they also cause tens of thousands of human injuries and hundreds of human fatalities each year (Huijser et al., 2008a; Huijser et al., 2009; Conover, 2019). In the United States, the financial costs related to vehicle repairs, human injuries, and human fatalities have been estimated to amount to multiple billions of US dollars annually (Conover et al., 1995; Huijser et al., 2009, 2022a).

While there is much emphasis on mitigating vehicle collisions involving large mammals in North America, these types of collisions are not the only reasons to consider wildlife mitigation along highways (Van der Ree et al., 2015). We identify five categories of road and traffic impacts on wildlife (Figure 1):

- Habitat loss: This includes the paved road surface, the heavily altered roadbed with non-native substrate, and the clear zone where native vegetation has been removed and where seeded species and regular mowing occur.
- Direct wildlife mortality: Animals are killed through collisions with vehicles.
- Barrier to wildlife movement: Roads function as barriers, reducing the likelihood that animals cross the road as frequently as they would in habitat without roads. Only a fraction of the animal crossing attempts are successful.
- Decrease in habitat quality near roads: Areas adjacent to roads suffer from noise and light pollution, air and water contamination, and increased human access, all of which degrade habitat quality.
- Right-of-way habitat and corridors: The right-of-way along roads can either promote the spread of non-native or invasive species in largely natural or semi-natural landscapes or serve as a refuge for native species in heavily human-impacted landscapes.

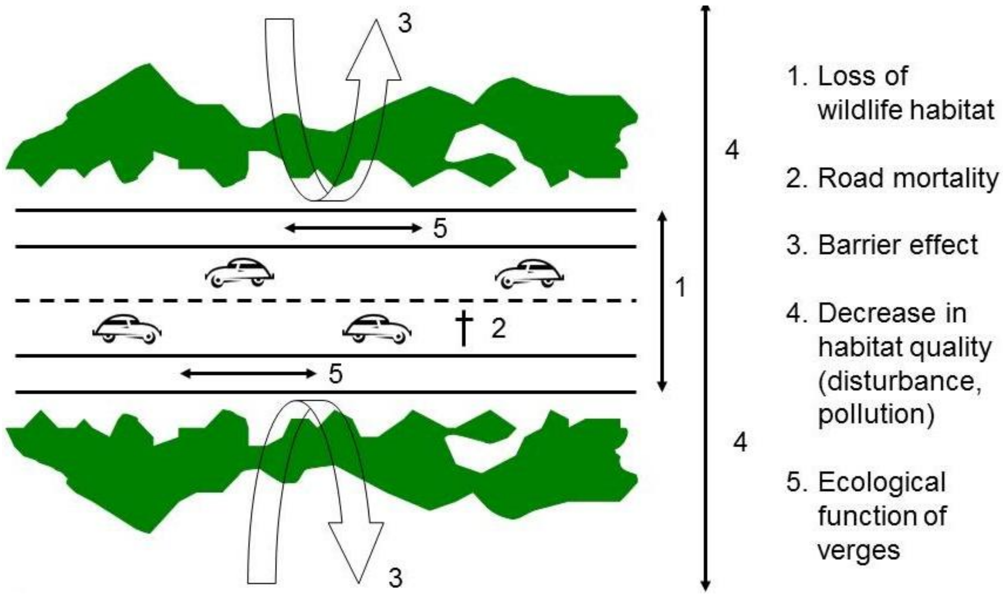

Figure 1: The effects of roads and traffic on wildlife.

In some cases, it is not just the individual animals that suffer from road mortality; entire populations may be affected (van der Zee et al., 1992; Huijser & Bergers, 2000). For some species, road mortality, habitat fragmentation, and other road-related impacts can substantially reduce population survival probability (Proctor, 2003; Huijser et al., 2008a). Additionally, certain species have an economic value that is lost when individual animals are killed (Romin & Bissonette, 1996; Conover, 1997; Huijser et al., 2022a). Finally, if road mortality has already depleted local populations in the past, or if animals rarely cross roads because of a substantial barrier effect, road mortality data alone may not be an accurate indicator of where mitigation efforts are most needed for wildlife conservation (Ewen et al., 2013). This issue is further compounded when road mortality data are biased towards large, common species, with little to no data on smaller or rarer species.

2.2 Taking action; the mitigation hierarchy

While reducing the severity of an impact is common, avoidance is preferable and should generally be considered first in the mitigation hierarchy (Cuperus et al., 1999; Arlidge et al., 2018). For instance, the negative effects of roads and traffic can be avoided entirely if a road is not constructed, or the most severe impacts may be avoided by re-routing roads away from sensitive areas (Figure 2). When avoidance is not possible, minimization of an impact becomes the next logical step. Minimization efforts typically take place in the road-effect zone (Figure 2) and may include measures aimed at reducing wildlife-vehicle collisions (e.g., installing wildlife fences) and alleviating the barrier effect by providing safe wildlife crossing opportunities (Clevenger & Huijser, 2011; Huijser et al., 2016; Huijser et al., 2021).

However, minimization may not always be possible, and even when it is, it may not be sufficient. In such cases, a third approach may be considered: remediation (within the immediate road-effect zone) and offsetting (outside the immediate road-effect zone) (Figure 2). Remediation and offsetting efforts might involve expanding existing habitat patches, creating new ones, or improving connectivity between the habitat patches to support larger, more connected, and thus more viable populations. Finally, in some situations, a combination of avoidance, minimization, and remediation/offsetting strategies may be implemented (Figure 2).

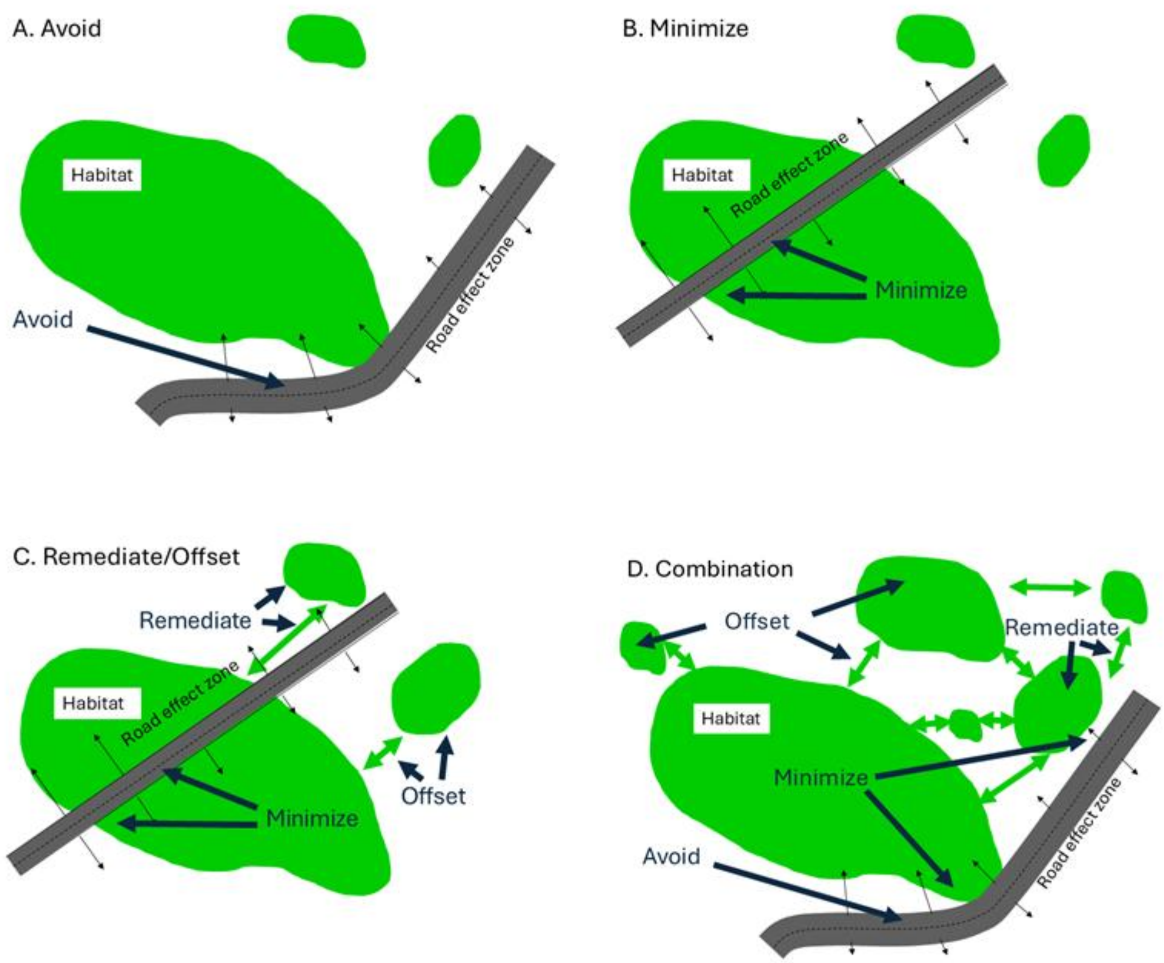

Figure 2: The mitigation hierarchy consists of a three-step approach: A. Avoidance, B. Minimization, C. Remediation/Offsetting. It is also possible to have a combination of avoidance, minimization, and remediation/offsetting (D.).

2.3 Goals and objectives

The goal of this project is to enhance road safety in Wisconsin through reducing collisions with large wild mammals on state-maintained routes, while also ensuring safe crossing opportunities for wildlife.

The primary objective of this project is to identify and prioritize road sections in Wisconsin along state-maintained routes that have a relatively high concentration of collisions involving large wild mammals. These road sections along state-maintained routes may then later be evaluated for potential future mitigation measures aimed at:

- Reducing collisions with large wild mammals and providing safe passage across roads for large wild terrestrial mammals.
- Reducing direct road mortality for species that are considered a conservation concern and providing safe passage across roads for these species, including terrestrial mammals (regardless of their body size and weight), reptiles, and amphibians.

Note that in this report, the term “collisions” relates to both crashes and carcasses (Huijser et al., 2007).

3 Crash data exploration

3.1 Introduction

This chapter (Chapter 2) contains an exploration of the wildlife-vehicle crash data from the state of Wisconsin, regardless of the type of road the crash occurred on. However, the identification and prioritization of road sections that may require mitigation for wildlife is limited to state-maintained routes (see Chapter 3).

3.2 Crash data sources

We acquired crash data collected by law enforcement personnel. These data involve more severe collisions, as there are thresholds for the inclusion in a crash database. In Wisconsin, a collision is only recorded in the crash database if (WisDOT, 2021; 2024; Personal communication Steven Parker, University of Wisconsin):

- The collision involved a registered motor vehicle with the Department of Motor Vehicles (DMV) in Wisconsin or if the vehicle is registered with a DMV outside of Wisconsin.

  And

- The collision resulted in a human injury or a human death.

  Or

- The collision resulted in damage to government-owned non-vehicle property to an apparent extent of $200 or more.

  Or

- The collision resulted in damage to property owned by any one person to an apparent extent of $1,000 or more.

  And

- A crash report was completed by a law enforcement officer.

The crash data related to all types of crashes, not just those related to wildlife. These crash data were obtained from the Wisconsin Department of Transportation (WisDOT). The crash data mostly relate to interstates, US Highways and State Highways, including on Native American reservations. The crash data are less consistently collected for county or tribal roads.

3.3 Crash data period

Crash data were available from 1 January 1994 through 31 December 2023, totaling 30 full calendar years. However, the crash data were retrieved from two different databases:

- MV4000 (1994 through 2016 (23 full calendar years)) (WisDOT, 2021).
- DT4000 (2017 through 2024 (7 full calendar years)) (WisDOT, 2024).

The DT4000 database "introduced important changes to the overall set of crash data elements and attributes, including adherence to the US DOT Model Minimum Uniform Crash Criteria (MMUCC) standard for crash data systems" (WisDOT, 2024).

3.4 Crashes by year

The average total number of crashes in Wisconsin per year was 137,502 (Standard Deviation (SD)=12,044) (Figure 3). The average total number of crashes per year that had a "deer flag" (a flag indicating whether a crash involved a deer) was 19,044 (SD=2,176), representing on average 13.84% (SD=0.88) of the total number of crashes (Figure 3). From 2017 onwards, the crash records included "animal type A" and "animal type B"). The average number of crashes per year that had "deer" or "bear" in one of these two parameters was 18,542 (SD=1,819), on average 4.74% (SD=0.41) higher than the number of crashes marked with a "deer flag" in the same years (Figure 3). The average number of crashes per year that had only "deer" in one of these two parameters was 18,397 (SD=1,812), on average 3.99% (SD=0.35) higher than the number of crashes marked with a "deer flag".

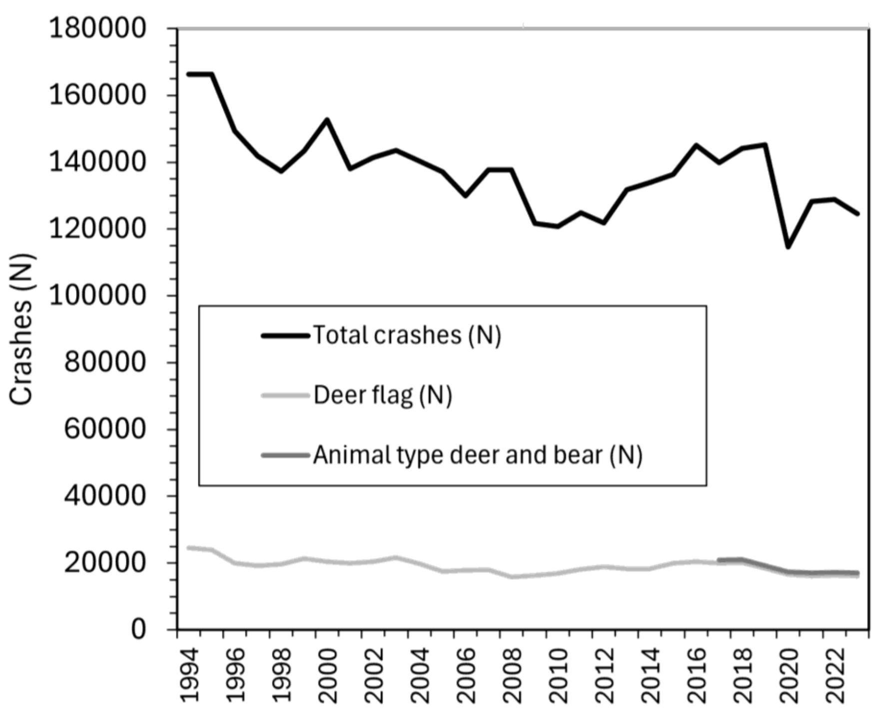

Figure 3: The number of crashes (total, "deer flag", and animal type "deer" or "bear") per year in Wisconsin (1994-2023).

3.5 Species involved with crashes

“Animal type A” and “animal type B” were recorded between 2017 and 2023 (Table 1). This means that there could be two animals, even two different species involved with the same crash. On average, 14.48% of the crashes related to an animal, whereas 85.52% did not have “animal type A” or “animal type B” filled out (Table 1). On average, 18397.29 (SD=1811.92) crashes per year related to “deer” (i.e., white-tailed deer (*Odocoileus virginianus*)), which represented 96.09% of all crashes that had “animal type A” or “animal type B” filled out. On average, 145.00 (SD=15.79) crashes per year related to “bear” (i.e., American black bear (*Ursus americanus*)), which represented 0.76% of all crashes that had “animal type A” or “animal type B” filled out. Other species that were recorded included coyote (i.e., coyote (*Canis latrans*)), opossum (i.e., Virginia opossum (*Didelphis virginiana*)), raccoon (i.e., raccoon (*Procyon lotor*)), turkey (i.e., wild turkey (*Meleagris gallopavo*)), and “other”.

Table 1: Species names recorded as “animal type A” and “animal type B” in the crash data (2017-2023).

Animal type A	Animal type B	Average per year	SD	% of Total animals	% of Total crashes
None	None	113,113.86	9,828.85	N/A	85.52
Bear		144.29	15.43	0.75	0.11
Bear	Coyote	1.00	N/A	0.01	0.00
Coyote		69.00	18.61	0.36	0.05
Deer		18,393.71	1,812.49	96.07	13.91
Deer	Bear	1.33	0.58	0.01	0.00
Deer	Coyote	1.00	N/A	0.01	0.00
Deer	Opossum	1.00	0.00	0.01	0.00
Deer	Other	1.80	1.30	0.01	0.00
Deer	Raccoon	1.75	0.50	0.01	0.00
Deer	Turkey	1.00	0.00	0.01	0.00
Opossum		8.71	2.29	0.05	0.01
Opossum	Coyote	1.00	N/A	0.01	0.00
Other		220.71	53.78	1.15	0.17
Raccoon		143.29	15.54	0.75	0.11
Raccoon	Opossum	1.25	0.50	0.01	0.00
Raccoon	Other	2.00	N/A	0.01	0.00
Turkey		161.14	20.18	0.84	0.12
Turkey	Other	1.50	0.71	0.01	0.00
Total "animal"		19,146.14	1,891.52	100.00	14.48
Total "Deer"		18,397.29	1,811.92	96.09	13.91
Total "Bear"		145.00	15.79	0.76	0.11
Total "Deer" and "Bear"		18,541.71	1,818.50	96.84	14.02
Total crashes		132,260.00	11,289.31	N/A	100.00

3.6 Crashes by month

Crashes with animals (based on "animal type A" being filled out), were relatively frequent in May and June, and especially in the fall (October and November) (Figure 4). Non-animal crashes were more consistently distributed throughout the year (Figure 4). Deer crashes had two distinct peaks, one in May-June, and another in October-November (Figure 5). The spring peak is likely associated with the dissolving of winter groups and migration from winter to summer habitat (Bíl et al., 2023). The latter peak is associated with the rut. Bear crashes were most frequent between April and November when they are most active (Figure 5).

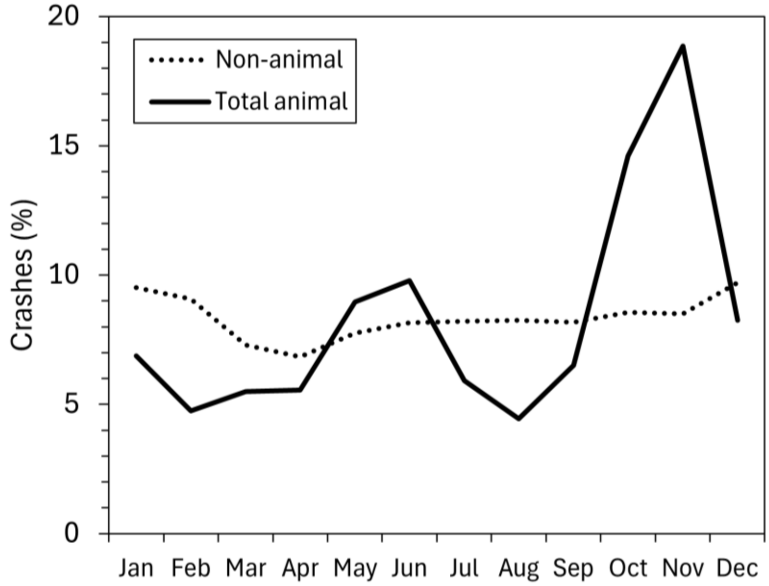

Figure 4: The percentage of crashes by month for non-animal and animal crashes (2017-2023).

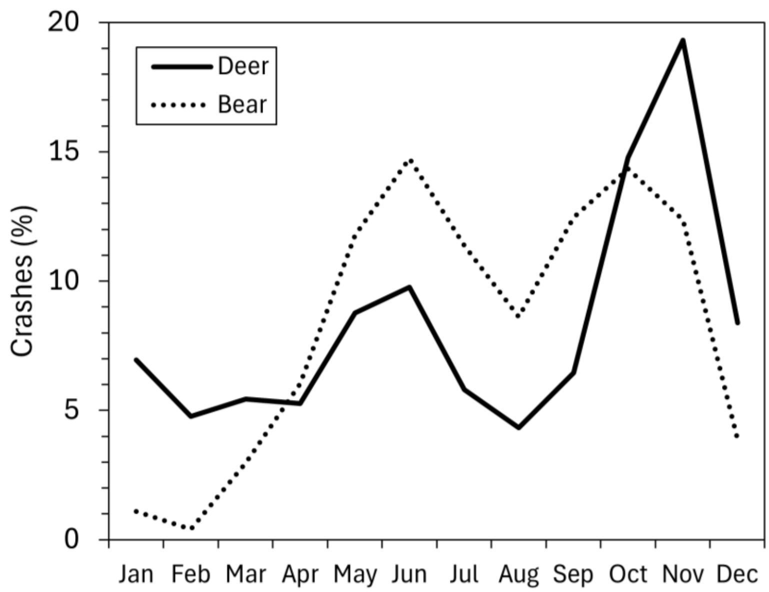

Figure 5: The percentage of crashes by month for deer and bear crashes (2017-2023).

3.7 Crashes by time of day

Non-animal crashes were most frequent during the day (6 am - 6 pm) whereas animal crashes peaked around dawn (4 am - 7 am) and in the evening hours (5 pm - 10 pm) (Figure 6). Because deer crashes formed 96.09% of all animal crashes, deer crashes followed a nearly identical pattern as animal crashes (Figure 7). However, bear crashes were most frequent in the evening (7 pm - 11 pm). Interestingly, a peak in bear crashes around dawn was absent (Figure 7).

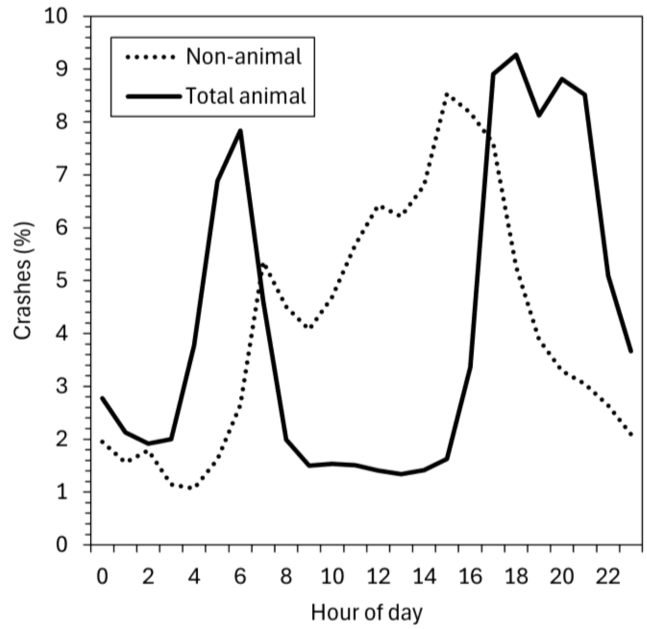

Figure 6: The percentage of crashes by hour of day for non-animal and animal crashes (2017-2023).

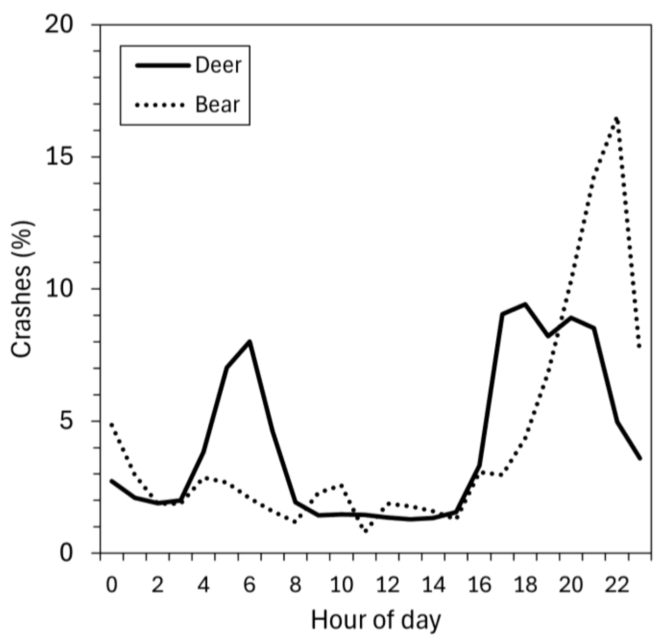

Figure 7: The percentage of crashes by hour of day for deer and bear crashes (2017-2023).

3.8 Crashes by driver's age

Non-animal crashes were most frequent for young drivers (peak at 17-18 years) (Figure 8). Beyond 18 years, the number of non-animal crashes declined until drivers reached their early 40s. The number of non-animal crashes then stabilized until the drivers reached their early 60s. Higher ages had further reduced non-animal crashes, presumably because of reduced driving activity. In contrast, for animal crashes, drivers do not appear to benefit from maturing and gaining driving experience. The number of crashes is relatively consistent for young and middle-aged drivers and only declined when drivers reached their early 60s (Figure 8). Higher ages may not only benefit from general reduced driving activity, but they may disproportionally benefit by reduced driving during the early morning and evening when animal crashes are most frequent. Deer and bear crashes followed a similar pattern (Figure 9).

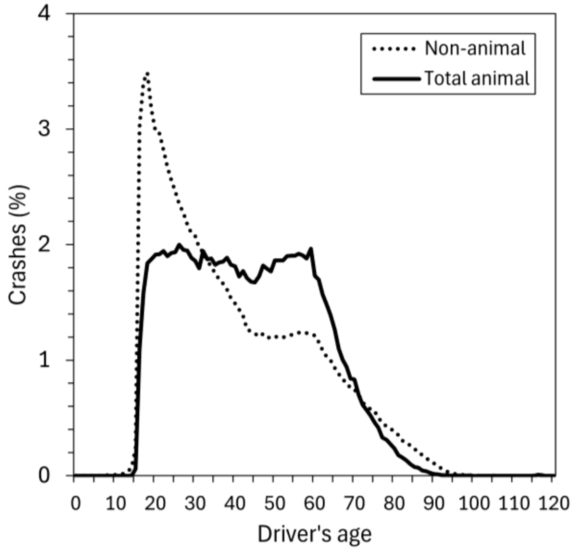

Figure 8: The percentage of crashes by driver's age for non-animal and animal crashes (2017-2023).

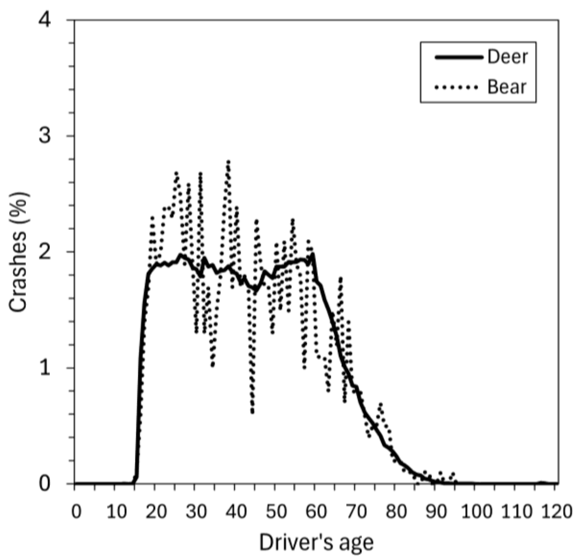

Figure 9: The percentage of crashes by driver's age for deer and bear crashes (2017-2023).

3.9 Crashes by overall severity for humans

On average, non-animal crashes were more severe for humans (23.15% human injuries, 0.46% human fatalities) than animal crashes (4.20% human injuries, 0.06% human fatalities) (Figure 10). On average, bear crashes (8.51% human injuries, 0.10% human fatalities) were more severe for humans than deer crashes (3.90% human injuries, 0.05% human fatalities) (Figure 11).

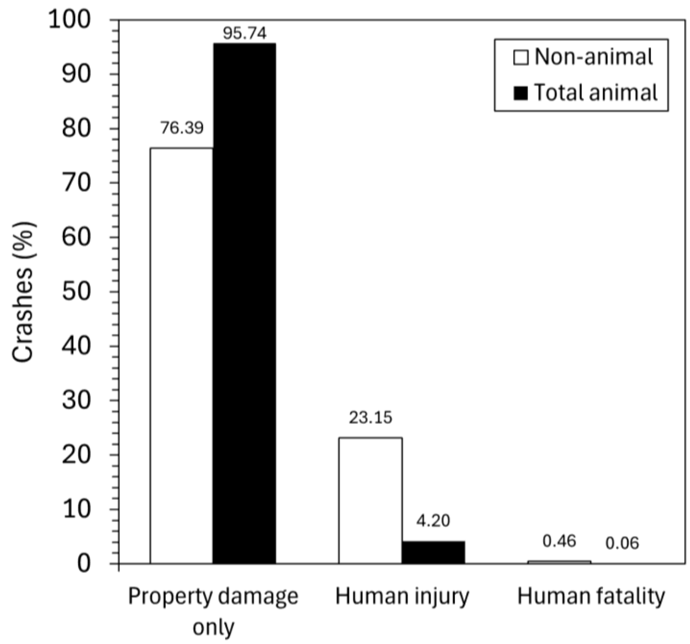

Figure 10: The percentage of crashes by overall severity of the crash for non-animal and animal crashes (2017-2023).

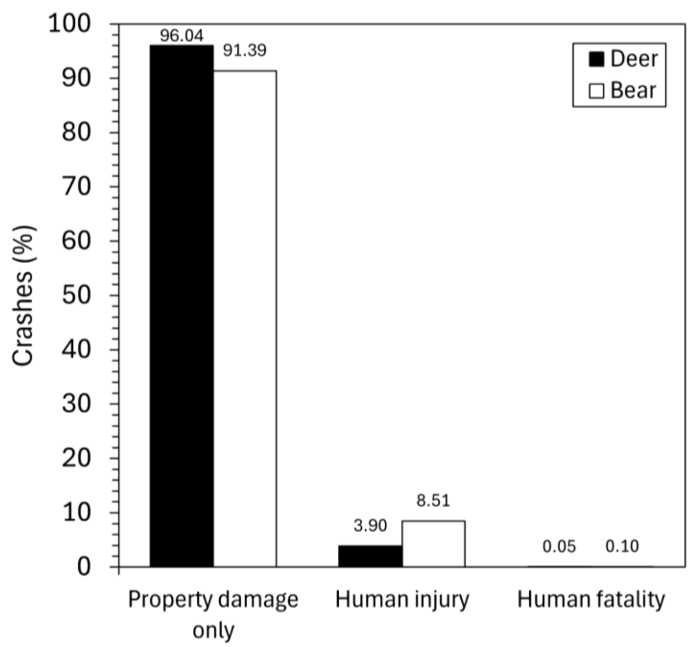

Figure 11: The percentage of crashes by overall severity of the crash for deer and bear crashes (2017-2023).

3.10 Crashes by the most severe injury to a human

On average, non-animal crashes resulted in more severe injuries to a human than animal crashes (Figure 12). Bear crashes resulted in more severe injuries to a human than deer crashes (Figure 13).

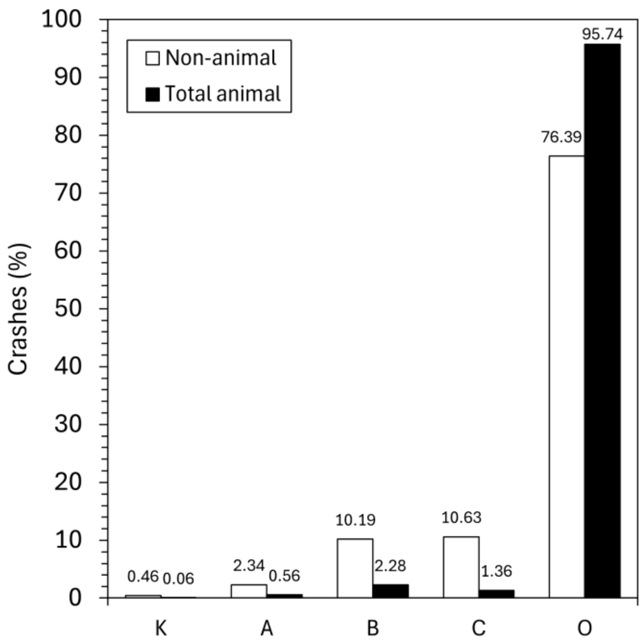

Figure 12: The percentage of crashes by the most severe injury to a human for non-animal and animal crashes (2017-2023). K=fatal injury, A=suspected serious injury, B=suspected minor injury, C=possible injury, O=no apparent injury.

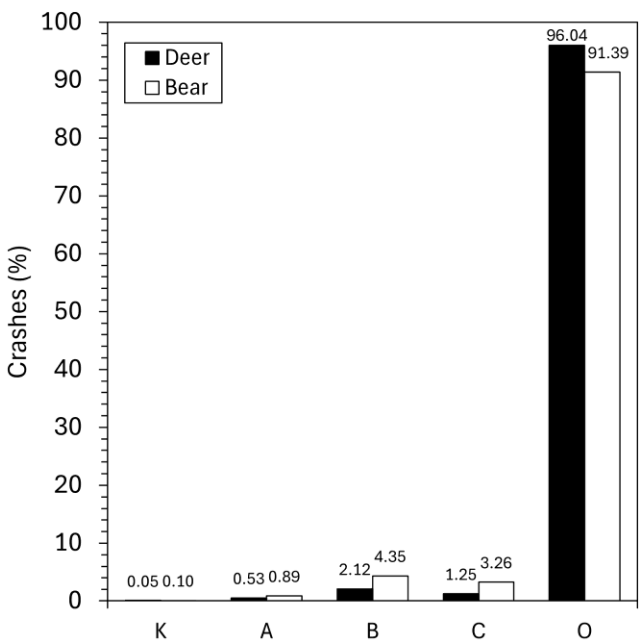

Figure 13: The percentage of crashes by the most severe injury to a human for deer and bear crashes (2017-2023). K=fatal injury, A=suspected serious injury, B=suspected minor injury, C=possible injury, O=no apparent injury.

3.11 Crashes by posted speed limit

Animal crashes were most frequent on roads with a posted speed limit of 55 MPH whereas non-animal crashes were frequent across a wider range of posted speed limits (25-55 MPH) (Figure 14). Interestingly deer crashes were slightly more frequent on 45-55 MPH roads than bear crashes and bear crashes were slightly more frequent on 25-30 MPH and 65-70 MPH roads (Figure 15).

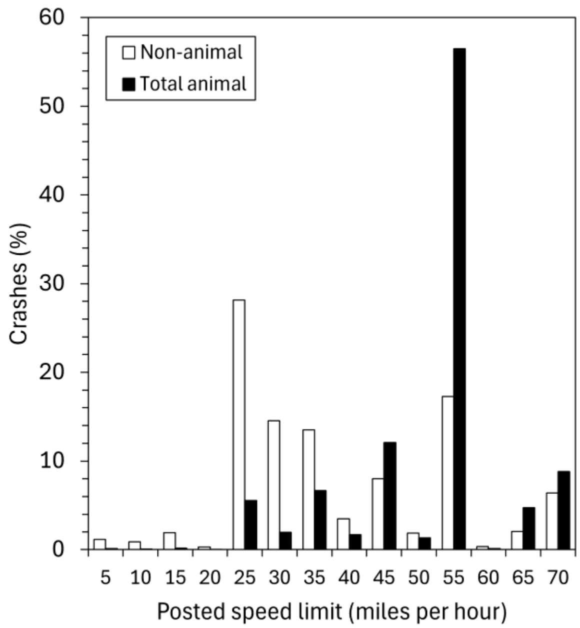

Figure 14: The percentage of crashes by posted speed limit for non-animal and animal crashes (2017-2023).

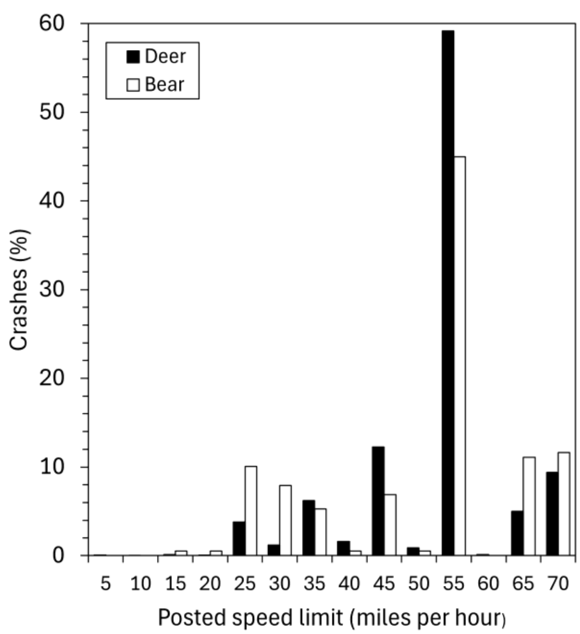

Figure 15: The percentage of crashes by posted speed limit for deer and bear crashes (2017-2023).

3.12 Crashes by highway type

Compared to non-animal crashes, animal crashes were more frequent on county highways, and less frequent on interstates (Figure 16). Interestingly bear crashes were less common on county roads than deer crashes, but more common on US Highways (Figure 17).

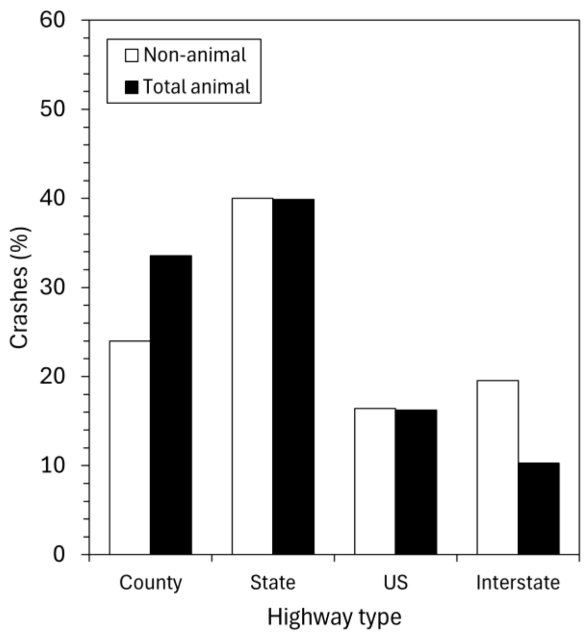

Figure 16: The percentage of crashes by highway type for non-animal and animal crashes (2017-2023).

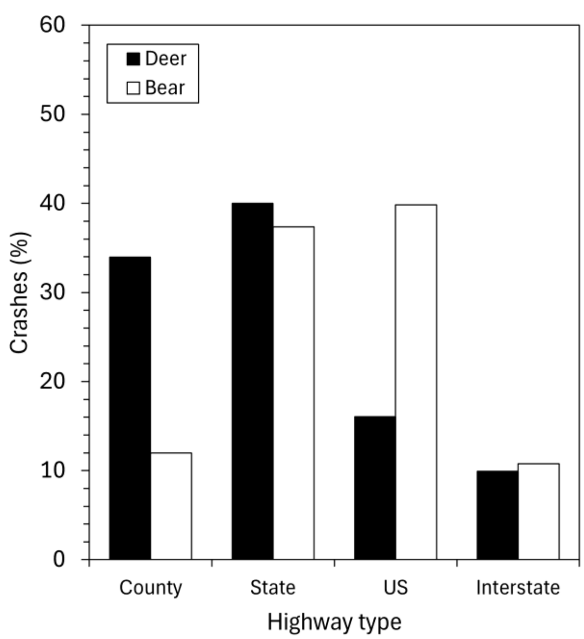

Figure 17: The percentage of crashes by highway type for deer and bear crashes (2017-2023).

4 Identification and prioritization of road sections

4.1 Introduction

This chapter focuses on identifying and prioritizing road sections along state-maintained highways in Wisconsin that have a relatively high concentration of wildlife-vehicle crashes. We could not identify road sections with a relatively high concentration of wild large mammal carcasses as the carcass data were summarized by county and the records could not be linked to individual state-maintained highways and highway segments. However, we did conduct analyses for carcass data on a county level (see Chapter 4). All spatial data were projected using the NAD 1927 Wisconsin TM coordinate system, with meters as the unit of measurement. All spatial analyses were conducted using ArcGIS Pro 3.3.2.

4.2 Methods

- Roads included: All state-maintained (or "on-system") roads in Wisconsin including Interstates, US Highways, and numbered Wisconsin Highways. Thus, roads maintained by counties and cities were excluded from the data analyses in this chapter.
- Species: Only records that related to wild animal species were included. Records that did not relate to a collision with an animal were removed. Records that related to domesticated animal species were also removed.
- Species size: For the crash database, we only evaluated "animal type A" and only records that related to "deer" or "bear" were included.
- Maximum distance from road: Collision records within 25 meters (m) of state-maintained roads were included, while those beyond 25 m were excluded from the analysis. In cases where locations could be projected onto more than one road, we verified the projections and removed duplicates.

The road network was preprocessed by merging road segments based on WisDOT's unique "HWY_DIR" to create continuous, singular road sections. For analysis purposes, divided highways and parallel road segments were consolidated by removing duplicate routes, ensuring that each road was represented as a singular linear feature. These processed road sections were then systematically divided into road segments of 0.1 mile (160.9 meters) in length. Wildlife-vehicle crash data within 25 m from a state-maintained road in Wisconsin were spatially joined to the nearest road analysis unit. We conducted two different types of spatial analyses to identify and prioritize road sections with the highest number of wildlife-vehicle crashes which are discussed in the following sections.

4.2.1 Kernel Density Estimation

The Kernel Density Estimation (KDE) analysis was used to assess point features of the crash locations. A bandwidth of 0.5 miles (804.67 m) was applied, meaning that crashes within 0.5 miles of each tenth-of-a-mile reference point influenced the hotspot analysis. This is consistent with the spatial scale at which mitigation measures (e.g., wildlife fences and crossing structures) need to be implemented, typically over several miles of road (Huijser et al., 2016). The search radius is also aligned with similar studies (Gomes et al., 2009).

The analysis produces a density surface where each cell's size is 161 m by 161 m and its value represents the estimated density of collisions per square mile. The resulting heat map was divided into five percentage-based categories (<5%, 5–<25%, 25–<50%, 50–<75%, and 75–100%), identifying road sections with the highest densities (i.e., <5%) of crashes and carcasses. This is a descriptive method that always indicates where the highest concentrations of incidents occur. The KDE analyses were conducted using the Spatial Analyst extension in ArcGIS Pro 3.3.2.

4.2.2 Getis-Ord Gi*

The Getis-Ord Gi* (GOG) analysis used the Getis-Ord Gi* statistic to identify statistically significant spatial clusters (hotspots and cold spots) of crashes. Unlike the KDE, which is purely descriptive, this analysis identifies road segments where the concentration of crashes significantly deviates from a random distribution. A fixed distance band of 0.5 miles was applied, consistent with the KDE analysis. No standardization of spatial weights was applied; all wildlife species (i.e., “deer” and “bear”) were considered equal in contributing to the collision events. This analysis was conducted using the Hotspot Analysis (Getis-Ord Gi*) tool within the Spatial Statistics toolbox in ArcGIS Pro 3.3.2.

4.3 Results

4.3.1 Kernell Density Estimation (KDE) analyses

The KDE hotspot maps for crashes are depicted in Figure 18 and Figure 19. The eastern ridges and lowlands are dominated by agriculture, especially along the outskirts of human population centers (e.g., Sheboygan-Milwaukee-Kenosha, Madison area, Green Bay - Appleton) and they have the highest concentration of large wild mammal crashes. Other high-density areas are in the agricultural areas around La Crosse, Eau Claire, and River Falls in the western uplands, and where the agricultural areas transition into more forested areas around Wausau-Merril, Wittenberg-Antigo, Woodruff-Minocqua, and Ashland in the northern highlands.

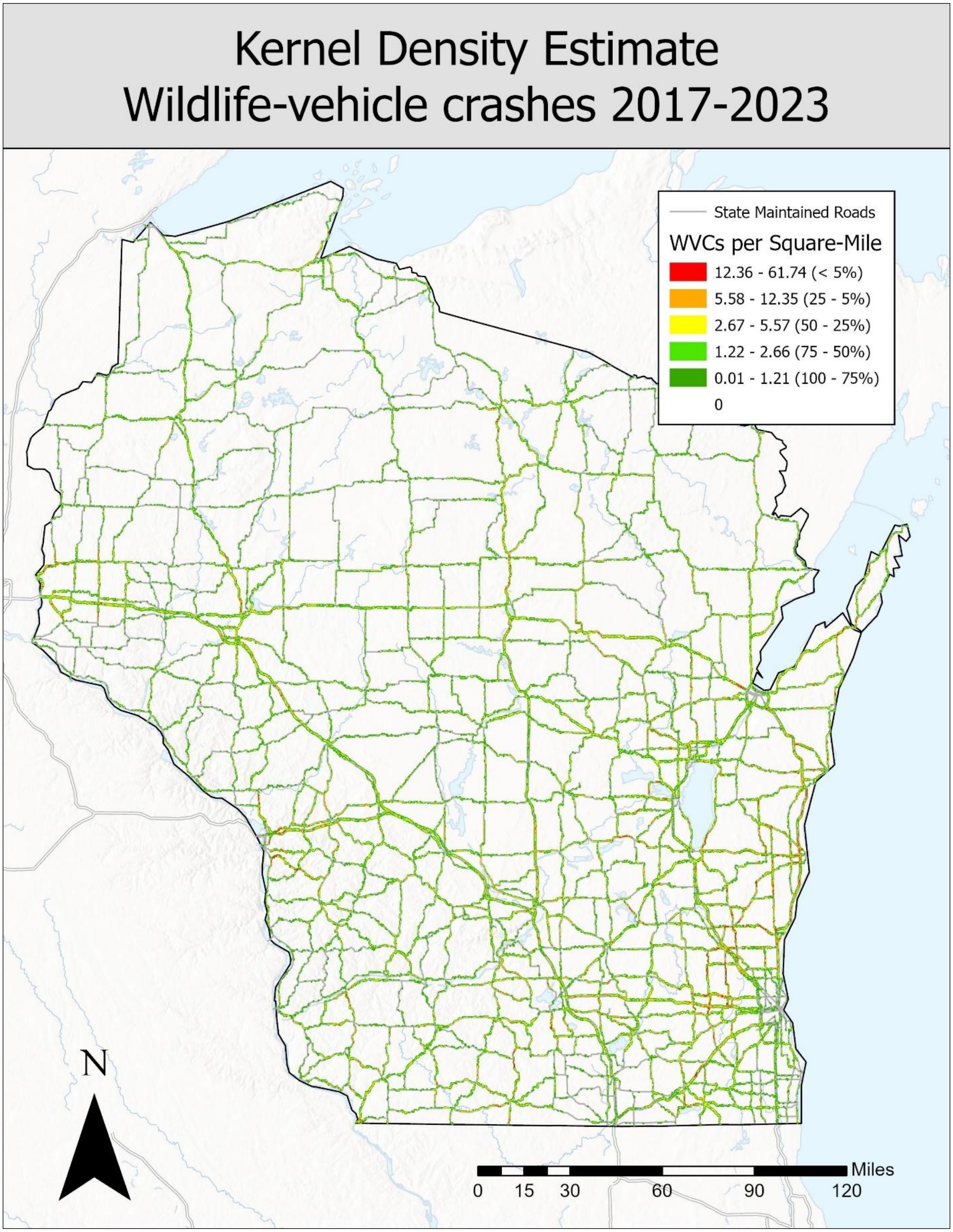

Figure 18: Kernel density hotspot map using percentiles for wildlife-vehicle crashes in Wisconsin (2017–2023).

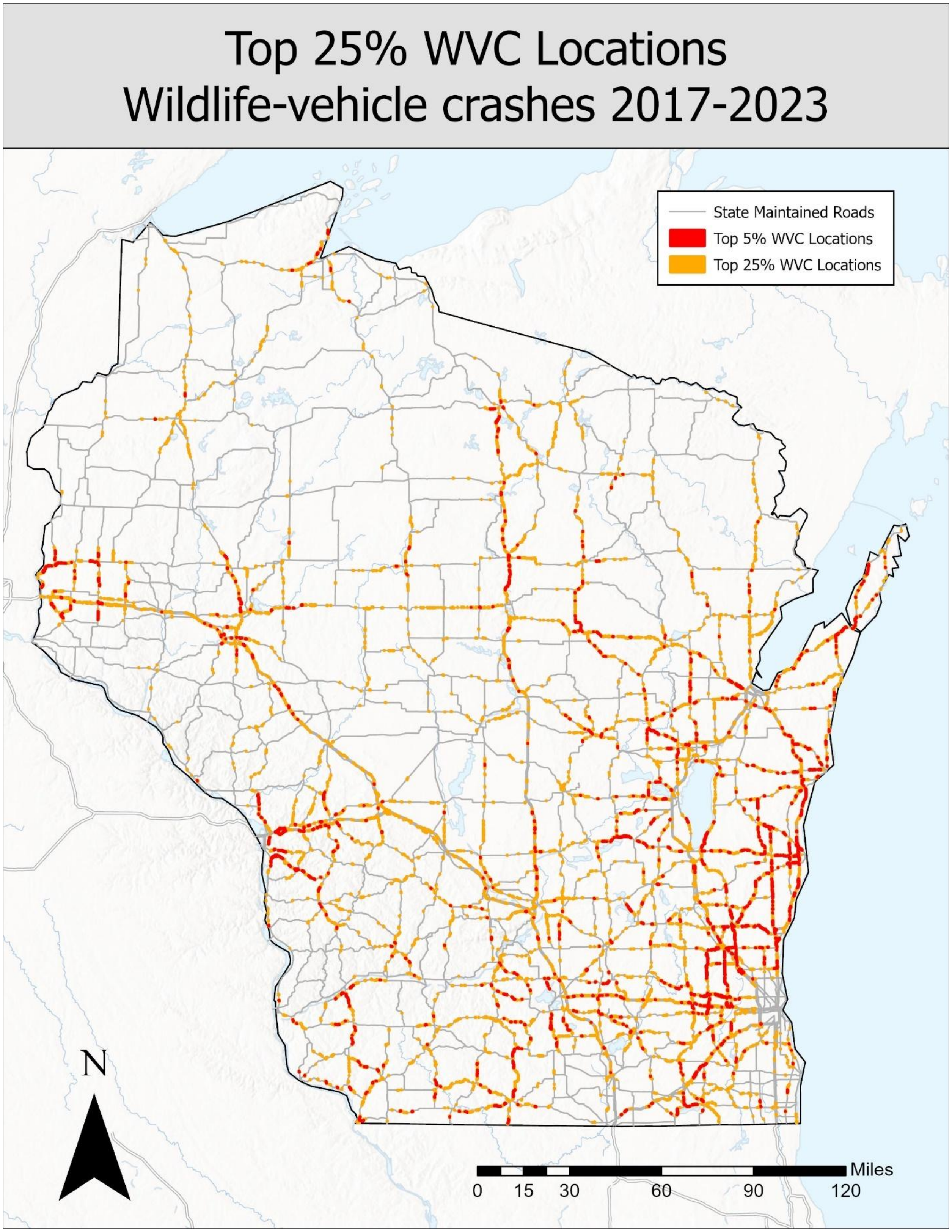

Figure 19: Top 5% and 25% Kernel density hotspot map using percentiles for wildlife-vehicle crashes in Wisconsin (2017–2023).

4.3.2 Getis-Ord Gi* analyses

The Getis-Ord Gi* hotspot maps for crashes are depicted in Figure 20.

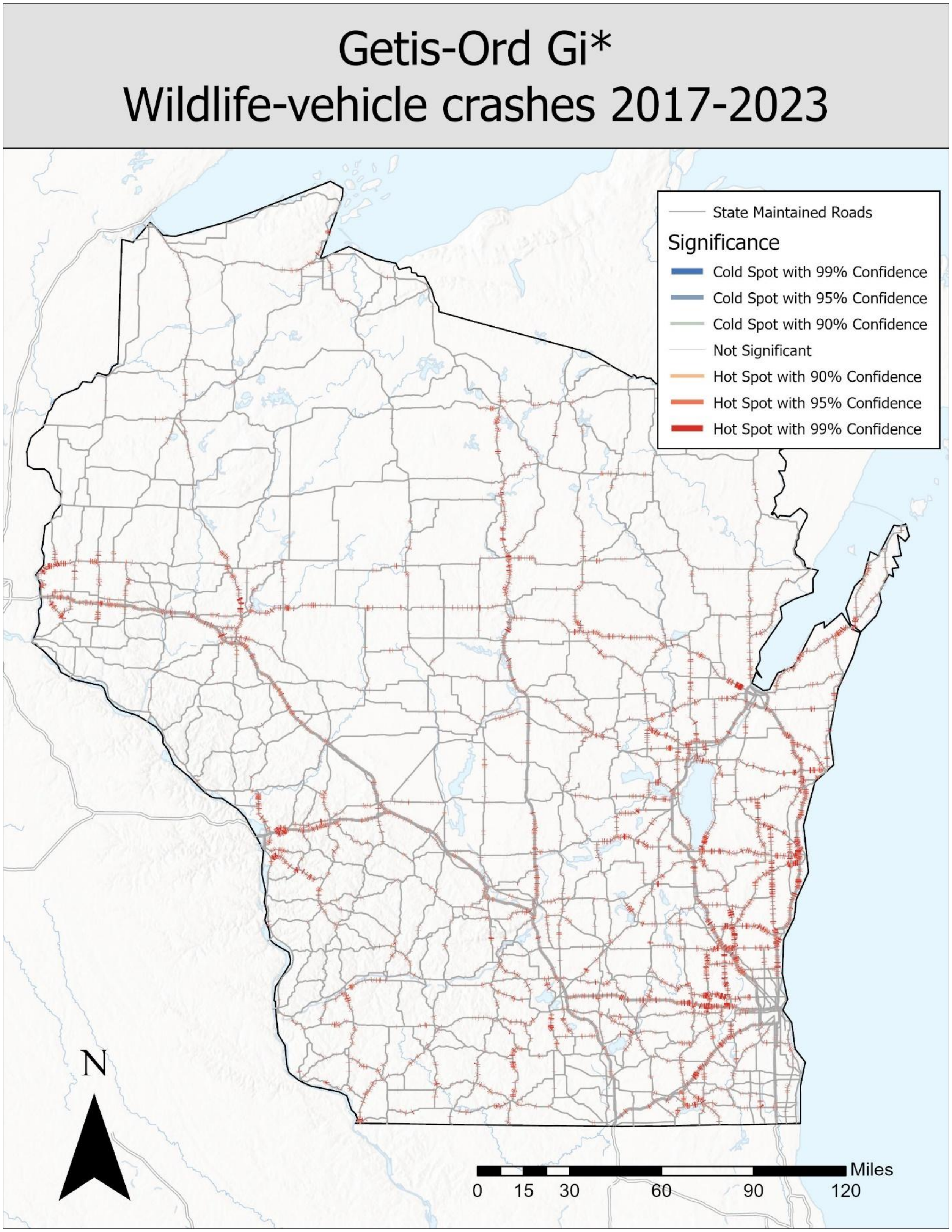

Figure 20: Significant hotspots (red) and cold spots (blue, but none were present) based on Getis-Ord Gi analysis for wildlife-vehicle crashes in Wisconsin (2017–2023).*

4.4 Discussion

There is great similarity between the general areas with large wild mammal hotspots (i.e., white-tailed deer and black bear) identified through the Kernel Density Estimate analysis and the Getis-Ord Gi* analyses. High-density areas of crashes generally had concentrations of crashes that were significantly higher than expected should the crashes have been randomly distributed. In other words, these road sections do not only have the highest concentration of crashes, but the identification of these road sections is not based on coincidence. These road sections have a concentration of crashes that is beyond random.

From a human safety perspective, it would make sense to explore potential mitigation options first along the identified road sections. Note that from the perspective of biological conservation, the reduction of direct road mortality for rare or threatened species would be of higher priority than white-tailed deer or black bear (Huijser et al., 2022b). This means that other road sections than the ones identified in this report may also require mitigation measures, but from a different perspective. In addition, from the perspective of biological conservation, reducing the barrier effect of roads and traffic may be required in yet other road sections (Huijser et al., 2022b).

5 Deer carcass removal data and deer crash data by county

5.1 Introduction

We acquired deer carcass removal data from 2018 through 2023 from the Wisconsin Department of Transportation. Carcass removal data are collected independently from crash data. In general, after a deer, black bear or turkey, has been hit, the driver can claim the carcass by notifying the Wisconsin Department of Natural Resources and completing a registration process (Wisconsin DNR, 2024a). If the driver or another passerby does not claim the carcass, and if the carcass is on the active traveled portion of the road where it is an urgent safety hazard to others traveling the road, drivers are asked to report the carcass by calling 911. Law enforcement personnel can then remove the carcass from the travel lanes. If the carcass is on the shoulder or another location where it is not an immediate safety concern to other road users, drivers who have hit a large animal are also asked to report the incident to have the carcass removed, but the removal will not be immediate. The entity to whom such carcasses should be reported depends on the road type (Wisconsin DNR, 2024b, WisDOT, 2025):

- Interstates, US highways, and state highways: To the local county sheriff department, using their non-emergency phone number.
- County roads: To the county.
- Local roads: To the municipality.

Law enforcement, county personnel, municipality personnel, or a contractor may all remove the carcass. If the carcass is in a rural area at least ¼ mile away from a residence or business, a carcass may be disposed of on-site within the right-of-way, if the carcass is not in direct view of the road, the disposal does not relate to multiple carcasses in the same location, and it is not in a ditch or mowed area (Wisconsin DNR, 2024c; WisDOT, 2025). If the carcass cannot be disposed of on-site in the right-of-way, the carcass may be transported to a landfill, incinerator, or chemical digester, or a rendering plant in counties not affected by Chronic Wasting Disease (Wisconsin DNR, 2024c; WisDOT, 2025). Carcass removal can be a substantial cost in terms of labor, labor related injuries, and in some cases also carcass disposal fees.

5.2 Search and reporting characteristics

Not all road sections of state-maintained routes are consistently inspected for large wild mammal carcasses. In Wisconsin, the reporting effort depends on the reporting by the driver involved in a crash, a passerby, or a contractor to the WisDOT. Once a carcass has been reported it should be removed, though this may not always be the case. Only the carcasses that are removed end up in the carcass database. In addition, the deer carcass data (i.e., white-tailed deer (*Odocoileus virginianus*)) are only available as the total number of removed deer carcasses per county per month per year. There is no link between individual carcass records, a specific highway, or a specific location on that highway. The deer carcass removal data only relates to state-maintained roads; carcasses from other roads are not included (Personal communication Jen Gibson, Wisconsin Department of Transportation). This means that it is not possible to use deer carcass removal data for spatial analyses, at least not on the level of a highway or a segment of a highway.

5.3 Deer carcasses by year

The average number of removed deer carcasses per year was 13,263.83 (SD=1,420.48) (Figure 21).

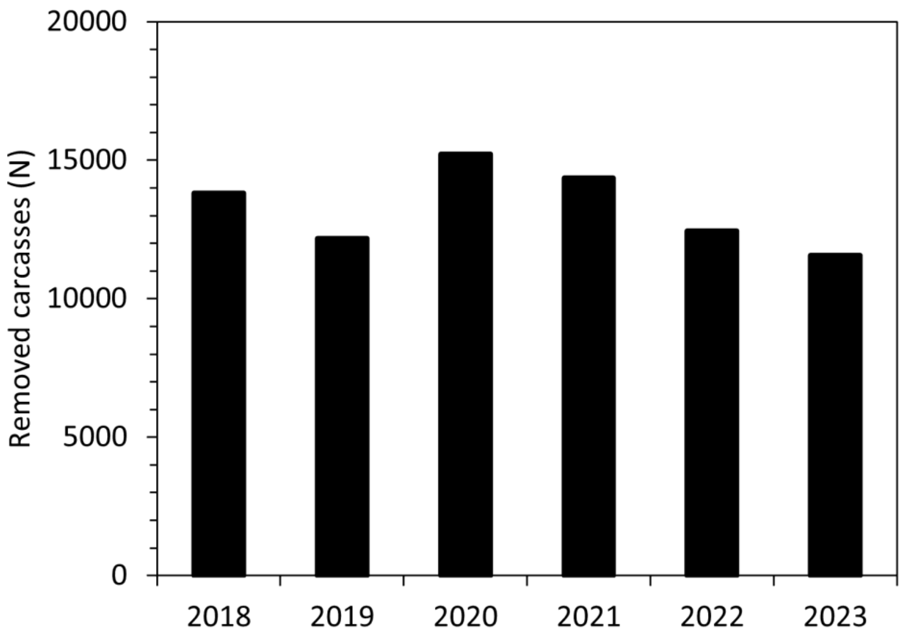

Figure 21: The number of removed carcasses per year in Wisconsin (2018–2023).

5.4 Deer carcasses by month

The number of reported deer carcasses per month had two peaks: one from March through June, and a second peak in October-November (Figure 22). Interestingly, the spring peak for carcasses (March-June) is longer than the one based on crash data (May-June) (see Crashes by month).

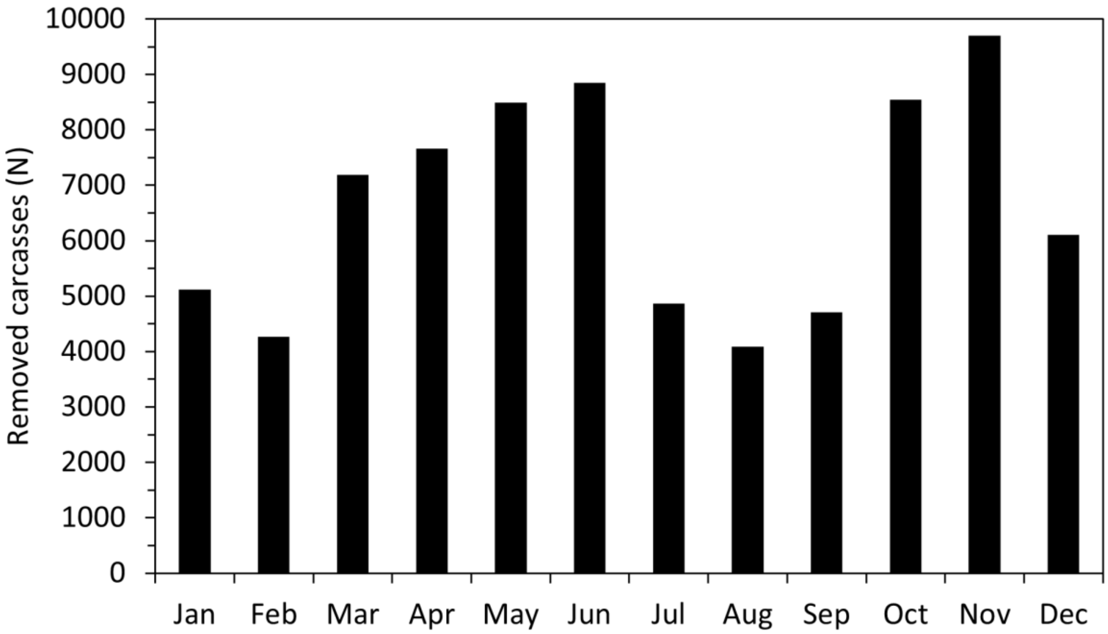

Figure 22: The number of removed deer carcasses per month in Wisconsin (2018–2023).

5.5 Deer carcasses by county

The deer carcass removal data only relate to state-maintained roads in Wisconsin. We summarized the number of removed deer carcasses for each county (Figure 23). Note that there were no deer carcass data reported from Menominee county. The reason is that this county entirely overlaps with the Menominee Indian Reservation and that the deer carcasses on the Menominee Indian Reservation are not reported to WisDOT. While there are other Native American Reservations in Wisconsin besides the Menominee Indian Reservation, other reservations do not overlap with an entire county. This means that other counties that have a Native American Reservation within their boundaries may have suppressed deer removal carcass numbers, but the carcass numbers in those counties are still higher than zero. In general, the total deer removal carcass numbers are highest in the counties in the east and southeast, and some counties in the north (Figure 23).

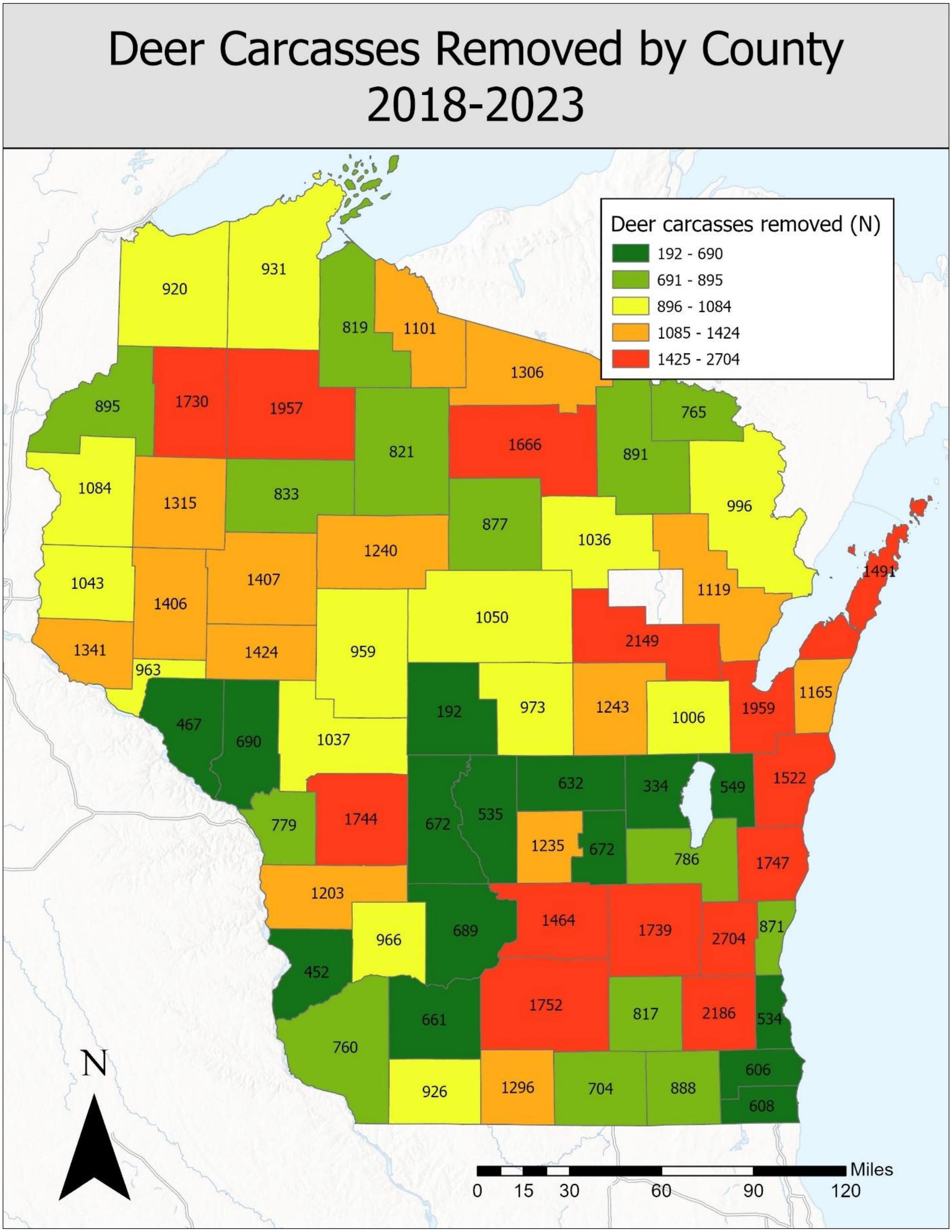

Figure 23: The number of deer carcasses removed in each county (2018-2023).

Since the length of these WisDOT maintained highways is known for each county, we calculated the density of deer carcasses removed per mile for each county for all years combined (2018-2023) (Figure 24). We calculated the density of deer carcasses removed in each county by dividing the number of deer carcasses removed (all along state-maintained routes) in a county by the length of state-maintained routes in each county (Figure 24). This allowed for a direct comparison between counties (as opposed to raw numbers for each county which are not corrected for the road length in each county). Central eastern counties tended to have the highest density of deer carcasses removed supplemented by other counties spread out in the north, central west and south (Figure 24).

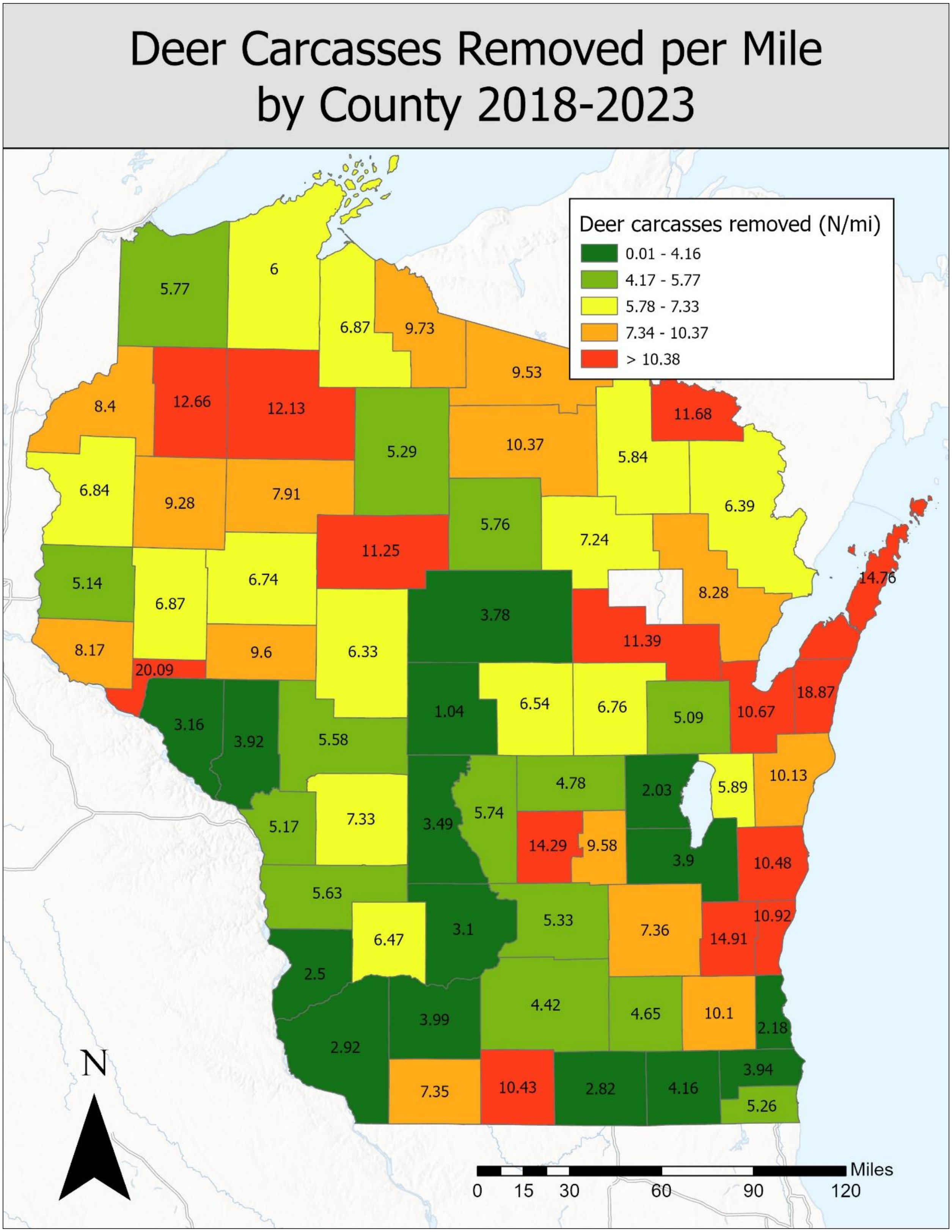

Figure 24: The density of deer carcasses removed (corrected for the highway length) in each county (2018–2023).

5.6 Deer carcass removal data compared to deer crash data by county

Deer crash and deer carcass removal data are independently collected. Therefore, we explored potential similarities and differences between these two data sources. Since deer carcass removal data were only available on a county level, we also summarized the deer crash data on a county level, and we restricted the crash data to the same years that deer carcass data were available for (2018-2023) and along the same roads (i.e., the state-maintained roads). Crash data along other roads were excluded (see Crash data sources for details of the crash data selection). In general, the total deer crash numbers were highest in the counties in the east and southeast of Wisconsin (Figure 25), a pattern similar to the deer carcass removal data (Figure 23).

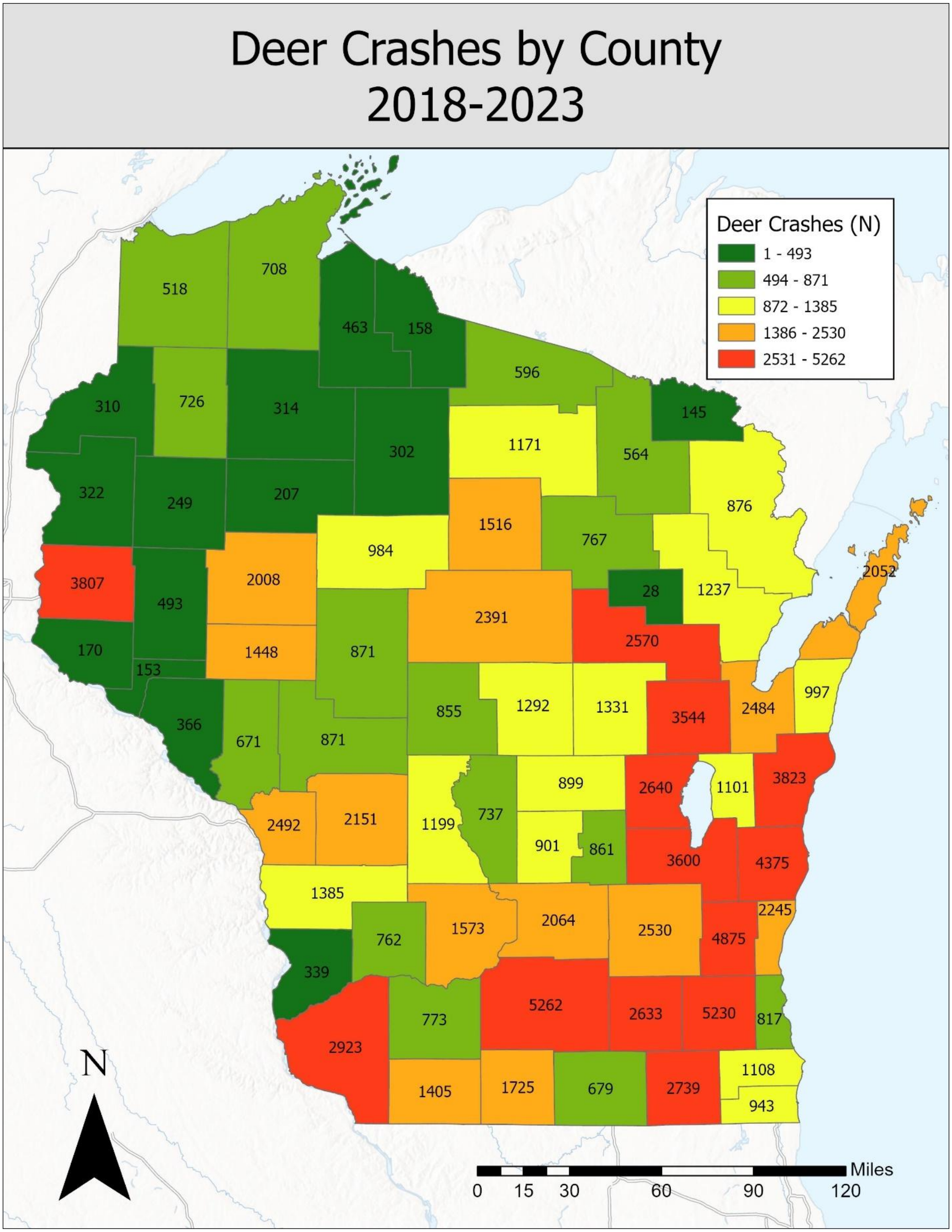

Figure 25: Total number of deer crashes (2018-2023) in each county.

We calculated the density of deer crashes in each county by dividing the number of deer crashes (all along state-maintained routes) in a county by the length of the state-maintained routes in each county (Figure 26). This allowed for a direct comparison between counties (as opposed to raw numbers that are not corrected for the road length in each county). Central eastern counties tended to have the highest density of deer crashes supplemented by other counties spread out in the central west and south (Figure 26).

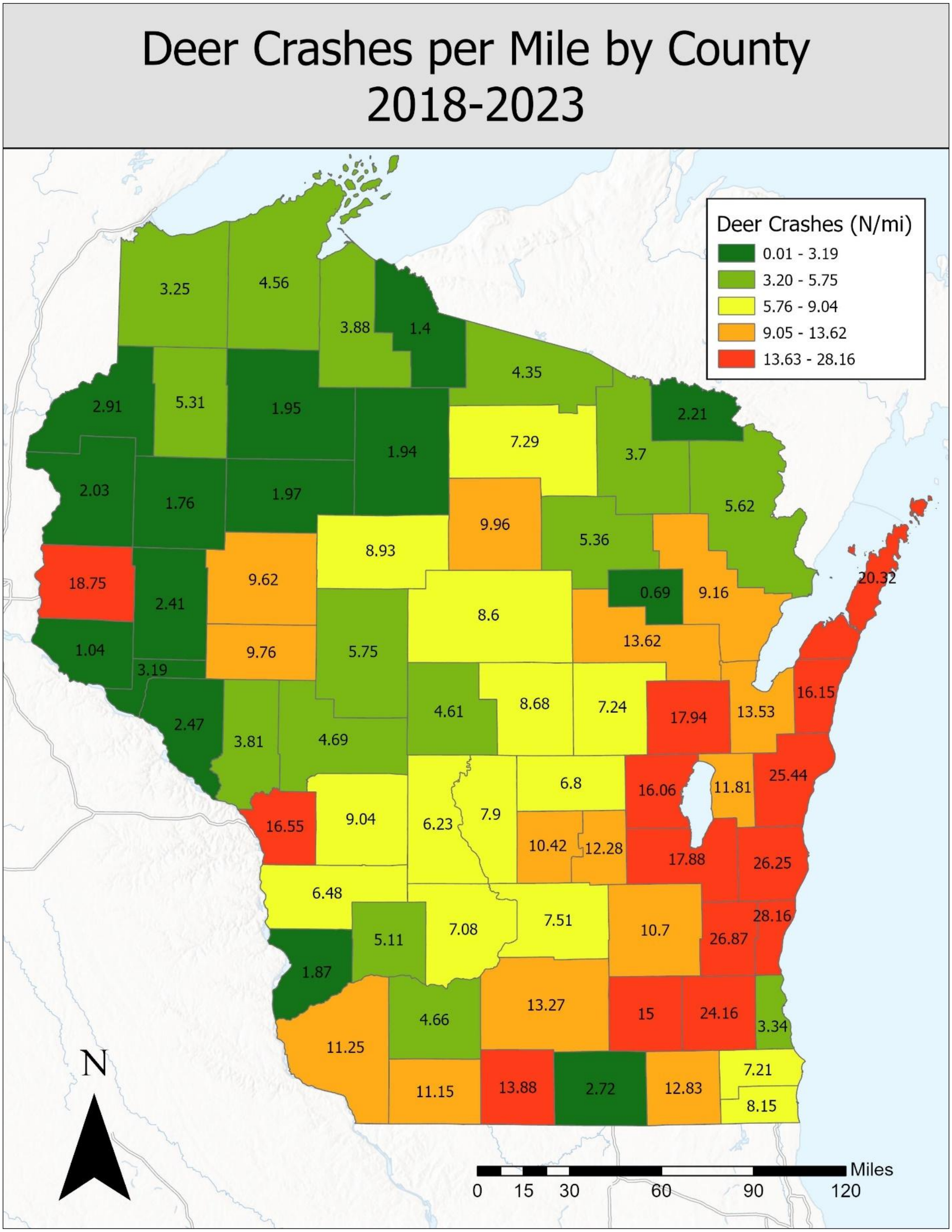

Figure 26: The density of deer crashes (corrected for the highway length) in each county in Wisconsin (2018–2023).

We then compared the deer crash and deer carcass removal numbers by calculating the ratio of deer crash and deer carcass removal numbers (number of deer crashes / number of deer carcasses removed) in each county (Figure 27). Ratios greater than one indicate there are more reported crashes than carcasses, whereas ratios less than one indicate the opposite. The highest crash-to-carcass ratio was in Winnebago county (7.9) and the lowest was 0.13 in Pierce County (Figure 27). Counties with the highest crash-to-carcass ratios are spread out throughout the southern and south-eastern counties. Counties with the lowest crash-to-carcass ratios are generally in the north-northwest counties (Figure 27). The average crash-to-carcass ratio across Wisconsin is 1.49, illustrating that there are generally 49% more reported deer crashes than deer carcasses. This implies that many deer carcasses go unreported (and not removed) compared to deer crashes. In many other states or regions, it is the opposite; large wild mammal crash data typically represent only a small portion (14-50%) of the carcass data (Tardif and Associates Inc., 2003; Riley & Marcoux, 2006; Donaldson & Lafon, 2008), though there are exceptions (Huijser & Begley, 2019). It is important to note that carcass removal data are also incomplete; animals that are not clearly visible from the road may not be reported or removed, and injured animals that may make it to outside of the right-of-way are also unlikely to be reported and removed. Studies have demonstrated that carcass counts often underestimate the number of large mammals hit by vehicles; correction factors of 2.8 (Lee et al., 2021) and nearly 8.0 (Fairbank et al., 2024) have been reported in other areas.

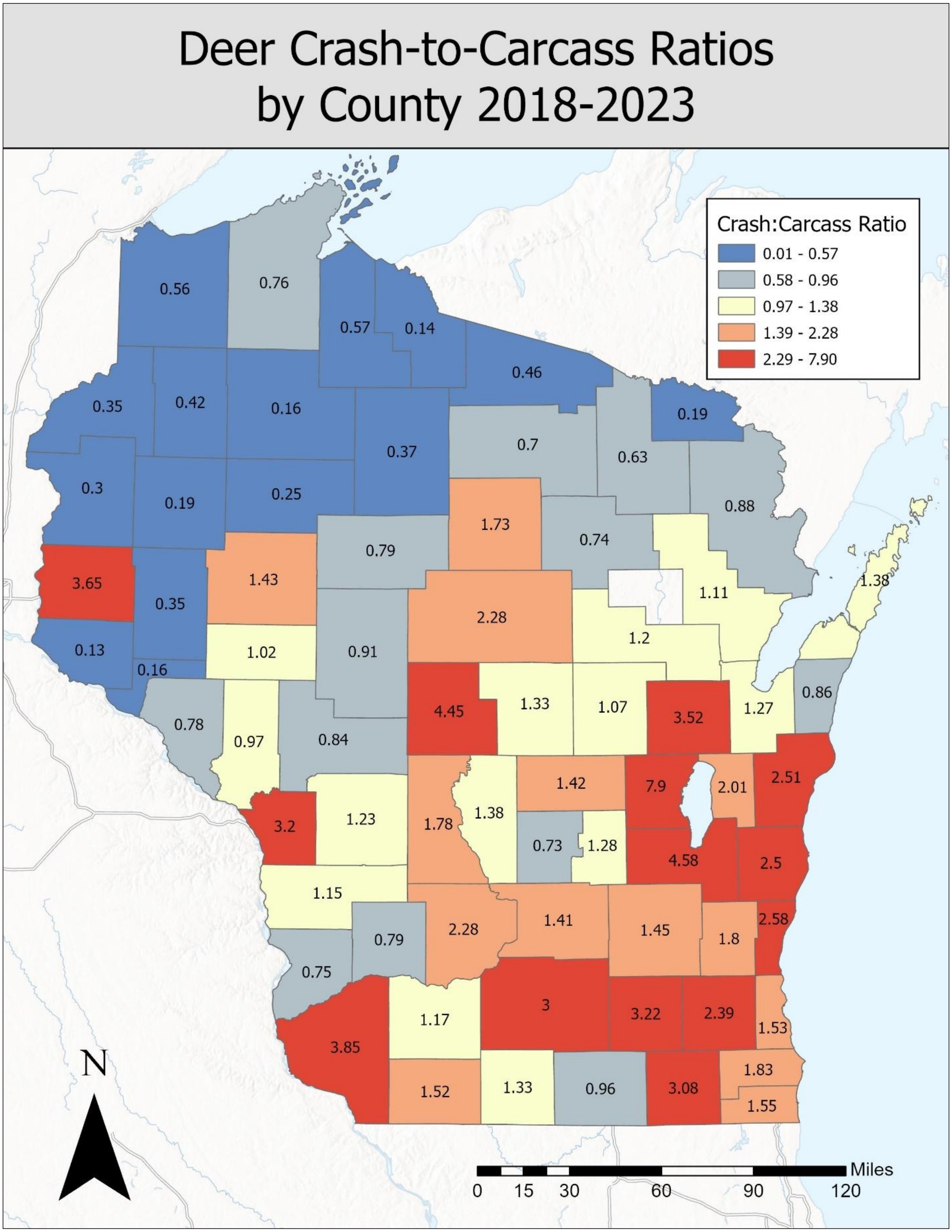

Figure 27: Ratio of deer crash and deer carcass removal numbers in each county (2018-2023).

6 Cost-benefit analysis

6.1 Introduction

There are costs associated with the implementation of mitigation measures aimed at reducing collisions with large wild mammals. However, there are also costs associated with not implementing mitigation measures allowing collisions to continue to occur. If the benefits of mitigation measures are greater than their costs, implementation of mitigation measures is economically attractive. While the outcome of cost-benefit analyses can be a useful tool in the decision process, it should not be used as a litmus test for the implementation of mitigation measures; models are only partially capturing what should be considered in the decision process (Huijser et al., 2009). For example, the model we apply for this project, is based on Huijser et al. (2009; 2022a), and it is mostly based on parameters and values associated with vehicle repair costs, human safety, and the costs of material and labor for mitigation measures. Even though there is some representation of economic values based on conservation (Huijser et al., 2022a), the economic parameters and values associated with conservation are likely still underrepresented, and the costs associated with different parameters can change over time at different rates (Huijser et al., 2022a).

While crash data were spatially explicit, the carcass data were not. This means we could only use the crash data for spatial analyses on a highway and a highway segment level.

6.2 Parameters and species categories

We based the cost-benefit analysis for crash data on Huijser et al. (2009, 2022). The costs associated with large wild mammal-vehicle collisions included the following types of parameters: vehicle repair costs, costs associated with human injuries and human fatalities, and passive use values. Passive use values, also known as non-use values, are the values individual people place on the existence of a given animal species or population as well as the bequest value of knowing that future generations will also benefit from preserving the species (Duffield & Neher 2019) (Table 2).

While there are differences in costs associated with different large wild animal species, the crash data related only to “deer” and “bear”. For the cost-benefit analysis and based on similarity in body size and body weight between white-tailed deer and black bear, all reported wild mammal-vehicle crashes were categorized as “deer”.

Table 2: The species categories and costs of a collision used for the cost-benefit analysis and the species as noted in the carcass removal data.

Species categories for the purpose of the cost-benefit analysis	Species as noted in the carcass removal data	Costs (in 2020 US$) (Huijser et al., 2022a)
"Deer"	"deer" (i.e., white-tailed deer), "bear" (i.e., black bear)	$19,089

6.3 Cost estimates for collisions for every tenth of a mile

The following steps were conducted in NAD 1927 Wisconsin TM coordinate system, with meters as the unit of measurement. All spatial analyses were conducted using ArcGIS Pro 3.3.2. The steps allowed us to estimate the costs associated with large wild mammal-vehicle crashes per mile per year for each 0.1-mile-long road segment. The wild large mammal crash data were limited to "animal type A" having a value of "deer" or "bear".

1. The study area's entire network of state-maintained routes was divided into 0.1-mile (161-meter) segments, with each segment containing the recorded number of reported WVC crashes (deer and bear) over a seven-year period (2017-2023).
2. Using the Generate Points Along Lines tool, a point was placed at the center of each 0.1-mile road segment to serve as a reference location for spatial aggregation.
3. Using the Buffer tool, a 0.5-mile (805 m) buffer was created around each center point. This created overlapping buffer zones, each representing the local area (up to 0.5 miles away) surrounding each road segment.
4. A Spatial Join was performed between the buffers and the road segments to sum the total number of large wild mammal crashes occurring within each buffer zone, standardizing the numbers per mile for each 0.1-mile-long segment.
5. The total large wild mammal crashes count from each buffer was then joined back to its corresponding 0.1-mile road segment, ensuring each segment contained a crash total that reflected its surrounding area (up to 0.5 miles away).
6. The total large wild mammal crash count was divided by 7 years (the dataset's time span) to derive the average number of large wild mammal crashes per year per mile for each 0.1-mile-long road segment.
7. The average annual crash count was then multiplied by the estimated cost of each deer or bear collision; $19,089 per collision (Huijser et al., 2022a). The resulting values are presented in cost per mile per year.

8. The calculated cost per mile per year was compared to economic thresholds (or break-even values) for two mitigation measure packages from Huijser et al. (2022a):
   - $40,857/mi/year: Justifies the installation of wildlife fencing and underpasses (based on the cost-benefit model).
   - $51,547/mi/year: Justifies the installation of wildlife fencing, underpasses, and overpasses (based on the cost-benefit model).

Road segments exceeding these economic thresholds were identified, mapped, and summarized to highlight areas where mitigation strategies are economically defensible, at least based on the cost-benefit model that was applied with its parameters and values for those parameters.

We only included two different combinations of mitigation measures and both include wildlife fences in combination with wildlife crossing structures. We restricted the mitigation measures to those that included both fences and wildlife crossing structures because:

- Fences are the most effective and robust measure to reduce wildlife-vehicle collisions (almost always 80-100% reduction) (Huijser et al., 2016, 2021).
- Fences alone would result in an absolute or near absolute barrier for the target species which is not ethical (Moore et al., 2021).
- Wildlife crossing structures provide safe crossing opportunities for wildlife and can increase permeability compared to an unmitigated road with a smaller footprint, allow for seasonal migration of large ungulates to continue, and can help improve population viability for select species (review in Huijser et al., 2021).

No other mitigation measures, other than fences in combination with wildlife crossing structures, can both substantially reduce wildlife-vehicle collisions and maintain or improve connectivity for wildlife (Huijser et al., 2021). There are many considerations for these cost estimates including a projected 25-year lifespan for fences, and a 75-year lifespan for crossing structures (see Huijser et al., 2009; 2022).

While the cost-benefit analysis estimated the economic thresholds for the two different mitigation packages per year per mile for each 0.1-mile-long road segment, However, the spatial scale of the mitigation measures affects their effectiveness:

- Mitigated road sections that are at least 3 miles long almost always reduce collisions with large wild mammals within the mitigated road section by 80-100% (Huijser et al., 2016). Shorter mitigated road sections are on average less effective (about 50%) and highly variable in their effectiveness depending on local circumstances (Huijser et al., 2016).
- For mitigated road sections to be effective on a larger spatial scale, we must avoid moving the collisions to adjacent road sections (Huijser & Begley, 2022). In this context, the mitigation measures may need to be implemented at road sections that are even longer than 3 miles in length. For example, it is considered good practice for the mitigation measures to cover the entire suitable habitat for the species, including an adjacent buffer zone based on the size of the home range of the target species (Huijser et al., 2022b). In practice this means that the length of the mitigated road sections should probably be many miles, potentially dozens of miles.

6.4 Results

Based on wild mammal-vehicle crashes (i.e., “deer” and “bear” crashes), the economic thresholds for two different combinations of mitigation measures were especially met or exceeded for highways in the east, south-east, south (Figure 28). A few additional highways where the economic thresholds were met or exceeded were in the central west, center, and north (Figure 28).

We identified a total of 1,920 miles of roads that exceeded the economic thresholds, 16.5% of the length of all state-maintained roads. Waukesha County has the highest total miles of mitigation thresholds reached at 113 miles, 52.41% of state-maintained roads in the county. However, Washington county was close with 112 miles, 62.26% of state-maintained roads in the county. Barron, Burnett, Florence, Iron, Menominee, Pepin, Polk, Price, Rusk, and Sawyer counties did not identify any roads that exceed the mitigation cost thresholds.

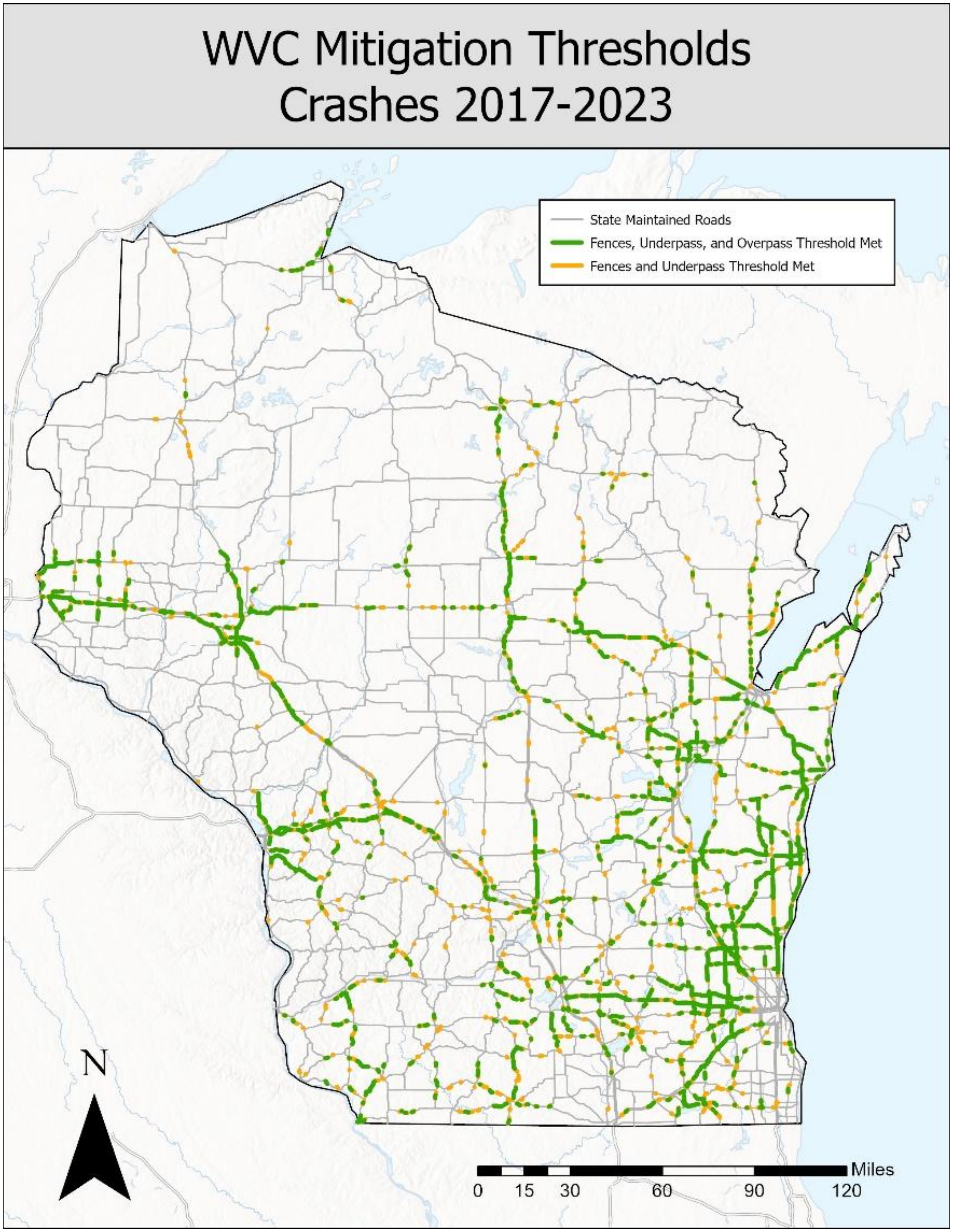

Figure 28: The road sections where the economic thresholds were met for the two different combinations of mitigation measures based on wild mammal-vehicle crash data (2017-2023).

6.5 Discussion

The cost-benefit analysis based on the large wild mammal crash data (i.e., “deer” and “bear”) identified many road sections that meet or exceed the economic thresholds for the two mitigation packages. However, the crash data are still likely to underestimate the true number of large wild animals that are hit by vehicles. Therefore, the results of the cost-benefit analysis should be regarded as conservative; it is likely that many other roads sections also meet or exceed the economic thresholds for the two mitigation packages.

7 White-tailed deer and black bear crashes in relation to traffic volume

7.1 Introduction

This chapter explores the effect of traffic volume on the number of white-tailed deer and black bear crashes on state-maintained routes in Wisconsin.

7.2 Methods

We calculated the total number of 0.1-mile road segments on the state-maintained roads within each traffic volume category, starting with 1,000 AADT increments. We then calculated the total number of observed white-tailed deer and black bear crashes on the road sections that fell into the individual traffic volume categories. We calculated the expected number of white-tailed deer and black bear crashes for each traffic volume category should the number of crashes in each category be proportional to the relative abundance of the 0.1-mile road segments within that traffic volume category. Then we calculated the ratio of observed versus expected number of white-tailed deer and black bear crashes for each traffic volume category. While the traffic volume categories initially had increments of 1,000 AADT, we combined these categories into larger categories (5,000, 10,000 or even larger AADT intervals) if the expected number of white-tailed deer crashes was lower than 100 or if the expected number of black bear crashes was lower than 10.

7.3 Results

The majority (n=41,229, 56.33%) of all white-tailed deer crashes occurred on roads with a traffic volume of 1,001-9,000 AADT (Figure 29). However, roads with a traffic volume between 5,001 and 90,000 AADT all had more white-tailed deer crashes than would have been expected if the number of white-tailed deer crashes were independent of the traffic volume (Figure 30). In other words, there is a higher-than-expected number of white-tailed deer crashes on roads with a traffic volume of 5,001-90,000 AADT, and road sections with lower and higher traffic volume have fewer white-tailed deer crashes than expected.

The majority (n=419, 51.47%) of all black bear deer crashes occurred on roads with a traffic volume of 1,001-9,000 AADT (Figure 31). However, roads with a traffic volume between 5,001 and 40,000 AADT all had more black bear crashes than would have been expected if the number of black bear crashes were independent of the traffic volume (Figure 32). In other words, there is a higher-than-expected number of black bear crashes on roads with a traffic volume of 5,001-40,000 AADT, and road sections with lower and higher traffic volume have fewer black bear crashes than expected.

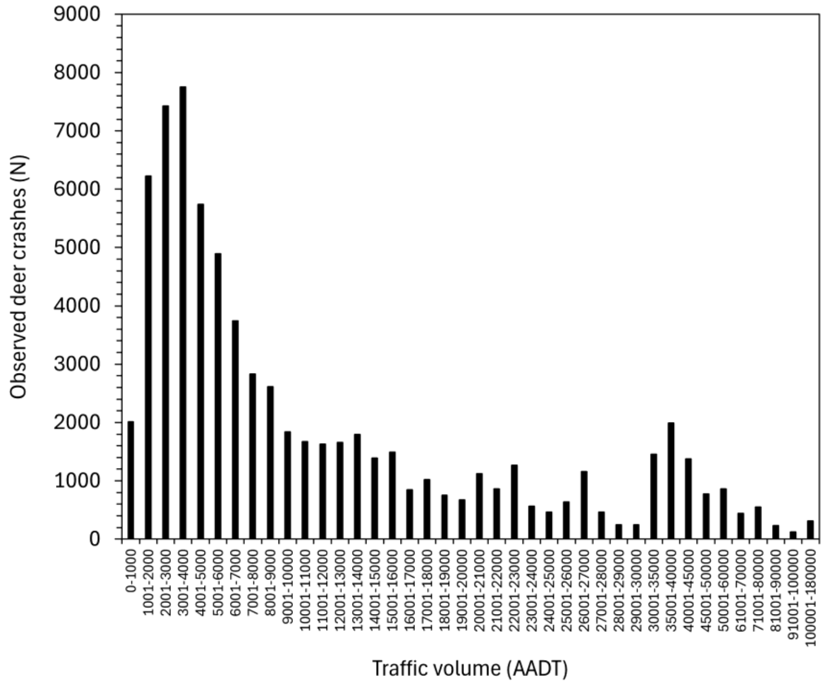

Figure 29: The recorded number of white-tailed deer carcasses for each traffic volume category (2017-2023).

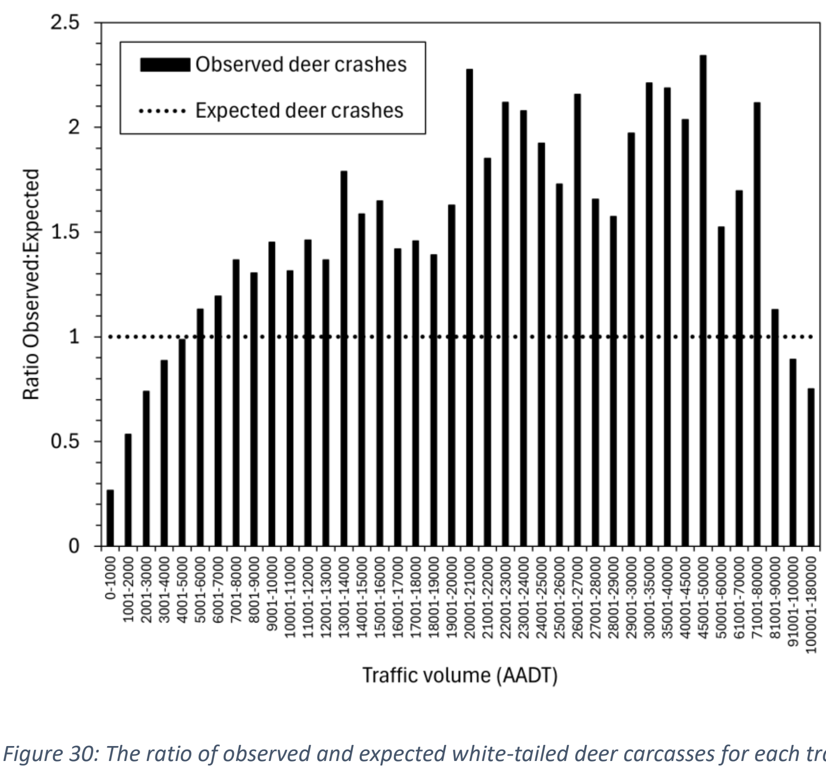

Figure 30: The ratio of observed and expected white-tailed deer carcasses for each traffic volume category (2017-2023).

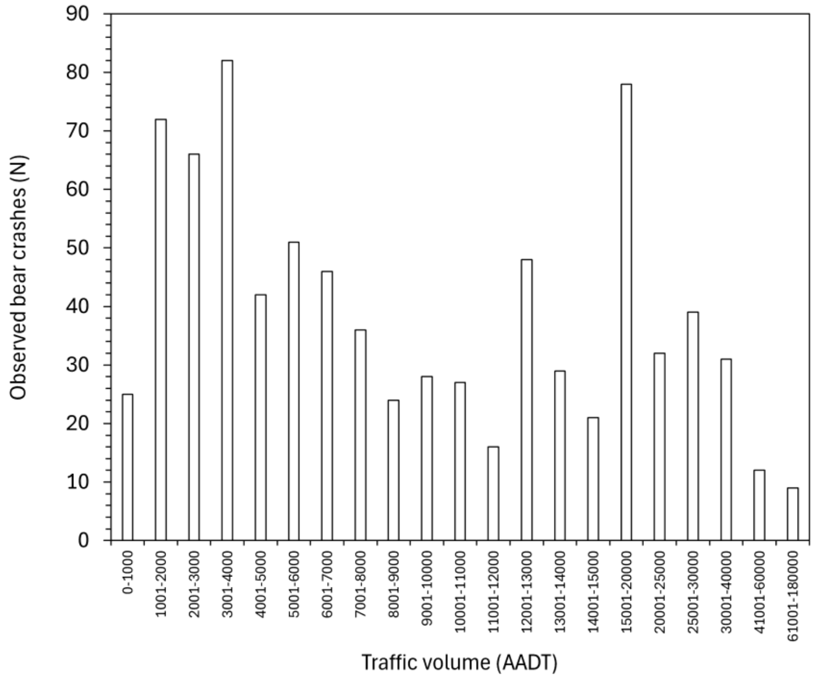

Figure 31: The recorded number of black bear carcasses for each traffic volume category (2017-2023).

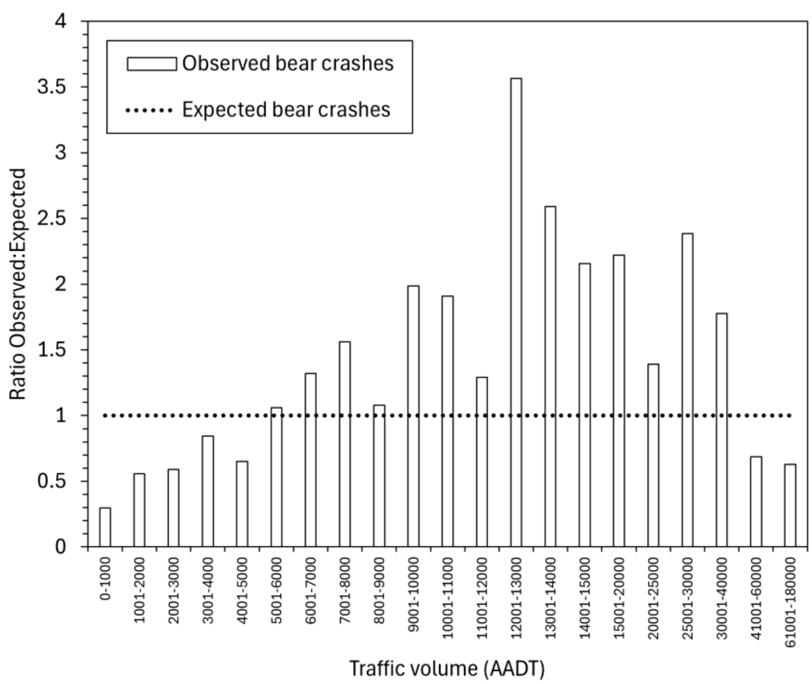

Figure 32: The ratio of observed and expected black bear carcasses for each traffic volume category (2017-2023).

7.4 Discussion

Most of the white-tailed deer (56.33%) and black bear crashes (51.47%) occurred on roads with a traffic volume of 1,001-9,000 AADT. However, roads with a traffic volume between 5,001 and 90,000 AADT all had more white-tailed deer than would have been expected if the number of white-tailed deer crashes were independent of the traffic volume. For black bears, this range was between 5,001 and 40,000 AADT.

Note that the results do not indicate that the barrier effect of roads and traffic for white-tailed deer and black bears only start at traffic volumes above 90,000 and 40,000 respectively. It is quite possible that far fewer animals attempt to cross roads at much lower traffic volumes already, but that the probability that an animal crossing results in a crash may increase with higher traffic volume. The increased risk of an animal crossing resulting in a crash may compensate for a potential decrease in the number of animals willing to cross at higher traffic volume. This can keep the number of recorded crashes relatively high, at least up to 90,000 or 40,000 AADT for white-tailed deer and black bear respectively, regardless of the potential for roads and traffic having already become a substantial barrier to white-tailed deer or black bear. The barrier effect of roads and traffic cannot be appropriately assessed based on road mortality data alone. The barrier effect could be measured in another way though, e.g., through analyzing the movements of GPS-collared animals that approach roads or that move in the immediate vicinity of different roads with a wide range of traffic volumes.

8 Habitat and corridors for species of conservation concern

8.1 Introduction

In this chapter we identify the species that were considered "of conservation concern" for the purpose of this project. For the species, or species groups, that spatially explicit data were available for, we incorporated the areas of their presence in ArcGIS. While this chapter contains several maps that show which road sections may need to consider mitigation for different species or different species groups, the ArcGIS layers provided to WisDOT should be consulted for individual projects as they not only show spatial information in greater resolution but also allow for a better evaluation of the potential presence of individual species.

8.2 Methods

First, we identified the species that were categorized as Species of Greatest Conservation Concern (SGCN) in Wisconsin in either Wisconsin's Wildlife Action Plan for 2005-2015 (WIDNR, 2008) or for 2015-2025 (WIDNR, 2015) (Table 3). We only selected SGCN species that were terrestrial mammals, reptiles, or amphibians. We supplemented these SGCN species with species for which little information was available in Wisconsin but that are considered rare. This included Canada lynx and cougar, and elk that were reintroduced in two areas over the last few decades (Table 3). For all these species we evaluated whether they were red listed by the International Union for Conservation of Nature (IUCN, 2025), federally listed in the United States (USFWS, 2025), or listed in Wisconsin (WIDNR, 2008) (Table 3). The 36 species of conservation concern, as defined for this report, included 4 amphibian species (3 frog species, 1 salamander species), 20 reptile species (3 lizard species, 13 snake species, 4 turtle species), and 12 mammal species (1 insectivore species, 5 rodent species, 1 mustelid species, 1 canid species, 2 felid species, 2 ungulate species).

While many species of conservation concern were identified, explicit spatial data (i.e., finer scale than county level) on their presence was only available for a few species or species groups:

1. Elk. Elk were reintroduced in two areas in Wisconsin: 1. Clam Lake Elk Range (1995) and 2. Black River Elk Range (2015). We used the "Northern Elk Zone 2024" and "Central Elk Zone 2021" data layers provided by WisDNR. We identified state-maintained roads that were within the two elk management zones and roads and road sections (0.1-mile road segments) that were up to 6.21 mi (10 km) from the boundaries of the elk management zone.
2. Gray wolf. We used the "WI_WolfEstimate_23_Draft layer" provided by WisDNR, which includes spatial explicit probability of gray wolf presence in polygons. We identified state-maintained roads that were within each gray wolf polygon and roads and road sections (0.1-mile road segments) that were up to 6.21 mi (10 km) from the boundaries of these polygons that indicated wolf presence. Where multiple wolf polygons intersected the same road segment, the average wolf occurrence probability was calculated and assigned to that road segment.

3. Herptiles. We used the "*Herp_mammal_twp_data_2025"* and "*WI_Herp_AVC_2025"* layers provided by WisDNR which includes data on the presence of amphibians and reptile species on a township-level, as well as records of road-killed individuals from these two species groups. For the purpose of this analysis, we grouped all amphibian and reptile species. None of the records related to the species identified in Table 3, or if they did, the species name was not present. We identified state-maintained roads and road sections (0.1-mile road segments) that were up 0.62 mi (1 km) from a township or a location with an amphibian or reptile observation.
4. Turtles. We used the "TurtleXings_2024" dataset provided by WisDNR. These data relate to live and dead observations of turtles on the road. For the purpose of this analysis, we grouped all turtle species. None of the records related to the species identified in Table 3, or if they did, the species name was not present. We identified state-maintained roads and road sections (0.1-mile road segments) that were up 0.62 mi (1 km) from a turtle crossing observation.

These spatially explicit data were obtained through a data request from the Natural Heritage Inventory (NHI) program from the Wisconsin Department of Natural Resources. Additional data for the species identified in Table 3 were obtained from Wisconsin DNR (2025a). Wisconsin DNR (2025a) contains maps of recorded presence by species by county.

These data described above are the most up-to-date and comprehensive datasets on the occurrence of rare species and amphibians and reptiles near and on highways available in Wisconsin. However, many areas of the state have not been inventoried. Similarly, the presence of one species at a location does not imply that comprehensive surveys have been completed at that site. Therefore, the data should be interpreted with caution, and absence of a species in an area does not equate to evidence of absence of that species in that area.

Table 3: Species of conservation concern selected for this project.

Species group 1	Species group 2	Scientific Name	Common Name	IUCN listed? *1	Federally listed? *2	Wisconsin listed? *3	SGCN in Wisconsin? *3,4	Source
Amphibians	Frog	*Acris blanchardi*	Blanchard's cricket frog			Endangered	WWAP 2	Wisconsin DNR, 2025a
Amphibians	Frog	*Lithobates palustris*	Pickerel frog				WWAP 2	Wisconsin DNR, 2025a
Amphibians	Frog	*Lithobates septentrionalis*	Mink frog				WWAP 2	Wisconsin DNR, 2025a
Amphibians	Salamander	*Hemidactylium scutatum*	Four-toed salamander				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Lizard	*Aspidoscelis sexlineata*	Six-lined racerunner				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Lizard	*Plestiodon septentrionalis*	Prairie skink				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Lizard	*Ophisaurus attenuatus*	Slender glass lizard			Endangered	WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Carphophis vermis*	Western wormsnake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Coluber constrictor*	North American racer				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Crotalus horridus*	Timber rattlesnake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Diadophis punctatus arnyi*	Prairie ring-necked snake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Pantherophis spiloides*	Gray ratsnake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Pituophis catenifer*	Gophersnake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Regina septemvittata*	Queensnake			Endangered	WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Sistrurus catenatus*	Eastern massasauga		Threatened	Endangered	WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Thamnophis butleri*	Butler's gartersnake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Thamnophis proximus*	Western ribbonsnake			Endangered	WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Thamnophis radix*	Plains gartersnake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Thamnophis sauritus*	Eastern ribbonsnake			Endangered	WWAP 2	Wisconsin DNR, 2025a
Reptiles	Snake	*Tropidoclonion lineatum*	Lined snake				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Turtle	*Apalone mutica*	Smooth softshell turtle				WWAP 2	Wisconsin DNR, 2025a
Reptiles	Turtle	*Emydoidea blandingii*	Blanding's turtle	Endangered			WWAP 2	Wisconsin DNR, 2025a
Reptiles	Turtle	*Glyptemys insculpta*	Wood turtle	Endangered		Threatened	WWAP 2	Wisconsin DNR, 2025a
Reptiles	Turtle	*Terrapene ornata*	Ornate box turtle			Endangered	WWAP 2	Wisconsin DNR, 2025a
Mammals	Canid	*Canis lupus*	Gray wolf*5		Endangered		WWAP 1	Data provided by Wisconsin DNR
Mammals	Felid	*Lynx canadensis*	Canada lynx*6		Threatened			Wydeven et al., 2004
Mammals	Felid	*Puma concolor*	Cougar*7					Wisconsin DNR, 2025b
Mammals	Insectivore	*Sorex palustris*	American water shrew				WWAP 2	Wisconsin DNR, 2025a
Mammals	Mustelid	*Martes americana*	American marten			Endangered	WWAP 2	Wisconsin DNR, 2025a
Mammals	Rodent	*Microtus ochrogaster*	Prairie vole				WWAP 2	Wisconsin DNR, 2025a
Mammals	Rodent	*Microtus pinetorum*	Woodland vole				WWAP 2	Wisconsin DNR, 2025a
Mammals	Rodent	*Napaeozapus insignis*	Woodland jumping mouse				WWAP 2	Wisconsin DNR, 2025a
Mammals	Rodent	*Peromyscus maniculatus bairdii*	Prairie deer mouse				WWAP 2	Wisconsin DNR, 2025a
Mammals	Rodent	*Poliocitellus franklinii*	Franklin's ground squirrel				WWAP 2	Wisconsin DNR, 2025a
Mammals	Ungulate	*Alces alces*	Moose				WWAP 1	Wisconsin DNR, 2025c
Mammals	Ungulate	*Cervus canadensis*	Elk				*9	Data provided by Wisconsin DNR

*1 IUCN (2025), *2 USFWS (2025), *3 WIDNR (2008), *4 WIDNR (2015), *5 Present in northern parts of WI, *6 No evidence of breeding, no habitat identified, but observed in northern WI, *7 No evidence of breeding, no habitat identified, *8 A few dozen individuals in northern WI, *9 Reintroduced Clam Lake Elk Range (1995) and Black River Elk Range (2015).

8.3 Results

8.3.1 Herptile map (all species combined) and turtle map (all species combined)

Herptiles (amphibians and reptiles), and turtles occur on or close to roads almost anywhere in Wisconsin, and highway mitigation may consider these species groups almost anywhere (Figure 33, Figure 34).

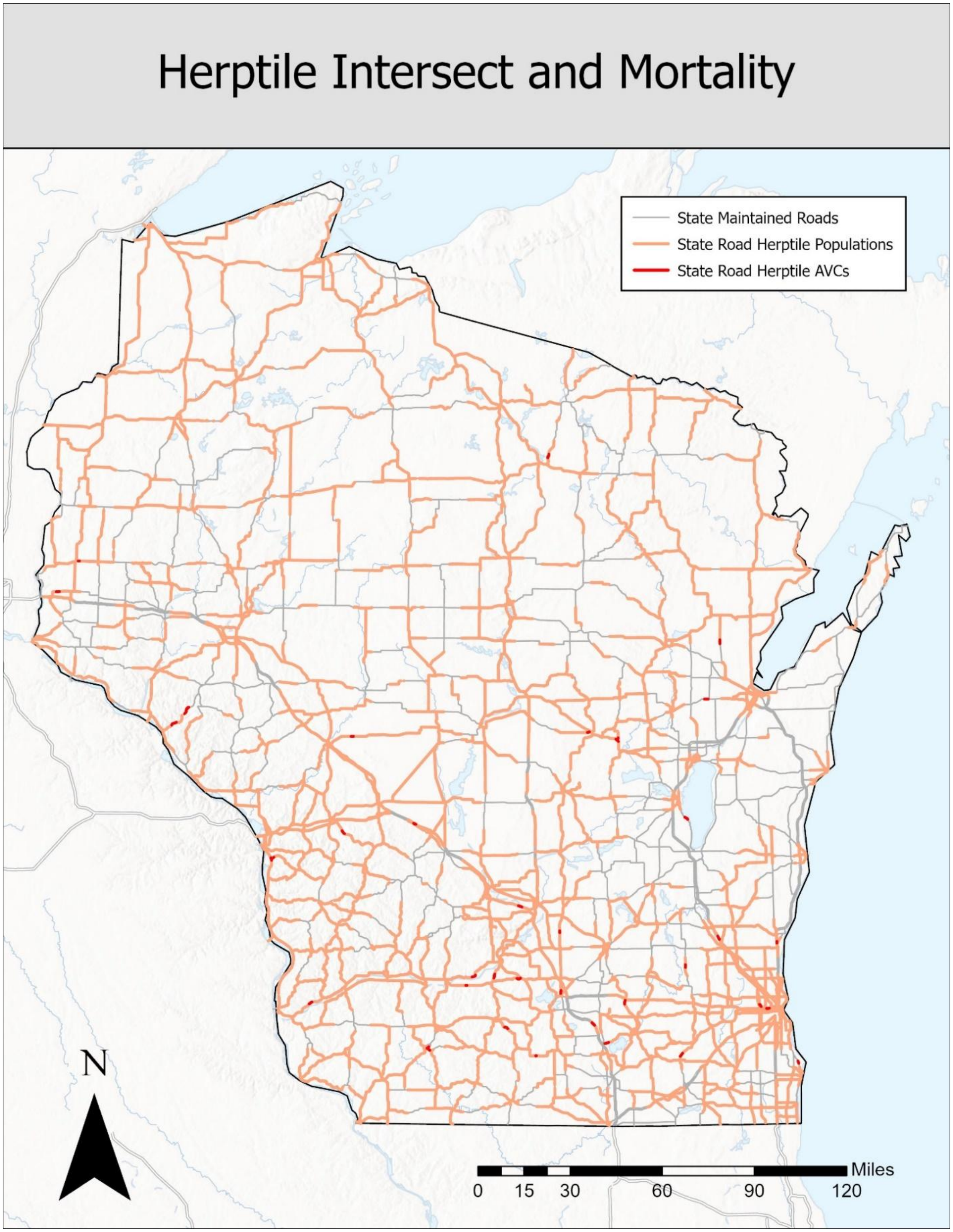

Figure 33: Roads and road segments that are up 0.62 mi (1 km) from recorded presence of amphibians and reptile species (all species, not necessarily species of conservation concern) on a township-level, as well as locations of road-killed animals from these two species groups (data provided by Wisconsin DNR).

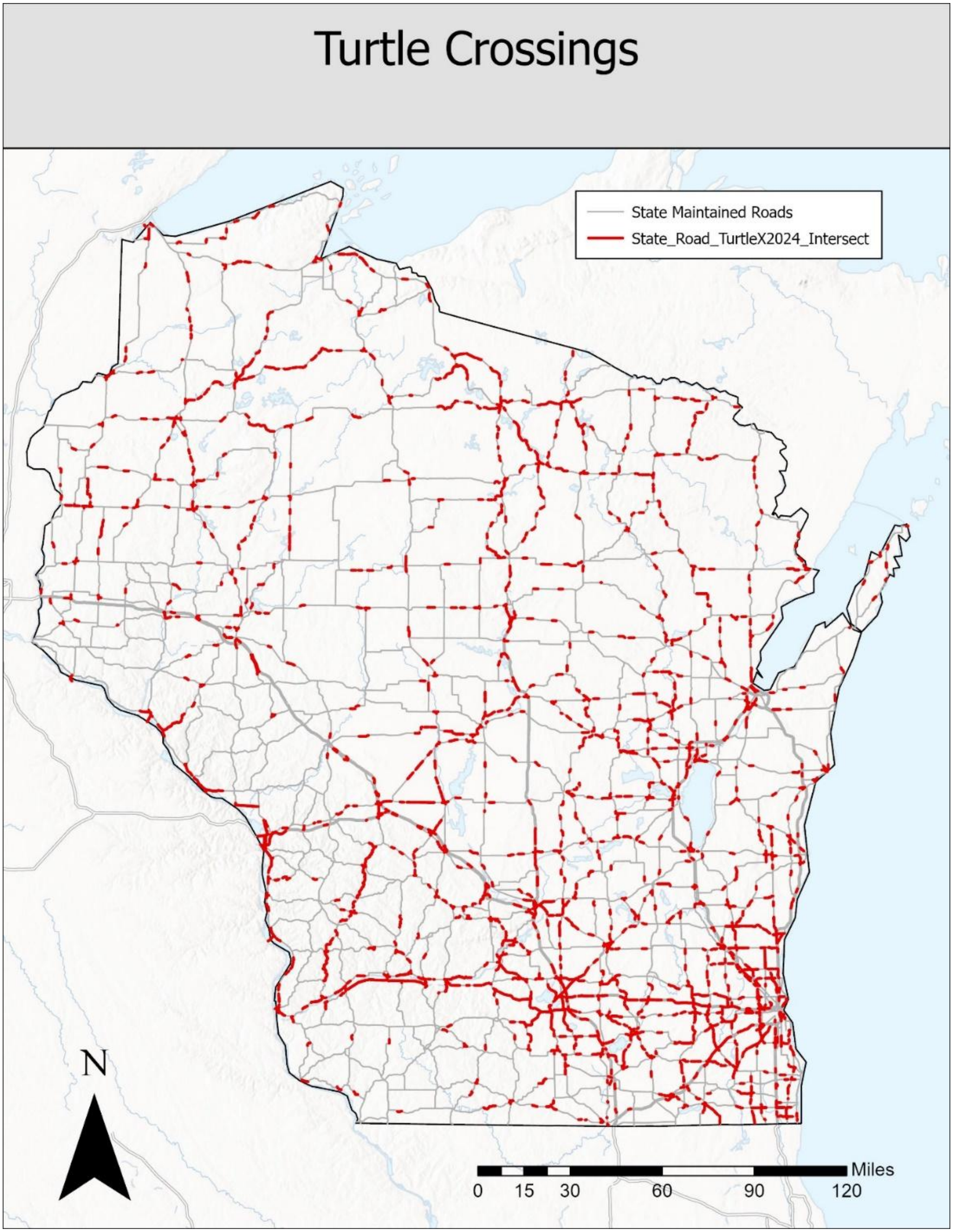

Figure 34: Roads and road segments that are up 0.62 mi (1 km) from recorded turtle (all species, not necessarily species of conservation concern) crossings (alive and dead on road) (data provided by Wisconsin DNR).

8.3.2 Species specific maps

The maps on the following pages show the counties where individual species of conservation concern have been recorded (Table 4). More detailed data were available for two species: elk and gray wolves. Elk may be considered in highway mitigation in two areas in Wisconsin. There are many more roads where gray wolf may be considered in highway mitigation, both in the northern and central parts of Wisconsin.

Table 4: Species of conservation concern selected for this project and figures showing their distribution in Wisconsin.

Species group 1	Species group 2	Scientific Name	Common Name	Figure A	Figure B
Amphibians	Frog	*Acris blanchardi*	Blanchard's cricket frog	Figure 35	
Amphibians	Frog	*Lithobates palustris*	Pickerel frog	Figure 36	
Amphibians	Frog	*Lithobates septentrionalis*	Mink frog	Figure 37	
Amphibians	Salamander	*Hemidactylium scutatum*	Four-toed salamander	Figure 38	
Reptiles	Lizard	*Aspidoscelis sexlineata*	Six-lined racerunner	Figure 39	
Reptiles	Lizard	*Plestiodon septentrionalis*	Prairie skink	Figure 40	
Reptiles	Lizard	*Ophisaurus attenuatus*	Slender glass lizard	Figure 41	
Reptiles	Snake	*Carphophis vermis*	Western wormsnake	Figure 42	
Reptiles	Snake	*Coluber constrictor*	North American racer	Figure 43	
Reptiles	Snake	*Crotalus horridus*	Timber rattlesnake	Figure 44	
Reptiles	Snake	*Diadophis punctatus arnyi*	Prairie ring-necked snake	Figure 45	
Reptiles	Snake	*Pantherophis spiloides*	Gray ratsnake	Figure 46	
Reptiles	Snake	*Pituophis catenifer*	Gophersnake	Figure 47	
Reptiles	Snake	*Regina septemvittata*	Queensnake	Figure 48	
Reptiles	Snake	*Sistrurus catenatus*	Eastern massasauga	Figure 49	
Reptiles	Snake	*Thamnophis butleri*	Butler's gartersnake	Figure 50	
Reptiles	Snake	*Thamnophis proximus*	Western ribbonsnake	Figure 51	
Reptiles	Snake	*Thamnophis radix*	Plains gartersnake	Figure 52	
Reptiles	Snake	*Thamnophis sauritus*	Eastern ribbonsnake	Figure 53	
Reptiles	Snake	*Tropidoclonion lineatum*	Lined snake	Figure 54	
Reptiles	Turtle	*Apalone mutica*	Smooth softshell turtle	Figure 55	
Reptiles	Turtle	*Emydoidea blandingii*	Blanding's turtle	Figure 56	
Reptiles	Turtle	*Glyptemys insculpta*	Wood turtle	Figure 57	
Reptiles	Turtle	*Terrapene ornata*	Ornate box turtle	Figure 58	
Mammals	Canid	*Canis lupus*	Gray wolf[*5]	Figure 59	Figure 60
Mammals	Felid	*Lynx canadensis*	Canada lynx[*6]	Figure 61	
Mammals	Felid	*Puma concolor*	Cougar[*7]	Figure 62	
Mammals	Insectivore	*Sorex palustris*	American water shrew	Figure 63	
Mammals	Mustelid	*Martes americana*	American marten	Figure 64	
Mammals	Rodent	*Microtus ochrogaster*	Prairie vole	Figure 65	
Mammals	Rodent	*Microtus pinetorum*	Woodland vole	Figure 66	
Mammals	Rodent	*Napaeozapus insignis*	Woodland jumping mouse	Figure 67	
Mammals	Rodent	*Peromyscus maniculatus bairdii*	Prairie deer mouse	Figure 68	
Mammals	Rodent	*Poliocitellus franklinii*	Franklin's ground squirrel	Figure 69	
Mammals	Ungulate	*Alces alces*	Moose	Figure 70	
Mammals	Ungulate	*Cervus canadensis*	Elk	Figure 71	Figure 72

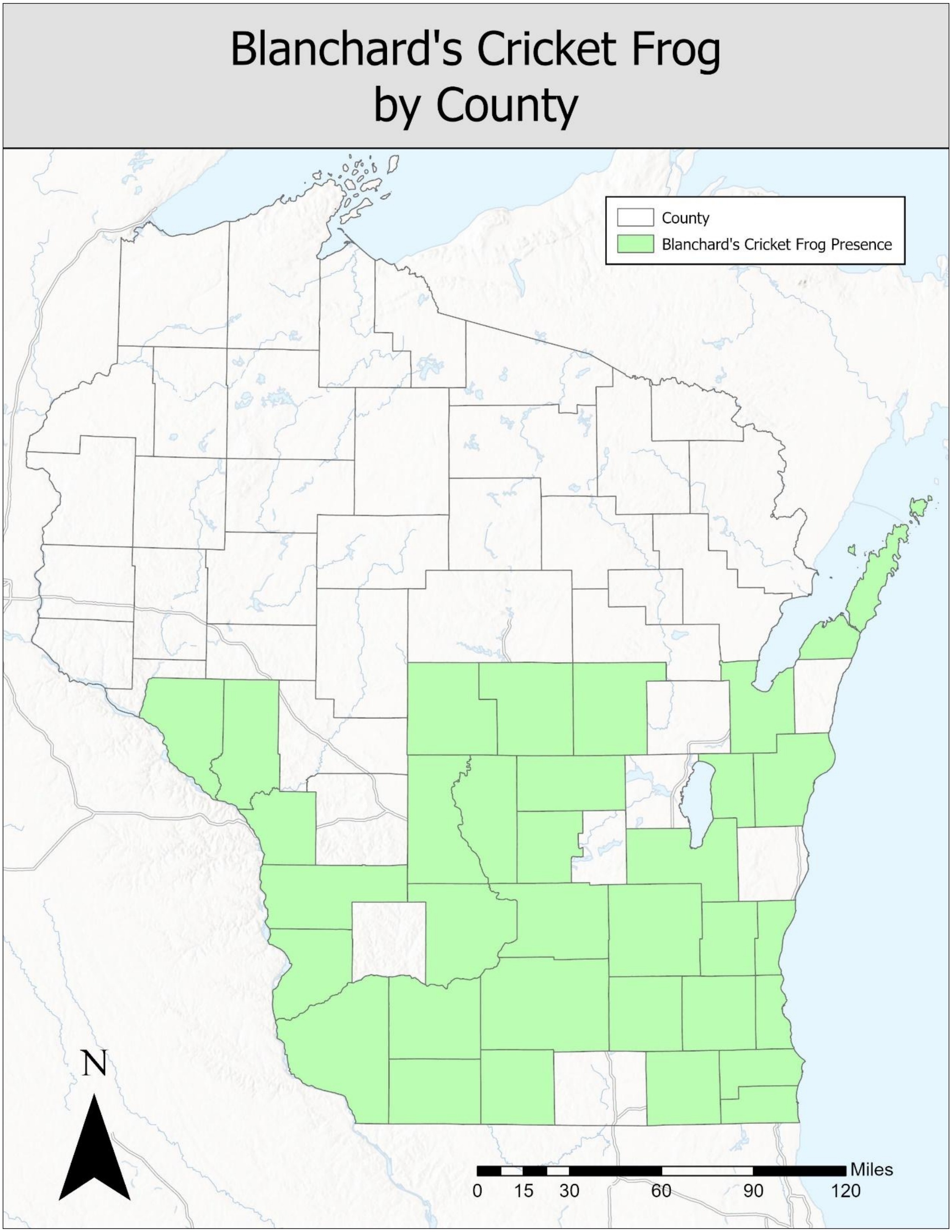

Figure 35: Counties with recorded presence of Blanchard's cricket frog (Acris blanchardi) (Wisconsin DNR, 2025a).

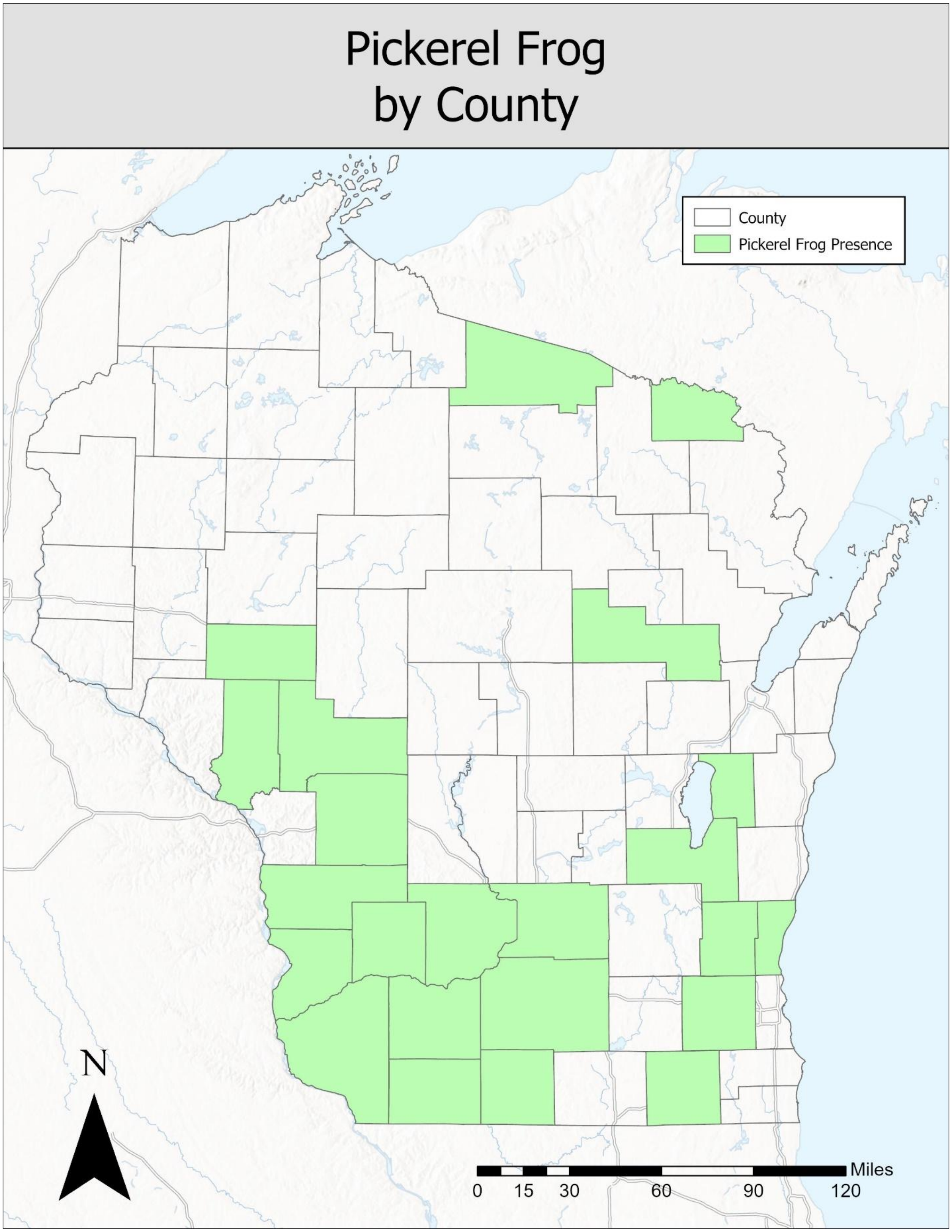

Figure 36: Counties with recorded presence of Pickerel frog (Lithobates palustris) (Wisconsin DNR, 2025a).

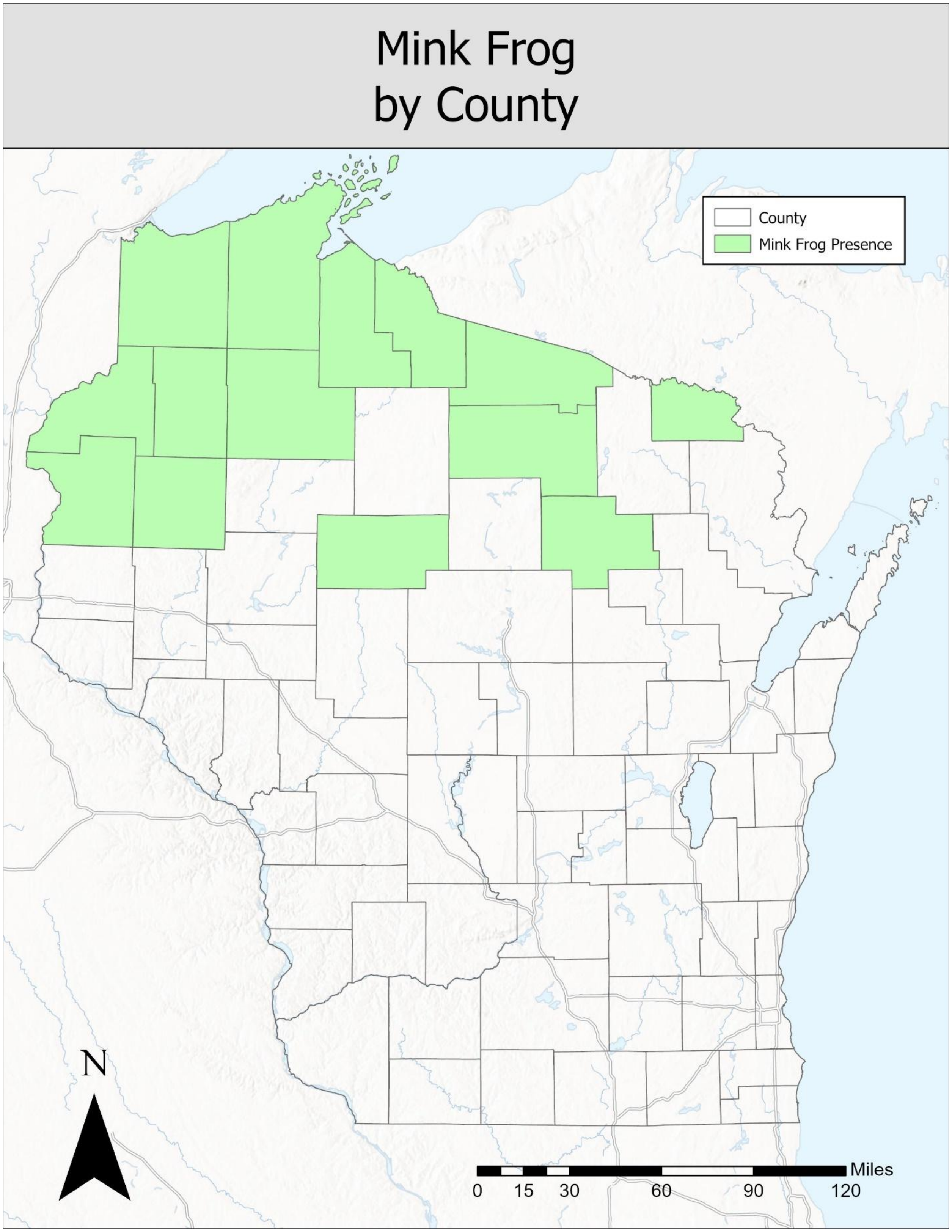

Figure 37: Counties with recorded presence of Mink frog (Lithobates septentrionalis) (Wisconsin DNR, 2025a).

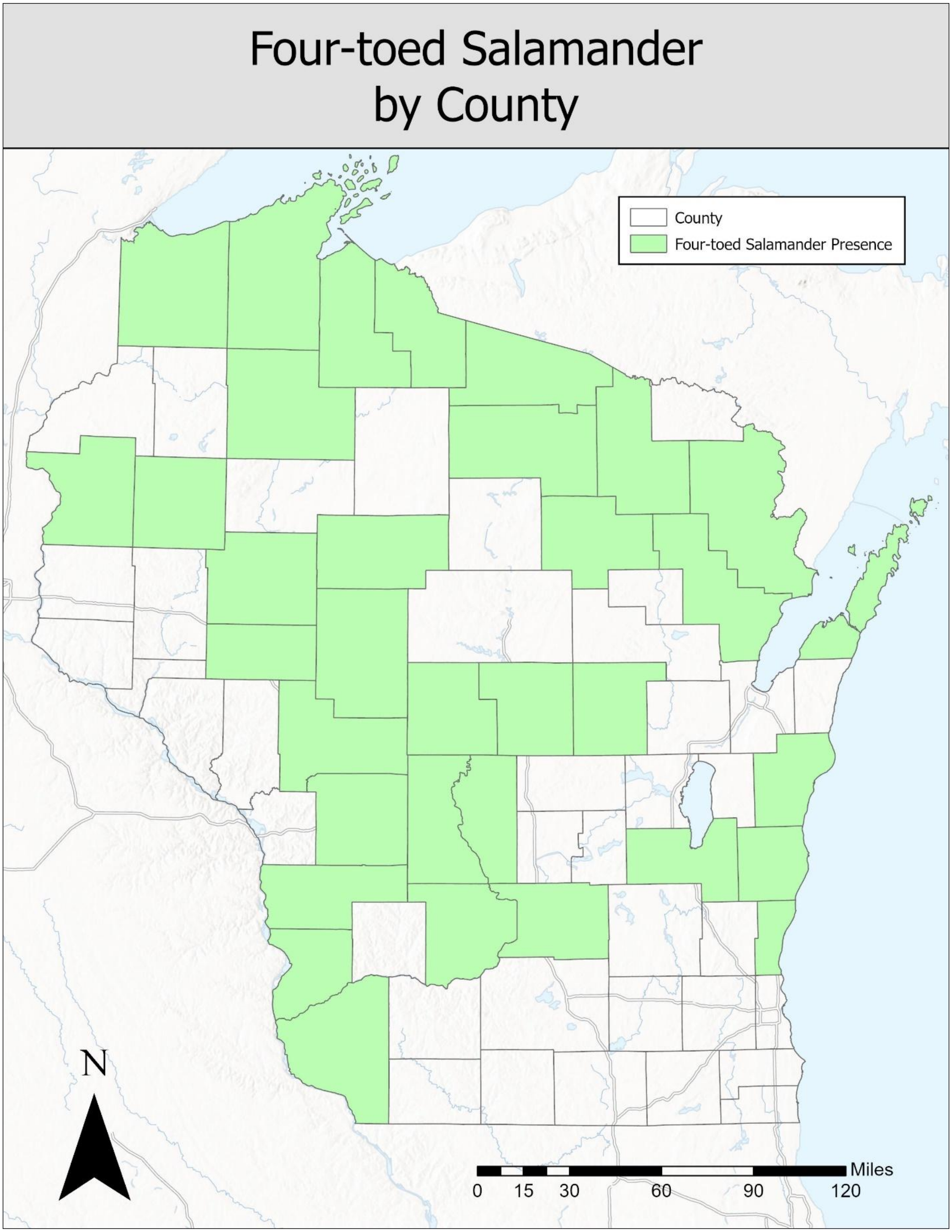

Figure 38: Counties with recorded presence of Four-toed salamander (Hemidactylium scutatum) (Wisconsin DNR, 2025a).

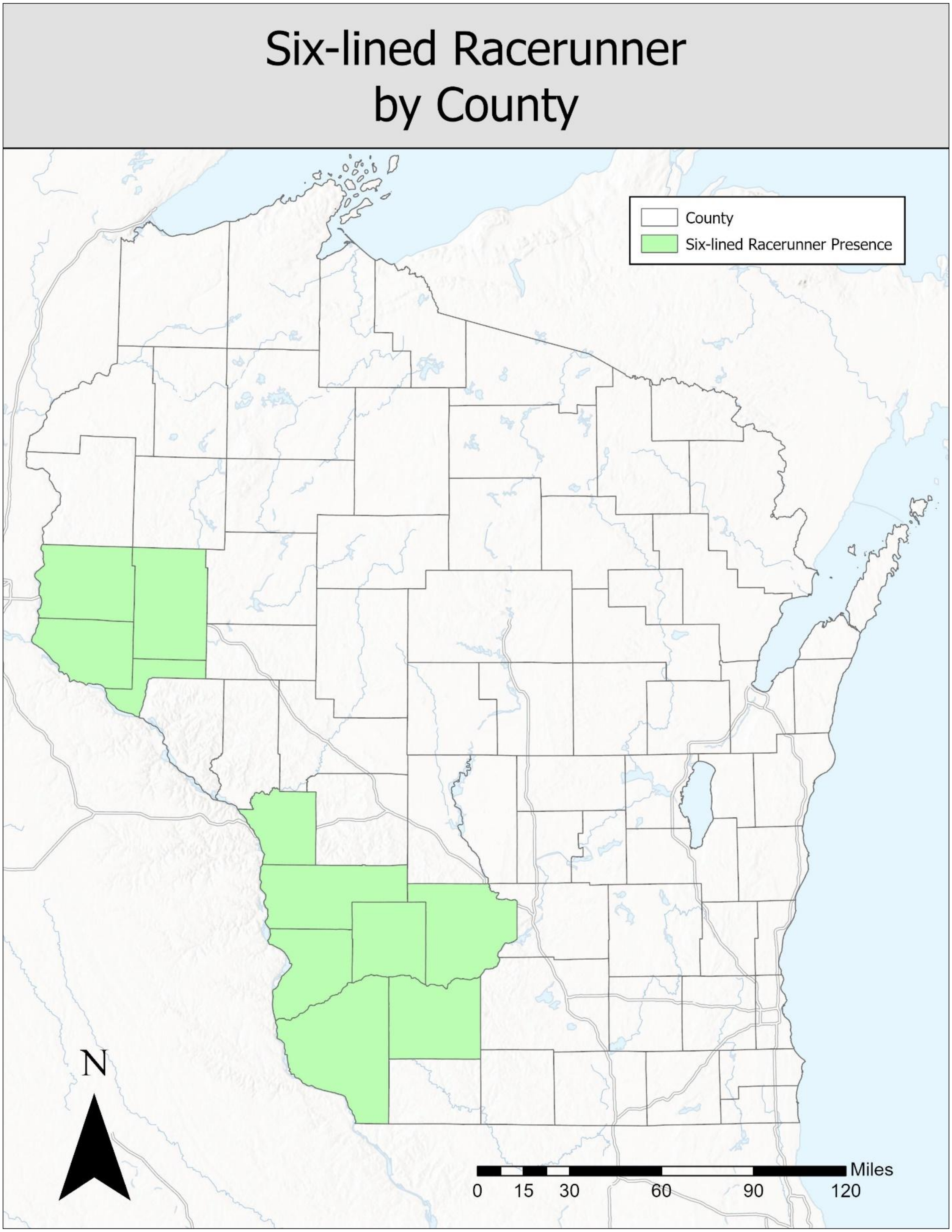

Figure 39: Counties with recorded presence of Six-lined racerunner (Aspidoscelis sexlineata) (Wisconsin DNR, 2025a).

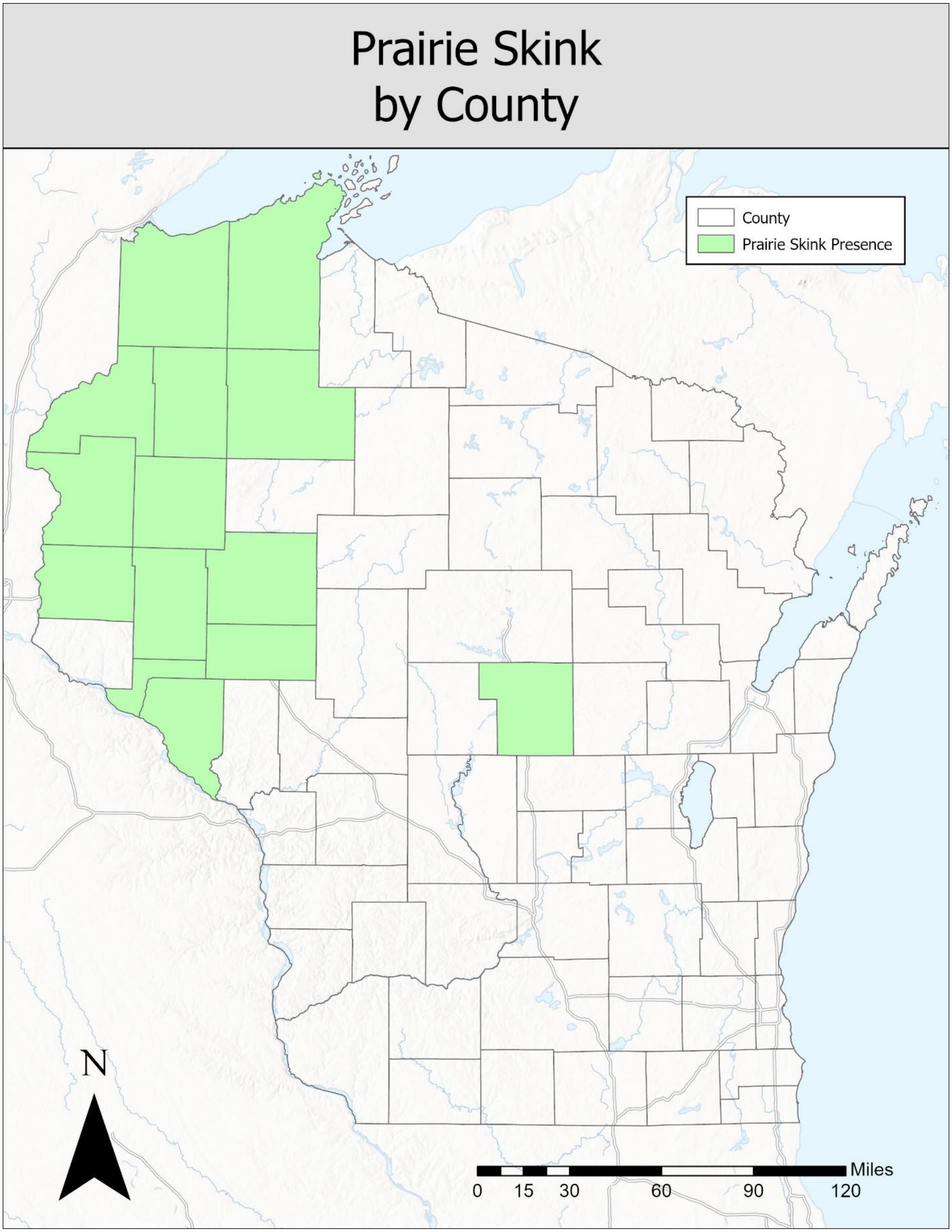

Figure 40: Counties with recorded presence of Prairie skink (Plestiodon septentrionalis) (Wisconsin DNR, 2025a).

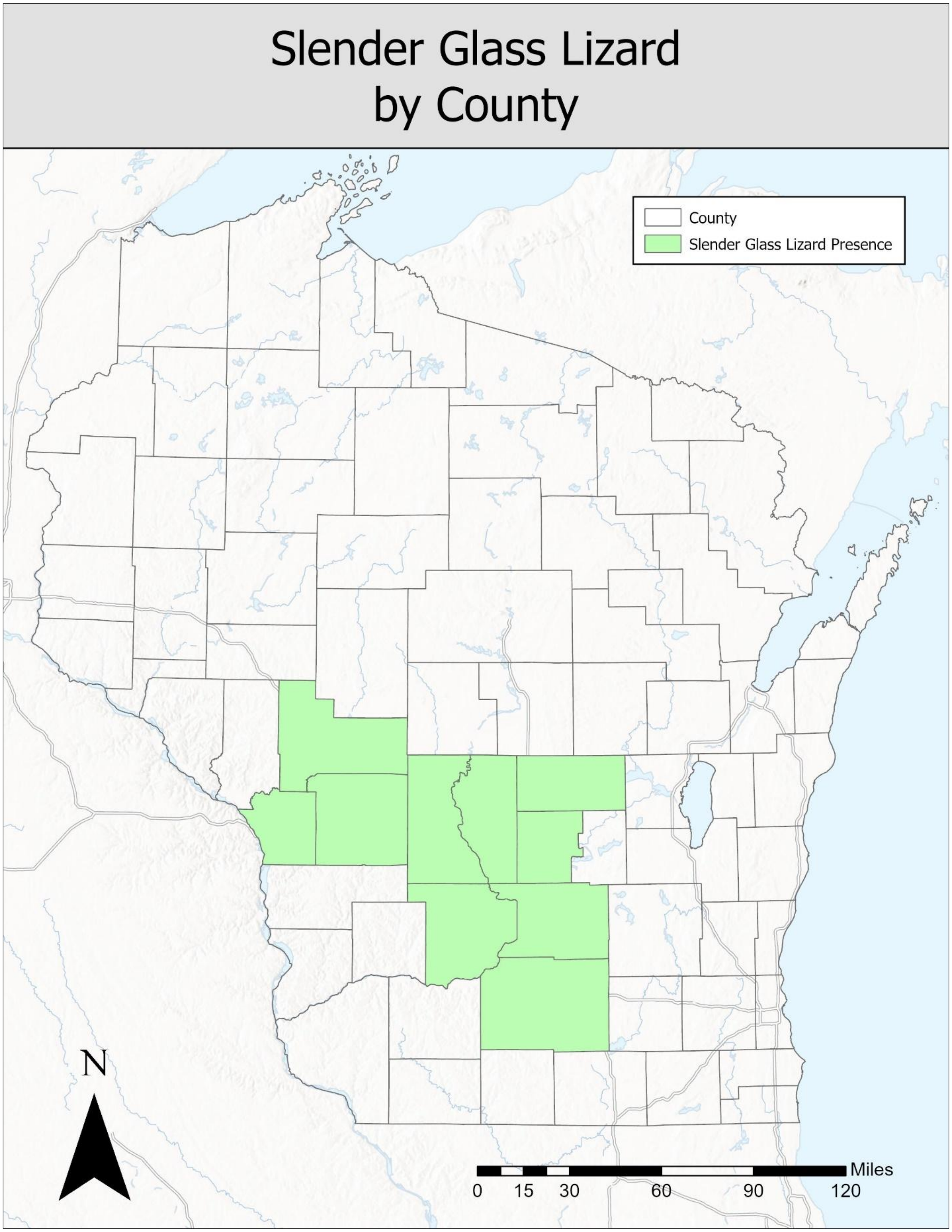

Figure 41: Counties with recorded presence of Slender glass lizard (Ophisaurus attenuatus) (Wisconsin DNR, 2025a).

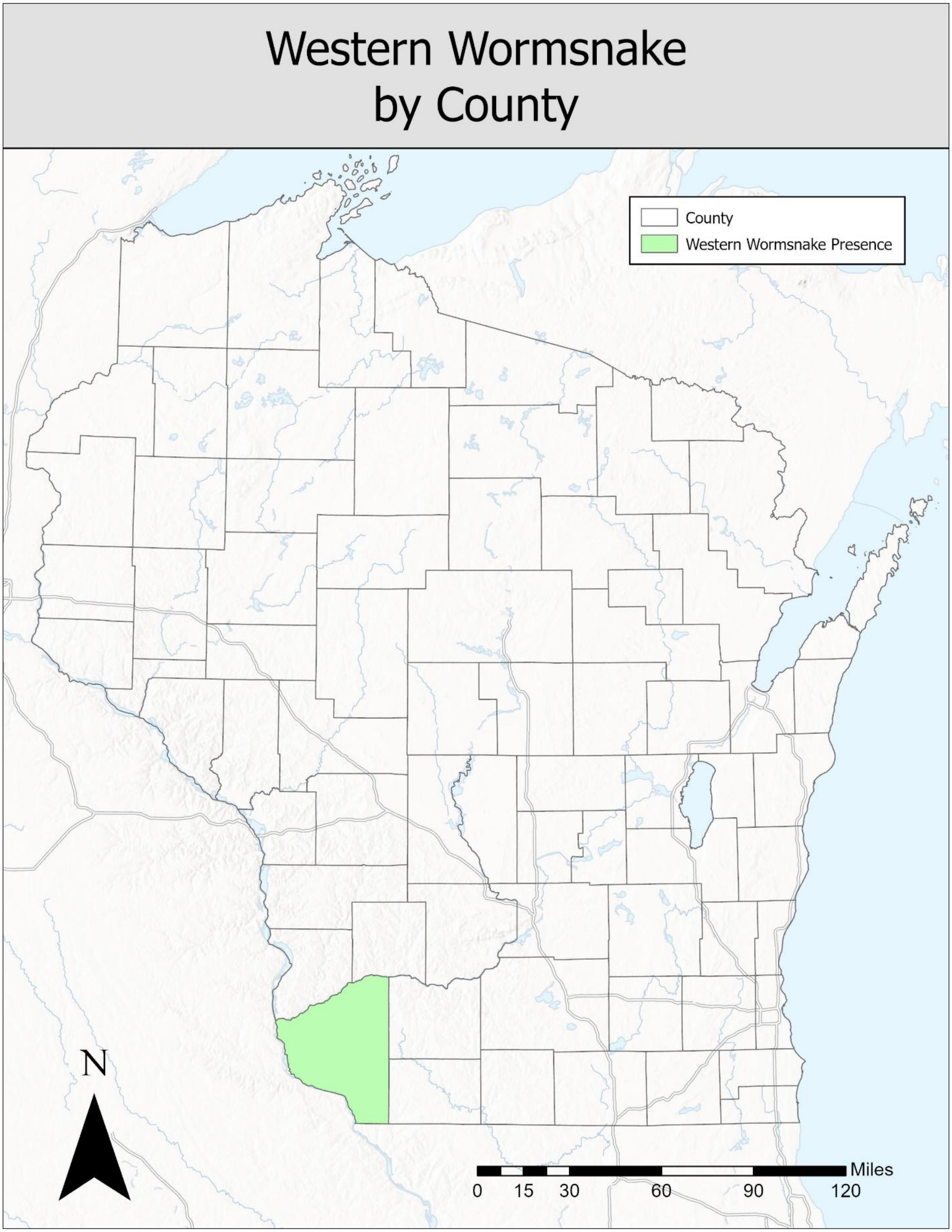

Figure 42: Counties with recorded presence of Western wormsnake (Carphophis vermis) (Wisconsin DNR, 2025a).

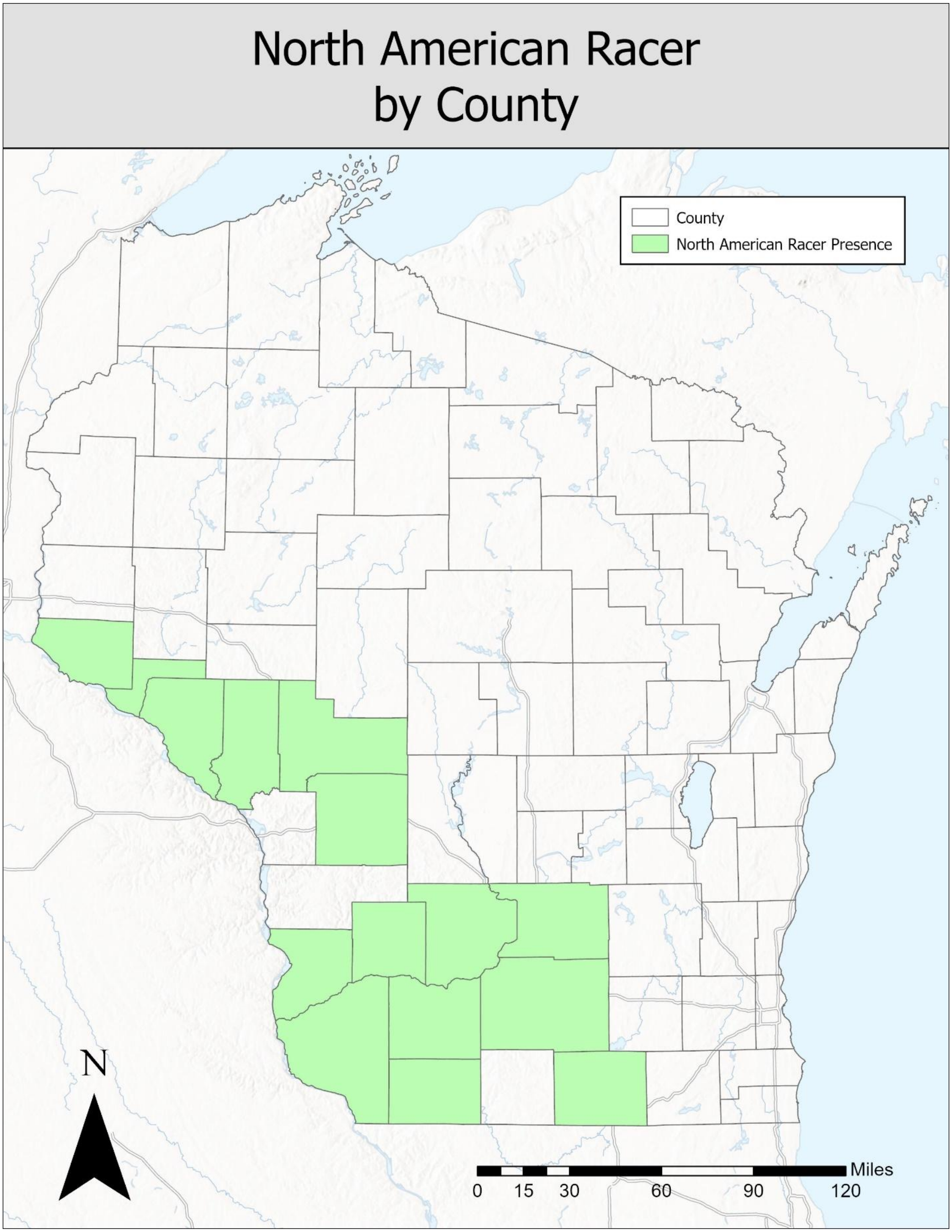

Figure 43: Counties with recorded presence of North American racer (Coluber constrictor) (Wisconsin DNR, 2025a).

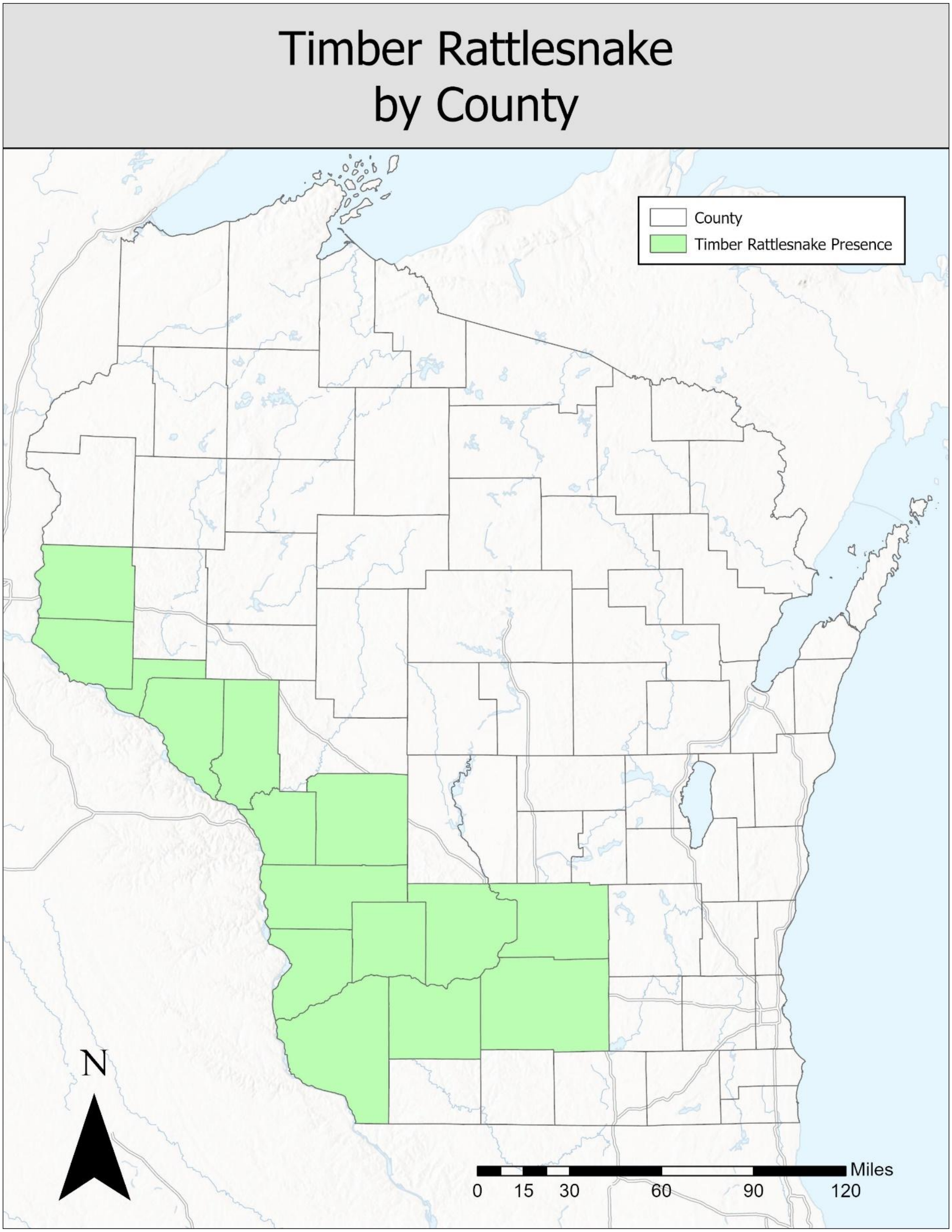

Figure 44: Counties with recorded presence of Timber rattlesnake (Crotalus horridus) (Wisconsin DNR, 2025a).

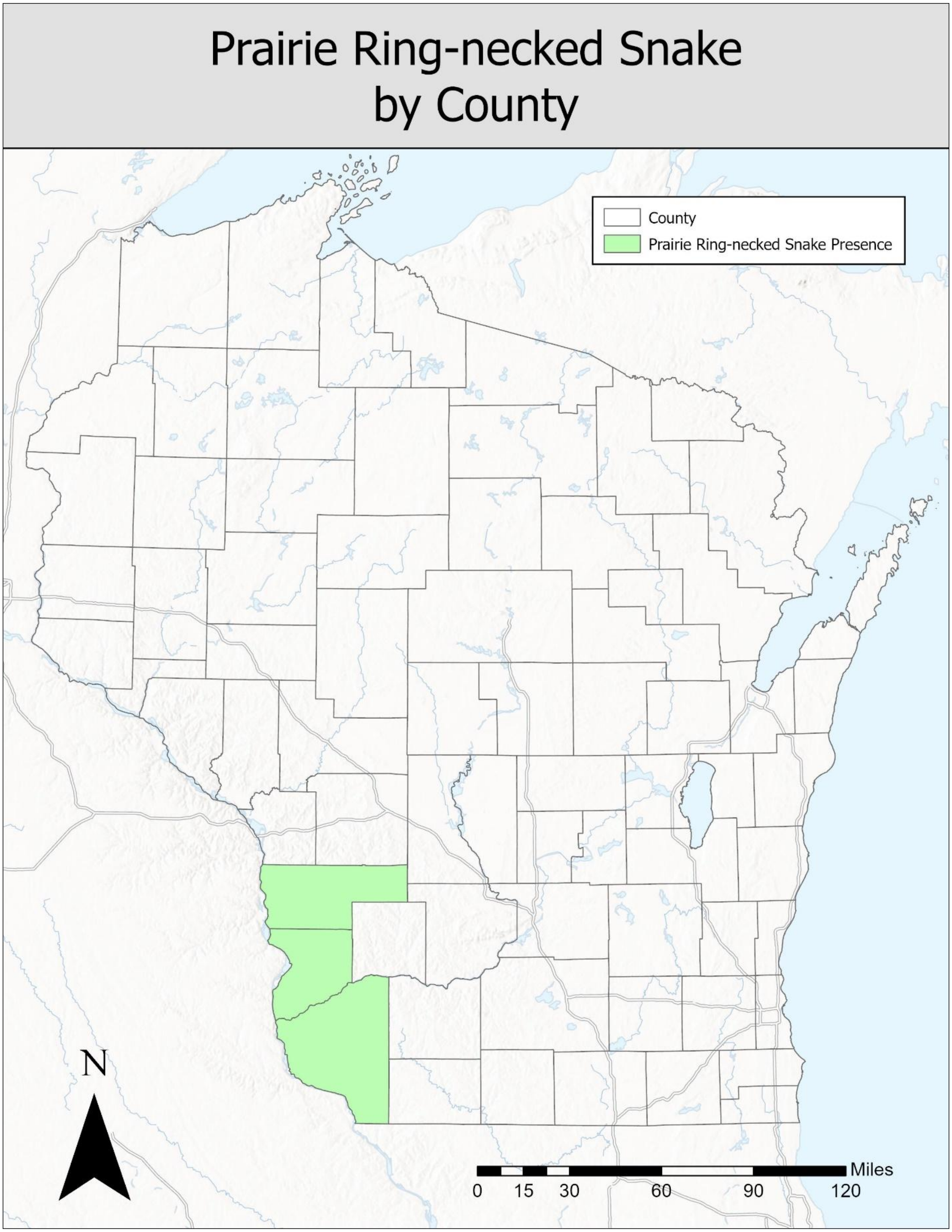

Figure 45: Counties with recorded presence of Prairie ring-necked snake (Diadophis punctatus arnyi) (Wisconsin DNR, 2025a).

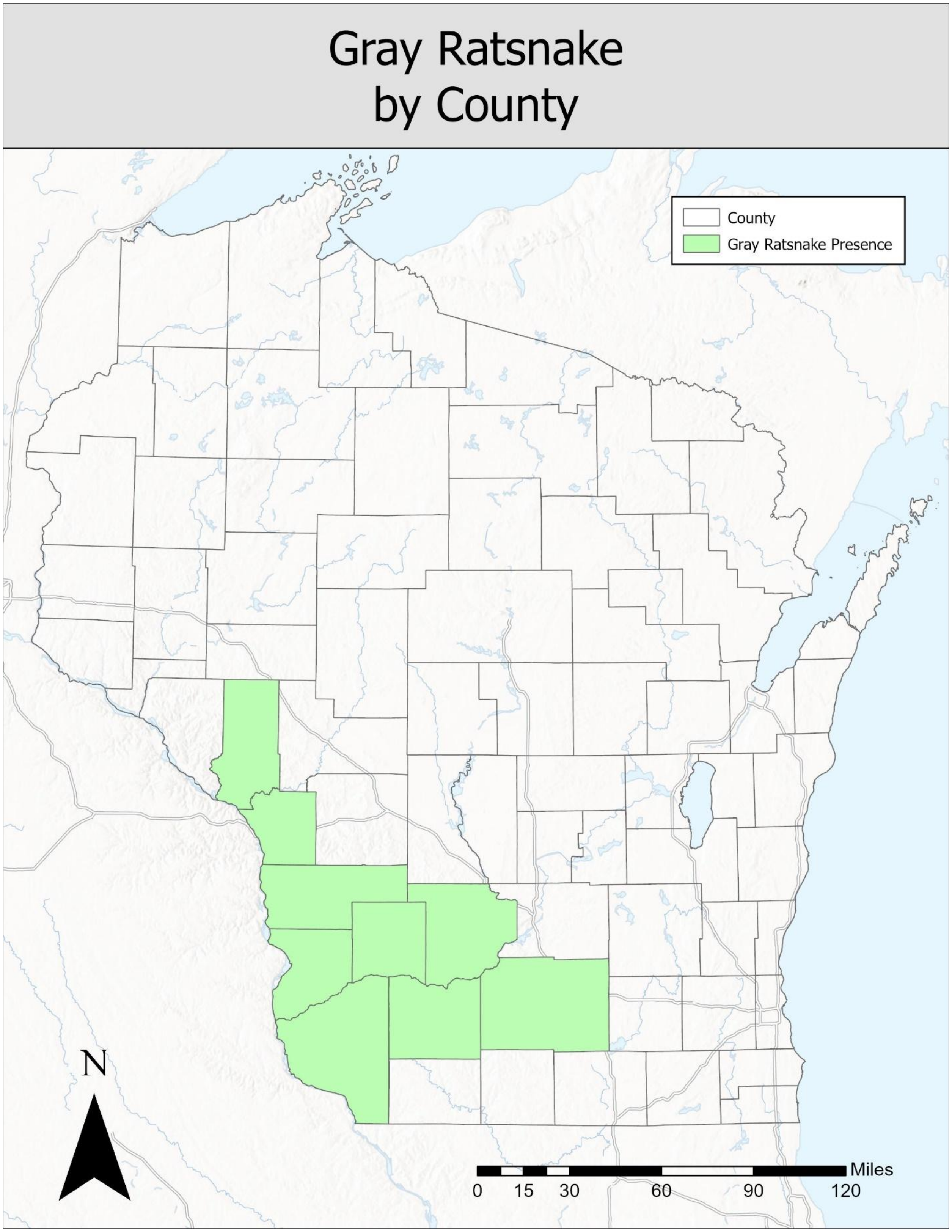

Figure 46: Counties with recorded presence of Gray ratsnake (Pantherophis spiloides) (Wisconsin DNR, 2025a).

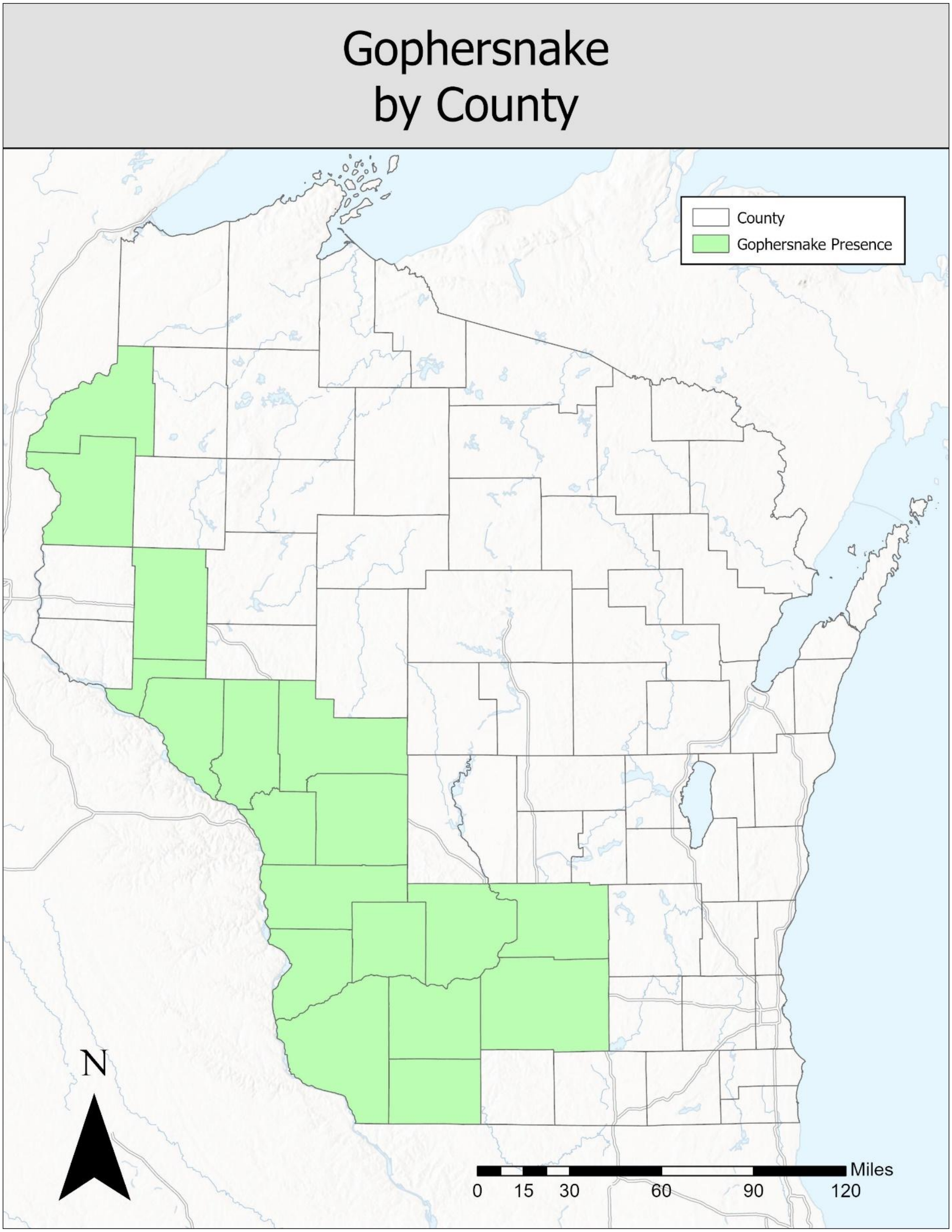

Figure 47: Counties with recorded presence of Gophersnake (Pituophis catenifer) (Wisconsin DNR, 2025a).

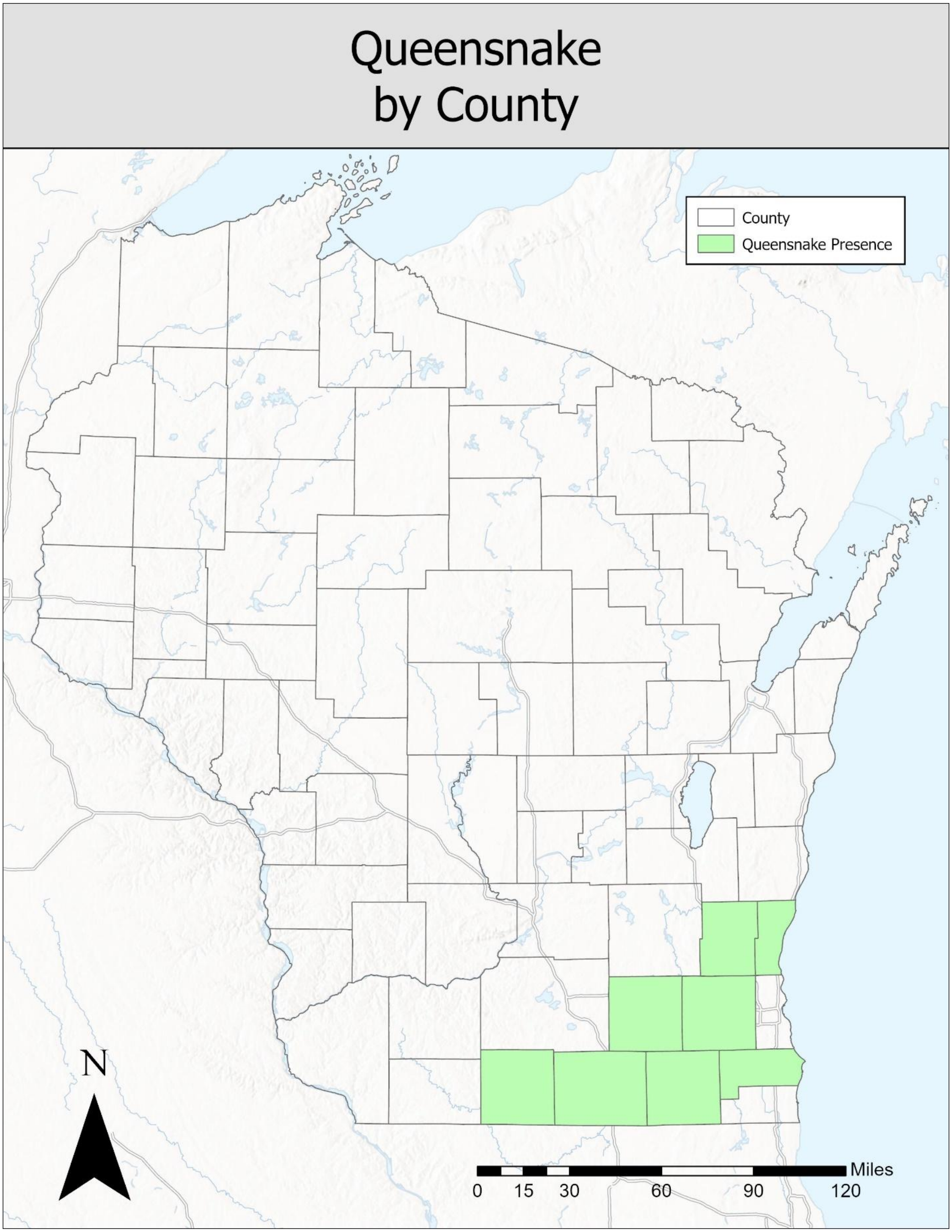

Figure 48: Counties with recorded presence of Queensnake (Regina septemvittata) (Wisconsin DNR, 2025a).

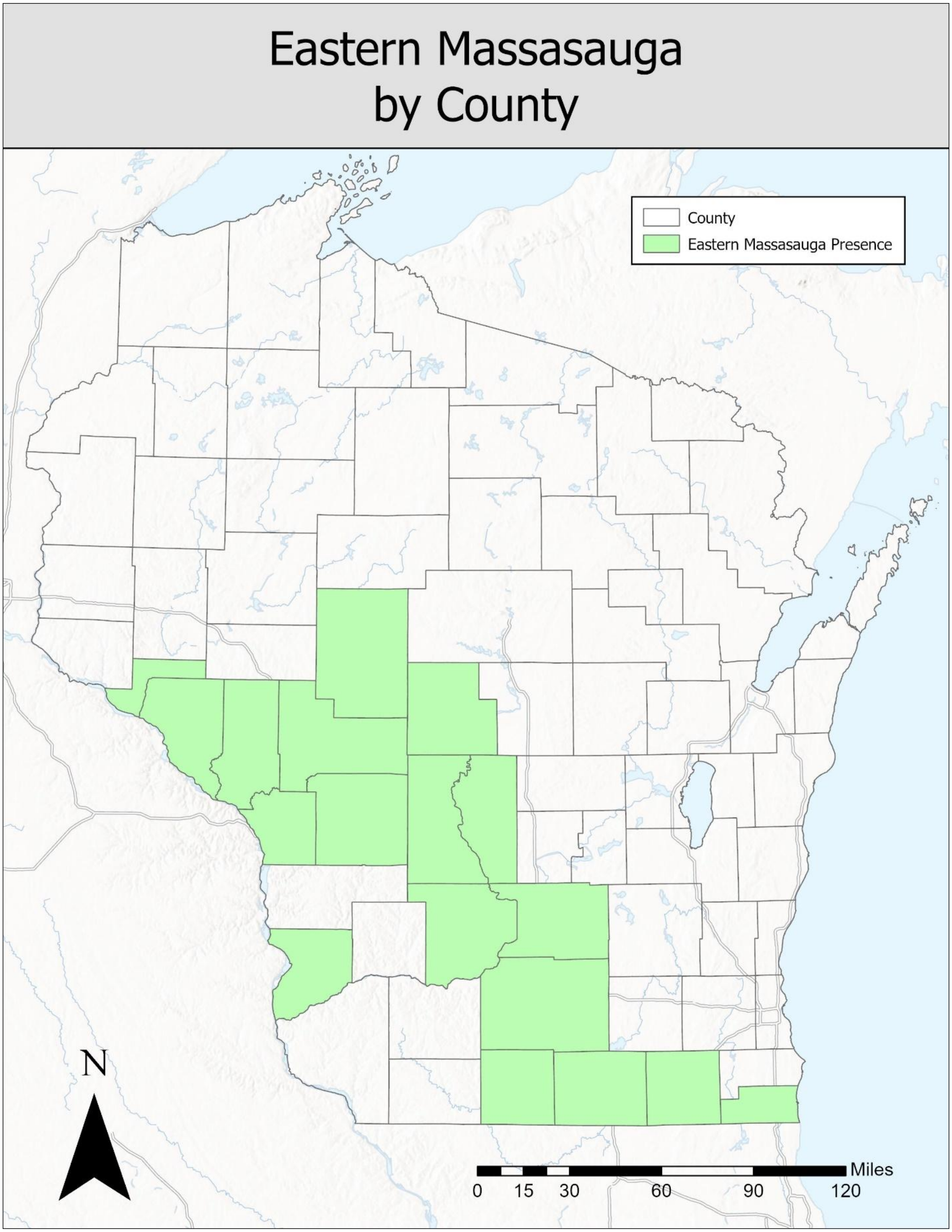

Figure 49: Counties with recorded presence of Eastern massasauga (Sistrurus catenatus) (Wisconsin DNR, 2025a).

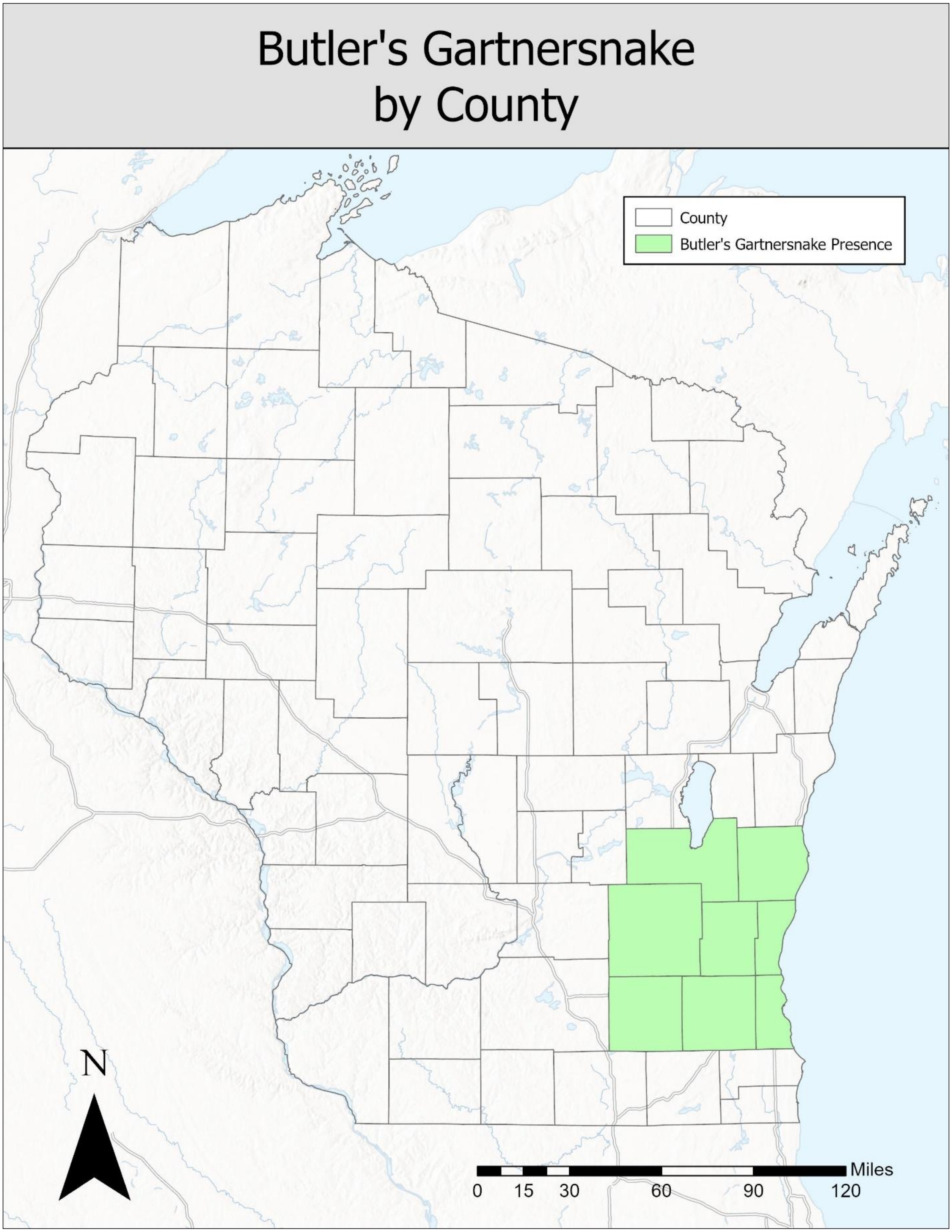

Figure 50: Counties with recorded presence of Butler's gartersnake (Thamnophis butleri) (Wisconsin DNR, 2025a).

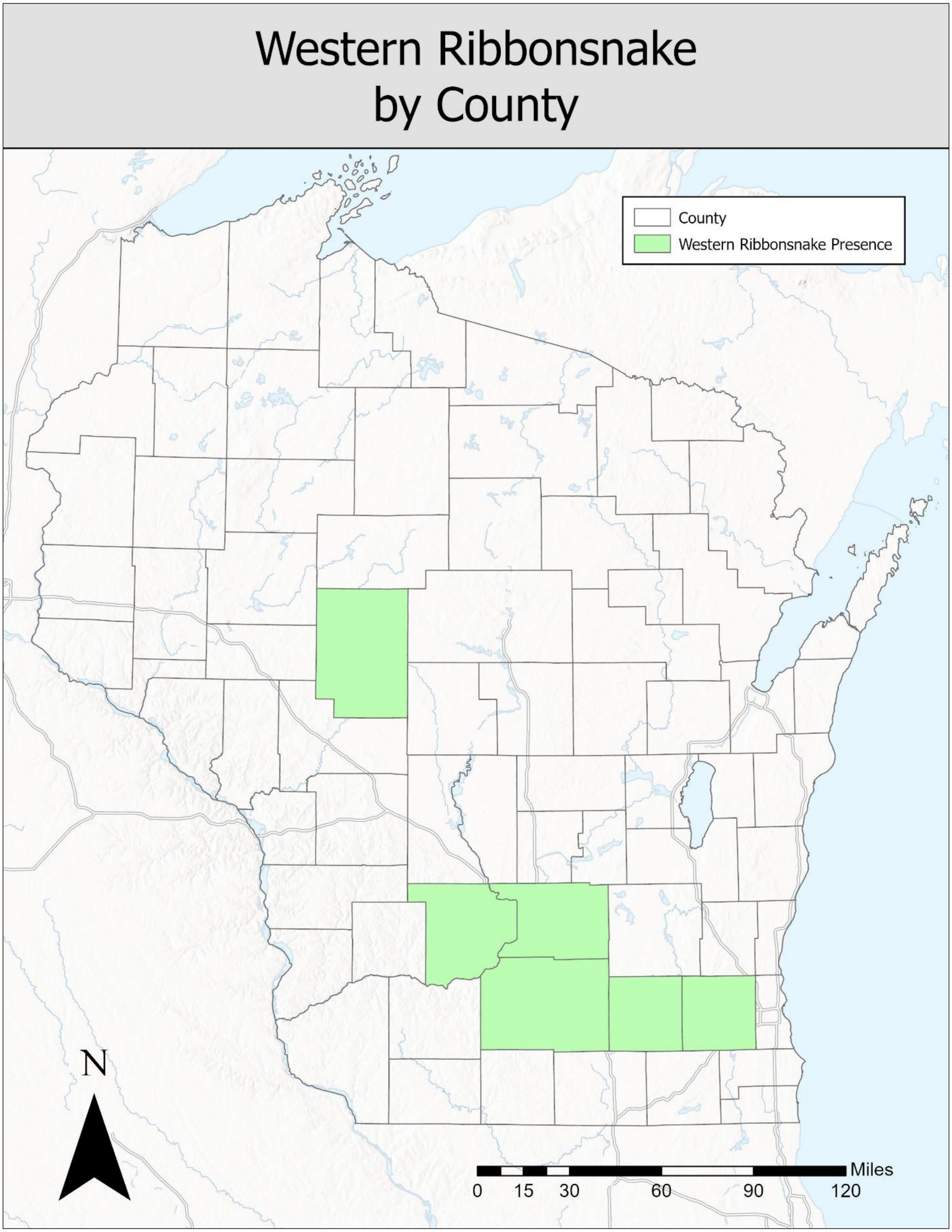

Figure 51: Counties with recorded presence of Western ribbonsnake (Thamnophis proximus) (Wisconsin DNR, 2025a).

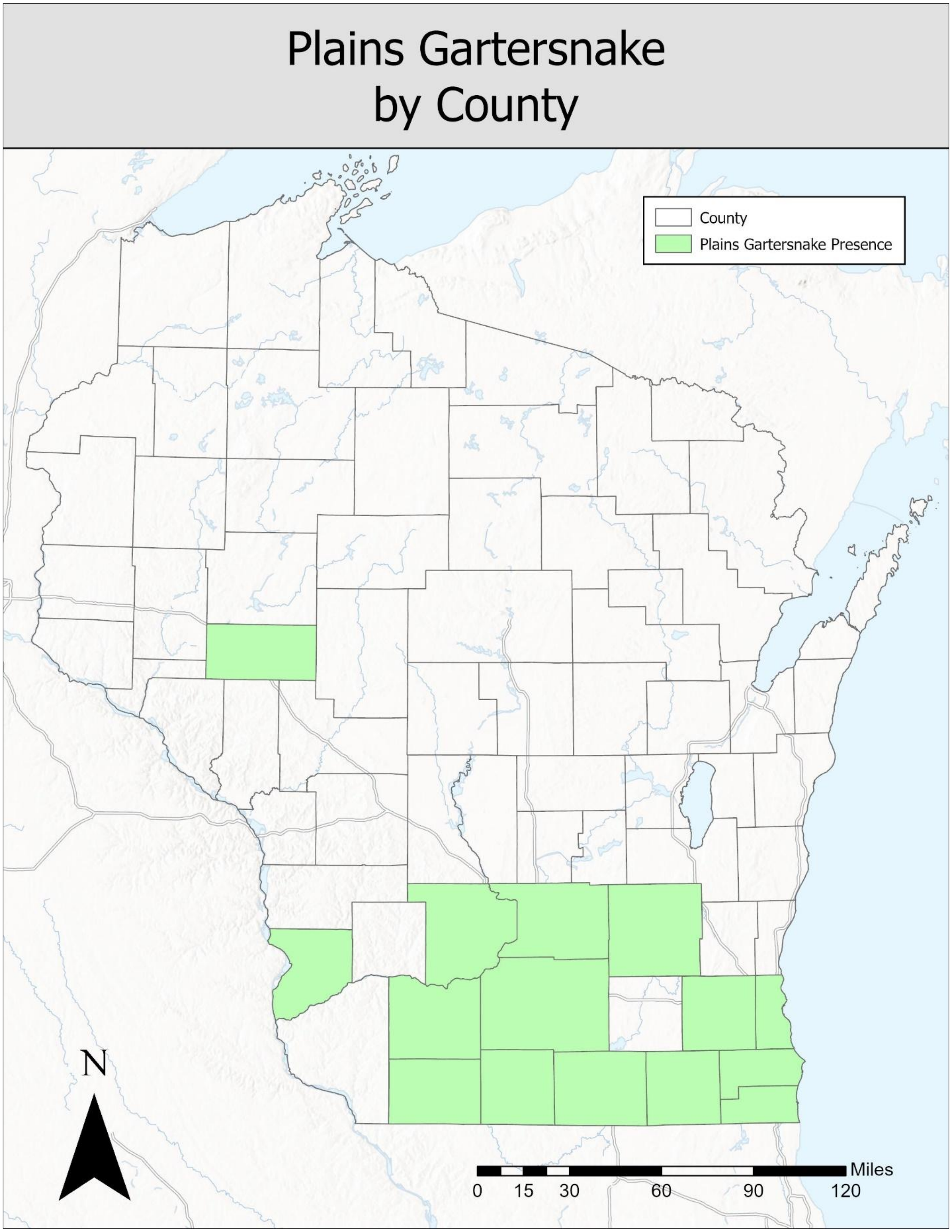

Figure 52: Counties with recorded presence of Plains gartersnake (Thamnophis radix) (Wisconsin DNR, 2025a).

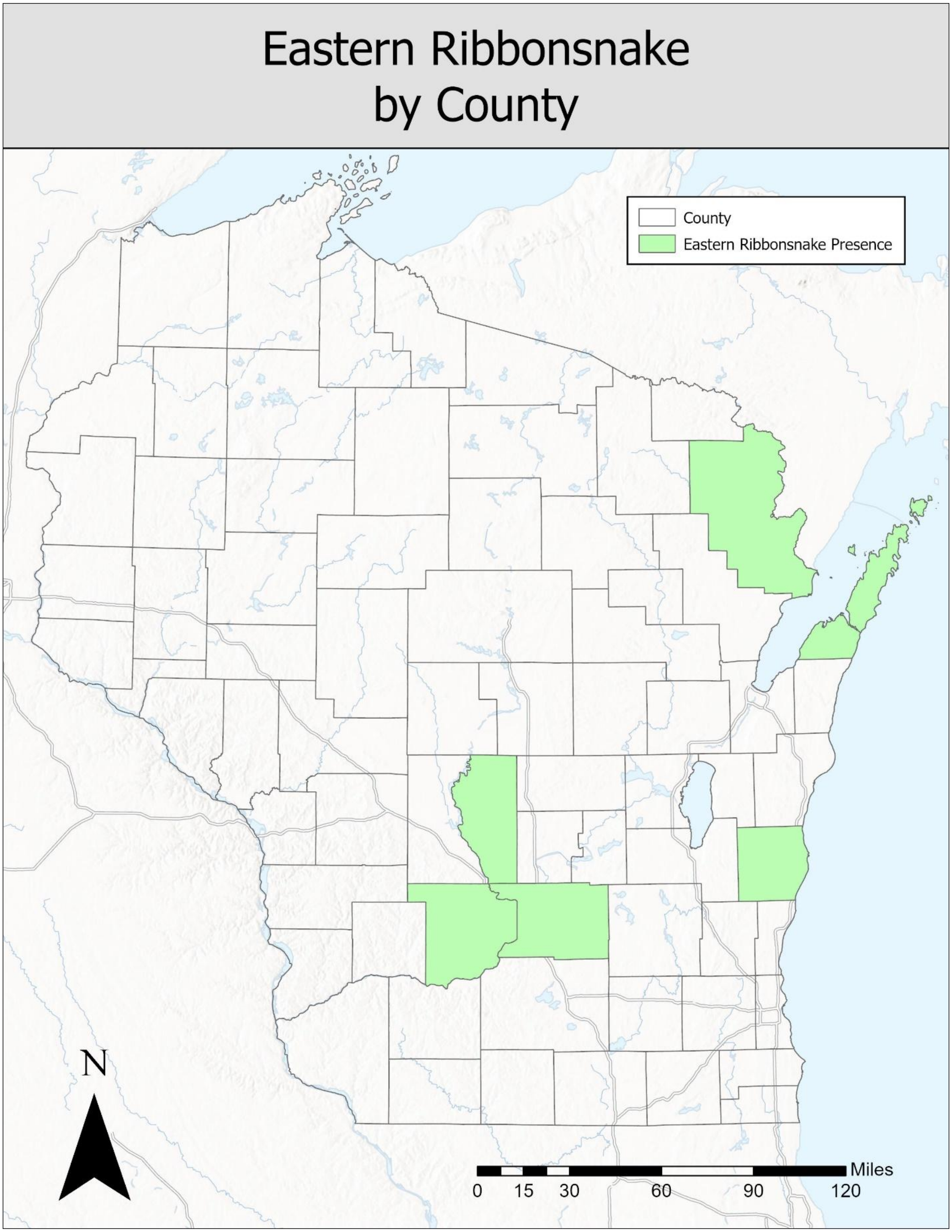

Figure 53: Counties with recorded presence of Eastern ribbonsnake (Thamnophis saurita) (Wisconsin DNR, 2025a).

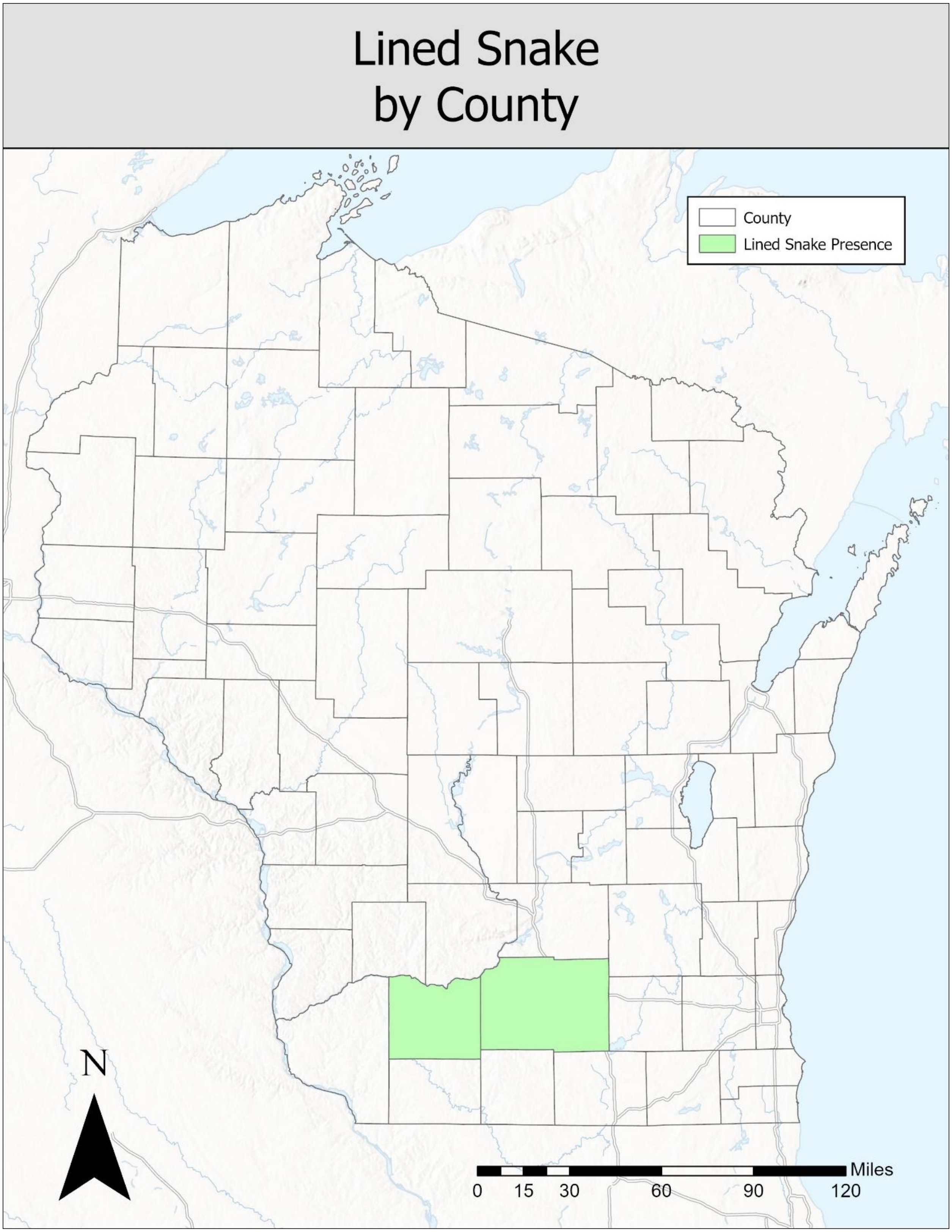

Figure 54: Counties with recorded presence of Lined snake (Tropidoclonion lineatum) (Wisconsin DNR, 2025a).

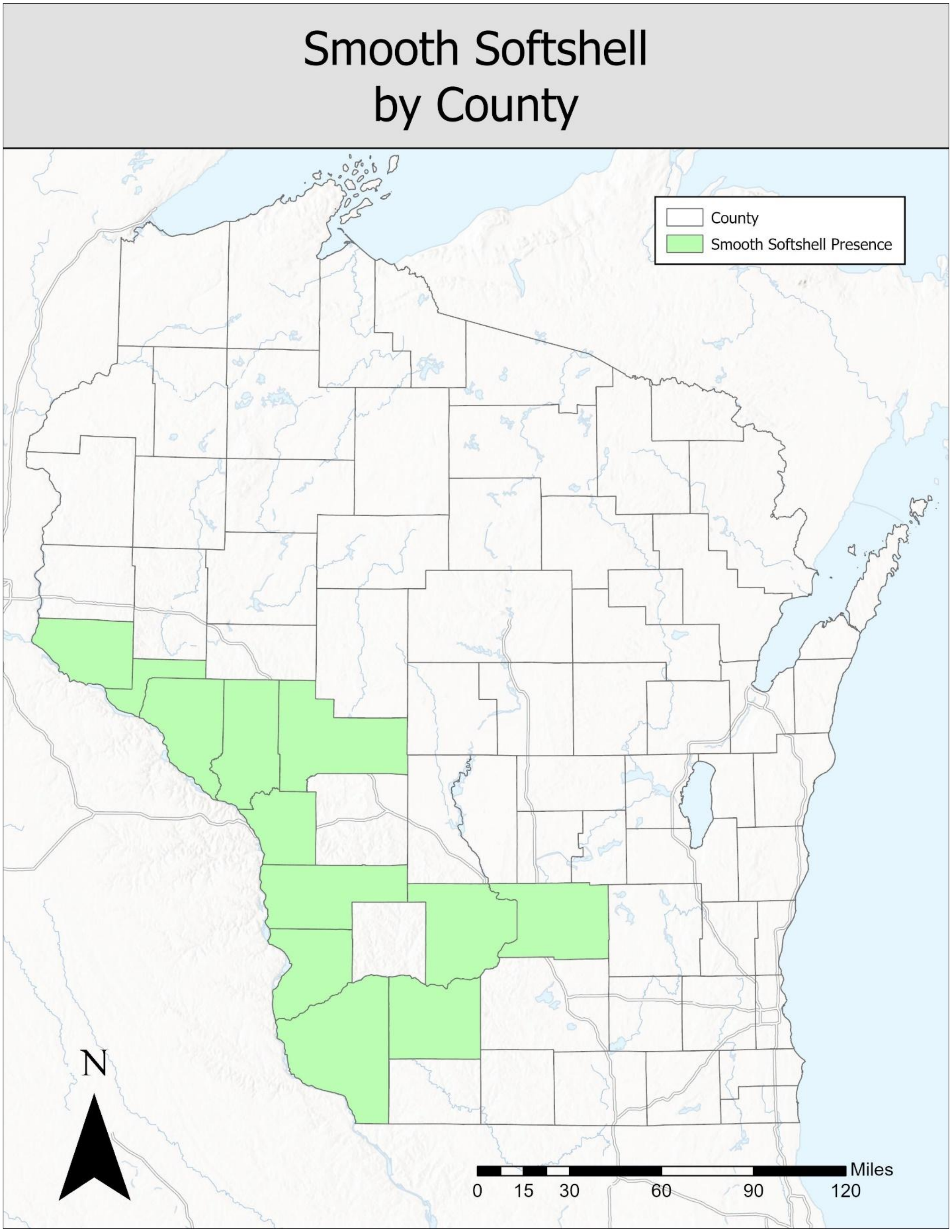

Figure 55: Counties with recorded presence of Smooth softshell turtle (Apalone mutica) (Wisconsin DNR, 2025a).

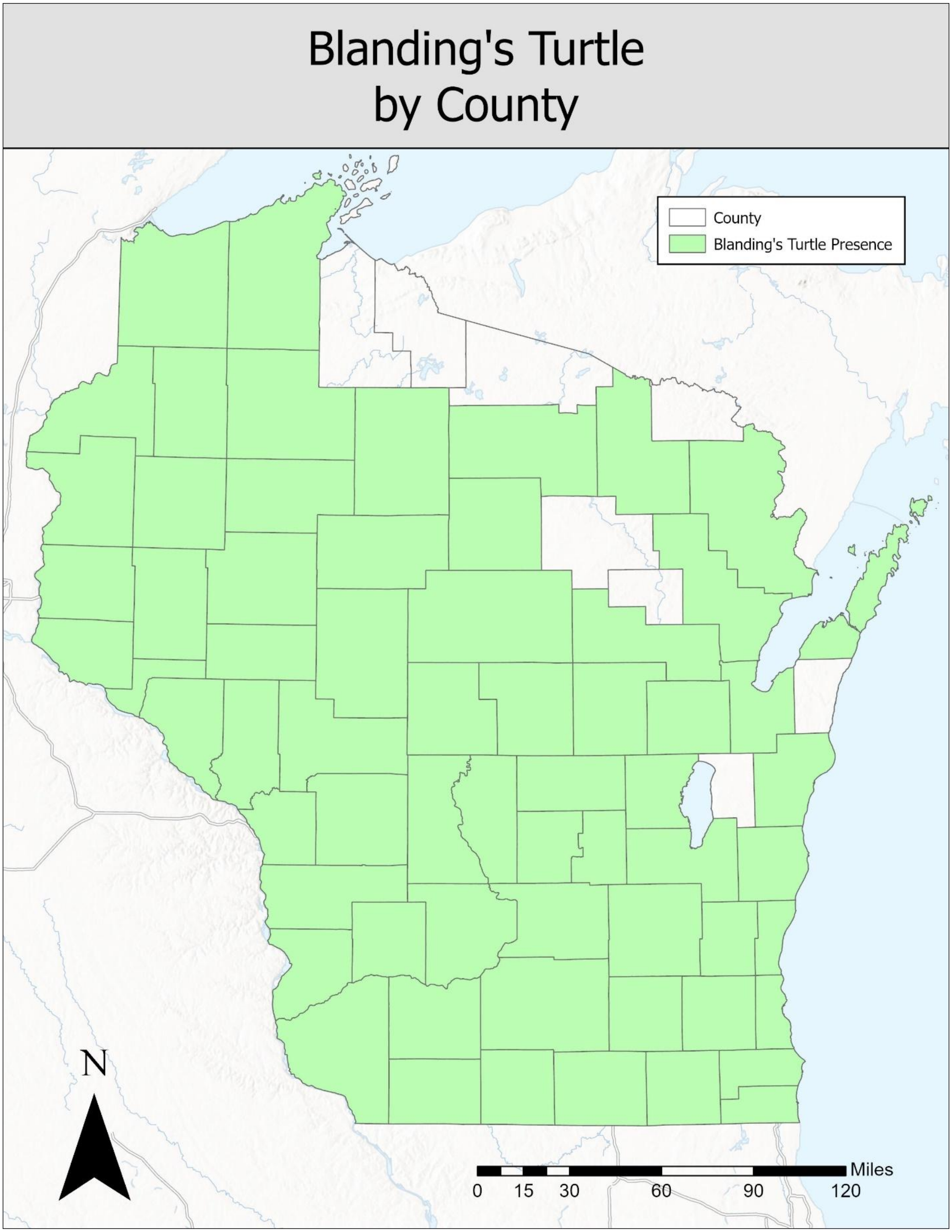

Figure 56: Counties with recorded presence of Blanding's turtle (Emydoidea blandingii) (Wisconsin DNR, 2025a).

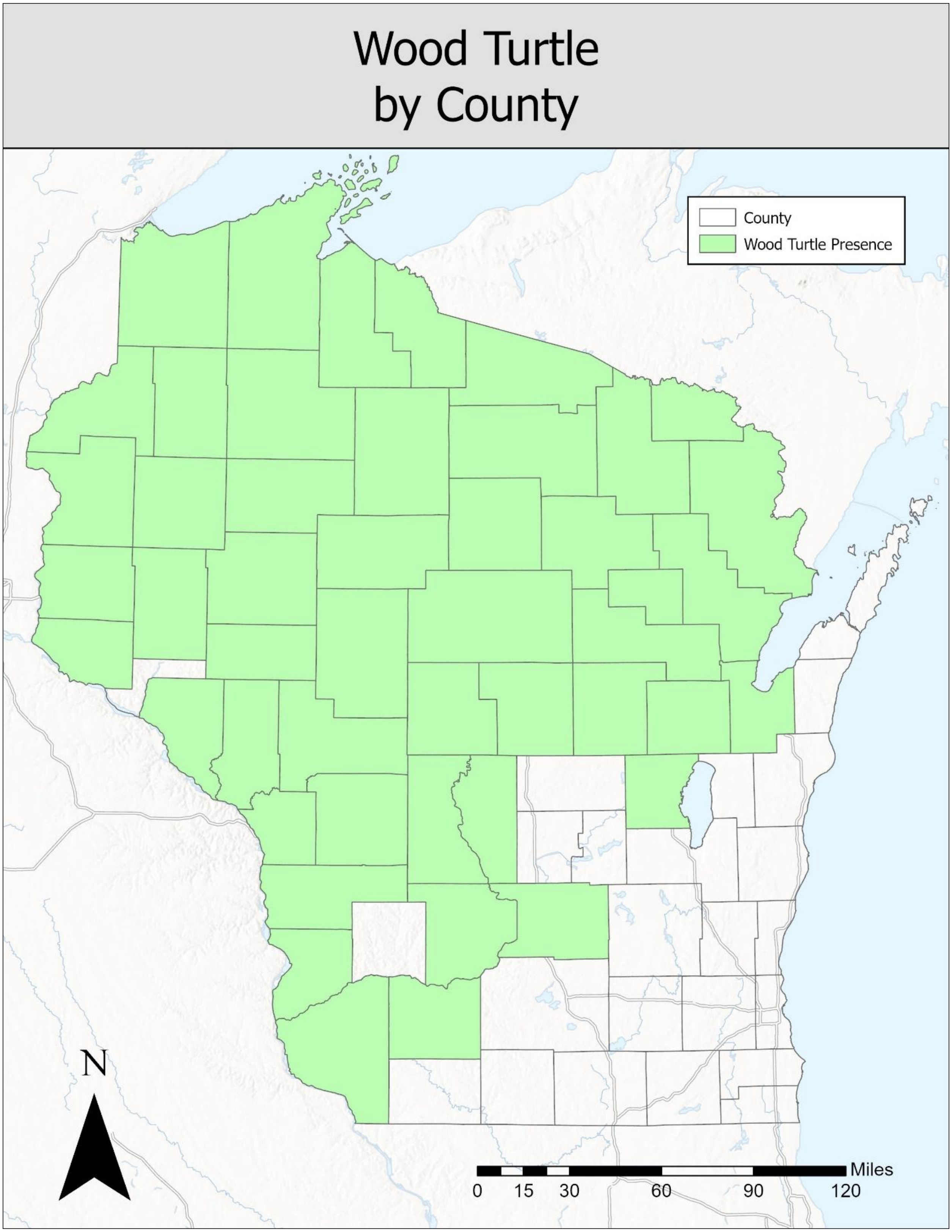

Figure 57: Counties with recorded presence of Wood turtle (Glyptemys insculpta) (Wisconsin DNR, 2025a).

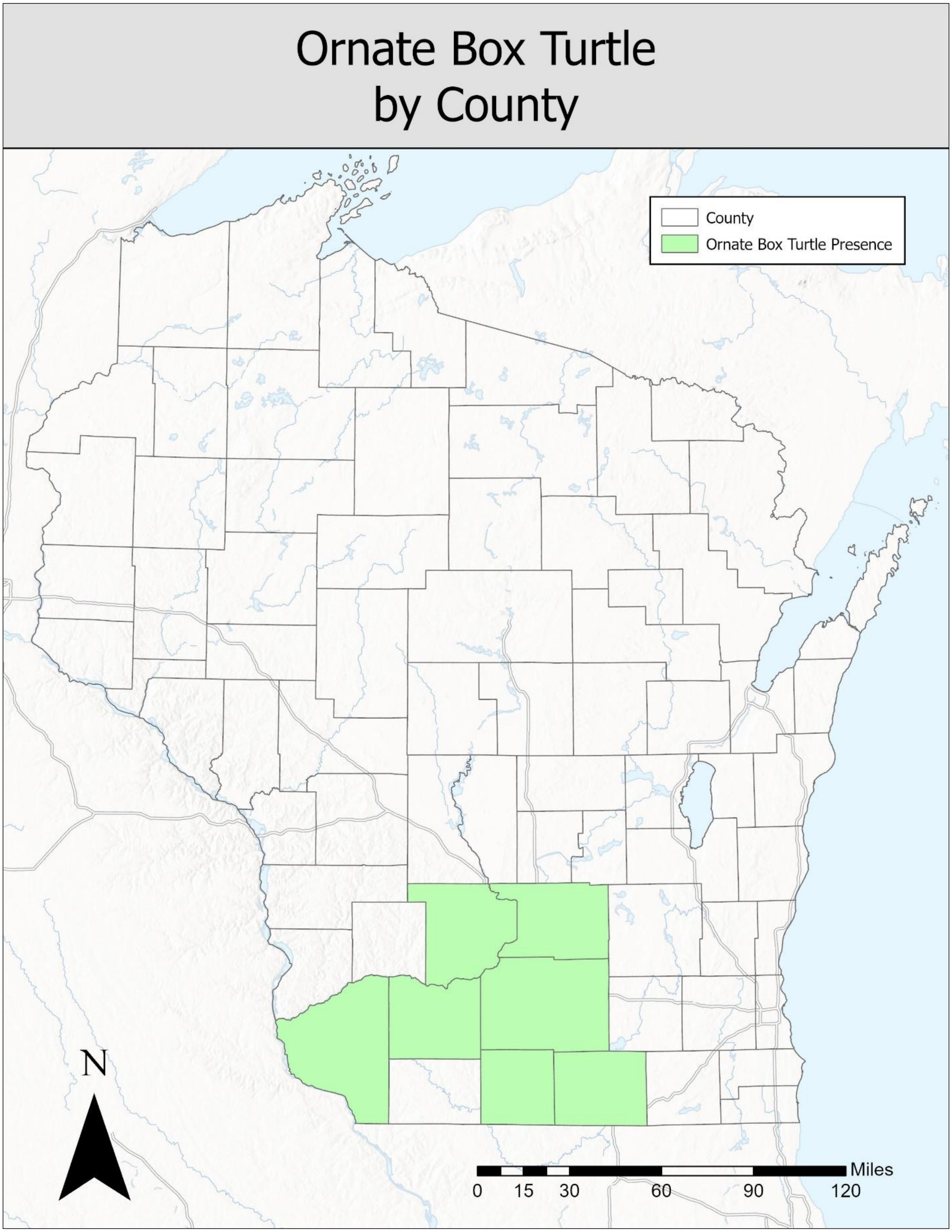

Figure 58: Counties with recorded presence of Ornate box turtle (Terrapene ornata) (Wisconsin DNR, 2025a).

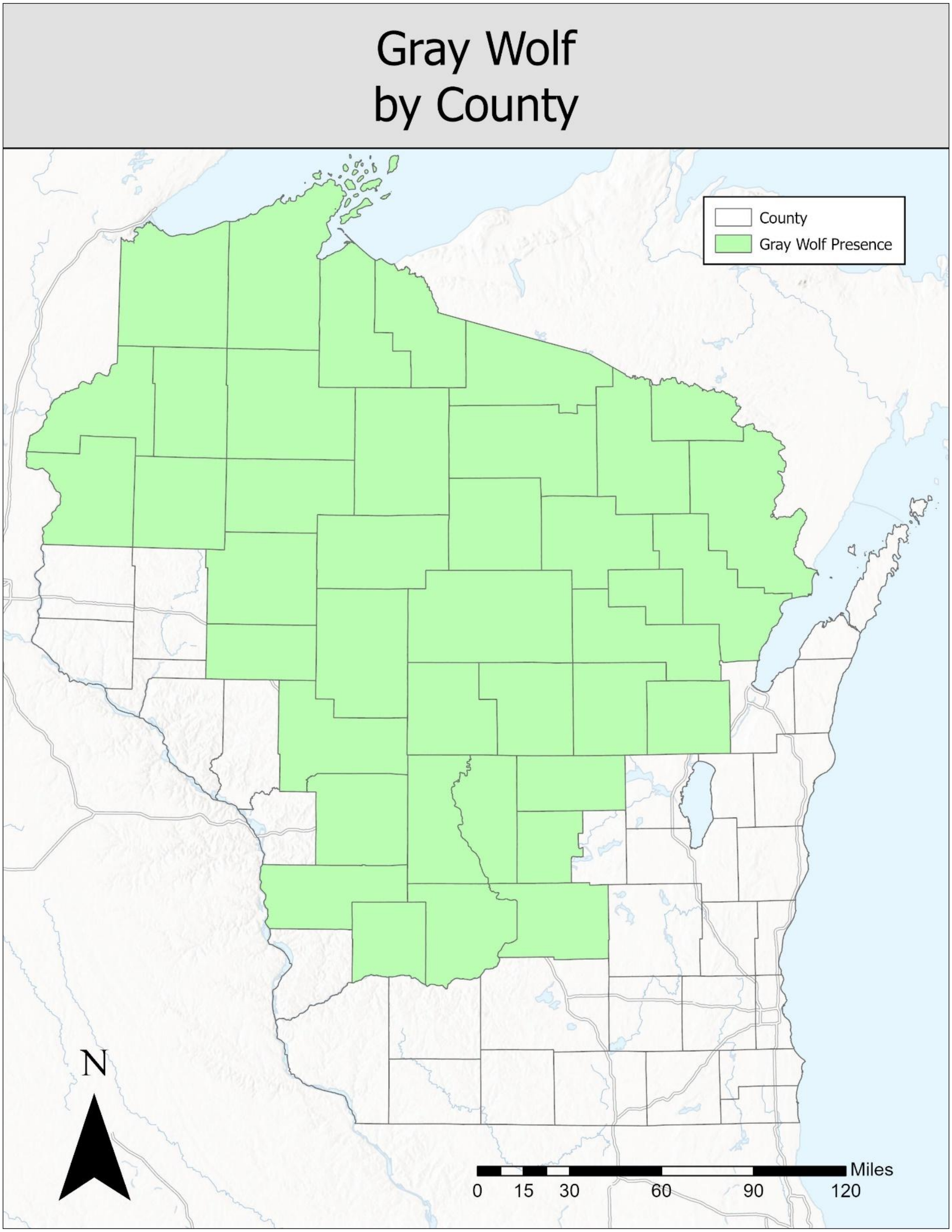

Figure 59: Counties with a probability of gray wolf (Canis lupus) presence greater than zero (Wisconsin DNR, 2025a).

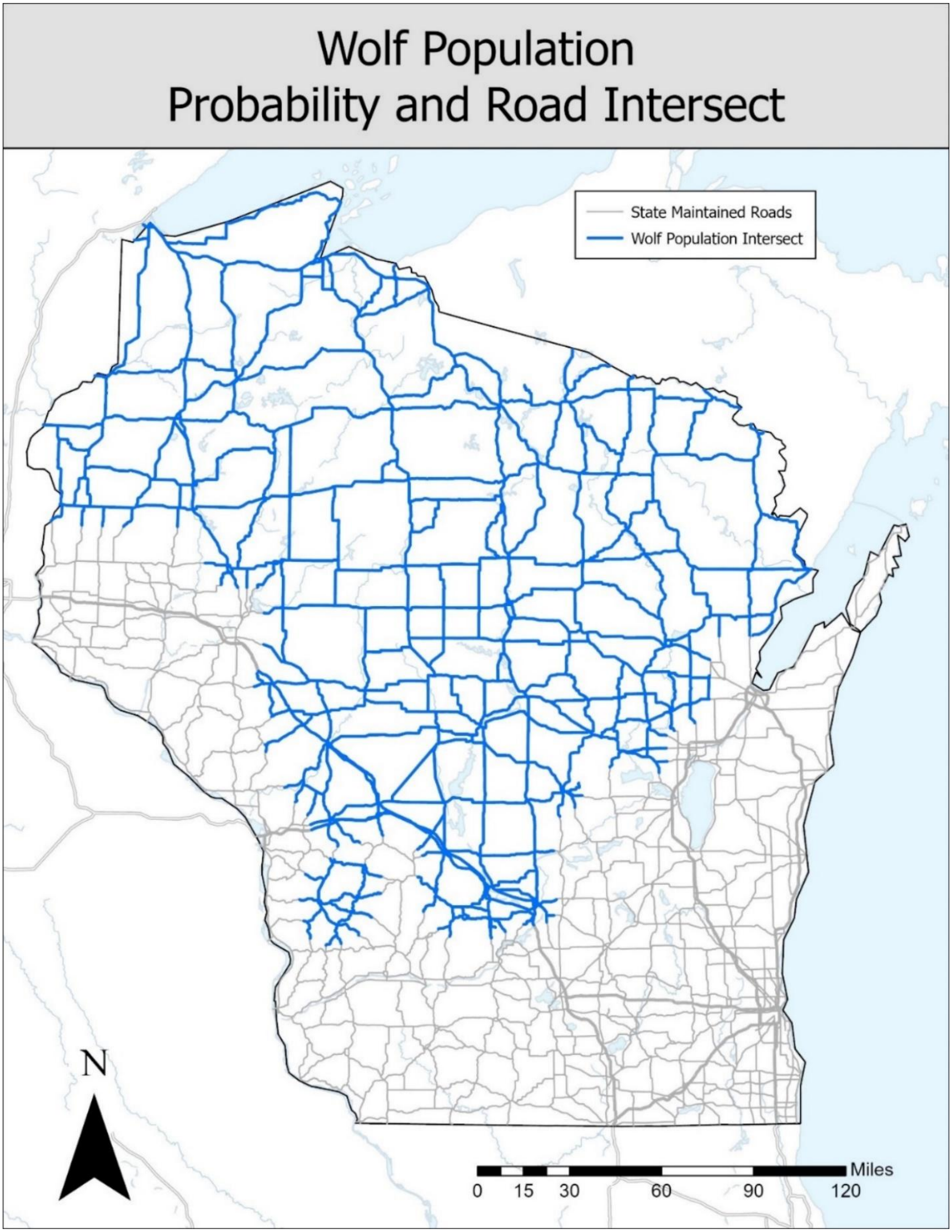

Figure 60: Roads and road segments that are inside polygons that have a greater than zero probability of gray wolf (Canis lupus) presence, and up to 6.21 mi (10 km) from the boundaries of a gray wolf polygon (data provided by Wisconsin DNR).

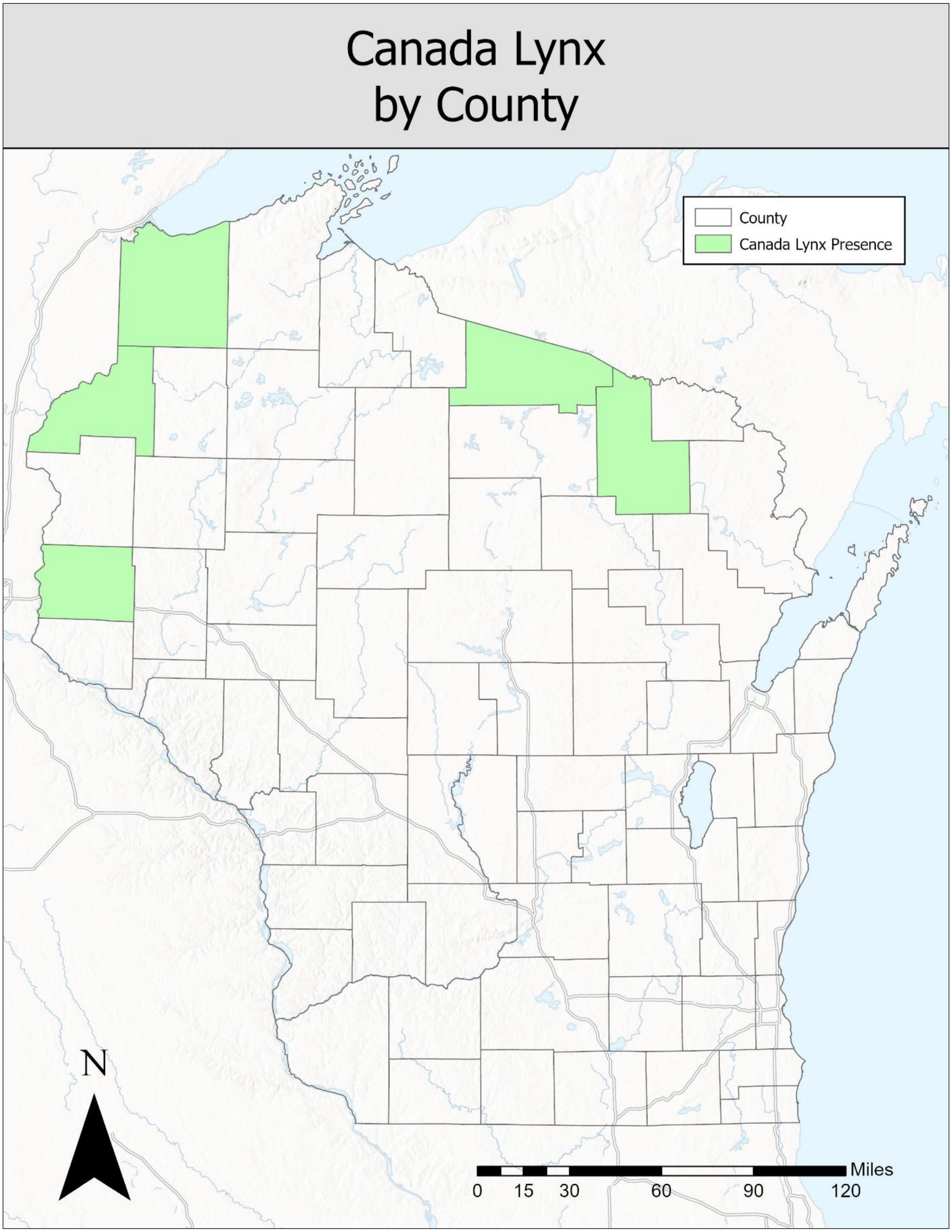

Figure 61: Counties with recorded presence (1992-2004) of Canada lynx (Lynx canadensis) (Wydeven et al., 2004).

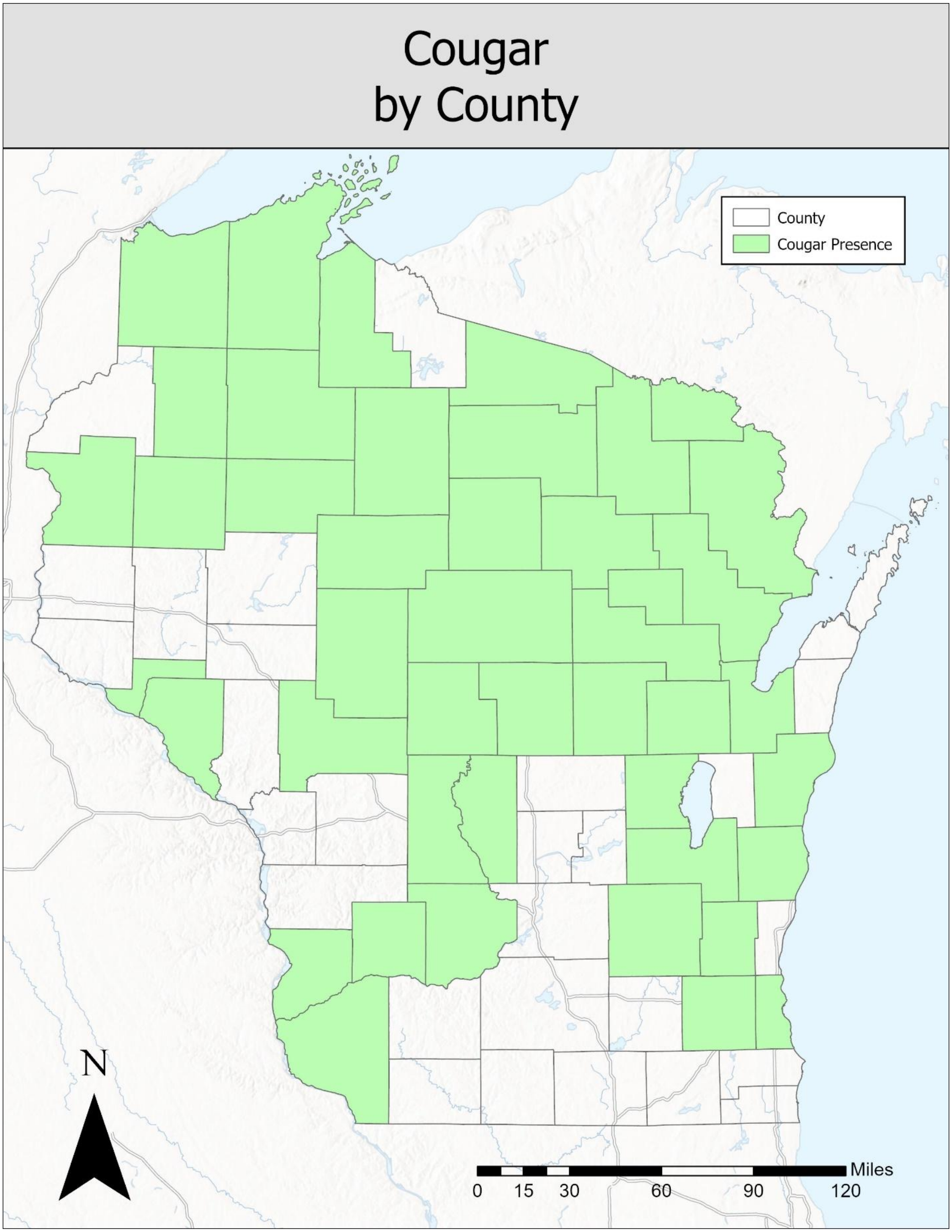

Figure 62: Counties with recorded presence (January 2017 – March 2025) of Cougar (Puma concolor) (Wisconsin DNR, 2025b).

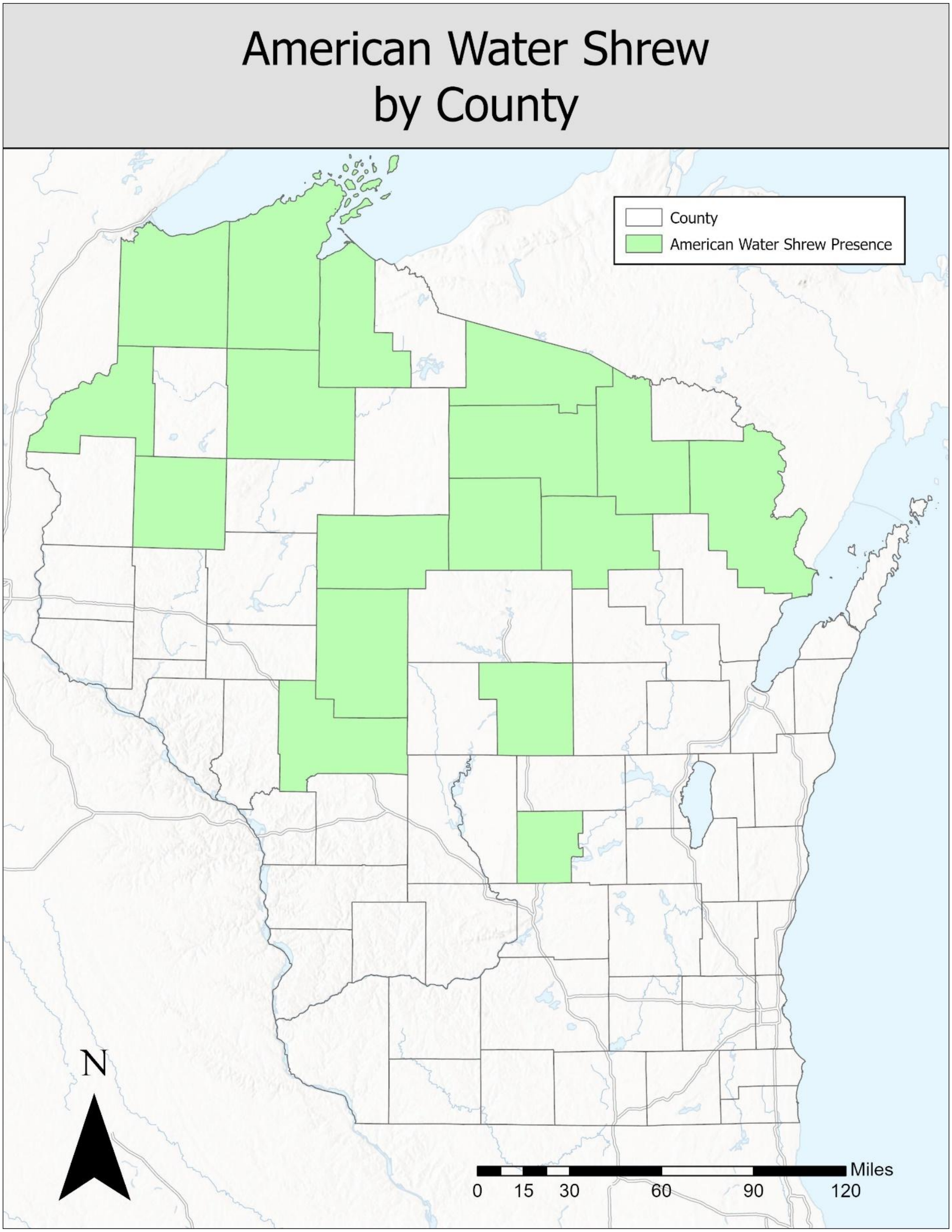

Figure 63: Counties with recorded presence of American water shrew (Sorex palustris) (Wisconsin DNR, 2025a).

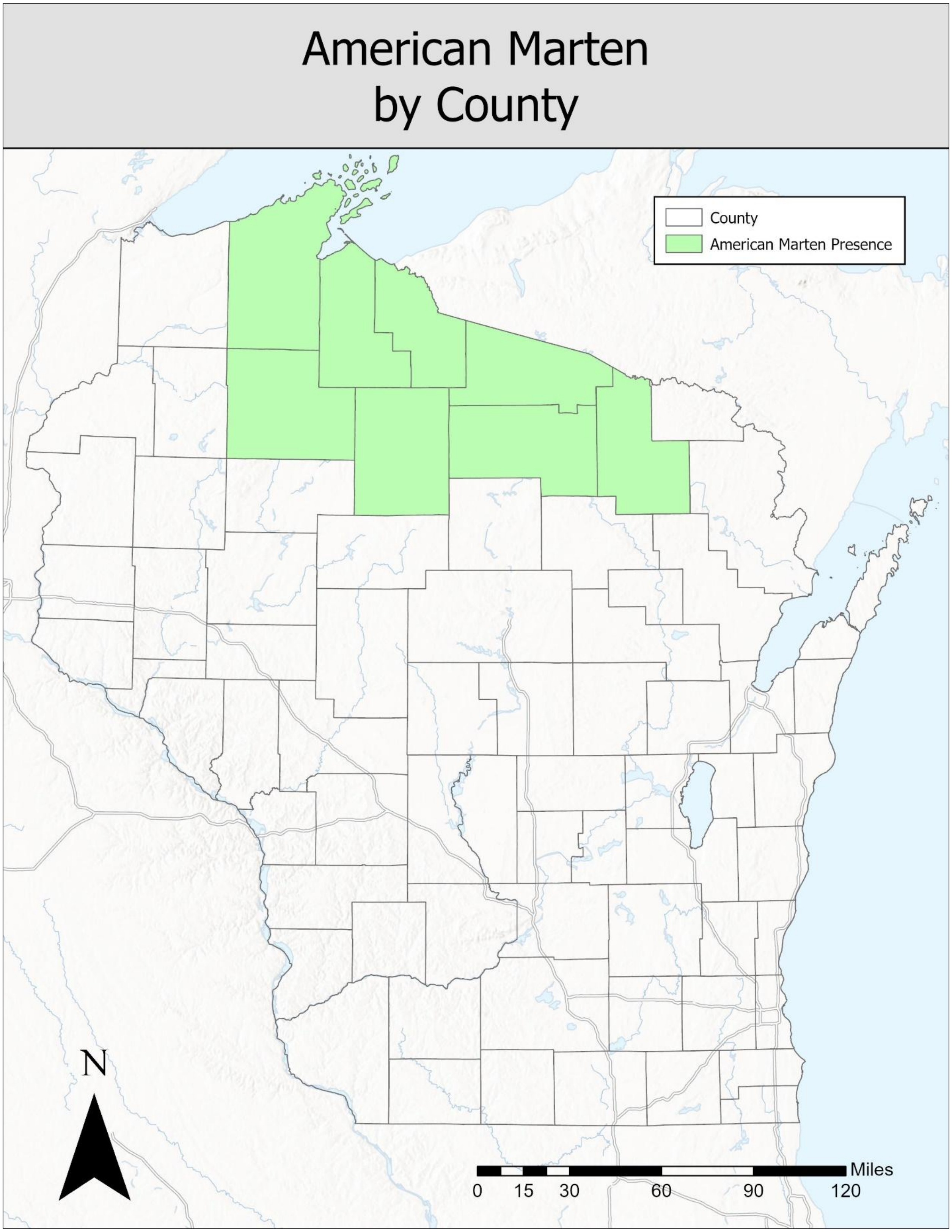

Figure 64: Counties with recorded presence of American marten (Martes americana) (Wisconsin DNR, 2025a).

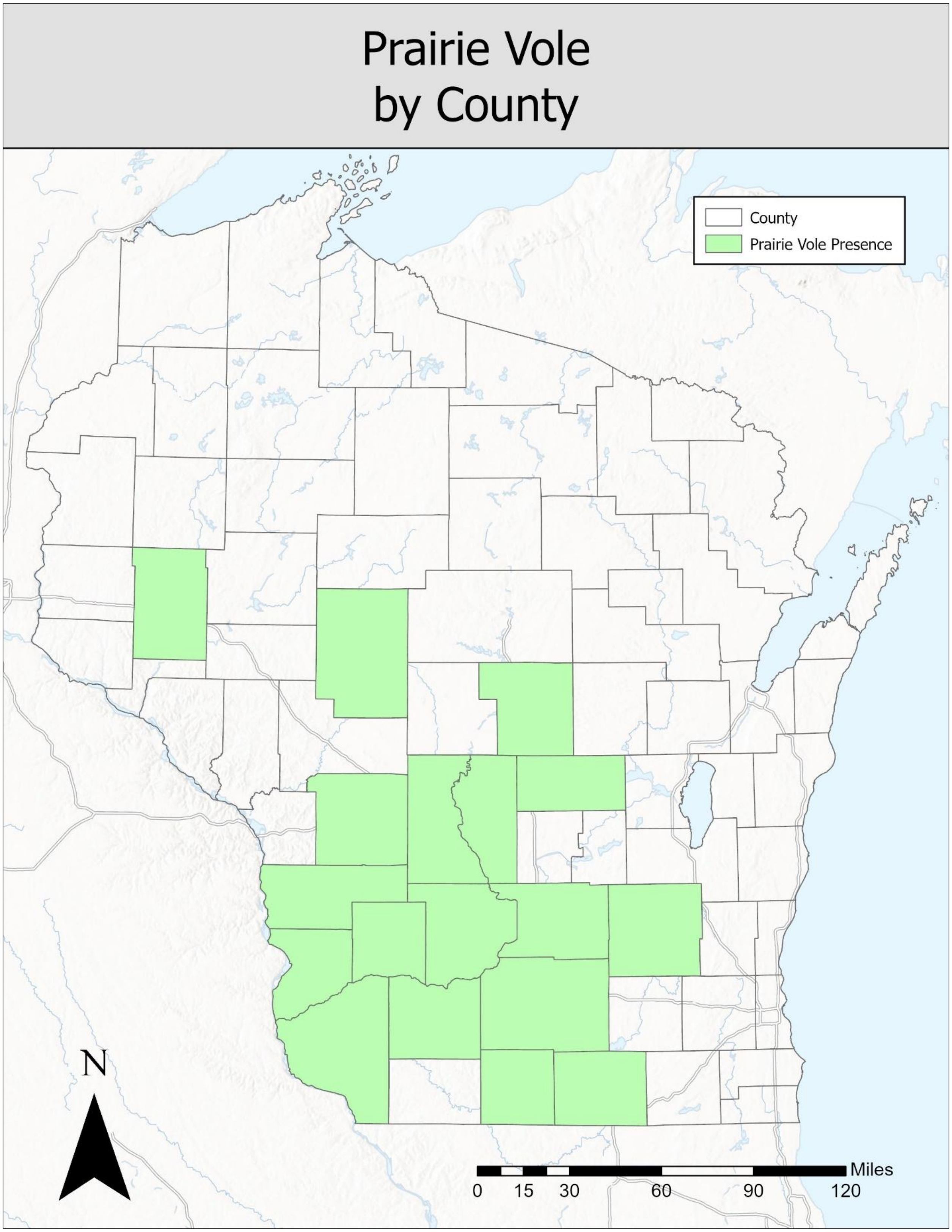

Figure 65: Counties with recorded presence of Prairie vole (Microtus ochrogaster) (Wisconsin DNR, 2025a).

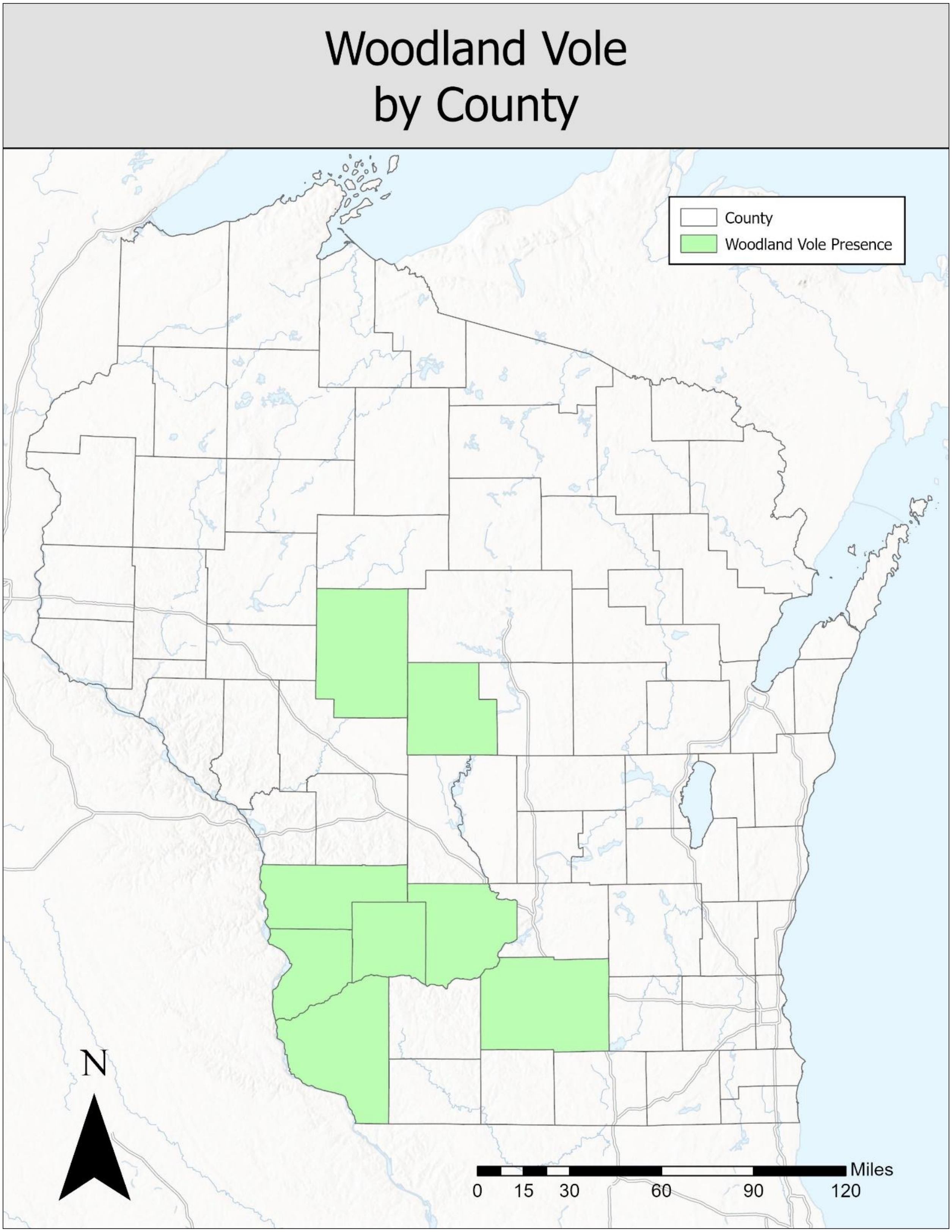

Figure 66: Counties with recorded presence of Woodland vole (Microtus pinetorum) (Wisconsin DNR, 2025a).

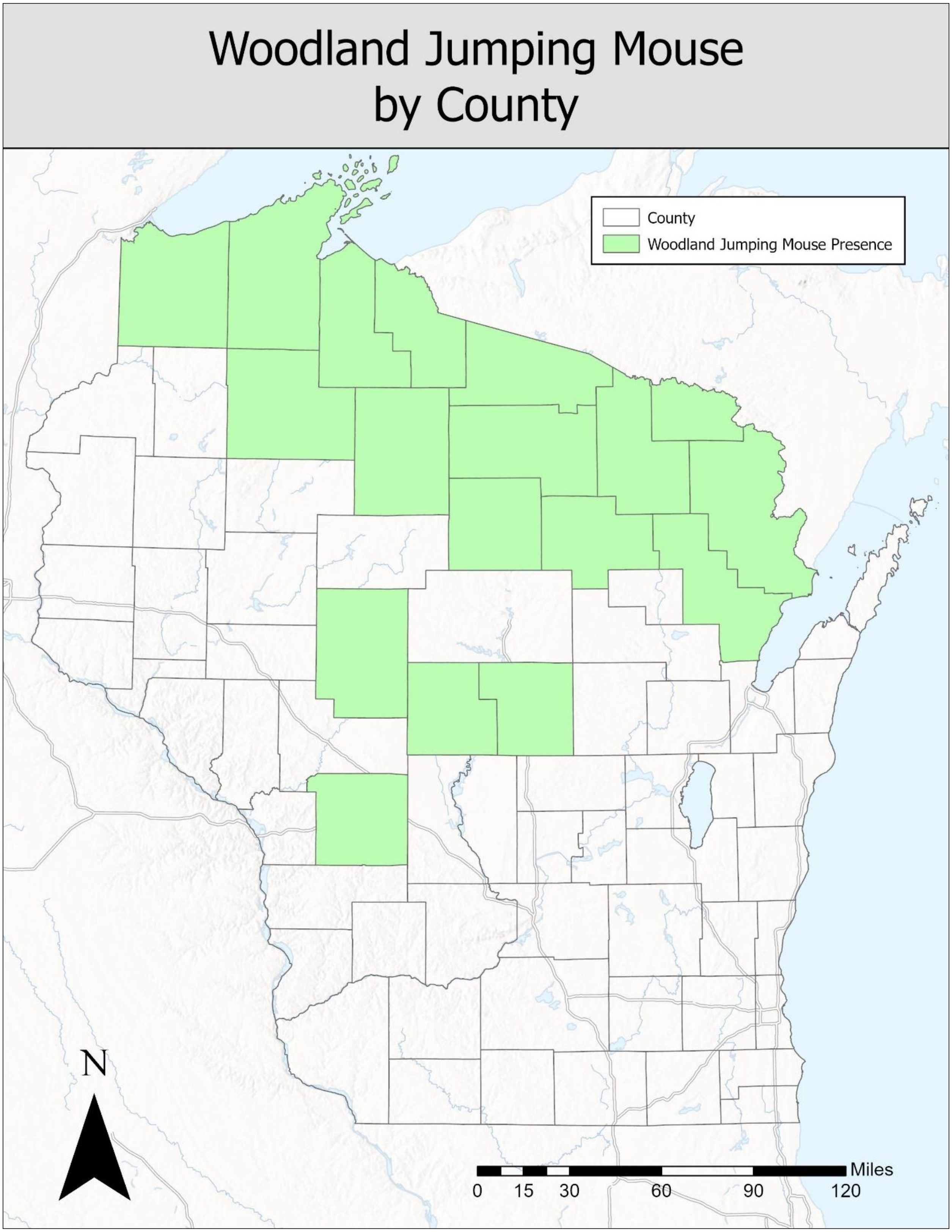

Figure 67: Counties with recorded presence of Woodland jumping mouse (Napaeozapus insignis) (Wisconsin DNR, 2025a).

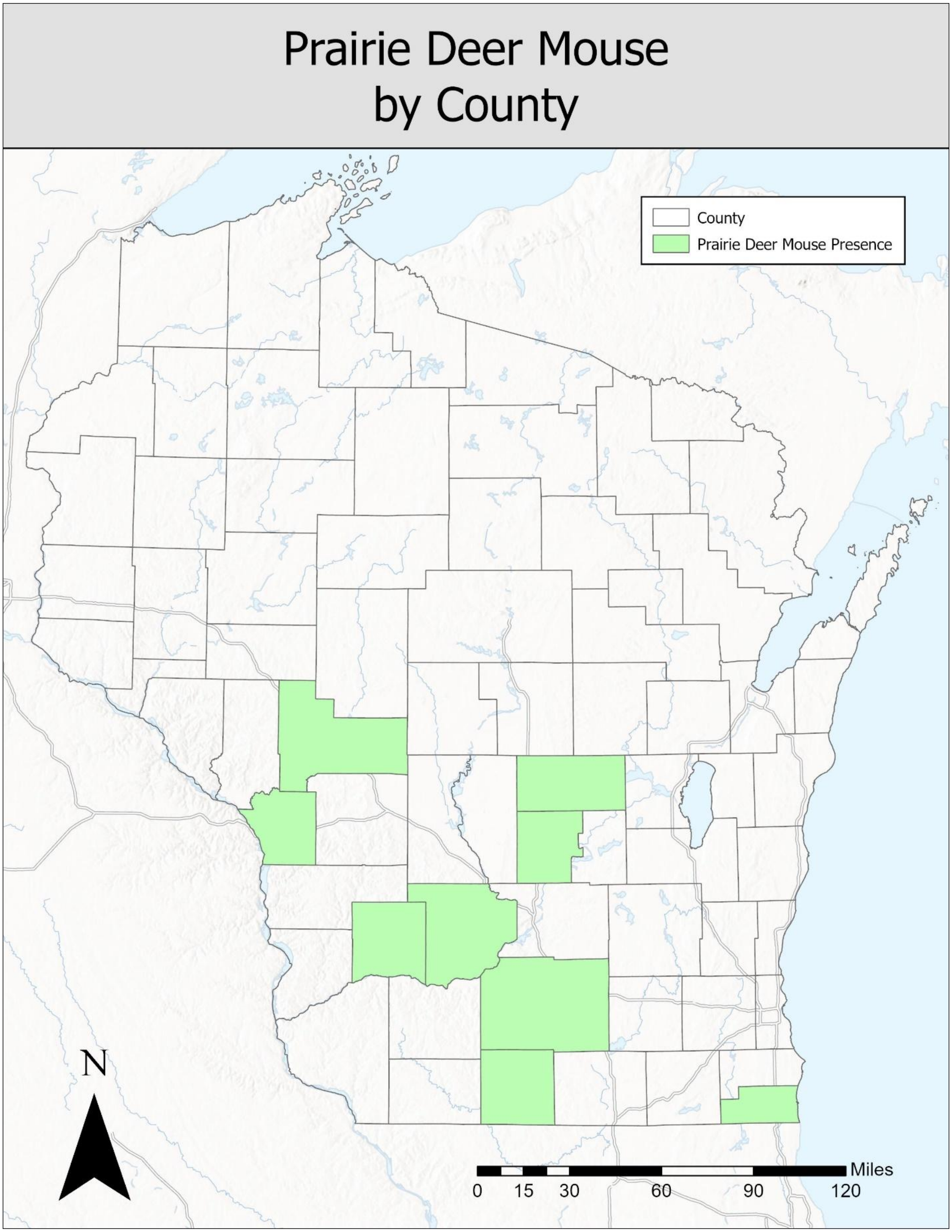

Figure 68: Counties with recorded presence of Prairie deer mouse (Peromyscus maniculatus bairdii) (Wisconsin DNR, 2025a).

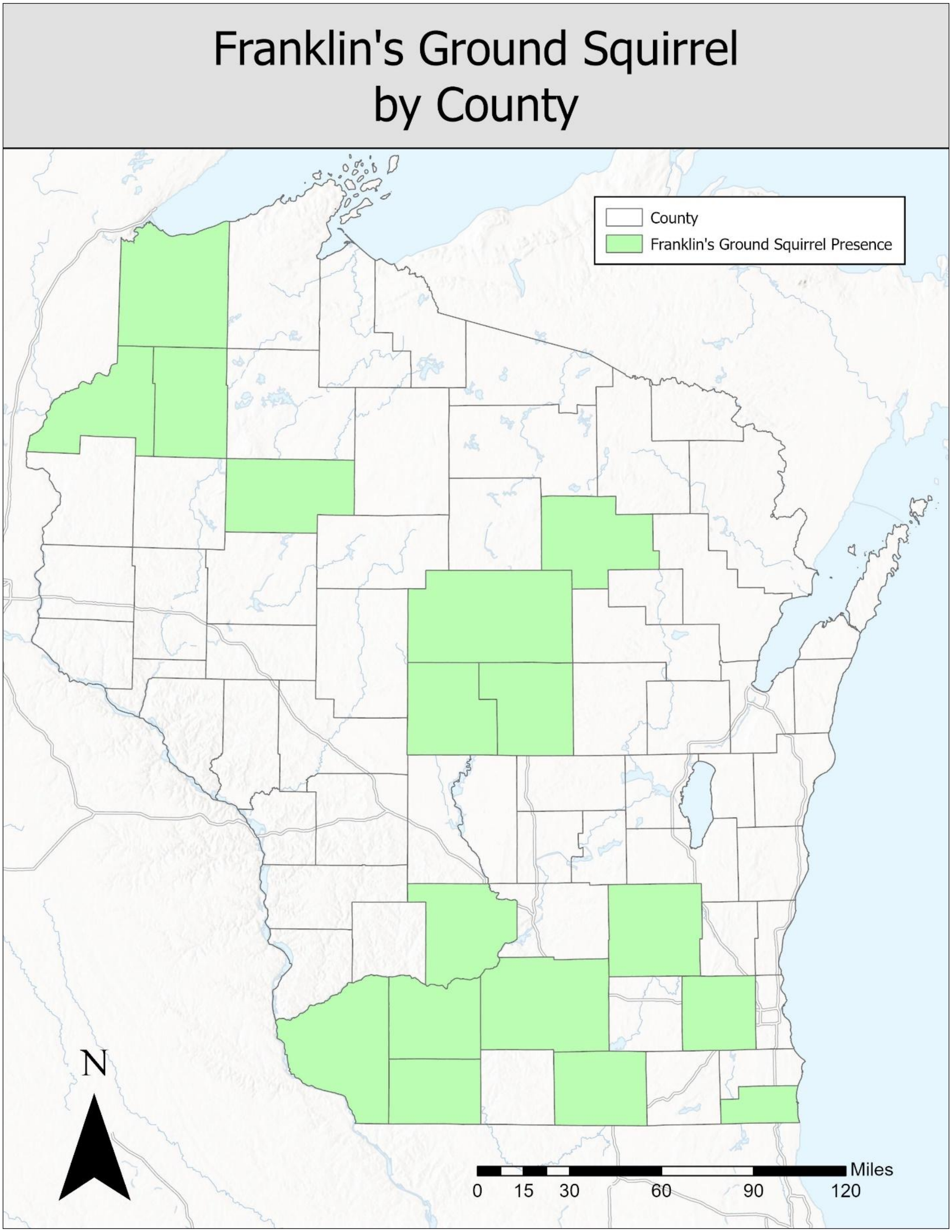

Figure 69: Counties with recorded presence of Franklin's ground squirrel (Poliocitellus franklinii) (Wisconsin DNR, 2025a).

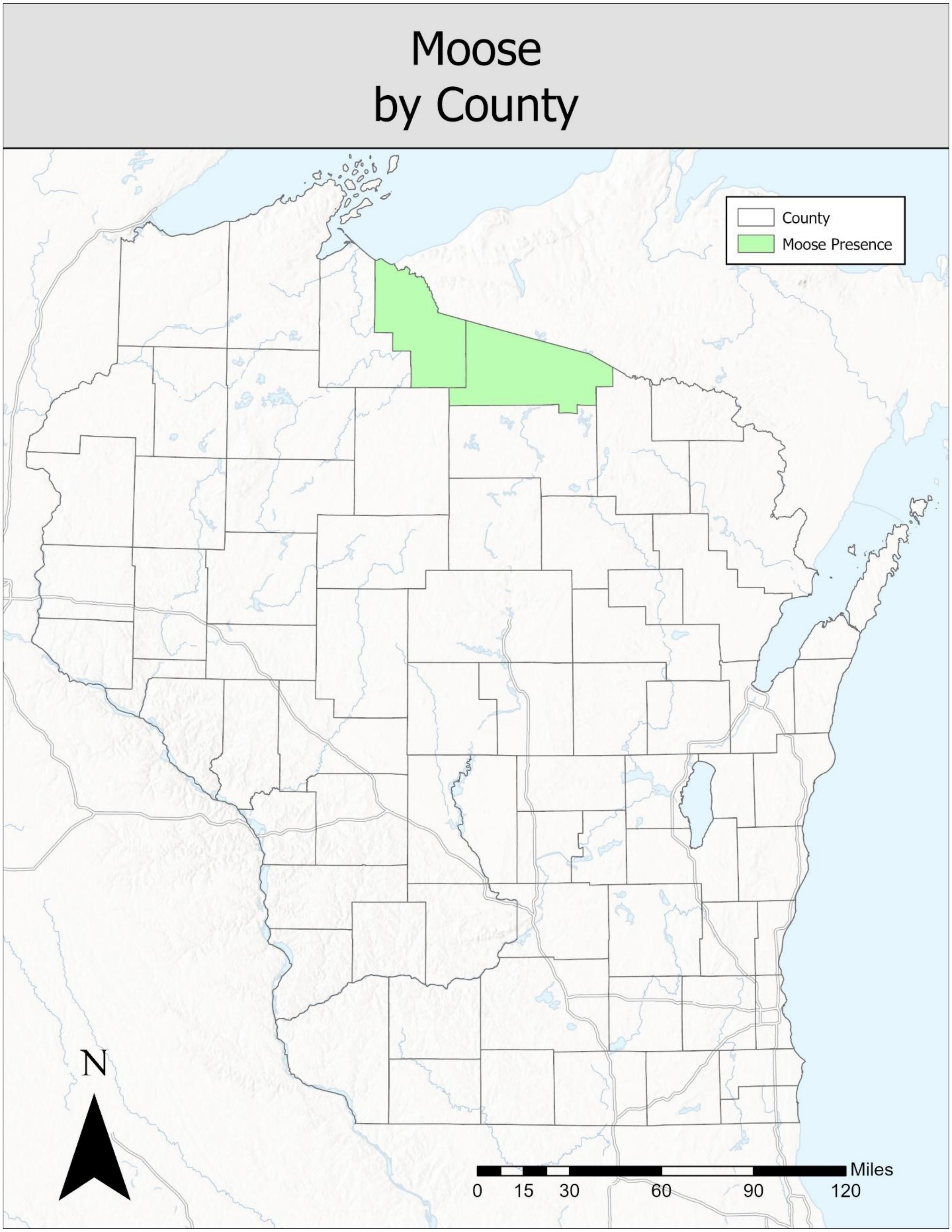

Figure 70: Counties with recorded presence of Moose (Alces alces) (Wisconsin DNR, 2025c).

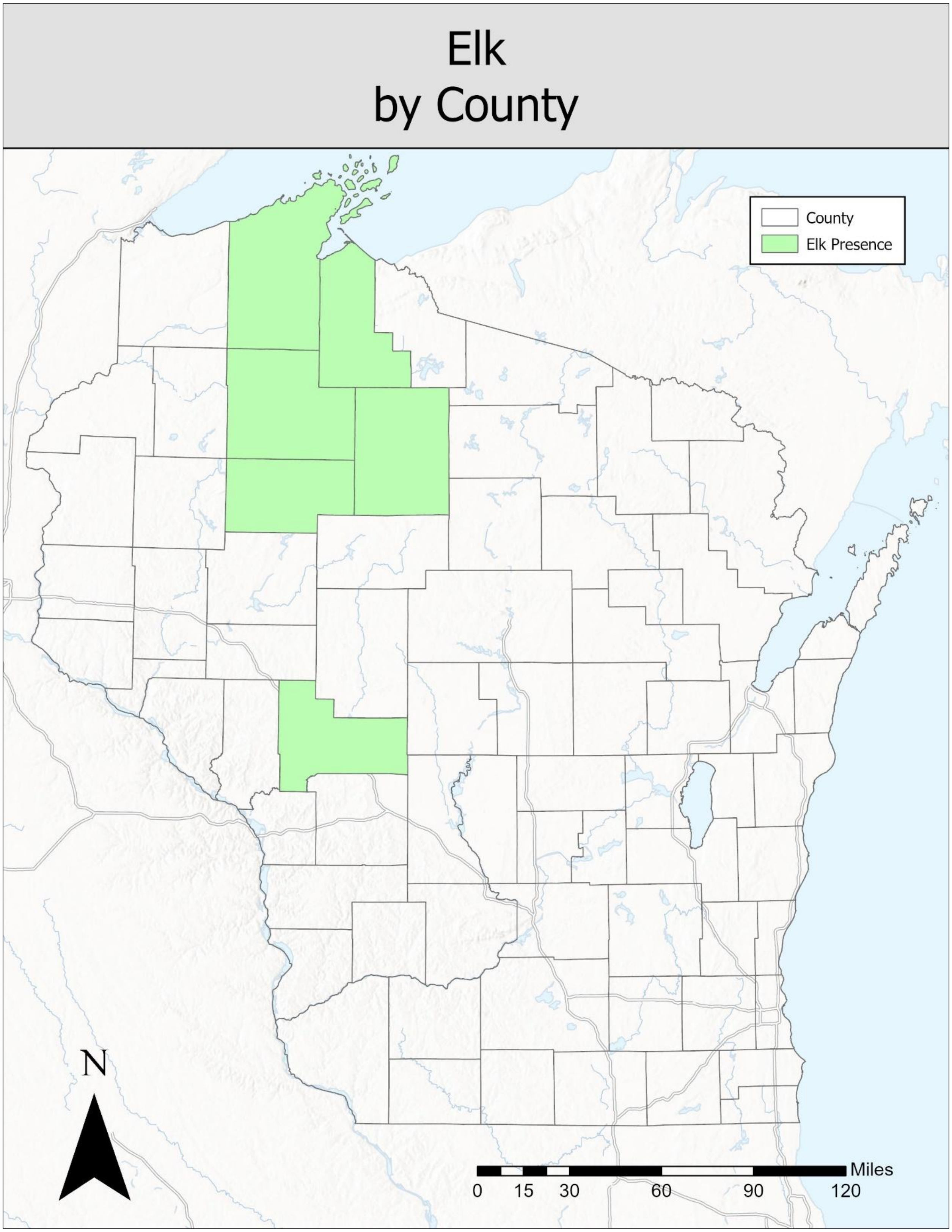

Figure 71: Counties with recorded presence of Elk (Cervus canadensis) (Wisconsin DNR, 2025c).

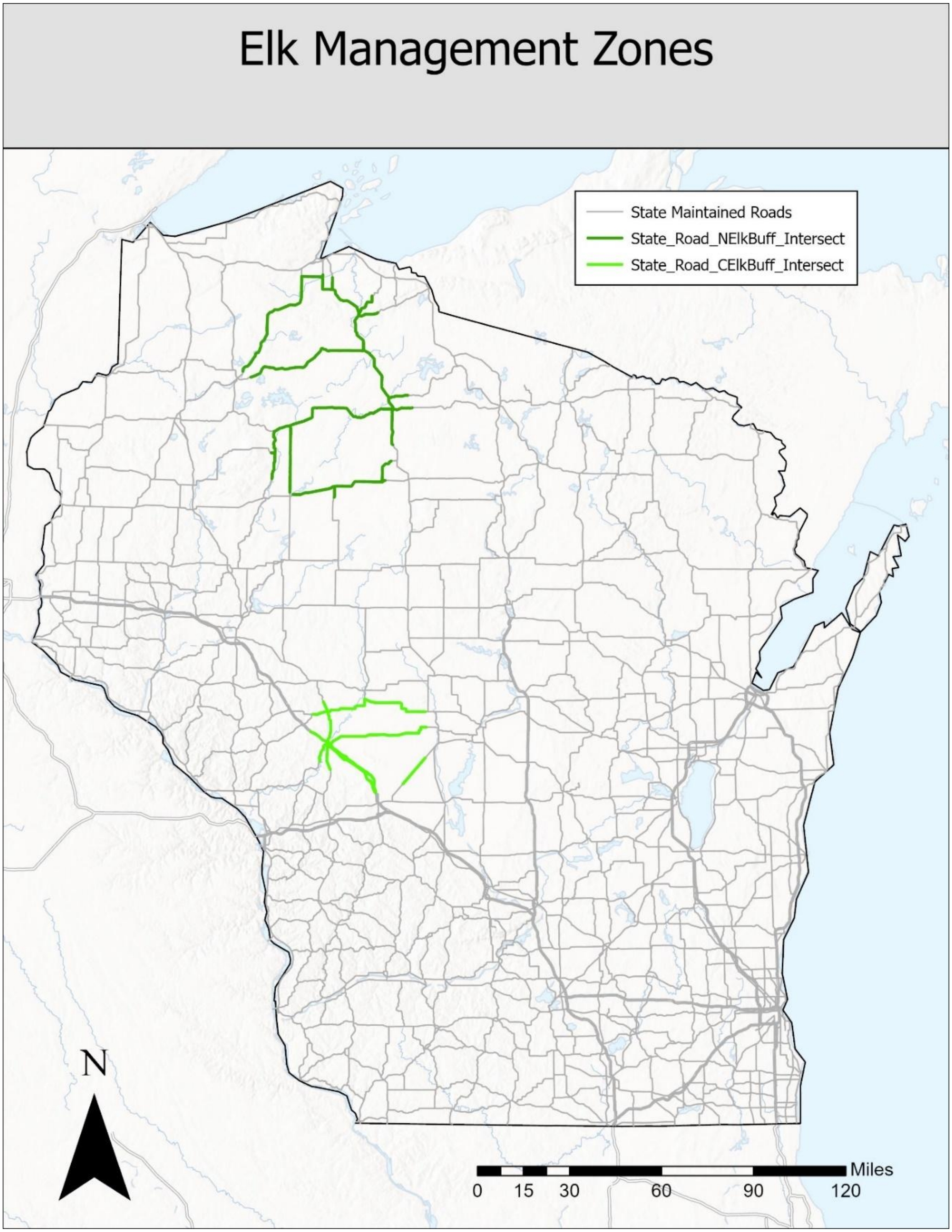

Figure 72: Roads and road segments that are inside the two elk management zones, and up to 6.21 mi (10 km) from the boundaries of an elk management zone (data provided by Wisconsin DNR).

8.3.3 Species groups maps

We counted how many amphibian, reptile, and mammal species that are of conservation concern were present in each county (Figure 73, Figure 74, Figure 75). The counties with the highest number of amphibian species were in southern Wisconsin. Reptile species of conservation concern were predominantly in counties in the southwest of the state. Mammal species of conservation concern were concentrated in northern and central Wisconsin. For all three species groups combined, the counties with the highest numbers were in southwestern Wisconsin (Figure 76).

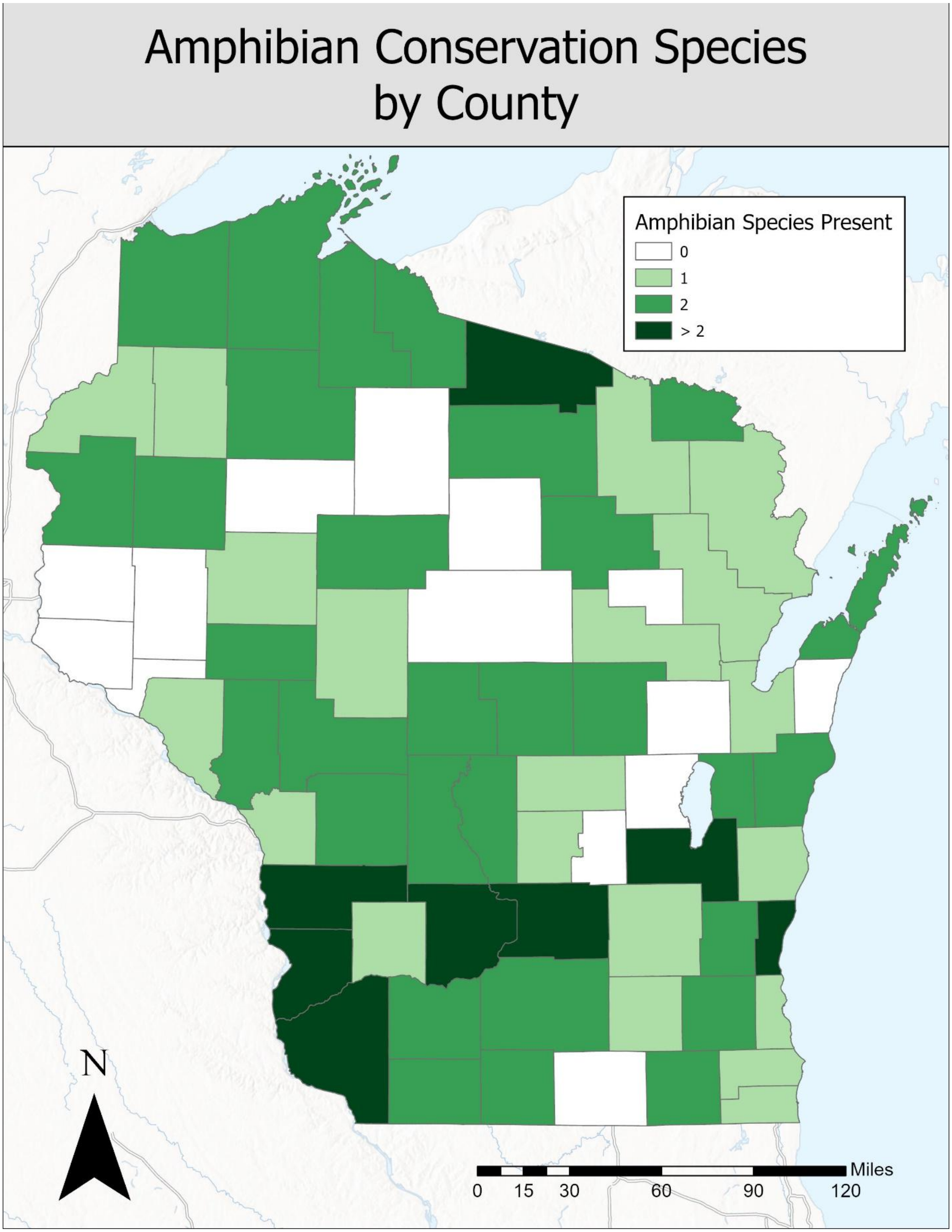

Figure 73: The number of amphibian species of conservation concern present in each county (based on Wisconsin DNR, 2025c).

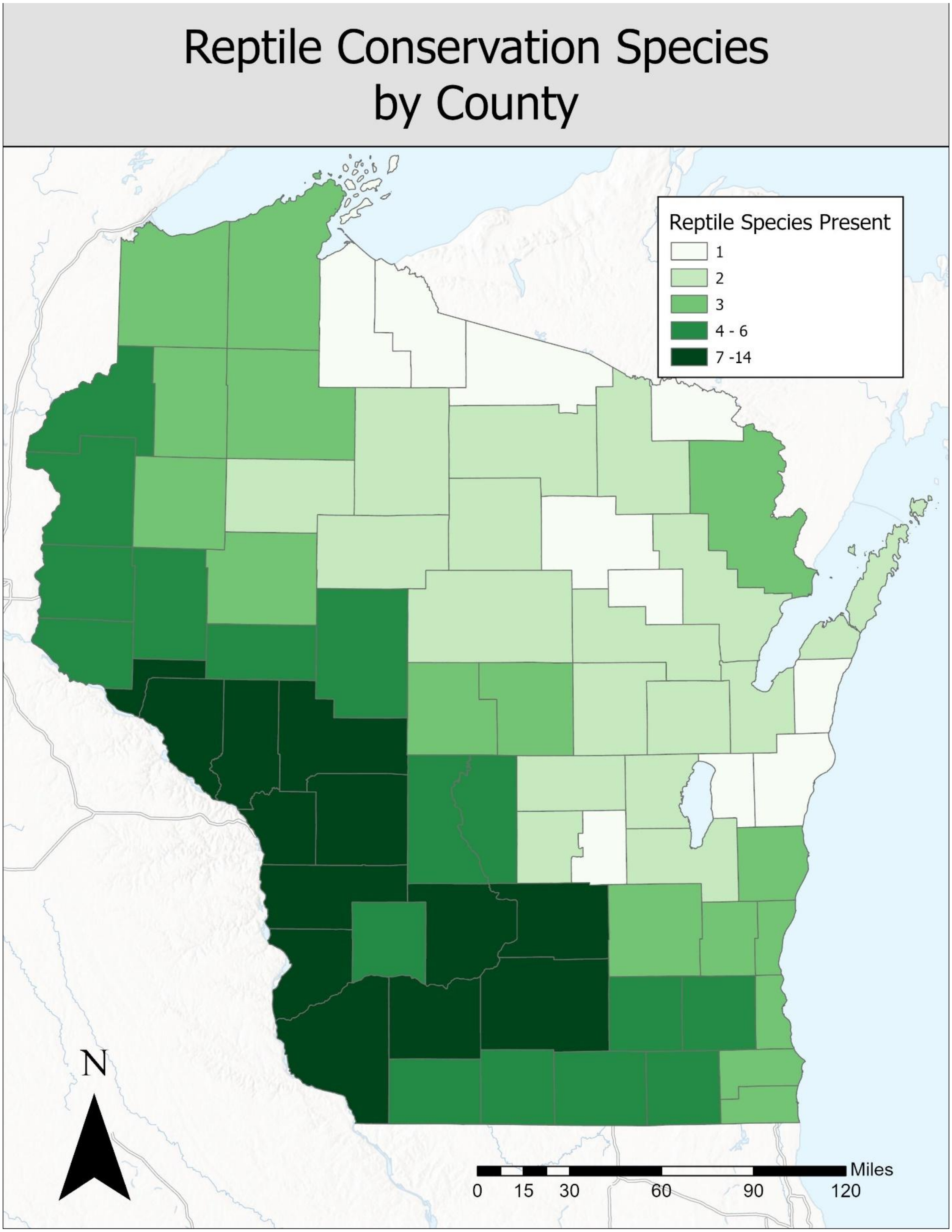

Figure 74: The number of reptile species of conservation concern present in each county (based on Wisconsin DNR, 2025c).

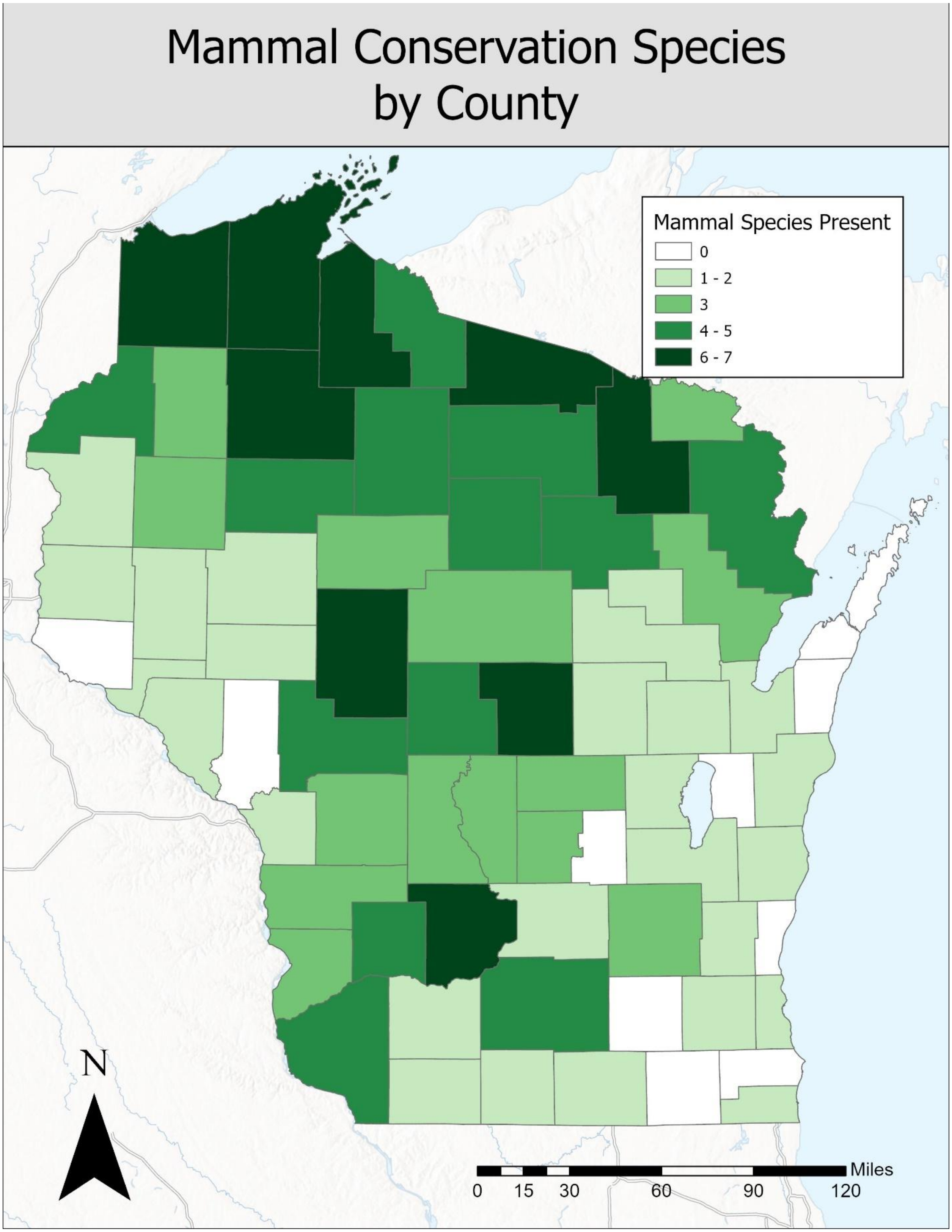

Figure 75: The number of mammal species of conservation concern present in each county (based on Wisconsin DNR, 2025c).

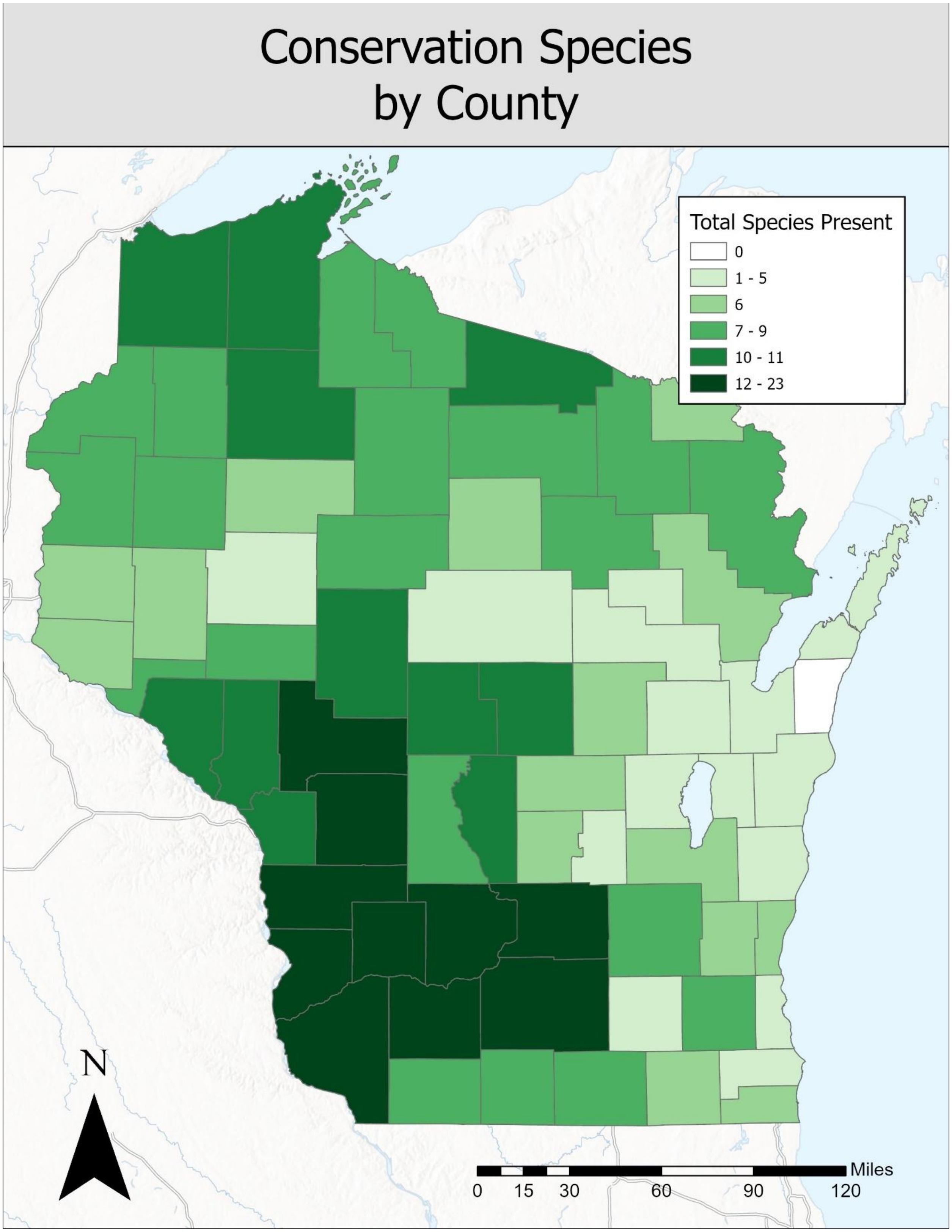

Figure 76: The number of species of conservation concern (amphibian, reptile and mammal species combined) present in each county (based on Wisconsin DNR, 2025c).

8.4 Discussion

We recommend consulting with the Wisconsin Department of Natural Resources, NGO's and volunteers for potentially more specific recorded locations of specific species when considering road (re)construction or wildlife mitigation.

Overall, the counties that have the highest number of species of concern for amphibians, reptiles, and mammals combined are in southwestern Wisconsin. This is a different part of Wisconsin compared to where the highest concentration is of deer carcasses and deer crashes (i.e., mostly in the counties in the east and southeast of Wisconsin). This illustrates the point that mitigating collisions with common large ungulates and mitigating direct road mortality for species of conservation concern needs to prioritize different road sections. This can be achieved through a two-track approach for policy, funding mechanisms and implementation programs; one to address human safety concerns in relation to collisions with large common ungulates, and another for objectives related to biological conservation.

9 Suggested mitigation measures

9.1 Introduction

In this chapter we suggest mitigation measures that are consistent with the goal and the objectives of this project. The goal of this project is to enhance road safety in Wisconsin though reducing collisions with large wild mammals on state-maintained routes, while also ensuring safe crossing opportunities for wildlife.

The primary objective of this project is to identify and prioritize road sections in Wisconsin along state-maintained routes that have a relatively high concentration of collisions involving large wild mammals. These road sections along state-maintained routes may then later be evaluated for potential future mitigation measures aimed at:

- Reducing collisions with large wild mammals and providing safe passage across roads for large wild terrestrial mammals.
- Reducing direct road mortality for species that are considered a conservation concern and providing safe passage across roads for these species, including terrestrial mammals (regardless of their body size and weight), reptiles, and amphibians.

Based on the literature review (Huijser & Begley, 2025) we selected mitigation measures that were substantially effective at reducing collisions with large wild mammals and that also provided for safe crossing opportunities for large wild mammals. We also selected measures that reduce direct road mortality for species that are considered a conservation concern and that provide safe passage across roads for these species, including terrestrial mammals (regardless of their body size and weight), reptiles, and amphibians.

9.2 Target species

We divided the target species into two groups: large wild mammals and small animal species that are a conservation concern. We did this because the measures and design of the measures are fundamentally different for species that are vastly different in body size and weight, and the distances over which they can move.

The large wild mammal target species include:

- Large wild mammals that are abundant, or relatively abundant, and that are most frequently involved with large mammal-vehicle collisions in Wisconsin, i.e., white-tailed deer and black bear.
- Large wild mammals that have been identified as being of conservation concern in Wisconsin including elk, moose, Canada lynx, cougar, and gray wolf.

The small target species considered a conservation concern include small terrestrial mammals, amphibians, and reptiles (see Table 3):

- 3 frog species
- 1 salamander species
- 3 lizard species
- 13 snake species
- 4 turtle species
- 1 insectivore species
- 1 mustelid species
- 5 rodent species

9.2.1 Selected measures

Apart from removing roads or seasonal or night-time closure of roads, wildlife barriers along highways are the most effective measure to reduce direct mortality of large wild mammals (80-100% reduction) (Huijser et al. 2021) and small animal species (on average 65% up to 100% reduction) (Gunson & Huijser, 2019a; Huijser et al., 2021). If fences are combined with wildlife crossing structures, the mitigation package can also provide safe passage opportunities. When enough crossing structures are provided at the correct locations, of the correct type and dimensions, they can also reduce the barrier effect of roads and traffic (e.g., Huijser et al. 2016a; Huijser et al., 2021). However, providing too few suitable crossing structures can lead to population decline, potentially even extirpation (e.g., Ottburg & van der Grift, 2019). While animal detection systems can be similarly effective in reducing direct road mortality of large mammals, their range of effectiveness is much wider, and animal detection systems do not reduce the barrier effect of roads and traffic (Huijser et al. 2021). Therefore, we only focus on wildlife fences in combination with wildlife crossing structures (underpasses and overpasses). In addition, there are associated measures that allow animals that end up in the fenced road corridor to escape to the habitat side of the fence, and wildlife guards (modified cattle guards) that can help keep animals out of the fenced road corridor at gaps in the fence at access roads.

9.3 General considerations for fences in combination with wildlife crossing structures

9.3.1 The function of the fences and crossing structures

Fences or barrier walls in combination with wildlife crossing structures are the most robust and effective mitigation measure package to both reduce collisions with large and small animal species and maintain or improve connectivity for wildlife. However, it is important to be aware of the different functions of fences vs. the function of crossing structures and how that relates to the “departure point” of a mitigation project.

If human safety and direct road mortality of a species are the primary concern, then:

- Road sections with a high concentration of collisions and dead animals are identified and prioritized (e.g. Spanowicz et al., 2020). The target species may be large common mammals if human safety is the primary concern (e.g. Huijser et al., 2008a). If reducing unnatural mortality for rare species is the concern, the target species can be of any body size (e.g. Kramer-Schadt et al., 2004; Huijser et al., 2008a; Boyle, 2021).
- From a human safety perspective, it is logical to identify and prioritize road sections that currently have a concentration of collisions. However, from a biological conservation perspective, direct road mortality may have already caused population depletion. This means that the greatest threat to population persistence due to direct road mortality may not always be along the road sections that currently have the highest concentration of dead individuals of the target species (Teixeira et al., 2017).
- Fences or other barrier types are the primary measure, as the primary purpose of fences along roads is to keep animals off the highway and reduce animal-vehicle collisions (Huijser et al., 2016).
- Since fences alone would result in an absolute or near-absolute barrier for the target species, fences are typically combined with safe crossing opportunities for wildlife, especially wildlife crossing structures (underpasses and overpasses).
- The secondary function of the wildlife fences is to guide or funnel wildlife species to these crossing structures (Dodd et al., 2007; Gagnon et al., 2010).

If habitat connectivity for wildlife is the primary concern, then:

- Road sections where habitat connectivity needs to be maintained or restored are identified and prioritized. This may be based on the connectivity needs (genetic, demographic) for individual species (the “target species”), a wide suite of species or species groups, seasonal migration of certain species (e.g. for ungulates), dispersal to allow for colonization or recolonization of areas nearby or further away, or ecosystem processes in general (biotic and abiotic parameters), including those associated with climate change (e.g. Kramer-Schadt et al., 2004; Clevenger & Huijser, 2011; Sawaya et al., 2013; 2014; Lister et al., 2015; Sawyer et al., 2016; Jarvis et al., 2018).
- While it seems logical to identify and prioritize road sections that currently have observations of animals living or moving close to the road and observations of animals crossing the road (both unsuccessfully and successfully), the greatest population level conservation benefit of reducing the barrier effect of a road may not be where most animals are currently. From the perspective of biological conservation at the population level, areas where most animals are now may have high population viability, potentially despite being isolated because of the barrier effect of transportation infrastructure. In such cases, reducing the barrier effect does not necessarily lead to an increase in population viability. Instead, the greatest population level benefits of reducing the barrier effect can be where small and isolated populations can be made more viable by providing safe crossing opportunities. This may even include road sections that currently isolate unoccupied habitat patches, and that bisect planned habitat corridors rather than existing ones. In other words, crossing structures may also be required or can also be beneficial for population persistence in areas where the target species has low abundance or where it is currently entirely absent.
- Wildlife crossing opportunities, especially wildlife crossing structures, are the primary measure, as the purpose of wildlife crossing structures is to provide safe crossing opportunities.

- Crossing structures on their own do not necessarily reduce collisions or direct road mortality (Rytwinski et al., 2016). Therefore, wildlife crossing structures are typically combined with wildlife fences.
- An added benefit of connecting crossing structures to wildlife fences is that it guides or funnels wildlife to the crossing structures and that this increases the use of the structures (Dodd et al., 2007; Gagnon et al., 2010).

In this context, it is also important to be aware of the limitations of existing crossing structures that were not built for wildlife versus designated wildlife crossing structures. While designated wildlife crossing structures should be located where connectivity for wildlife is needed most, existing structures that were not built for wildlife are not necessarily located where connectivity for wildlife is needed most. Nor are existing crossing structures necessarily of the right type (e.g. overpass vs. underpass) or dimensions given the target species, and there are typically limits to potential modifications to existing structures to improve the suitability for the target species.

In conclusion, fences and wildlife crossing structures are almost always implemented together, regardless of whether the primary objective is to reduce animal-vehicle collisions or to reduce the barrier effect of roads and traffic for wildlife. However, the road sections where the measures are implemented are very much dependent on the primary objectives or departure points, and they may include road sections where the target species is not hit or no longer hit, and where the target species may have low population density or where it is currently not present at all.

9.3.2 Spacing of wildlife crossing structures

The appropriate spacing of wildlife crossing structures can be determined in more than one way and is dependent on the goals one may have. Examples of possible goals are:

- Provide permeability under or over the road for ecosystem processes, including but not restricted to animal movements. Ecosystem processes include not only biological processes, but also physical processes (e.g. water flow). It is good practice to design structures that are primarily needed for hydrology in such a way that they can also function for terrestrial wildlife. However, only providing wildlife crossing opportunities in low and wet areas means that no connectivity is provided for species that depend on high and dry habitat. Thus, a possible strategy is to identify the different ecosystems and habitat types (not just streams, rivers or wetlands) and ecosystem processes that permeability needs to be provided for and then provide appropriate mitigation measures in each of those ecosystems or habitat types.
- Allowing a wide variety of species, or selected targets species, to change their spatial distribution drastically, for example in response to a change in environmental conditions.
- Maintaining or improving the population viability of selected species based on their current spatial distribution. This includes striving for larger populations with a certain degree of connectivity between populations (including allowing for successful dispersal movements).
- Providing the opportunity for individuals (and populations) to continue seasonal migration movements (e.g. mule deer, pronghorn or elk in the western United States) as this can be seen as a component of the biological integrity of an ecosystem.

- Allowing individuals of selected target species that have their home ranges on both sides of the highway to continue to use these areas. This may result in a road corridor that is substantially permeable to those species, at least for the individuals that live close to the road.

A further complication is that individuals that disperse, that display seasonal migration, or that live in the immediate vicinity of a road may display differences in behavior with regard to where and how they move through the landscape, how they respond to roads, traffic, and associated barriers (e.g. wildlife fencing), and their willingness to use safe crossing opportunities. For example, dispersing individuals may grow up far away from the areas adjacent to roads and may shy away from human disturbances and human made features, they may not move through habitat the way we might expect them to, and they typically travel long distances, much further and quicker compared to resident individuals. Safe crossing opportunities may not be encountered by dispersing individuals as they are new in the area and are not familiar with their location, and when confronted with a road or associated wildlife fence, they may return or change the direction of their movement before they encounter and use a safe crossing opportunity. Furthermore, if dispersing individuals do encounter a safe crossing opportunity, they may be more hesitant to use it compared to resident individuals that not only know about their location, but that also have had time to learn that it is safe to use them. Since dispersal can be a relatively rare phenomenon, one may not be able to afford to have a dispersing individual fail to cross the road. Therefore, even though dispersers travel much further than resident individuals, safe crossing opportunities for dispersers may not allow for a greater distance between safe crossing opportunities compared to safe crossing opportunities for resident individuals.

Full scale population viability analyses can be very helpful to compare the effectiveness of different configurations of safe crossing opportunities. However, for this manual the authors choose a simpler approach and suggest the distance between safe crossing opportunities to be equal to the diameter of the home range of the species concerned (Figure 77). In theory, this allows individuals that have the center of their home range on the road to have access to at least one safe crossing opportunity. However, individuals that may have had their home range on both sides of the road do not necessarily have access to a safe crossing opportunity (Figure 78). Finally, this approach assumes homogenous habitat and distribution of the individuals and circular home ranges, while in reality habitat quality may vary greatly, causing variations in density and home range size of individuals and irregular shaped home ranges. Species that have smaller home ranges need the crossing structures to be closer together than species with large home ranges (Figure 77). For example, while white-tailed deer may have a home range of about 1,000 m (0.62 mi) (Table 5), small animal species such as salamanders may require suitable crossing structures every dozen meters (41 ft) or so (Brehme et al., 2021, Huijser et al., 2022b). Similarly, passages spaced 20 m (66 ft) apart should provide connectivity to 90% of Yosemite toads (*Anaxyrus californica*) on seasonal migration (Brehme & Fisher, 2021), and about half of all migrating common toad would have access to culverts that are 60 m apart (197 ft) (Ottburg & van der Grift, 2019). While the species mentioned above do not occur in Wisconsin, they do illustrate the principle that small animal species needs crossing structures that are relatively close together. Home range sizes and movement distances of species of conservation concern in Wisconsin confirm that, in suitable habitat for the target species, suitable crossing structures should be every dozen meters (41 ft) or so up to several hundreds of meters (up to e.g. 1,000 ft) apart (Table 6).

This approach does not necessarily result in viable populations for every species of interest, and that not every individual that approaches the road and associated wildlife fence, will encounter, and use a safe crossing opportunity. In addition, the approach described above is not necessarily the only approach or the approach that addresses the barrier effect of the road corridor and associated fencing sufficiently for all species concerned. However, the approach chosen is consistent, practical, can be based on available data, and is likely to result in considerable permeability of the road corridor and associated wildlife fencing for a wide array of species.

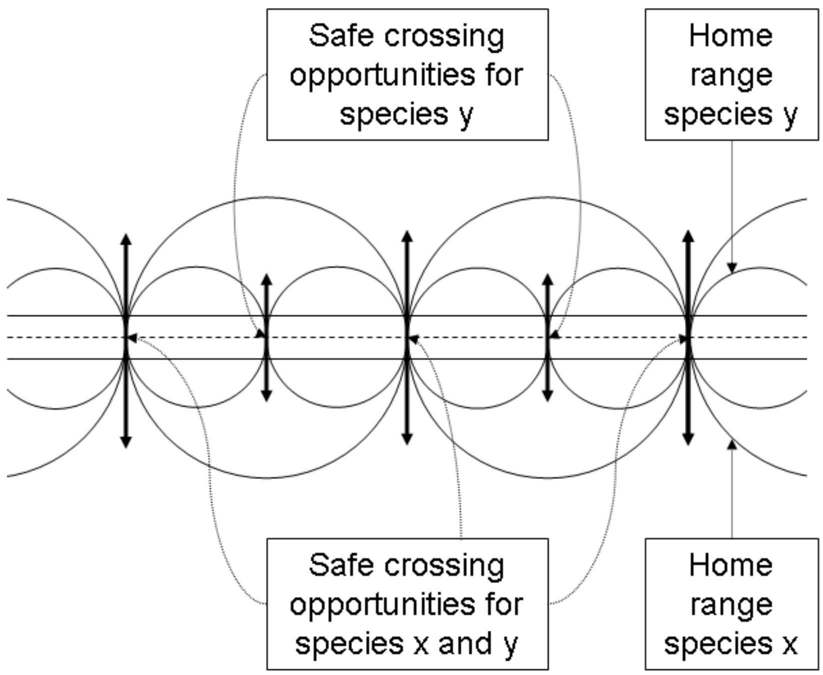

Figure 77. Schematic representation of home ranges for two theoretical species projected on a road and the distance between safe crossing opportunities (distance is equal to the diameter of their home range).

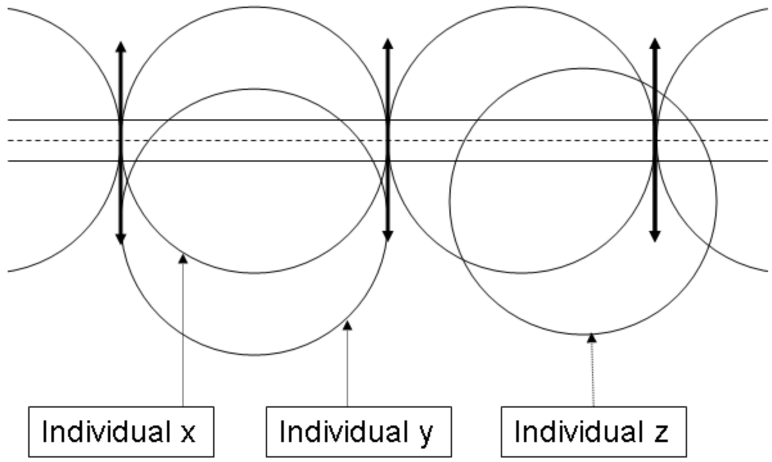

Figure 78. Schematic representation of home range for an individual (x) that has the center of its home range on the center of the road (access to two safe crossing opportunities), an individual (y) that has the center of its home range slightly off the center of the road exactly in between two safe crossing opportunities (no access to safe crossing opportunities), and an individual (z) that has the center of its home range slightly off the center of the road but not exactly in between two safe crossing opportunities (access to one safe crossing opportunity).

Another way to decide on "appropriate distance" between safe crossing opportunities is to evaluate what the spacing is for wildlife crossing structures on other wildlife highway mitigation projects. The average spacing for large mammal crossing structures in Montana (US Hwy 93 North and South), I-75 in Florida, SR 260 in Arizona, Banff National Park in Canada, and ongoing reconstruction on I-90 in Washington State is 1.2 mi (1.9 km) (range for the average spacing of structures in these individual areas is 0.5-1.8 mi (0.8-2.9 km)). However, the 1.2 mi (1.9 km) spacing is simply what people have done elsewhere, and it is not necessarily based on what may be needed ecologically, and the requirements for the target species in one area may be different from what is needed in another area.

Table 5: Home range size and diameter home range for large wild mammal species for the spacing of wildlife crossing structures.

Species	**Home range (ha) and diameter (m)**	**Source(s)**
White-tailed deer	70 ha 944 m	70.5 ha for adult females in summer (Leach & Edge, 1994), <80 in summer (Mundinger, 1981), 60-70 ha for females in summer (review in Mackie et al. 1998), 89 ha (range 17-221 ha) for females in summer and 115 ha (range 19-309 ha) in winter (review in Mysterud et al., 2001)
Elk	5,000 ha 7,981 m	3,769 ha (range 820-9,520 ha) for females in summer and 181 ha (range 152-210 ha) in winter (review in Mysterud et al., 2001), 5,296 ha for adult females in summer and 10,104 ha in winter (Anderson et al., 2005), 8,360-15,720 ha for elk populations (Van Dyke et al., 1998). Long distance seasonal migration can occur.
Moose	2,500 ha 5,643 m	2,612 ha (range 210-10,300 ha) for females in summer and 2,089 ha (range 200-11,300 ha) in winter (review in Mysterud et al., 2001).
Canada lynx	5,000 ha 7,981 m	Males (range 2,900-52,200 ha), females (range 500-9,500 km^2) (Burdett et al., 2007).
Cougar	4,000 ha 7,138 m	3,500 ha (range 1,900-5,100 ha) for adult females in summer and 2,600 ha (range 1,400-4,300 ha) in winter (Spreadbury et al. 1996), 6,730 ha for females (review in Lindstedt et al. 1986), 9,700 ha (range 3,900-22,700 ha) for adult females in summer and 8,700 (range 3,100-23,900 ha) in winter (Ross & Jalkotzy 1992).
Gray wolf	50,000 ha 25,238 m	6,250 ha (range 700-6,800 ha) (review in Lindstedt et al. 1986). 65,000 ha (Fritts et al. 1997).
Black bear	4,000 ha 7,138 m	1,960 ha for females (Young & Ruff 1982), 5,960 ha (range 2,300-16,000 ha) for adult females (McCoy, 2005).

Table 6: Home range size and diameter home range for small animal species for the spacing of wildlife crossing structures. Note that we did not find information for all the species listed in Table 3.

Species	Home range (ha) and associated diameter (m), and other range or movement rates	Source(s)
Blanchard's cricket frog	Daily movements 0.3-15.0 m, seasonal migrations up to 1.3 km.	Review in Wisconsin DNR (2025a).
Slender glass lizard	Home range adult males 0.07-0.44 ha (30-75 m); juveniles 0.14 ha (42 m).	Review in Wisconsin DNR (2025a).
Timber rattlesnake	Average home males 68.8 ha (936 m); non-gravid females 22.7 ha (538 m); gravid females 11.7 ha (386 m). Average distance traveled per day 40.3 (±15.0) m for males and 22.3 (±6.9) m for females.	MacGowan et al. (2017)
Gophersnake	Average home range 10.5 ± 1.7 ha (366 m). Maximum distance traveled from a hibernation site 2,400 m. Maximum distance dispersed averaged 520 ± 65 m.	Williams et al. (2012)
Queensnake	Within 3-6 m from water.	Review in Wisconsin DNR (2025a).
Eastern massasauga	Average home ranges 1.3 ha (129 m); Average daily movement 6.9 m/day.	Moore et al. (2006)
Butler's gartersnake	Home range females 0.9 ha (107 m). Daily movement about 14 m/day). Maximum distances moved typically < 100 m.	Shonfield et al. (2019)
Eastern ribbonsnake	Home-range 0.16-0.78 ha (45-100 m). Average seasonal movements 17-84 m for juveniles; 21-130 m for adults. Maximum distance travelled 391 m in one season. Within 10 m of water.	Imlay et al. (2015); Review in Wisconsin DNR (2025a).
Smooth softshell turtle	Average home range 18.1 ha (480 m). Average movement 142.3 m/day, with some movements >2 km/day.	Ross et al. (2019)
Blanding's turtle	Annual home range 25.5 ha (570 m). Some females moved up to 1,115 m.	Schuler & Thiel (2008); Review in Wisconsin DNR (2025a)
Wood turtle	Average home-range areas of 28.3 ha (600 m). Home range <1.0->29.9 ha (113-617 m). Up to 80-300-500 m from water.	Arvisais et al. (20202; Review in Wisconsin DNR (2025a)
Ornate box turtle	Average home range males 58 ha (860 m), females 26.9 ha (585 m). Home ranges 0.2-58.0 ha (50-860 m).	Bernstein & Richtsmeier (2007); Review in Wisconsin DNR (2025a)
Pine marten	Females: 100 ha (1,129 m); Males 200-400 ha (1,596-2,257 m).	University of Wisconsin (2025)
Prairie vole	Home range 0.01-0.05 ha (11-25 m).	Desy et al. (1990)
	Home range females 0.4-2.6 ha (71-182 m); males 0.4-3.6 ha (71-214 m).	Blair (1941)
Franklin's ground squirrel	Home range males 24.6 ha (560 m); females 8.7 ha (333 m).	Choromanski-Norris et al. (1989)

9.4 Mitigation for large wild mammal species

9.4.1 Fences and associated measures

Wildlife barriers can either be fences or walls, and the latter may be integrated in the roadbed when landscape aesthetics as observed from the road are a concern. However, wildlife fences are far more commonly applied than wildlife walls, especially over long distances.

Effective wildlife fences must be designed with the climbing, digging, and jumping capabilities of the target species in mind, as well as their strength. White-tailed deer is by far the most abundant species of concern with regard to human safety. But there are other large wild mammal species in the area too, including species that are a conservation concern. Therefore, one may decide to improve human safety and reduce direct road mortality for those other large mammal species with the same fence. This means that one may design a wildlife fence to keep multiple species from accessing highways in the area (Table 7). This means that the target species with the greatest ability to breach a fence would dictate the fence characteristics.

Table 7: Potential large wild mammal target species and the recommended wildlife fence characteristics (adapted from Huijser et al. 2022b).

Species name	Fence height	Post material	Fence material	Dig barrier/ apron	Over-hang	Electric fence or wires
White-tailed deer (*Odocoileus virginianus*)	8 ft	Wood	Mesh-wire	No	No	No
Elk (*Cervus canadensis*)	8 ft	Wood	Mesh-wire	No	No	No
Moose (*Alces alces*) [1]	8 ft	Wood	Mesh-wire	No	No	No
Canada lynx (*Lynx canadensis*) [1]	10 ft	Metal	Chain-link	Yes	Yes	Yes
Cougar (*Puma concolor*)[2]	10 ft	Metal	Chain-link	Yes	Yes	Yes
Gray wolf (*Canis lupus*)	10 ft	Wood	Chain-link	Yes	Yes	Yes
Black bear (*Ursus americanus*)	10 ft	Metal	Chain-link	Yes	Yes	Yes

[1] Presence in northern Wisconsin, but there is no distribution map available.
[2] Occasional presence in Wisconsin, but there is no distribution map available.

The recommended height is based on the jumping and climbing capabilities of a species, as well as tolerance or intolerance when some individuals breach the barrier. The material for the fence post depends on whether the species can climb wooden posts (metal recommended) or not (wood recommended), but the substrate (rocks) can also dictate the post material (Figure 79, Figure 80). The fence material is based on the size of a species and whether they would be able to pass through the meshes or if they can use the meshes as “steps” when climbing the fence. A dig barrier is usually a 4-5 ft wide galvanized chain-link fence that is attached to the bottom of the actual fence, angled towards the habitat side of the fence (Figure 81). The buried fence should extend approximately 3.5 ft (1.1 m) under the ground (Clevenger & Huijser 2011). An overhang is attached to the top of the main fence and angles towards the habitat side of the fence (Figure 82). Species or individuals that climb a fence would also have to navigate the overhang to make it to the road side of the fence. Electric fences or electrified wires attached to mesh-wire or chain-link fences can also be considered in the design of a wildlife fence, especially for species that can climb, including Canada lynx, cougar, gray wolf, and black bear (Figure 83). Finally, a high-tensile top wire is recommended when trees are in the vicinity of the wildlife fence (Figure 84). High-tensile top wires can reduce the damage of a fallen tree and prevent a temporary gap in the fence.

Figure 79. Typical large ungulate fence in North America, 8 ft tall, wooden posts and mesh-wire fence material, US Hwy 93 North, Montana, USA. Note that there is a dig barrier attached to the main fence material (e.g., for canids).

Figure 80. Fence for Florida panther (Puma concolor coryi), 10 ft tall, metal posts, chain-link fence material, and overhang or outrigger, SR 29, Florida, USA).

Figure 81. Wildlife fence and dig barrier ("buried fence" or "apron"), Trans-Canada Highway, Banff National Park, Alberta, Canada. The dig barrier in the soil angles (45°) towards the safe side or habitat side; it angles away from the fence and the road on the other side (Clevenger and Huijser 2011). The dig barrier keeps animals from digging under the fence. The dig barrier may consist of a 4-5 ft (1.0-1.2 m) wide galvanized chain-link fence that is attached to the bottom of the actual fence. The buried fence should extend approximately 3.5 ft (1.1 m) under the ground (Clevenger & Huijser, 2011).

Figure 82. Outrigger or overhang on a fence for Florida panther (Puma concolor coryi), SR 29, Florida, USA. Note that the outrigger faces the safe side, the habitat side of the fence. One may consider a longer overhang from chain-link fence material.

Figure 83: Wildlife fence along A28 motorway, near Spier, Drenthe, The Netherlands. The fence is a barrier for medium and large mammal species. The electrified wire is an additional barrier to keep animals out of the fenced road corridor.

Figure 84. Wildlife fence with high-tensile top wire to reduce damage from falling trees, Trans-Canada Highway, Banff National Park, Alberta, Canada.

For a wildlife fence to be effective in reducing direct road mortality for large mammals consider the following (based on Huijser et al., 2015; 2022b):

- Design the fence for the target species (see above for the fence design characteristics for the different target species) and have a goal and objectives formulated for its effectiveness (e.g., at least 80% reduction in direct road mortality of the target species inside the fenced road corridor). When there is a discrepancy between the stated objectives and the proposed mitigation measures, either adjust the objectives or the proposed measures. Proceeding with a discrepancy between the stated objectives and the proposed measures almost certainly causes the project to fail.
- Construct and install the fence correctly. Have a road ecologist oversee fence design and installation to reduce the likelihood of design and installation errors. Once installed, design and installation errors are hard and expensive to correct, or the errors may never be corrected at all. This can severely jeopardize the effectiveness of the mitigation measures. Connections to crossing structures, the installation of dig barriers and measures at access roads, and addressing erosion and sedimentation processes are major concerns.
- Implement the fence on both sides of a highway for at least three miles of road length (Huijser et al. 2016). This almost always results in 80-100% reduction in direct road mortality of large mammals, but this is largely based on ungulates (i.e., deer, elk) rather than wide ranging carnivores. Almost always, wildlife fencing should be installed on both sides of a highway, not only on one side (Clevenger & Huijser, 2011).
- Cover the road length that may have a concentration of wildlife-vehicle collisions with the target species (i.e., “hotspots”) as well as adjacent buffer zones to keep the animals from simply crossing the highway at the fence ends (Ward, 1982; Huijser et al., 2015). The length of the

buffer zone is at least partially influenced by the home range size of the target species. For white-tailed deer in North America 0.62 mi (1 km) long buffer zones have been suggested (starting from each end of the hotspot) (Huijser et al., 2008b).

- "Fence-end runs" are situations where animals cross the road in high numbers at or near fence-ends (Figure 85) (Huijser & Begley, 2022). Such fence-end runs are best addressed by having the fence-end at appropriate locations, well away from known movement areas or suitable habitat.
- Fence-end treatments are especially important if the fenced road length is relatively short (e.g., shorter than 3 miles) (Huijser et al. 2016). To reduce the likelihood of animals accessing the fenced road corridor at a fence-end, consider bringing the fence-ends close to the edge of the pavement, potentially in combination with a wildlife guard or electrified barrier embedded in the pavement (Figure 86, Figure 87) (Allen et al., 2013; Huijser & Getty, 2022). To further reduce the likelihood of animals getting on the road at or near a fence-end, consider angling the fence away from the road at the fence-end. This may encourage animals to turn back into the surrounding area, walk back along the fence and potentially find and use a suitable wildlife crossing structure, or it may result in them crossing the road further away from the fence-end. A split fence-end is possible where the other fence-end angles towards the road.
- Note that fences may also need to be implemented over long distances if the objective is to reduce the overall number of collisions rather than just reduce the number of collisions in the fenced road section (Huijser & Begley, 2022). It is possible to substantially reduce direct mortality in a relatively short, fenced section, but not have any benefit on a larger spatial scale as collision locations may have moved rather than truly reduced.
- If the objective is to protect a threatened or vulnerable population or species, the fences road sections should ideally include all roads or all major roads in the area that is occupied by the target species as any unnatural mortality can be considered a threat to the continued existence of a threatened or vulnerable population (Huijser & Begley, 2023).
- Minimize the number of access points for side roads and trails along a fenced road corridor. Each access point is a potential weak spot where animals may enter the fenced road corridor. Consider implementing wildlife guards (similar to cattle guards) or electric mats embedded in the roadway to reduce wildlife intrusions into the fenced road corridor at fence ends and at access roads (Figure 88, Figure 89). Wildlife guards or "cattle guards" may be a substantial barrier to ungulates, but not to species with paws (Allen et al., 2013). For species with paws, including bears, canids and felids, electrified barriers may be required, sometimes in combination with a wildlife guard (e.g., Huijser & Getty, 2022; 2024).
- Include escape opportunities for wildlife from the fenced road corridor. The main measure available is wildlife jump-outs or escape ramps. However, the effectiveness for large ungulates may need fine-tuning, and the data on jump-out use by canids are very rare (Huijser & Getty, 2023).
- Almost always, include wildlife crossing opportunities that are suitable for the target species, and consider the needs of other species in the area, especially those that are not a target species but for which the fence may also result in a barrier. Solving one problem (direct road mortality, human safety) should not cause another problem (barrier effect for the target species or other wildlife species) (Moore et al., 2021).
- Apart from reducing direct road mortality by keeping animals from accessing the road, fences can also guide wildlife towards safe crossing opportunities (i.e., wildlife crossing structures under or over the road). Connecting crossing structures to wildlife fencing can result in a substantial increase in wildlife use of those structures (Dodd et al., 2007; Gagnon et al., 2010).

Figure 85. Wildlife trail at a fence-end, US Hwy 95, Bonners Ferry, Idaho, USA. This is an indication that there is a concentration of wildlife crossings at the fence-end (a "fence-end run"), potentially resulting in a concentration of collisions at or near the fence-end, just inside or just outside the fenced road section.

Figure 86. Fence-end brought close to the edge of the pavement, protected by Jersey barriers. Also note that there is a wildlife guard embedded in the travel lanes, Alberta, Canada.

Figure 87. Electrified barrier embedded in travel lanes to keep large mammals, including bighorn sheep, out of fenced road corridor, MT Hwy 200, Thompson Falls, Montana, USA.

Figure 88. Wildlife guard at an access road to US Hwy 93S, near Victor, Montana, USA. This type of wildlife guard is less suited for pedestrians and cyclists.

Figure 89. Electrified barrier, designed for low traffic volume and low traffic speed, on top of a wildlife guard at an access road to US Hwy 93S, near Ravalli, Montana, USA.

There are likely other medium-sized mammal species (e.g., bobcat), reptiles (e.g., turtles, snakes, lizards) and amphibians (e.g., frogs, toads, salamanders) in the area that one may choose to also substantially reduce direct road mortality for. Barrier designs for small to medium-sized mammals, amphibians and reptiles are also species-specific or specific to the species group, but they can be integrated in a fence that is designed for large wild mammals (see section 8.5.1) (Clevenger & Huijser, 2011; Huijser et al. 2022b).

9.4.2 Crossing structures

The type (underpass vs. overpass), the approach slope of the structure, the dimensions (width, height) and the associated habitat inside or on top of the crossing structure should be based on the biological requirements and behavior of the target species as well as the surrounding landscape (Table 8, Table 9). Different species are more or less likely to use certain types and dimensions of wildlife crossing structures. For a crossing structure type and dimension to be considered suitable for a species, the likelihood that the structure will be used by an animal that approaches the structure should be "high". While there are no established minimum norms for acceptance, selecting a structure type and dimensions that have a high acceptance rate (perhaps at least 70-80%) for the target species is logical. In this context it is important to remember that having observed "use" by a species does not mean that it is defensible to claim that that that structure type and its associated dimensions are “suitable”; even a structure with a very low acceptance rate still has some “use”. By definition, a crossing structure that is “suitable” for the target species is much more likely to be found effective in reaching objectives related to the connectivity than a crossing structure that may be “used” but that may not have a high acceptance rate.

Data on acceptance (and thus suitability) are not common (but see e.g., Purdum, 2013; Huijser et al., 2019; Denneboom et al., 2021), and they are not available for all large mammal species in the project area of the report. Therefore, published data on structure types and their acceptance by the large wild mammal species in the area were supplemented by “use” data (Table 8). From a human safety perspective, white-tailed deer is the most important target species for this project, but it makes sense to have these crossing structures also be functional for other large wild mammal species that may be present in the area, especially if those species are of conservation concern (Table 9).

Table 8: Crossing structure types and dimensions.

Safe Crossing Opportunity type	Indicative dimensions (as seen by the animals)
Wildlife overpass	50-70 m wide
Open span bridge	12-30 m wide, ≥5 m high
Large mammal underpass	7-8 m wide, 4-5 m high
Medium mammal underpasses	0.8-3 m wide, 0.5-2.5 m high

Safe Crossing Opportunity type	Indicative dimensions (as seen by the animals)
Small-medium mammal pipes	0.3-0.6 m in diameter

Table 9. Suitability of different types of mitigation measures for selected large mammal species (for 2-3 lane highways [25-35 m (82-115 ft)] wide road without median).

● Recommended/Optimum solution; (●) Likely, but no data, ○ Likely marginal or somewhat possible if adapted to species' specific needs; ⊗ Not recommended; ? Unknown, more data required; — Not applicable (Clevenger & Huijser 2011, Huijser et al., 2022b).

Species	Wildlife overpass	Open span bridge	Large mammal underpass	Medium mammal underpass	Small-medium mammal pipes
White-tailed deer (*Odocoileus virginianus*)	●	●	●	⊗	⊗
Elk (*Cervus canadensis*)	●	●	○	⊗	⊗
Moose (*Alces alces*) [1]	●	●	○	⊗	⊗
Canada lynx (*Lynx canadensis*) [1]	●	●	●	●	⊗
Cougar (*Puma concolor*) [2]	●	●	●	⊗	⊗
Gray wolf (*Canis lupus*) [2]	●	●	○	⊗	⊗
Black bear (*Ursus americanus*)	●	●	●	⊗	⊗

[1] Presence in northern Wisconsin, but there is no distribution map available.
[2] Occasional presence in Wisconsin, but there is no distribution map available.

For wildlife crossing structures, also consider the following:

- The number of wildlife crossing structures, or the spacing between them, depends on the objectives and how much movement of the target species is needed to reach those objectives. This is often difficult to determine, and it may require substantial modelling that requires data and a series of assumptions. An alternative approach would be to calculate the home range size of the target species (see Spacing of wildlife crossing structures).

- Whereas the correct location of a crossing structure is critical to its functioning, also consider the soil stability and ground water levels in the surroundings of potential sites for wildlife crossing structures. Soil stability and ground water level can impact site selection and design.
- Where there is a median, separate structures may be required for the two travel directions. Design these structures as a pair with one continuous line of sight to the area on the other side of the road and ensure consistency in the design, including the dimensions.
- Avoid dividing walls or pillars inside a structure; make the structure as open as possible to allow wildlife to see the sky and vegetation on the other side of the structure. If a structure needs support, choose pillars rather than closed dividing walls.
- Crossing structures are usually built with concrete and steel. However, overpasses can also be constructed out of other materials that may reduce the CO_2 output, have longer lifespan, and would allow for a modular structure that may be disassembled and moved should wildlife change where they approach the road (e.g. in response to development) (Bell et al., 2020).
- A very gradual approach to an underpass and overpass (perhaps 10-15% at a maximum) is recommended. This may be especially relevant in open and flat landscapes compared to landscapes with lots of cover and topography. Gradual approaches may impact natural vegetation beyond the right-of-way. However, the vegetation on the approaches may be restored after construction, and the disturbance is only once. The structure itself may only have a lifespan of 75-80 years (Huijser et al., 2009). Therefore, only the soil and vegetation on top of an overpass or at an underpass may be disturbed each time the structure is replaced.
- Consider ponds or water holes on either side of a crossing structure to attract wildlife to the structure (Figure 90).

Figure 90. Wildlife pond at the approach of wildlife overpass "Groene Woud" across A2 motorway, The Netherlands.

- The soil and vegetation on top of wildlife overpasses should be similar to that of the surrounding area. In some cases, one may choose to engineer a variety of habitat types on an overpass (e.g. cover, edge habitat, open areas). Choose soil depth and associated water retention carefully as it allows or does not allow for shrubs and trees, and the weight likely has design consequences for an overpass (Figure 91, Figure 92). Use native soil and do not introduce non-native invasive species.

Figure 91. Shrubs and trees on a wildlife overpass, Ruta 101, Misiones, Argentina.

Figure 92. Cover and open habitat on top of multifunctional overpass (farm road and wildlife, about 100 m wide), across A4 motorway, Parndorf, Austria. The overpass is designed for farmers, agricultural machinery, hunters and wildlife including roe deer (Capreolus capreolus) and European hare (Lepus europaeus).

- If crossing structures not only need to provide connectivity for large wild mammal species, but also for small wild animal species, then appropriate habitat should be provided for these small animal species as well. Because of slow travel speed and short travel distances, small animal species may require everything they need during their life at a wildlife crossing structure (e.g. water, food, cover)
- Light and noise from vehicles can be reduced through berms and solid fences (e.g. planks) on the two sides of a wildlife overpass, or along the road above an underpass (Figure 93, Figure 94, Figure 95, Figure 96). Light and noise barriers can be combined with a wildlife fence.

Figure 93. Visual barrier combined with large mammal fence on an overpass, The Netherlands.

Figure 94. Berm on wildlife overpass "Groene Woud" across A2 motorway, The Netherlands. The berm with rootwads and shrubs provides cover on either side and reduces visual and noise disturbance barrier combined with large mammal fence on an overpass, The Netherlands.

Figure 95. Visual barrier above a wildlife underpass, Amersfoortseweg, Hoog Soeren, The Netherlands. The fence reduces visual and noise disturbance from traffic for the animals that approach the underpass.

Figure 96. Visual barrier on a multifunctional underpass (water, wildlife), The Netherlands. The fence reduces visual and noise disturbance from traffic for the animals that approach the underpass.

- While some people have expressed concern about wildlife crossing structures acting as a prey trap, there is no evidence that predators select wildlife crossing structures to hunt (Ford & Clevenger, 2010).
- In general, try to minimize human presence and disturbance at and near wildlife crossing structures (e.g. no human co-use, no hunting, no cutting of trees or other vegetation, no frontage or other roads near the approaches, no street lights). Large boulders or tree trunks at structure entrances can be used to discourage motorized use of the structures (Figure 97). Native, natural, and undisturbed habitat at and near the crossing structures is especially important for rare and sensitive species.

Figure 97. Boulders block access to unauthorized vehicles at wildlife underpass, US Hwy 95, Chilco, Idaho, USA.

- For a bidding process, try not only including engineering specifications but also ecological specifications to increase the probability that the structure will function as intended for wildlife species.
- In multi-functional landscapes with common species that are accustomed to a certain level of human disturbance, one may consider combining wildlife use and non-motorized human use (e.g. pedestrians, bicyclists, equestrian use) (Figure 98). In general, human co-use pushes wildlife use to the dark hours, but one should be careful with widespread implementation until better data are available (van der Ree et al., 2015). It may be advantageous to have a strategic partnership with other stakeholders (e.g. non-motorized recreational interest groups), potentially allowing for a greater number of structures to be built with an overall better

outcome for wildlife connectivity. If human co-use is desired, place the path for humans on one of the outer sides of a structure, and minimize human presence and disturbance to other areas of the structure, e.g. through a berm, trees and shrubs places between the path and the area designed for wildlife.

Figure 98. Hiking and biking trail combined with wildlife overpass across railroad tracks, Soest, The Netherlands. The "wildlife area" on the overpass is further to the left, separated from the trail by a berm and shrubs and trees.

- Crossing structures originally designed for other purposes (e.g. water), should have a path for large wild mammals that is at least 8 ft (2.4 m) wide and they should have a clearance of at least 13 ft (4 m) (Clevenger & Huijser, 2011) (Figure 99).

Figure 99. Pathway for large mammals in an underpass (bridge) primarily designed for water (stream), US Hwy 93 S, Bitterroot Valley, Montana, USA.

- For rivers and streams, bottomless structures are recommended. This allows for natural substrate and stream dynamics (Figure 100).

Figure 100. Bottomless multifunctional underpass, Hwy 88 near Jackson, California, USA. The underpass is for a creek (hydrology) and wildlife (e.g. mule deer).

- If culverts or other structures are used that have a “bottom” consider placing native soil on the bottom (Figure 101). Note that that may not be possible if the crossing structure also has flowing water.

Figure 101. Multi-functional underpass for wildlife and water with soil and rocks that cover the bottom of the culvert, US Hwy 93, near St Ignatius, Flathead Indian Reservation, Montana, USA.

9.5 Mitigation for "small species" of conservation concern

9.5.1 Fences and other barriers

- As a general rule, barriers for small wild animal species should be combined with crossing structures; these measures should be regarded as a package. For high volume roads and roads that cannot be closed or removed, the combination of barriers and crossing structures is the most robust and effective way to reduce direct road mortality for small animal species while also allowing the animals to cross to the other side of a road. Note that while crossing structures as a stand-alone measure can provide connectivity, they need to be combined with fences or other barriers to reduce direct road mortality.
- It is essential to carefully define the problem and identify the target species. This will help identify the road sections of concern, including buffer zones adjacent to a mortality hotspot. (Gunson & Huijser, 2019b). The best approach is to mitigate the entire road length (and associated buffer zones) that bisect suitable habitat for the target species, regardless of where current concentration of direct road mortality may be located (Langton & Clevenger, 2020). Many mitigation measures are not implemented at a sufficiently large spatial scale (Huijser & Begley, 2022). In some cases, the habitat may be homogeneous and extensive and occur for more than several miles alongside a road. If barriers cannot extend along the entire habitat for practical or monetary reasons, they should at least extend the full length of known roadkill hotspots, animal crossing areas, and adjacent buffer zones.
- Barriers for small animal species tend to be, on average, less effective than those for large mammal species. This is likely because it is harder to design effective barriers for species that are small or species that are good at climbing or digging. A review of the effectiveness of barriers in reducing direct road mortality of small animal species found an average reduction of 65% (minimum 16%, maximum 100%) (Gunson & Huijser, 2019a). It is possible to design barriers for small animal species that would be 80-100% effective in reducing direct road mortality. However, this requires more effort during the design and installation (Huijser et al., 2021).
- A permanent barrier fence or guide wall may be more easily installed along roads that are newly constructed or reconstructed, e.g., twinning expansions and widenings when the road surface and roadbed are reconstructed for transportation needs already (Gunson & Huijser, 2019c).
- Guide walls are a specific form of barrier. They differ from fences as they present an open face in one direction, similar to a retaining wall, and they are flush to the ground surface on the other side (Figure 102, Figure 103). These are "one way" barriers and allow animals that do get into the roadway to easily return to the safe side of the barrier at any location. When designed and constructed appropriately, guiding walls require less maintenance effort over time than fences as fences are more easily damaged by mowing or falling trees and in some cases erosion (Jackson et al., 2015; Gunson & Huijser, 2019c; Langton & Clevenger, 2020).

Figure 102. A "fence" designed for Eurasian badger (Meles meles) (the taller metal fence material with small mesh size) and for common toad (Bufo bufo) (the plastic sheets at the bottom of the fence), Rijksstraatweg Elsterstraatweg N225 just west of Elst, Utrecht, The Netherlands.

Figure 103. A "barrier wall" (polymer concrete) for common toads (Bufo bufo), integrated into roadbed, Deelenseweg, between Hoenderloo and Arnhem, Gelderland, The Netherlands.

- More detailed specifications include the height, the fence material, post specifications, and mesh size (Figure 104, Figure 105, Figure 106, Figure 107, Figure 108). Fence design should be based on the behavior and agility of the target species. Considerations include the ability for an animal to move, jump, swim, climb, dig, and exercise force against the barrier. As a general rule, for small animal species, Langton & Clevenger (2020) note that fencing should be at least 90 cm (3 ft) above ground and 30 cm (1 ft) below ground. This may vary depending on the target species (see below for more specifics based on species and size).

Figure 104. Wildlife fence for Eurasian badger (Meles meles) and wild boar (Sus scrofa), N302, Leuvenumseweg, Sonnevanck, east of Harderwijk, The Netherlands.

Figure 105. A chain-link turtle fence continues above a culvert for turtles, Valentine National Wildlife Refuge, Nebraska, USA.

Figure 106. Barrier wall for turtles, alligators, snakes and amphibians, Lake Jackson Ecopassage, Tallahassee, Florida, USA. The barrier wall was under construction when the image was made.

Figure 107. A "barrier wall" (concrete) integrated into the roadbed for common toads (Bufo bufo), Deelenseweg, between Hoenderloo and Arnhem, Gelderland, The Netherlands.

Figure 108. Fence to keep desert tortoise (Gopherus agassizii) off the highway, California, USA.

- If there are multiple target species, ranging from large wild mammals to amphibians, different fence materials can be integrated into one barrier design (Figure 109, Figure 110).

Figure 109. Mesh wire wildlife fence with metal poles on top of multifunctional overpass (wildlife, bicyclists, pedestrians; about 100 m wide), across A4 motorway, Parndorf, Austria. The overpass is designed for farmers, agricultural machinery, hunters and wildlife including roe deer (Capreolus capreolus) and European hare (Lepus europaeus). Mesh size is small towards the bottom.

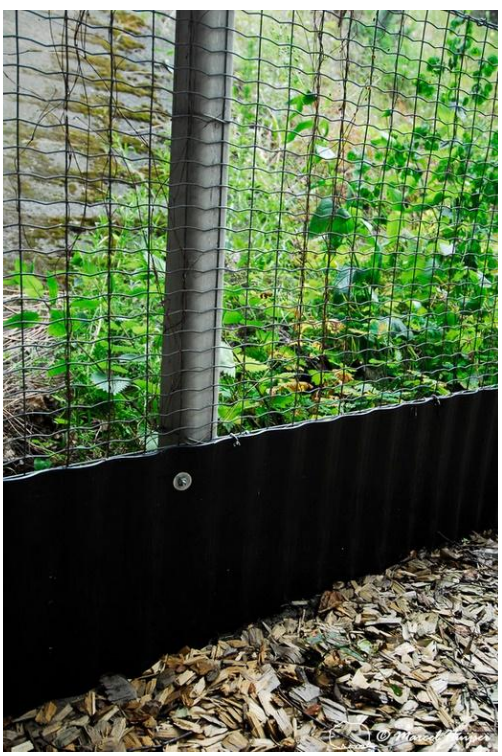

Figure 110. Wildlife fence for Eurasian badger (Meles meles) (mesh wire) and common toad (Bufo bufo) (ABS sheets), The Netherlands.

- Fences should typically be buried to deter animals from digging under the barriers (Figure 111, Figure 112). Buried fencing recommendations range from 5 cm to 30 cm (Langton & Clevenger, 2020; Smith & Noss, 2011), and a 20 cm wide flat platform at the base of a guide wall is recommended to deter vegetation growth which may allow small animal species to climb over the barrier (SETRA, 2005; Jackson et al., 2015).

Figure 111. Wildlife fence and dig barrier (or "apron"), mostly for canids and bears (Ursus sp.), Trans-Canada Highway, Banff National Park, Alberta, Canada. The dig barrier angles away from the road.

Figure 112. If a dig barrier cannot be dug into the soil, angling it away from the road and covering it with soil and rocks and boulders may be an option. Trans-Canada Highway, Banff National Park, Alberta, Canada.

- Fences sometimes require an overhang or top lip to deter animals from climbing over the barriers (Figure 113, Figure 114, Figure 115). Fences for small animals typically have an overhang (4–6 cm (2–3 in)) at a 45–90º or greater angle away (Langton & Clevenger, 2020).

Figure 113. Barrier wall integrated into the roadbed with overhang for reptiles, amphibians and small mammals, U.S. 441, Paynes Prairie Ecopassage, south of Gainesville, Florida, USA.

Figure 114. Fence with overhang for American crocodile (Crocodylus acutus), Key Largo, Florida, USA.

Figure 115. Fence designed to keep koala (Phascolarctos cinereus) off the highway, M79, between Harcourt and Faraday, Victoria, Australia. This fence is about 2.1 m high, and the top 50 cm or so angles away from the road. The last 30 cm or so is not supported by the post and forms a 'floppy top' making it difficult to cross by species that climb well.

- Barriers are most likely to be effective at locations where target species predictably cross in the same location every year. Prioritize the installation of barriers along road sections that have shown a consistent mortality problem over many years to minimize the risk of mitigating the wrong road sections (Gunson & Huijser, 2019b).
- The known daily (or nightly) movement distances (or home range) of the target species can inform decisions about the minim functional barrier length along roads as well as the appropriate spacing of crossing structures (Gunson & Huijser 2019c; Langton & Clevenger, 2020).
- Partial barriers (i.e., barrier on one side of the road or with gaps) are typically not effective. Implement barriers on both sides of a road and start and end the barriers at the same location on opposite sides of the road when suitable habitat or terrain exists (i.e., no staggered fence ends). Mitigate gaps at access roads or driveways (Gunson & Huijser, 2019b) (Figure 116).

Figure 116. ABS plastic sheets to keep common toads off the highway (highway is to the left of the image), and an amphibian tunnel under an access road. Amphibians that approach the access road would fall in between the bars. Amphibians that travel along the barrier would go through the tunnel, continue to travel along the barrier on the other side of the access road until they encounter a tunnel that allows them to cross to the other side of the highway.

- Height of fencing should consider the potential of vegetation or debris to build up against it, which may allow small animals to crawl over the fence (Dodd et al., 2004; Langton & Clevenger, 2020). This may result in higher fences than what would be required based on the jumping or climbing abilities of the target species alone.
- The main types of permanent barrier materials for small animals are wood, plastic, concrete, metal sheeting, chain-link, and hardware cloth. Chain-link or woven wire are common fence materials, and chain-link and plastic sheets were deemed the most effective in some studies (Gunson & Huijser, 2019c; Langton & Clevenger, 2020).
- The life span of barriers varies with materials used, site conditions, installation procedures, and frequency or extent of maintenance. Langton and Clevenger (2020) examine pros and cons of different fencing materials for small animals.
- Mesh size and wire thickness (gauge) are considerations for metal fencing. Typically, wire fencing used for large animals has mesh sizes that are too large for small animal species, and they may move freely through the fencing and onto the roadway.
- Mesh wire fences may be appropriate though for medium sized mammals, and large reptiles (e.g. most turtle species). Mesh wire is available in different gauges. Thick wire (e.g. 2.5 mm diameter (American Wire Gauge 10) or thicker) is more durable than thin wire and results in a greater life span (Kruidering et al., 2005; Clevenger & Huijser, 2011). Most woven wire mesh fencing is galvanized with the highest degree of protection resulting in a life span of at least 15-20 years (Clevenger & Huijser, 2011).
- According to Smith et al. (2015), metal mesh (0.25 inch, hot-dipped, galvanized metal mesh of at least 23-gauge and with at least 29% weight in zinc) is the most cost-effective fencing for small animal species, while aluminum flashing is the most effective biologically but can be cost prohibitive and can cause drainage issues as it can block water flow.
- Hardware mesh cloth is commonly used and allows drainage, but it is not recommended as a "stand alone" installation because the fence is subject to trampling, and the material is exceptionally sharp and dangerous for animals when displaced. Applications of hardware cloth with a sturdy wood or metal framework have been successfully installed in Ontario, Canada, and have lasted up to six years (Gunson & Huijser, 2019c).
- To direct small animals toward the entrance of a passage structure, a septum fence or barrier, also called a passage entrance deflector board can be placed at the entrance of the structure to reduce the likelihood that animals bypass it (Jackson et al. 2015; Langton & Clevenger 2020).
- On overpasses, an opaque barrier should be included to prevent small and medium-sized species from falling off the overpass.
- Maintenance of fences or other barrier structures is critical to their effectiveness in reducing direct road mortality (Baxter-Gilbert et al., 2015; Reses et al., 2015).

9.6 Barrier considerations for mammal species

- For medium-sized mammals, fences should be substantially longer than 100 m (on both sides of a passage), as 100 m was insufficient for avoiding increased amounts of fence-end mortality (Plante et al., 2019). Fence length should be determined by locations of collisions or suitable habitat, and associated buffer zones based on the mobility of the target species.

- Fencing for medium-sized mammals is typically 0.9-1.8 m (3-6 ft) high; a 1.15 m (4 ft) high fencing combined with a 60 cm (2 ft) curved 'floppy' overhang is also effective (Huijser et al., 2015).
- Oftentimes smaller meshes (8 cm (3 inches)) are used at the bottom of a large mammal fence to also exclude medium sized mammals (Kruidering et al., 2005; Clevenger & Huijser, 2011). For small mammals, fine mesh sizes (1 x 1 cm (0.5 x 0.5 in)) may be used at the bottom of the fence, usually as separate fencing material that is tied into the main large mammal fence.
- Some fencing designs have included electrical fencing for medium-sized animals along the bottom (about 9 cm (3.5 inches) above the ground) and at the top to prevent animals from digging under or climbing over (Huijser et al., 2015) (Figure 117).

Figure 117. Wildlife fence along A28 motorway, near Spier, Drenthe, The Netherlands. The fence is a barrier for medium and large mammal species. The electrified wire is an additional barrier to keep animals from climbing the fence.

- Conan et al. (2022) found wire netting fence ineffective, particularly for agile rodent species such as hamsters and voles. In Western Europe, wire netting fence between 30 and 60 cm high (with a typical mesh size of 6.5×6.5 mm) is, despite research showing its ineffectiveness, commonly used for small vertebrate species and is attached to the large-fauna fences (2022). Hamsters and voles could easily climb the fencing, even when including a slight (10 cm (and voles, up to 15 cm) overhang. It is recommended that overhangs must be included and should be longer and made of solid/non-climbable material such as metal plating. More effective, durable, and less climbable fence materials than wire netting fence are also recommended for small mammals.

9.7 Barrier Considerations for amphibian and reptile species

- Minimum barrier height varies based on the target species. Some species will also require an overhang and dig barrier to stop the animals from being able to cross over or under the barrier. Minimum barrier heights can range from only 13 inches (7.6 cm) for some small lizards to 60 inches (152 cm) for large snakes (snakes are less likely to cross over a fence if it is at least as high as the snake is long). Overhangs on barriers are needed for lizards, snakes, salamanders, newts, toads, and frogs, but may not be needed for turtles and tortoises so long as the barrier material cannot be climbed. Due to the behavioral characteristics of different species in terms of climbing, jumping, and digging it is helpful to consult with specialists that have specific knowledge of the species to determine the best material to prevent fencing breaches (Huijser et al., 2021; Langton & Clevenger, 2020).
- Barrier material and solid versus open mesh construction is crucial to consider when designing for reptiles and amphibians. Species that rely heavily on visual and olfactory cues will often spend more time investigating and trying to breach non-solid barriers. Brehme and Fisher (2021) found that California tiger salamanders moved an average of nearly twice as fast along solid barriers as they did along open mesh fence and they were 3 times less likely to turn around and pace the fence when solid. Open mesh fencing is also easier to climb, and some species may become trapped in the mesh if trying to push through. Where open-mesh fencing is already installed, it can be retrofitted by adding a visual barrier at ground level to the existing fencing (Milburn-Rodríguez et al., 2016; Langton & Clevenger, 2020; Brehme & Fisher, 2021)
- Chelonid species such as turtles and tortoises are more likely to walk along barriers that they can see through and more likely to move away from solid barriers, so this is an important distinction for these species if the fencing is meant to guide the animals to a safe crossing opportunity (Figure 118). These species may dehydrate and die from heat exhaustion in some cases if they do not find shade or cover and may require shade structures to be provided at appropriate intervals based on movement speeds (Langen, 2011; Peaden et al., 2017; Boyle et al., 2019; Langton & Clevenger, 2020).
- Table 10 shows the fence characteristics for different species groups based on a stand-alone application. However, fences for small animal species are often combined with fenced for large mammal species (see e.g., Huijser et al., 2022b).

Table 10: Potential small and medium sized wild animal species or species groups and the recommended stand-alone wildlife fence characteristics (adapted from Ontario Ministry of Natural Resources and Forestry, 2016; Langton & Clevenger, 2020; Huijser et al. 2022b; van der Grift et al., 2023, Animex, 2025).

Species group name	**Fence height**	**Post material**	**Fence material**	**Buried fence**	**Over-hang**	**Electric fence or wires**
Frogs	2-3 ft	Metal	Plastic sheeting	8-12 inches	Yes	No
Salamanders	2-3 ft	Metal	Plastic sheeting	8-12 inches	Yes	No
Lizards	2-3 ft	Metal	Plastic sheeting	8-12 inches	Yes	No
Snakes	2-3 ft*5	Metal	Plastic sheeting	8-12 inches	Yes	No
Turtles	2-3 ft	Metal	Plastic sheeting	8-12 inches	No	No
Insectivores	2-3 ft	Metal	Plastic sheeting	8-12 inches	Yes	No
Mustelids (American marten)	7.3 ft (smooth between 1.0 - 2.25 m)	Wood	Small mesh size fence (or chain-link) in combination with plastic sheeting	8-12 inches	No	No
Rodents	2-3 ft	Metal	Plastic sheeting	8-12 inches	Yes	No

Figure 118. Common snapping turtles (Chelydra serpentina) have been walking along a chain-link turtle fence, both on the road side and safe side, Valentine National Wildlife Refuge, Nebraska, USA. One turtle is visible on the roadside (right) of the fence.

- Particular habitat types, landscapes, and climate considerations may make different materials better suited for precipitation, wind, and soil and water erosion. Landscape aesthetics may also be important. Solid barriers including guide walls tend to be more expensive, but also more durable, as long as soil and water erosion processes are not too extreme. Barrier longevity will be influenced by temperature, light and moisture patterns, and vegetation/landscape attributes (Langton & Clevenger, 2020).
- Mesh fencing allows the movement of air, water, and soils to pass through and may be the most suitable material in harsh environments with high winds and/or poor soil drainage and associated in sheet flow runoff.
- Fence-end treatments are critical for reptile and amphibian species (see section on fence-ends below).
- Barrier angle in relation to the road and the crossing structures is an important consideration for reptiles and amphibians, especially migrating adults who may turn back and not breed if barriers are not constructed at the correct angles to guide them to a crossing location, or if they are not able to reach a safe crossing opportunity within their active movement period. Where crossing structures are provided very frequently (60 feet or less spacing between structures), the barriers can be installed parallel to the road. However, if the structures are provided less frequently, the barrier needs to be installed at a suitable angle moving toward the crossing location to guide animals to the structure (Langton & Clevenger, 2020).
- Passage entrance deflector boards, short sections of barrier can keep animals from walking past the structure and direct their movement into the structure. These may be made of wood or

other materials and should extend into the structure slightly, but not block animal movements out of the structure (Langton & Clevenger, 2020).

- Fence effectiveness is reduced and road mortality can occur at gaps in barriers at intersections, access roads, driveways, etc. Consider effective treatments such as passages or grates and barriers at these gaps to reduce animal breach locations (Langton & Clevenger, 2020).

9.8 Planning and design of wildlife crossing structures

- Mitigation measures aimed at reducing collisions with small animal species such as small mammals are partially similar to those for large wild mammals. While some crossing structures include small mammals among the target species and while they are designed to meet their specific habitat requirements, many overpasses and underpasses are primarily constructed for large mammals and happen to also accommodate small animal species.
- The distance between large structures for larger wildlife is typically much larger than the home range of small animal species; smaller suitable structures are typically required at much shorter intervals (e.g., ten or several dozens of meters up to perhaps hundreds of meters depending on the species) (Bissonette & Adair, 2008; Ottburg & van der Grift, 2019; Brehme et al., 2021). Spacing intervals of structures should be a function of home range size and dispersal capabilities of the target species, and those movement distances can be quite short for many small animals (Grilo et al., 2018; Matos et al., 2019). Therefore, the location of a crossing structure and the spacing between them are among the most important factors that influence passage success and the level of connectivity that the crossing structures provide (Jackson et al., 2015; Langton & Clevenger, 2020).
- Designated structures for small animals should be located where improved connectivity for target species would have the greatest benefit for survival of the population (Clevenger & Huijser, 2011). Understanding the biology and motivations for movement of the target species is essential for locating structures (Jackson et al., 2015; Langton & Clevenger, 2020).
- There are usually fewer data on small animals than large animals, so planners must use a variety of sources of data and natural resource agencies should be prepared to maintain and share species occurrence data with transportation agencies (Langen et al., 2015).
- If crossing structures are not used by the target species, the road can become an absolute barrier. When crossing structures are not adequately spaced or there are not enough structures to match the movement distances of the target species, animals will either turn back or find a way to cross at-grade. While the impacts of roads on small mammal species may not appear problematic because their population densities are generally high, this is not always the case (Conan et al. 2022). For instance, some European species are endangered and declining at an alarming rate, such as the garden dormouse (*Eliomys quercinus*) and the European hamster (*Cricetus cricetus*) and roadkill is important to address (Conan et al., 2022). Well intended mitigation of barriers and crossing structures, can also lead to a population crash for amphibians such as the common toad (*Bufo bufo*) if the number of crossing structures is insufficient and keeps a sizeable portion of the population from moving between winter and breeding habitat (Ottburg & van der Grift, 2019).
- Typically for small animals, more wildlife crossing structures are better than fewer. Some guidelines include a general rule of one passage every 300 m, though this minimum sometimes must be exceeded with passages every 10-30 m (i.e., for amphibians) (SETRA, 2005; Brehme et

al., 2021; Langton & Clevenger, 2021). A density of >1.0 small culvert per km was found to allow small mammal movement in one study (Hennessey et al., 2018).

- If there are multiple target species with different habitat requirements, multiple structures that accommodate different species requirements may be required (Table 11). Alternatively, larger structures that accommodate various habitat types and environmental conditions can help address this issue (Mata et al., 2005; Jackson et al., 2015; Hennessey et al., 2018) (Figure 119, Figure 120).

Figure 119. Cover, grassland, and edge habitat on top of multifunctional overpass (wildlife and farm road, about 100 m wide), across A4 motorway, Parndorf, Austria. The overpass is designed for farmers, agricultural machinery, hunters and wildlife including roe deer (Capreolus capreolus) and European hare (Lepus europaeus).

Table 11. Suitability of different types of mitigation measures for selected small and medium-sized mammal species (for 2-3 lane highways [25-35 m (82-115 ft)] wide road without median).

● Recommended/Optimum solution; ⭘ Possible if adapted to species' specific needs; ⊗ Not recommended; ? Unknown, more data required (Clevenger & Huijser, 2011; O'Brien et al., 2013; Ford et al., 2017, Huijser et al. 2022).

	Wildlife overpass	Open span bridge	Large mammal underpass	Medium mammal underpass	Small-medium mammal pipes
Frogs	●	●	●	●[1]	●[1]
Salamanders	●[2]	●	●[3]	●[3]	●[1]
Lizards	●	●	●[3]	●[3]	⊗
Snakes	●	●	●[3]	●[3]	⊗
Turtles	●	●	●[2]	●[2]	⊗
Insectivores	●	●	●[3]	●[3]	⭘
Mustelids	●	●	●[3]	●[3]	⭘
Rodents	●	●	●[3]	●[3]	⭘

[1] With open or slotted roof.
[2] With wet habitat provided on top of overpass and on the approaches.
[3] With cover (e.g., rootwads, branches) provided on top, inside and on the approaches.

Figure 120. Wildlife underpass and fence with grasses, shrubs, and trees in the median and also some under the bridges, US Hwy 64, near Roper, North Carolina, USA.

- Topographic features like draws, valley bottoms, and ridges, and habitat edges are often where wildlife are channeled. When habitat is continuous or without topographic features, animals may have no apparent areas of concentration; directional fences or guide walls leading to multiple structures are highly important. If there is evidence of certain areas having high movement, clusters of small structures may be useful (Jackson et al., 2015; Langton & Clevenger, 2020).
- Structures vary in shape from round, elliptical, arched, or box and are made of materials that range from metals (e.g., corrugated steel pipe), plastics (e.g., high-density polyethylene), polyvinyl chloride, or cement. Use of polyethylene as a construction material for culverts was negatively correlated with wildlife use in one study (Brunen et al., 2020).
- Maintain natural substrate on the bottom (Figure 121). This is more likely to match nearby natural conditions (soil, soil and air temperature and humidity). Design features should mimic conditions in the surrounding environment.

Figure 121. Corrugated metal culvert with soil covering the bottom.

- Open-bottom structures like arched culverts on footings or three-sided culverts allow for natural substrate and moisture conditions to be more similar to the surroundings (Gunson & Huijser, 2019b) (Figure 122).

Figure 122. Bottomless culvert.

- When structures have a solid floor (i.e., are a round tube) rather than an open bottom, it is preferable to be placed below grade and filled with natural substrate to match the adjacent ground level (Jackson et al., 2015; Brehme & Fisher, 2021; Langton & Clevenger, 2020) (Figure 123).

Figure 123. Corrugated metal culvert with bottom placed below the ground level of the surroundings, US Hwy 93, near Ravalli, Flathead Indian Reservation, Montana, USA.

- Data on specific size for crossing structure are not available for most species of small and mid-sized mammals; a focal or target species is often used as a representative for an area of species, or a structure is made large enough for many smaller species. In theory, wider tunnels work better for smaller animals that move short distances because they are more likely to find the entrance when migrating across the landscape (Gunson & Huijser, 2019b).
- Some sizing generalities can be made: an analysis of research articles found that box culverts are on average 2.4 m wide by 1.8 m high and have been installed and shown use by amphibians, reptiles, and small mammals (Gunson & Huijser, 2019d). Small-sized underpasses (1–1.5 m wide) are also used by small- to medium-sized species, such as marten, coyote and bobcat (Cain et al., 2003; Ng et al., 2004; Grilo et al., 2008). Further guidelines can be found in Clevenger and Huijser (2011) and Langton and Clevenger (2020) (Figure 124, Figure 125).
- In general, overpasses tend to be well suited for small animal species, since overpasses are typically large enough to host a variety of habitat types and micro-climates (McGregor et al., 2015).

Figure 124. Culvert for long-toed salamander (Ambystoma macrodactylum), Waterton Lakes National Park, Alberta, Canada.

Figure 125. Wildlife underpass, Nuevo Xcan-Playa Del Carmen highway, Quintana Roo, Mexico.

- Since it may take considerable time to cross the length of a crossing structure, it is important that small animals find everything they need on top of or inside a crossing structure, including continuous suitable habitat or steppingstones of suitable habitat with relevant amounts or types of cover, food, and water, as well as light, temperature, and soil (McGregor et al., 2015) (Figure 126, Figure 127).

Figure 126. Wildlife underpass with branches along the side for cover for small mammals, Montana, USA.

Figure 127. Root wads leading up to and on top of wildlife overpass as cover for small animal species, The Netherlands.

- Underpasses usually have limited light and precipitation, and this severely reduces vegetation, cover, and food inside many underpasses. To be made more suitable for small animals, over-size the structure to maximize light, moisture and air at the entrance of the structure (Figure 128) and allow for multiple design features such as shelving for multiple species and animal groups.

Figure 128. Tall bridges allow for light and moisture under the structure, and for continuous habitat for nearly all species, including small animal species, China.

- Keep structure length to a minimum (Jackson et al., 2015; Chen et al., 2021); small mammals are more likely to use shorter passages (McDonald & Cassady St. Clair, 2004). To address this, consider increasing the width and/or height of a structure for wider roads (Gunson & Huijser, 2019b)
- Water may be available in some underpasses if the underpass is combined with a stream or river crossing, or where it crosses a wetland. A stream or river crossing should preferably have natural stream dynamics and natural substrate so that the hydrological conditions are similar to those outside the structure. For rivers and streams, bottomless structures are recommended. This allows for natural substrate and stream dynamics.
- At the area approaching the crossing structure, ensure there is sufficient cover and that the approach matches that of the surroundings (Figure 129, Figure 130). Available cover and natural characteristics in the approach areas to crossing structures is important for small and mid-size

mammals (Clevenger & Waltho, 1999; Ascensao & Mira, 2007; Grilo et al., 2008). Riparian and terrestrial habitat at entrances further increases the use by species that depend on those habitat types. However, vegetation that is too dense and obscures the visual opening or prevents small mammal passage of a culvert should be selectively removed or thinned (Smith et al. 2015).

Figure 129. Cover close to the entrance of an amphibian tunnel, The Netherlands.

Figure 130. Vegetation providing cover at the approach of a wildlife underpass, US Hwy 95, Bonners Ferry, Idaho, USA.

- Cover is highly important for small mammals and some reptile and amphibian species; small and confined structures may be used more readily by certain small mammal species than larger structures that have no or limited cover (Foresman, 2004; McDonald & Cassady St. Clair, 2004; Hennessey, 2018; Brehme et al., 2021). Incorporating elements that match the natural habitat into underpasses is also important for mid-size mammals (Grilo et al. 2008).

- Provide cover for resting or hiding within both underpasses or overpasses, using natural materials such as branches, logs, root wads, and rocks or artificial materials including concrete cinder blocks or PVC pipes (D'Amico et al., 2015). Shrubs, grasses, and other understory vegetation also provide important cover (Millward et al., 2020). Tubes or pipes can be placed within a larger structure to assist species that prefer small, confined spaces like weasels and other small mammals (Clevenger & Waltho, 1999; Foresman, 2004) (Figure 131, Figure 132). These can be integrated into the walkway design or attached to the walkway to encourage small mammals (mice, voles) to use the walkway.

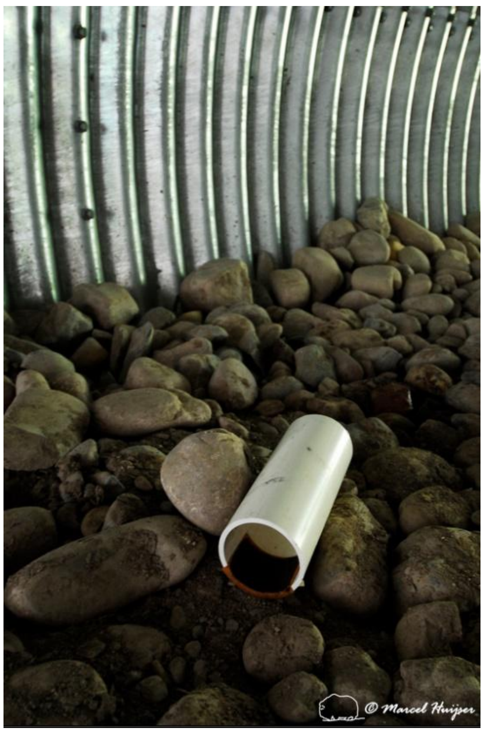

Figure 131. PVC pipe as artificial cover in an underpass, Montana, USA.

Figure 132. Boulders provide cover to small animal species and block access to unauthorized vehicles at wildlife underpass, US Hwy 95, Chilco, Idaho, USA.

- Wildlife passages should be designed and managed to exclude stormwater and areas where flooding may occur, as most small mammals are deterred by flooding or standing water (Jackson et al. 2015). Barriers are often compromised with high water levels and wash-outs from groundwater flow, especially when barriers are near the road pavement surface. Consider effective placement of barriers, selection of materials, and installation methods to reduce water flow impacts (Gunson & Huijser, 2019b).
- When this is not possible and when drainage culverts or underpasses are frequently flooded but not fully submerged, adequately sized ledges, shelves, or rails placed above high-water levels are recommended to facilitate drier passage for terrestrial animals (Goldingay et al., 2018; Brehme & Fisher, 2021) (Figure 133). Concrete, wood, or grate shelving are successfully used for small and mid-sized mammals like mice, voles, bobcats, skunks, weasels, and raccoons (Cain et al., 2003; Foresman, 2004; Meaney et al., 2007; Martinig & Bélanger-Smith, 2016) (Figure 134). Shelves should be well-connected to the ground surface with an entrance ramp or similar. There may be some maintenance concerns about using bolt-on metal brackets for metal shelving due to shelves becoming dislodged. Some transportation agencies prefer molded concrete shelving, which would require construction prior to installation of drainage culverts in roads (Gunson & Huijser, 2019a).

Figure 133. Pathway for large mammals in an underpass (bridge) primarily designed for water (stream), US Hwy 93 S, Bitterroot Valley, Montana, USA.

Figure 134. Shelf for small mammals in culvert originally designed for hydrology only, US Hwy 93 South, Montana, USA.

- For small- and medium-sized species (up to marten and rabbit size), a minimum walkway width of 0.5–0.7 m (1.6–2.3 ft) is recommended, with a preferred walkway width of about 1 m (3.3 ft) (Huijser et al., 2022b). A dry ledge width larger than 0.5 m (1.6 ft) has been recommended for successful carnivore crossings (Craveiro et al., 2019). A minimum clearance between the walkway and the ceiling of an underpass is about 0.6 m (2 ft) or greater (Huijser et al., 2008a).
- The surface of the walkways should consist of material that animals will not slip on. In some situations, where erosion danger is low, soil may be placed on the walkways (Huijser et al., 2008a) (Figure 135).

Figure 135. Imprints in concrete surface in wildlife underpass to make it less slippery for wildlife, US Hwy 93 S, Bitterroot Valley, Montana, USA.

- A berm the length of the underpass can be added to an underpass that contains water; water can rise while still allowing wildlife to use the berm.
- If drainage culverts are placed and shelving cannot be implemented, small dry pipes can be installed on higher ground adjacent to the drainage culverts. Dry pipe culverts can also be placed not only adjacent to drainage culverts but interspersed between drainage culverts if spacing is not adequate for the target species, to improve connectivity for small mammals (Gunson & Huijser, 2019a).

9.9 Additional considerations for amphibians and reptiles

- Underpass structures vary in size from small diameter culverts (e.g. 2 ft in diameter) to box culverts (2-3 m wide and high), to large underpasses (e.g. 7 m wide, 4-5 m high) up to bridges (e.g. 30-100 m wide or more) or elevated road sections (Langton & Clevenger, 2020). Blockage of underpasses with leaves and other dead plant material, larger branches, logs, and other debris carried by water in a stream or river, and snow can be an issue, especially for relatively small culverts (Ford & Clevenger, 2019; Schroder & Sato, 2017; Langton & Clevenger, 2020) (Figure 136).

Figure 136. Tumbleweed blocks culverts, primarily for hydrology, but also for Mojave desert tortoise (Gopherus agassizii), Hwy 58 near Kramer Jct, California, USA.

- Abiotic factors influence passage by reptile and amphibian species. Because these species are cold-blooded, their body temperatures can be highly sensitive to temperature changes as well as moisture levels. Light levels can also influence use even for nocturnal species including many amphibians and some reptiles. Structures must be designed to match ambient environmental conditions given the lack of research for most species (Brehme & Fisher, 2021; Langton & Clevenger, 2020).
- Micro passages (<3ft/1m) with small grates or openings on the top on the road surface can provide effective crossings for reptile and amphibian species in places where larger structures may not be technically or economically feasible (Brehme & Fisher, 2021) (Figure 137).

Figure 137. Amphibian tunnel with open slotted roof and barrier or wall for amphibians, integrated into roadbed, Deelenseweg, between Hoenderloo and Arnhem, Gelderland, The Netherlands.

- Passage substrate is critical and should be as similar as possible to the surrounding soil in terms of moisture and temperature. Untreated cast concrete floors may release efflorescence that can leach and burn amphibians' skin. Corrugated metal can be hard to navigate for some species, and because of its conductive properties metal can become much hotter or colder than the ambient environmental conditions and potentially be harmful (Brehme & Fisher, 2021; Langton & Clevenger, 2020).
- Openings such as a semi-open roof or grates in an underpass allows for more similar conditions inside and outside an underpass (Figure 138). The latter is often an integral part of the design of an amphibian tunnel or culvert (Andrews et al., 2015; Langton & Clevenger, 2020). However, run-off from the road containing toxins may be a concern.

Figure 138. Opening (with bridge grate cover) in median to allow light and moisture in the wildlife underpass Hwy 331 Hwy 83 near Freeport Florida USA.

- Placement and spacing of crossing structures are critical for reptiles and amphibians. This can be related to the specific habitat and environmental requirements of the species, and well as the ability and willingness of species to travel along fencing. Ottburg and van der Grift (2019) found that the common toad, *Bufo bufo*, turned around after an average of 50 m if they did not reach a crossing structure. Similarly, Brehme and Fisher (2021) found that California tiger salamanders were only willing to travel an average distance of 40m before "giving up", and Yosemite toads were only willing to travel an average of 52m. This means that in crucial movement areas safe crossing opportunities need to be provided very frequently. Moreover, insufficient number of suitable crossing structures can cause a population crash (Ottburg & van der Grift, 2019).

9.10 Enhancing existing structures

- Small animals may use existing passages not originally designed for wildlife, such as drainage culverts that were installed to convey water. The structures need to be evaluated to assess whether they are in the correct location and are designed adequately to meet the passage criteria of the target species. Several passage assessments have been developed for small animal passage (Kintsch & Cramer, 2011; Langton & Clevenger, 2020; Brehme & Fisher, 2021).

- In some cases, an existing passage will not require any modifications other than supplementary exclusion fencing, such as the addition of both temporary or permanent exclusion barriers and/or funneling guide walls to direct small animals to existing structures (Figure 139).

Figure 139. Turtle fence tied into an existing culvert for hydrology, US Hwy 83, Valentine National Wildlife Refuge, Nebraska. The camera monitors potential turtle crossings at the culvert.

- Drainage structures are generally constructed in lower wet areas, often along streams or adjacent to wetlands, and are only functional for small animals that occur in or can move through this type of habitat. However, natural substrate and stream dynamics such as water velocity are critical. Smaller animals that move in relatively dry upland habitat will require designated structures installed in higher ground that remain dry when drainage structures are filled with water. Dry wildlife passage opportunities are created through the installation of concrete, wood, and metal shelves into the existing structure, as discussed above.
- To facilitate and enhance use of existing structures by small animals, create or restore habitat such as vegetation, natural substrate, and water sources at crossing approaches, in medians, inside structures, and on top of structures (Gunson & Huijser, 2019e) (Figure 140, Figure 141, Figure 142).

Figure 140. An existing underpass for a low volume road under a 4-lane A27 motorway, near Hilversum, The Netherlands. The structure was made more suitable for small animal species by placing rows of root wads along the sides.

Figure 141. A provincial road crossed under the 4-lane A27 motorway, near Hilversum, The Netherlands. The structure was made wider to anticipate potential future additional lanes. Instead, this space was used to create habitat for small animal species. Note the black screen on the left that reduces light and other visual disturbance originating from the provincial road. The trail on the right is for non-motorized traffic, including equestrian use.

Figure 142. A bridge across the A28 motorway near Utrecht, The Netherlands. One of the lanes was later devoted to habitat for small animal species, including invertebrates.

- In some cases, screens are placed at culvert entrances to deter debris from plugging culverts or to inhibit other wildlife such as beavers from damming inside the structures. Problematically, these screens may trap other wildlife and block animals from entering the culverts. One potential solution includes modifying the screen (i.e., changing the mesh size to allow permeability of the target species while still excluding debris and beavers). Other solutions include using flow devices, diversionary dams, and fence barriers strategically placed to deter beavers from damming culverts and entrances. Wildlife passage must be considered in these solutions, and include integration of a gap, gate, or door in the diversionary barrier (Danby & Gunson, 2020).

9.11 Fence-ends

- Effective barrier-end treatments are required to reduce direct road mortality at or near fence-ends. The best fence-end treatment is to extend a fence beyond the road crossing hotspot and adjacent buffer zone, and to tie the fence-end into an appropriate feature, such as a concrete bridge abutment, or rock cliff. If this is not possible, then, technical designs such as curved ends that limit crossings at or immediately beyond a fence-end are advisable (Gunson & Huijser, 2019f).
- For reptile and amphibian species, turnarounds can be effective at reducing fence-end runs by redirecting animals back along the fence line towards the safe crossing opportunity, or at least

directing them away from the road (Figure 143). Turnarounds should not be angled and should be smooth curves. The turn-back should be at least 3ft/0.9m from the barrier and would ideally be 6ft/1.8m-15ft/4.5m long and 6ft/1.8m wide and would curve back in towards the barrier to direct animals back along the fence to a safe crossing opportunity (Langton & Clevenger, 2020; Brehme & Fisher, 2021).

Figure 143. Though not meeting the recommended specifications for a "turn-around fence-end", this is an attempt at discouraging turtles from crossing the road in high numbers at the fence-end, US Hwy 83, Valentine National Wildlife Refuge, Nebraska, USA.

- Brehme and Fisher (2021) found that >90% of lizards, snakes, and toads and 69% of small mammals were redirected back towards the fencing after leaving a turnaround.
- Ideally the barrier ends beyond where the suitable habitat is of the target species (Langton & Clevenger, 2020).
- Treatments are also needed where fencing intersects with access roads, driveways, or other locations where there is another feature that bisects the barrier (Figure 144, Figure 145, Figure 146). Cattle guards or other similar structures can be used to stop animals from crossing at-grade, however these must include openings on the sides or ramps to allow animals that fall into the pit to be able to escape back to the safe side of the fence.

Figure 144. A gate for pedestrians and bicyclists at a barrier wall for amphibians, The Netherlands. The rubber flap is designed to keep common toads (Bufo bufo) from crawling under the gate and gaining access to the main road.

Figure 145. Combined drainage and escape for small animals under wildlife guard, Arizona, USA. The openings on the side allow for drainage under the culvert. The openings also allow invertebrates, amphibians, reptiles, small mammals and other species that may fall in between the metal bars to escape. For wildlife guards that have a fully enclosed pit with contiguous walls sometimes wooden planks or metal strips are attached, allowing animals to climb out of the pit.

Figure 146. Escape ramp for small animals from pit under wildlife guard National Park Hoge Veluwe, The Netherlands.

9.12 Jump-outs, escape ramps or one-way gates

- Wildlife jump-outs and one-way gates have been constructed for small and medium-sized mammals, as well as for reptiles and amphibians (Figure 147, Figure 148). The height of the escape ramps will be determined by the barrier height and as well as the behavioral characteristics of the target species. (Kruidering et al., 2005; Langton & Clevenger, 2020).
- Goldingay et al. (2018) documented that the effectiveness of jump-outs, escape ramps, or other right-of-way exits for small animals is unevaluated, and preliminary documentation suggest that these structures may provide more harm than good (Huijser & Gunson, 2019a). However, Brehme and Fisher (2021) found that earther ramps and modified rectangular plastic mesh cones did allow small animals including reptiles and amphibians to escape the road corridor and move back to the safe side of the barrier. They do note that the modified rectangular plastic mesh cones could be an entrapment hazard for some species and should only be considered in specific scenarios (Langton & Clevenger, 2020; Brehme & Fisher, 2021).

Figure 147. Wildlife fence and jump-out for medium sized mammals and roe deer, along A28 motorway, near Spier, Drenthe, The Netherlands.

Figure 148. Escape gate for Eurasian badger (Meles meles) in wildlife fence Harderwijk, The Netherlands. Note that these types of gates are often left open because of debris which threatens their functioning.

9.13 Implementation/construction of fences and other barriers

- Have a road ecologist oversee fence installation to reduce the likelihood of installation errors. Once installed, installation errors are hard and expensive to correct, or the errors may never be corrected at all. This can severely jeopardize the effectiveness of the mitigation measures.
- Make sure no gaps or other weak points in the fence occur because of installation errors or challenges.
- Make sure that no gaps remain where the fence connects to the ground. If a dig barrier is added, this is less likely to be a concern.
- Note that the digging of a trench for a dig barrier may require erosion control measures to reduce the probability that sediments end up in streams. Erosion control measures will likely add costs to the installation of a dig barrier (Huijser et al., 2015).
- Although material types and sizes considerations are essential, often more important to the success of a fencing project are the more subtle details of how the fence is constructed. For example, the plans and specs could specify the maximum gap below the wire mesh fence and the natural ground, but not specify this requirement for vehicle access gates. For instance, a vehicle gate installed on uneven ground that has a large gap on one side may allow animals to enter the fenced road corridor which threatens the effectiveness of the entire set of mitigation measures (Huijser et al., 2015).

9.14 Implementation/construction of wildlife crossing structures

- Riprap is often used at entrances of culverts and pilings; however, riprap can impede many species from entering into a culvert. Entrances into structures should be clear of rock sizes that impede target species, or spaces between riprap could be filled with smaller material for more even substrate (Jackson et al., 2015; Langton & Clevenger, 2020; Brehme & Fisher, 2021) (Figure 149).

Figure 149. Riprap in front of culverts to reduce erosion, but the boulder are a barrier to Mojave desert tortoise (Gopherus agassizii), I-11, near Boulder City, Nevada, USA.

- Erosion and sedimentation control measures need to be put in place at steep slopes and low-lying wet areas, especially with flowing water. Use natural products that decompose. Do not use plastic or nylon netting as animals may get entangled and die.
- It is helpful to minimize impacts to existing vegetation and soil during construction, to reduce effort in restoring cover and soil type, especially in sensitive environments. Restrictions for where machines and personnel can go can help minimize vegetation removal and soil and hydrology impacts during the construction of a bridge or other structure.
- A tight connection between crossing structures and wildlife fence is essential. Where fencing meets tunnels or other wildlife crossing structures, it is advisable that fence material is well connected to the wing walls or sides of the structures, not allowing any gaps where they meet. Where fences meet drainage culverts, they should either pass above or integrate the culvert into the fence (Clevenger & Huijser, 2011).

9.15 Implementation/construction of jump-outs or escape ramps

- One-way escape gates have been designed for medium sized mammals such as the Eurasian badger (Kruidering et al., 2005). These one-way gates are made of aluminum and are set at an angle, allowing gravity to automatically close the gate. These gates are vulnerable to damage and debris keeping the gates from closing properly. If used, to minimize debris and vegetation growing around such one-way gates, it can be effective to install them on a concrete slab (Huijser et al., 2015).
- Jump-outs or escape ramps need to be provided so that animals that have entered the fenced road corridor can get back to the safe side of the fence.

9.16 Operation and maintenance of fences and other barriers

- Without effective fence maintenance, wildlife fences typically become ineffective quickly (Figure 150). This can severely jeopardize the effectiveness of the mitigation measures. A maintenance plan should be developed in the early phases of a project before implementation. Adequate funding and capacity must also accompany these plans so that they are more likely to succeed and reach the stated objectives.

Figure 150. A barrier wall for common toads (Bufo bufo) has collapsed, The Netherlands.

- All barrier materials are subject to "wear and tear" maintenance concerns such as holes, burrowing, wash-outs, erosion, vegetation overgrowth, falling trees, vandalism, tampering, car crashes, and damage from mowing and snow removal (Gunson & Huijser, 2019f) (Figure 151).

Figure 151. An animal (probably a nine-banded armadillo (Dasypus novemcinctus)) dug a gap under a wildlife fence. The burrow is visible on roadside of the fence, SP-225 motorway, near Brotas, São Paulo, Brazil.

- Time spent in initial planning, consultation, and retaining experts reduces the need for maintenance and increases probability of effectiveness. More durable materials, careful and robust installations, as well as educating maintenance workers will help optimize routine maintenance procedures.
- Routine maintenance, such as vegetation clearance, will always be required and must be budgeted for and allocated to responsible agencies early in the planning stages. Implement fence inspection and maintenance programs.
- Fence maintenance is typically not a priority for road maintenance crews. Consider including maintenance requirements in contracts with toll road companies or outsourcing fence inspection and maintenance along state and federal highways.

9.17 Operation and maintenance of wildlife crossing structures

- A maintenance protocol for wildlife crossing structures and fencing should be created; maintenance needs for right-of-way along structures are usually different from right-of-way or shoulders of most roads without structures. Vegetation needs to be mowed in the clear zone, and sometimes also alongside barriers. Thus, mowing schedules are required for each location. Small animal fencing material may be more fragile than other fencing material and requires careful maintenance. Alternatively, more robust barriers can be designed and installed.
- Crossing structure functionality can be compromised by erosion, flooding, and overgrown vegetation and debris and garbage blocking the entrances (Figure 152). Blockage of underpasses with leaves and other dead plant material, larger branches, logs, and other debris carried by water in a stream or river, and snow can be an issue, especially for relatively small culverts (Ford & Clevenger, 2009; Schroder & Sato, 2017; Langton & Clevenger, 2020). Monsoon season in some areas can lead to soil accumulation inside small culverts, which can limit culvert use by wildlife (Chen et al., 2021).

Figure 152. A culvert blocked by rocks under the road to the overlook, Childs Mountain, Cabeza Prieta National Wildlife Refuge, Arizona, USA.

- Shelving systems and ramps installed in an underpass may require annual cleaning for debris or if the units have become dislodged (Huijser et al., 2021).
- In some cases, screens may be added to culvert entrances to deter debris and beavers from damming or plugging culverts. Because these screens may trap other wildlife and block animals

from entering through culverts, thought must be given to the design, such as mesh size or spacing of rods.

- At structures with water, specific maintenance is needed to ensure scouring or erosion does not create a “perched entrance” or other barriers that prevent the target animal access to a structure (Langton & Clevenger, 2020) (Figure 153).

Figure 153. A culvert with a heavily eroded outflow near Indian Springs, Nevada, USA. Inaccessible to desert tortoises.

- Vegetation that is too dense and obscures the visual opening or prevents small animal passage of a culvert should be selectively removed or thinned (Smith et al., 2015; Langton & Clevenger, 2020). Vegetation such as cattails and common reed may need to be cleared routinely around structures with water.
- Depending on the climate and soil, plantings on wildlife overpasses and approaches to the structures may require watering for the first few years.

10 Decision support tool

10.1 Objectives and characteristics of the different approaches

Any decision process should start with the goal (broad, long-term aspirations) and the objectives (specific, measurable, and time-bound). We distinguish between three objectives (Figure 154, Table 12Table 12. High-level objectives and characteristics of the associated approaches.), and we describe the characteristics of the actions associated with these objectives for wildlife mitigation along roads.

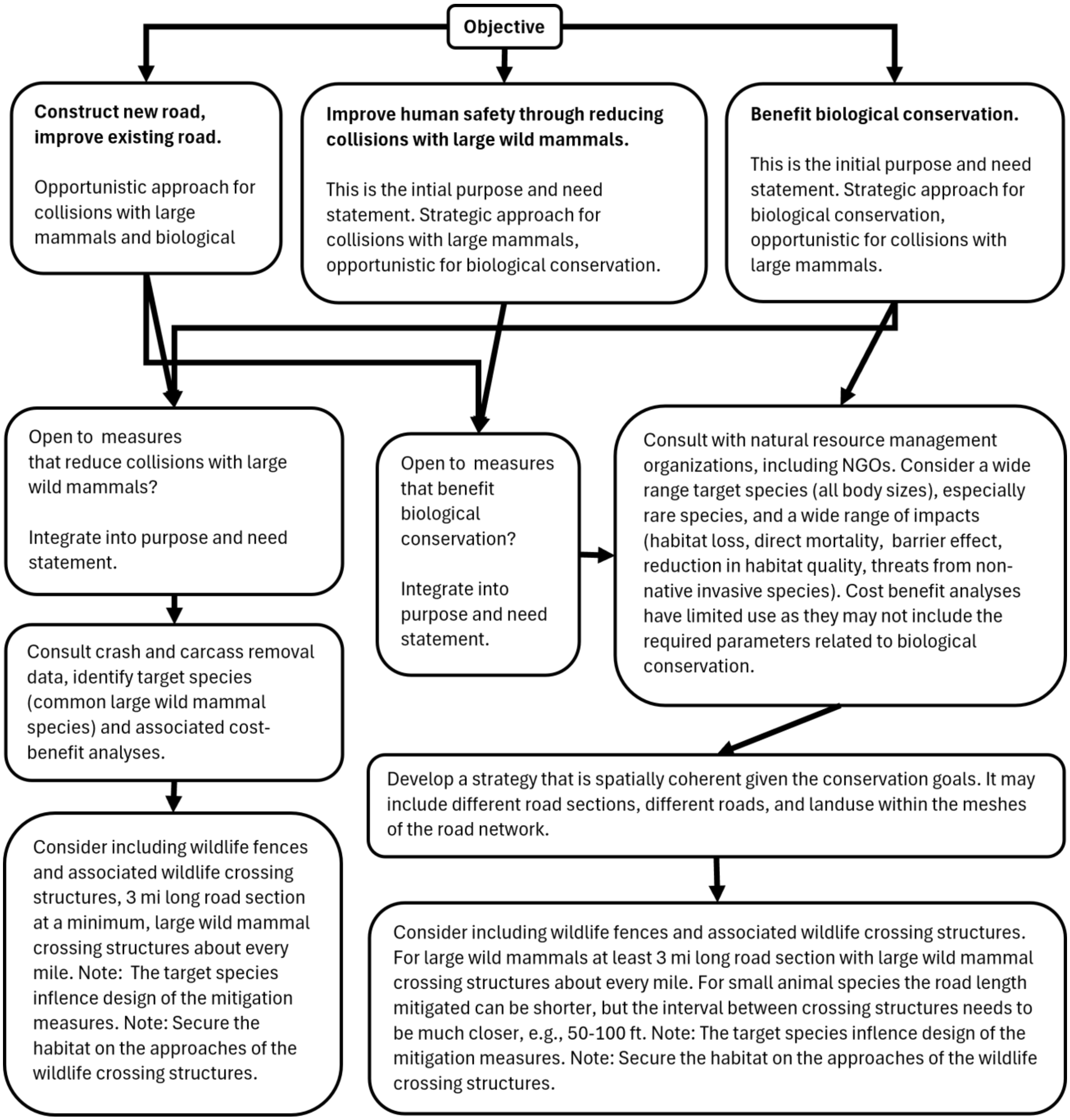

Figure 154. Flowchart of mitigation measures, given three different objectives.

Table 12. High-level objectives and characteristics of the associated approaches.

Characteristics	Potential objectives		
	Construct a new road or improve an existing road	**Improve human safety (related to animals)**	**Benefit biological conservation**
Selection of road or road section.	Based on (new) transportation needs or general maintenance needs of existing roads. Human safety associated with wildlife-vehicle collisions or biological conservation concerns do not influence the selection of the road section (at least not typically).	Based on road sections with a relatively high concentration of collisions with common large mammals.	Based on road sections with relatively severe impacts of roads and traffic on the natural environment, especially for rare species (including, but not necessarily restricted to those listed under the Endangered Species Act).
Species that may be included in the identification and prioritization process of road sections.	None.	Common large wild mammal species (e.g., white-tailed deer, elk, black bear). The species involved with collisions are typically large and relatively common. They need to be large to be a concern to human safety, and they need to be common as infrequent collisions would not warrant action. Note: in theory the species can also include large livestock or feral species. However, these are not wildlife species and are excluded from this analysis.	This can include any type of environmental impact and any wildlife species, regardless of its taxonomic group, body weight or body size. However, the species involved are typically rare, or the biological processes or the ecological integrity associated with common species are considered vulnerable (e.g., seasonal migration or dispersal).
What type of data (related to wildlife) is required for the identification and prioritization process?	None.	The absolute number of collisions with common large wild mammals for each road section over a certain road length and over a certain period (e.g., the number of reported	Data on the occurrence of species (common and rare species) and the type of threats to their local, regional, overall persistence, or the biological processes or

		collisions for each 0.1-mile road segment per year). These collision data are typically collected by law enforcement personnel (crash data) and road maintenance personnel (carcass removal data). Note: Correcting the absolute number of collisions for the traffic volume would show the relative risk of road sections per moving vehicle. However, the costs and benefits of roadside mitigation are based on the absolute number of collisions in a road section, not on the relative risk per vehicle.	ecological integrity that originate from roads and traffic. The types of threats may include habitat loss, direct road mortality, the barrier effect, a reduction of habitat quality, and non-native invasive species. However, in the table rows below the focus is with reducing the barrier effect of roads and traffic (i.e., improving connectivity for wildlife). While rarely available, data that would indicate how much avoidance, minimization, remediation or offset strategies would benefit biological conservation goals for each road section, potentially in conjunction with other road sections in the area, would be useful in the identification and prioritization process.
Strategic or opportunistic regarding addressing collisions with common large wild animals and improving human safety.	Opportunistic. The selected road sections are not necessarily the worst road sections for collisions with common large wild mammals; they can potentially have none.	Strategic. There is a potential to start with the "worst" road sections and then move down the list to the next worst road section based on the relatively high numbers of collisions with large wild mammals. Note: An identification and prioritization process for road sections with common large wild mammal collisions is most useful if it is associated with a strategic approach to address these road sections, starting with the "worst" ones, rather than	Opportunistic. The selected road sections are not necessarily the worst road sections for collisions with common large wild animals. In fact, the road sections that may require action to address the barrier effect most may have no road mortality of the target species at all because the animals no longer venture out on the road, indicating a near absolute barrier.

		having generated this information but falling back on an opportunistic approach where the selected road sections are based on (new) transportation needs or general maintenance needs.	
Strategic or opportunistic regarding addressing the impacts on biological conservation.	Opportunistic. The selected road sections are not necessarily the worst road sections for the impacts on biological conservation; they can potentially have none or very few.	Opportunistic. The selected road sections are not necessarily the worst road sections for the impacts on biological conservation; they can potentially have none or very few.	Strategic. There is a potential to start with the "worst" road sections and then move down the list to the next worst road section based on the impacts to biological conservation.
Spatial coherence between the road sections that are addressed.	None. The selected road sections may not have any spatial coherence. The "project" is regarded as a line (however long or short), independent of the land use in the surrounding landscape and the presence of other linear infrastructure.	None. The selected road sections may not have any spatial coherence. The "project" is regarded as a line (however long or short), independent of the land use in the surrounding landscape and the presence of other linear infrastructure.	Great need for spatial coherence. Biological conservation success cannot be achieved through only taking action within the boundaries of the right-of-way of a traditional road project. The impacts of roads and traffic on biological conservation, and the benefits of addressing these impacts, depend on actions, or lack thereof, along other roads (or other linear infrastructure) in the wider landscape and the land use within the meshes of the road network. Note: An identification and prioritization process for road sections that may require addressing the impacts on biological conservation, including the barrier effect, is most useful, perhaps only useful, if it is associated with a

			strategic approach to address these road sections in a spatially coherent manner, rather than having generated this information but falling back on an opportunistic approach where the selected road sections are based on (new) transportation needs or general maintenance needs.
Potential measures to address wildlife issues associated with roads and traffic.	Any effective measures aiming to address collisions with common large wild mammals, or to address the impacts on biological conservation.	Any effective measures aiming to address collisions with common large wild mammals. Excluding potential road removal or road closure, the most effective measures include (potential >80% reduction in collisions with common large wild mammals): Roadside animal detection systems (33-97% effective), but many projects struggle with technical issues (including reliability). This measure is only suited for large mammal species, and it does not address the barrier effect for any wildlife species (regardless of body size). Likely only suited for roads up to around 5,000 AADT. Wildlife barriers (fences, walls) along the road corridor that keep large mammals off the road (80-100% effective), without wildlife crossing structures. To reach this level of effectiveness for collision reduction, the fences need to be implemented at the correct spatial scale (at least 3 miles of road length, but often much longer).	Any effective measures aiming to address collisions with common large wild mammals and the impacts on biological conservation, especially the barrier effect. Here we only include measures that address the barrier effect, excluding potential road removal or road closure: Wildlife crossing structures (i.e., wildlife underpasses and overpasses) without wildlife fences. While such wildlife crossing structures can have substantial use by wildlife, they do not necessarily result in collision reduction with wildlife (regardless of the taxonomic group, body weight or body size). Wildlife crossing structures (i.e., wildlife underpasses and overpasses) in combination with wildlife fences. The use of crossing structures that are connected to wildlife fences is higher than that of structures that are not connected to fences. In addition, if the wildlife fences are implemented at the correct spatial scale (at

		However, this measure is likely to be in direct conflict with biological conservation objectives or ethical considerations as it results in a (near) absolute barrier of the road corridor for the species concerned. Wildlife barriers (fences, walls) along the road corridor that keep large mammals off the road (80-100% effective) in combination with wildlife crossing structures (i.e., wildlife underpasses and overpasses). To reach this level of effectiveness for collision reduction, the fences need to be implemented at the correct spatial scale (at least 3 miles of road length, but often much longer). This combination of measures can substantially reduce collisions with common large mammals while still allowing for wildlife connectivity across the road corridor.	least 3 miles of road length, but often much longer), they can reduce collisions with large wild mammals 80-100%.

10.2 Incorporating potential mitigation measures in WisDOT's improvement concepts

WisDOT has a standard list job types related to highways; "improvement concepts" (Table 13). In the table we describe how the different improvement concepts could be used to reduce collisions with large wild mammals or to reduce the barrier effect of roads and traffic for wildlife.

Table 13. Improvement concepts (from WisDOT), their definitions, and potential actions to reduce collisions with wildlife, and to reduce the barrier effect of roads and traffic for wildlife.

FIIPS Improvement Concept	Improvement Concept Definition	Potential actions that reduce collisions with common large wild mammal species or small animal species	Potential actions that reduce the barrier effect for wildlife
Bridge preventive Bridge rehabilitation	Preservation of existing structure by treatments that decelerate future deterioration and maintains or improves the functional condition. Preservation or restoration of the structural integrity of an existing structure, or work to correct safety defects on existing structure	None, unless there is an option to implement a fence, wall or other type of barrier that is connected to the structure and that runs along the road corridor away from the structure for a sufficiently long distance. Note that barriers can only be so long before another crossing opportunity would need to be present or newly constructed. The interval for these crossing structures depends on the species (e.g., 50-100 ft interval for small species up to a mile or more for larger species).	Make the structure better passable for wildlife: A dry pathway through the riprap with relatively fine material (not boulders which are a barrier, especially to large ungulates). A dry pathway for small animal species or medium sized mammals (e.g., northern river otter) that is attached to the existing structure. Providing cover for small animal species (e.g., invertebrates, amphibians, reptiles, small mammals). The cover may consist of boulders, smaller rocks, root wads or branches.
Bridge replacement	BRIDGE ELIMINATION Removal of existing bridge without replacement. BRIDGE REPLACEMENT Replacement of existing bridge and replacing with new bridge with same footprint.	None, unless there is an option to implement a fence, wall or other type of barrier that is connected to the structure and that runs along the road corridor away from the structure for a	BRIDGE ELIMINATION This would potentially remove a safe crossing opportunity for wildlife and increase the barrier effect of the transportation corridor.

	BRIDGE REPLACEMENT EXPANSION Removal of existing bridge and replacing with larger footprint for roadway expansion.	sufficiently long distance. Note that barriers can only be so long before another crossing opportunity would need to be present or newly constructed. The interval for these crossing structures depends on the species (e.g., 50-100 ft interval for small species up to a mile or more for larger species).	BRIDGE REPLACEMENT Adding pathways for wildlife and cover for small species could increase wildlife use of the structure and reduce the barrier effect of the transportation corridor. Keeping the same footprint of the structure means that the dimensions are not modified to allow for more or better wildlife use of the structure. BRIDGE REPLACEMENT EXPANSION This provides an opportunity to adapt the bridge dimensions to increase use by wildlife. The width, and potentially also the height of the structure (from the animal's perspective), are most likely to be modified rather than the length (i.e., road width).
Bridge inspection and bridge related training Other asset inspection	Bridge inspection and training Inspection of other assets (culverts, sign structures, retaining walls, etc.).	None. However, inspection of existing bridges of fences that already also need to function for wildlife can lead to repairs or other modifications that benefit wildlife.	None. However, inspection of existing bridges that already also need to function for wildlife can lead to repairs or other modifications that benefit wildlife.
Preservation / restoration	Preservation/restoration treatments may address cracks, joints and surface imperfections, seal and protect the road surface, improve friction and/or remove and apply a minimal riding surface (code varies by treatment type).	None, unless there is an option to implement a fence, wall or other type of barrier that is connected to a structure and that runs along the road corridor away from the structure for a	None. Unless work on the roadbed also allows for the installation of new wildlife crossing structures, including relatively small crossing structures for small animal species (e.g., invertebrates,

Resurfacing Reconditioning Pavement Replacement	Placing a new surface on an existing pavement. May add surface layer or mill/replace of existing pavement. Can include pavement marking alterations while perpetuating pavement footprint (code varies by thickness of resurface). Work in addition to perpetuation that can be justified by safety, environmental or ancillary factors. Cold-in-place recycling when applicable RECONDITIONING – Cannot be used for legislative program 303. Work in addition to resurfacing. Minor reconditioning (10) includes intersection work, pavement widening and/or shoulder paving. Major reconditioning (20) includes improvement of an isolated grade, curve, intersection or sight distance problem to improve safety. Removal of the total thickness of all paving layers from an existing roadway and providing a new paved surface. Can include replacement or improvements to the base and subgrade. Can include pavement marking alterations while perpetuating or reducing pavement footprint. Work in addition to perpetuation pavement replacement at spot locations that can be justified by safety, operations, environmental or ancillary factors. Full depth Cold-in-place recycling where applicable	sufficiently long distance.	amphibians, reptiles, small mammals), potentially with an open slotted roof embedded in the pavement. If replacement of culverts is included in these activities, it could allow for larger structures or similar sized structures that have modifications for wildlife (e.g., a dry pathway or shelf). This can enhance connectivity for wildlife.

Reconstruction	Work in addition to perpetuation pavement replacement that can be justified by safety, operations, environmental or ancillary factors which alters the existing pavement footprint for the entire length of the project.		
Expansion	RECONSTRUCTION EXPANSION & NEW BRIDGE includes the same types of work associated with reconstruction, but also involves the construction of additional through travel lanes or new structures.	None, unless there is an option to implement a fence, wall or other type of barrier that is connected to the structure and that runs along the road corridor away from the structure for a sufficiently long distance. Note that barriers can only be so long before another crossing opportunity would need to be present or newly constructed. The interval for these crossing structures depends on the species (e.g., 50-100 ft interval for small species up to a mile or more for larger species)	This provides an opportunity to build new bridges in locations that are complete (designated wildlife crossing structure) or at least partially influenced by wildlife needs (multi-functional crossing structure). The type of structure and its dimensions can also be based on the requirements of the target species.
Miscellaneous	Work that isn't classified under other Improvement Concept codes, including Construction Work Zone Traffic Mitigation/Service Patrol, Bank Developed Wetland Mitigation, Project Specific Wetland Mitigation, Jurisdictional Transfer, placeholders, ITS incidental items acquired via purchase order or request for proposal, Service Patrol Service Order	None, unless there is an option to implement a fence, wall or other type of barrier that is connected to a structure and that runs along the road corridor away from the structure for a sufficiently long distance.	Remediation or offset measures such as creating or enlarging wetlands or other habitat patches in the road effect zone or further from roads and improving the connectivity between these habitat patches.

	Contract, TOPS Lab safety studies, salt sheds, temporary widening, temporary bridges, Majors satellite field office costs.		

10.3 Structure designations

The authors distinguish among the following designations of structures:

- **Existing structures that are built for other purposes without modifications for wildlife.** The primary purpose of crossing structures that were not originally constructed for wildlife is often to allow people (including e.g., vehicles), livestock, or water to cross under (underpasses) or over (overpasses) the road. Their location, type, dimensions, and the distance between them is dictated by their primary - non-wildlife - function. No modifications have been made to encourage use by wildlife species.
- **Modified structures.** These structures are similar to the previous category. However, modifications have been made to enhance use by wildlife species**. Modifications can make existing structures, originally built for other purposes, more suitable, or somewhat suitable, for some wildlife species**. For a modified structure to be considered successful, it should at least result in enhanced use by wildlife, compared to unmodified structures. However, their location, type, dimensions, and the distance between them are **not influenced** by the need or goal to provide safe crossing opportunities for wildlife.
- **Multifunctional structures.** Structures that are truly multifunctional would have their location and design influenced by the different functions, in this case including functions related to wildlife movement. For example, a multifunctional structure could be a structure across a stream or river and designed to pass both water and allow for use by wildlife species associated with aquatic or riparian habitat. Both the hydrological function and the movement by the wildlife associated with the water or riparian zone **influence** the location, design (including type and dimensions), construction, and maintenance. For a multifunctional structure to be considered successful, it should achieve certain stated objectives, including those related to wildlife movements.
- **Designated wildlife crossing structures.** Designated wildlife crossing structures have their location and design primarily informed by goals related to wildlife movement of certain target species. For example, the location, design, construction and maintenance of a crossing structure, or set of crossing structures, is **optimized** for the movement of one or more target species. For a designated wildlife crossing structure to be considered successful, it should achieve certain stated objectives related to the movements of the target species.

The location of existing structures is known (Figure 155). The map of existing structures can help identify structures that may allow for wildlife passage already, or structures that may require some modifications for wildlife. Furthermore, some structures may be redesigned as multifunction crossing structures at some point in the future. The map does not include designated wildlife crossing structures.

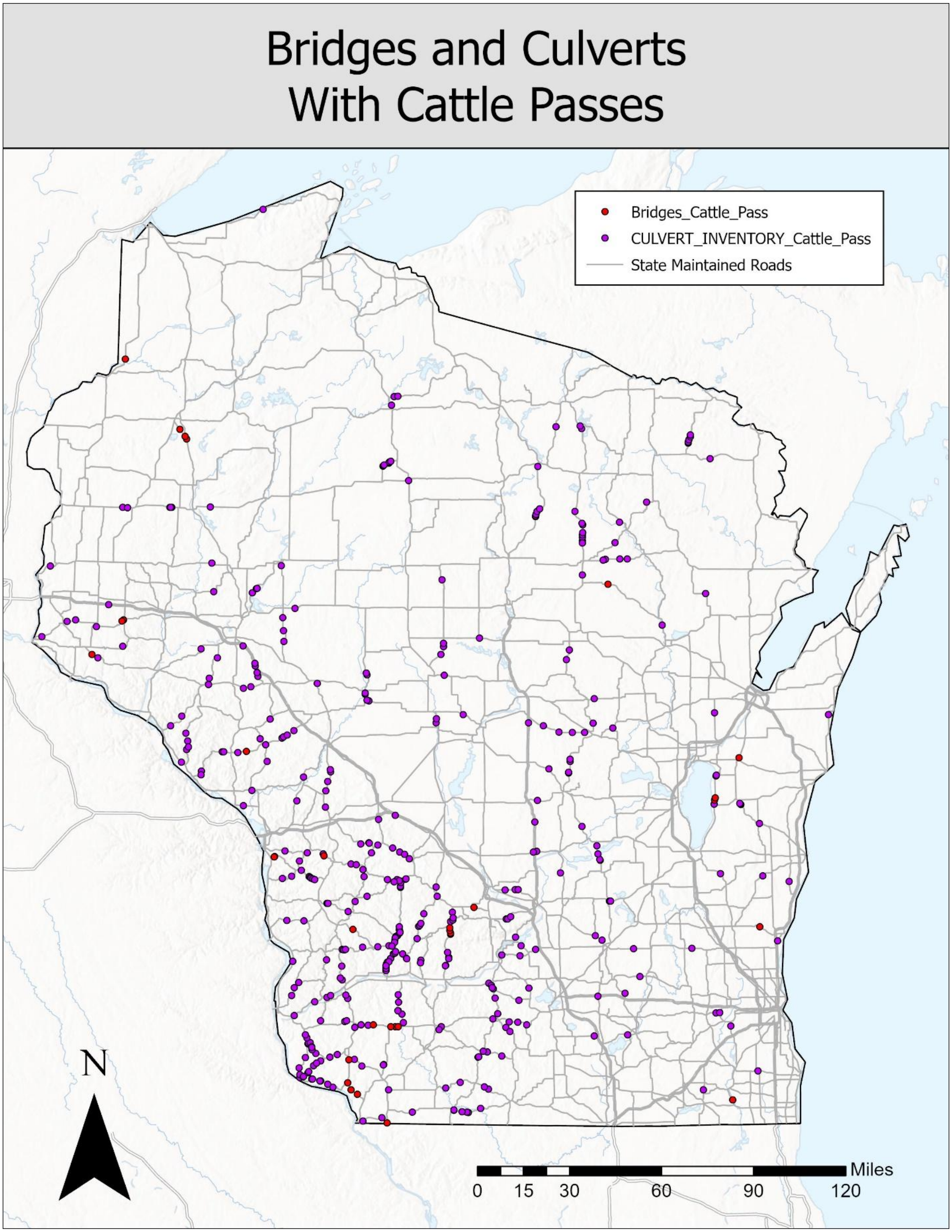

Figure 155. Map of existing structures created using the Bridges_Cattle_Pass and CULVERT_INVENTORY_Cattle_Pass data layers provided by WisDOT.

11 Recommendations

Step 1. Objectives

Decide on the objective(s) for work related to roads and traffic. Do the objectives (also) relate to:

- Improving human safety through reducing collisions with large wild mammals?
- Benefitting biological conservation through reducing direct road mortality and/or through reducing the barrier effect of roads and traffic, especially for species that have been identified as a conservation concern?

Step 2. Policy, funding mechanisms and implementation program

If the two objectives formulated in step 1 are adopted, then a strategic approach is required for each objective with associated policy, funding mechanisms and implementation programs as the two objectives are likely to relate to actions along different road sections. This implies a two-track system related to highways and wildlife; one that is rooted in human safety through reducing collisions with large wild mammals (in Wisconsin dominated by white-tailed deer), and a second one that is rooted in biological conservation through reducing unnatural mortality and improving connectivity, especially for species that have been identified as a conservation concern. Not having strategic approaches for these two objectives means that the objectives are unlikely to be reached. While it is good practice to also consider including wildlife mitigation in general road (re)construction, such an opportunistic approach is unlikely to reach the objectives related to biological conservation on its own as the selected road sections are not necessarily the same road sections that are important to biological conservation and there would be no spatial coherence on a landscape scale (see next step).

Step 3. Species-specific action plans and spatial coherence on a landscape scale

Conservation objectives, especially those that relate improving connectivity across roads, need to be spatially coherent to be successful. Conservation related objectives need to consider the landscape in which the animals live, not just the road and associated right-of-way. Since different species likely require different measures along different road sections, action plans related to biological conservation should be species-specific. This means that species specific action plans need to be compiled in coordination with natural resource management agencies, counties, and NGO's and volunteers. These spatially explicit plans need to have an overarching vision on landscape scale, not just at the scale of a road or road segment. However, detailed information needs to be integrated about the exact locations in relation to the specific habitat of individual species and where roads may cut through that habitat or where roads may be close to that habitat. This is where spatially precise data and local knowledge and experience knowledge is required from natural resource management agencies, NGO's and (other) volunteers.

Step 4 Combine the species-specific action plans into one action plan

Combine the species-specific action plans into one overarching action plan. Decide on a method that allows you to rank which mitigation measures need to be implemented along different road sections and in what order. This method may be based on achieving the greatest benefits for most species of conservation concern with the least effort.

Step 5. Implementation

Assuming the policy and funding has been arranged for, implement the mitigation measures. Have experienced and knowledgeable people oversee the entirety of the design and implementation process, including inspection in the field during construction.

Step 6. Monitoring

After implementation, monitor the effectiveness of the measures in terms of achieving stated objectives. These objectives may initially be the scale of a road section and the adjacent lands. But once multiple road sections are mitigated in a spatially coherent manner, the effectiveness of the measures may be evaluated in the context of higher-level objectives.

Step 7. Adaptive management

If the stated objectives are not reached, or only partially reached, identify what may need to be changed to still reach the stated objectives and implement these changes through an adaptive management approach.

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