

Michigan Amphibian & Reptile Best Management Practices

Second Edition

A Complete Guide to the Conservation of Michigan Herpetofauna

Herpetological Resource and Management, LLC



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Acronym List

ATV - All-terrain Vehicles
BMP - Best Management Practices
CARL - Conservation and Recreation Lands
CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora
CRP - Conservation Resource Program
C-Scores - Coefficient of Conservatism Scores
DDT - Dichloro-Diphenyl-Trichloroethane
EGLE - Michigan Department of Environment, Great Lakes, and Energy
EID - Emerging Infectious Disease
EMR - Eastern Massasauga Rattlesnake
EPA - Environmental Protection Agency
ESA - Endangered Species Act
FDA - Food and Drug Administration
FSA - Farm Service Agency
GIS - Geographic Information Systems
HDD - Horizontal Directional Drilling
Herp HAT - Herpetology Habitat Assessment Tool
HRM - Herpetological Resource and Management
IMR - Inadvertent Mud Release
IPaC - Information for Planning and Conservation
LEED - Leadership in Energy and Environmental Design
MCL - Maximum Containment Level
MDNR - Michigan Department of Natural Resources
MDOT - Michigan Department of Transportation
MIPN - Midwest Invasive Plant Network
MiRAM - Michigan Rapid Assessment Method for Wetlands
MNFI - Michigan Natural Features Inventory
NAP - Natural Area Preservation
NOAA - National Oceanic and Atmospheric Administration
NPE - Nonlyphenol Ethoxylates
NRCS - Natural Resources Conservation Science
NREPA - Natural Resources and Environmental Protection Act
PAH - Polycyclic Aromatic Hydrocarbons
PAPP - Paraaminopropiophenone
PARC - Partners in Amphibian and Reptile Conservation
POEA - Polyethoxylated Tallowamine
RD - Rural Development
ROW - Right-of-Way
SCA - Service Center Agencies
SEC - Soil Erosion Control
SFD - Snake Fungal Disease
SGCN - Species of Greatest Conservation Need
TFM - 3-Trifluoromethyl-4-Nitrophenol
USDA - United States Department of Agriculture
USFWS - United States Fish and Wildlife Service
USGS - United States Geological Survey
UV - Ultraviolet
WBF - Wildlife Barrier Fencing
WBHG - Woody Biomass Harvesting Guidelines
WDD - Wildlife Detector Dogs

1. Introduction

Purpose and Intended Use of This Manual

Herpetological Resource and Management, LLC (HRM) created the Michigan Amphibian and Reptile Best Management Practices (BMPs) Second Edition manual for the Michigan Department of Environment, Great Lakes, and Energy (EGLE), formerly the Michigan Department of Environmental Quality (MDEQ), to provide an updated comprehensive guide to improve and maintain the viability of Michigan amphibian and reptile populations. Building off the information of the original manual, the Second Edition expands upon the success of its predecessor by incorporating expanded content sections and updated scientific research. Similar to the original, this manual addresses existing and emerging threats to Michigan's amphibian and reptile (i.e., herpetofauna) communities posed by development and conservation management practices. The manual contains alternatives that are based on the best available science to facilitate conservation actions to protect specific species and the communities that support them. These BMPs are designed to inform land management, development, and conservation activities, including restoration. This BMP manual is a Michigan-focused guide that provides specific recommendations to regulators, agency land managers, consultants, commercial and residential developers, and private citizens to protect, preserve, and restore the herpetofauna of Michigan.

1. The American Toad, once a species incredibly abundant throughout the state, is currently experiencing population decline. Best Management Practices target such species in an effort to prevent a shifting baseline and keep common species common.

The Michigan Amphibian and Reptile BMP Second Edition features new informative sections including rare species showcases, vernal pool protection and conservation, and an overview of geologic and climatic history of herpetofauna in Michigan. Other additions to the Second Edition include new case studies, updated photographs and illustrations and large expansions of the restoration, management, and development chapters of the manual. In addition to new content, the Michigan Amphibian and Reptile BMP Second Edition incorporates the most recent scientific literature and updated State and Federal regulations to provide the most accurate and valuable information.

To be of value, BMPs must be supported by scientifically sound information, and as such, must be both monitored to assess their effectiveness and revised to reflect new information. Since the publication of the original manual, approximately a

decade-worth of data regarding the testing, implementation, and resulting efficacy of various BMPs has been gathered and incorporated into the Second Edition. As the recommended BMPs within this manual continue to be implemented and evaluated, new information will continue to be used to refine protection efforts. The process should reduce costs while maximizing wildlife protection value. This manual, while primarily targeted at amphibian and reptile communities, complements the ecosystem management approach described in the Michigan Department of Natural Resources (MDNR) Michigan's Wildlife Action Plan (Clark-Eagle et al. 2005, Derosier et al. 2015) and incorporates current climate change adaptation recommendations (Angel et al. 2018). The restoration, management, and development practices recommended in this manual not only benefit amphibian and reptile populations, but all of Michigan's flora and fauna.

1. Protecting and restoring high quality, functional landscapes is essential for supporting amphibian and reptile abundance and diversity across Michigan.

2. Wood Turtles, generally uncommon to very rare across the Great Lakes range, benefit from environments with low disturbance.

3. Wood Frog adults are mainly terrestrial except during the breeding season when they rely on seasonal wetlands absent of fish for reproduction.

This work was initially started in 1999 in an effort to provide an introduction to the habitat needs, management, and conservation of turtles and amphibians in Southeast Michigan for the MDNR and EGLE. This document was a catalyst for developing a more comprehensive and detailed document focused on all of Michigan's amphibians and reptiles. In 2014, the original BMP manual was published to meet the demand for an all-encompassing guide for amphibian and reptile conservation in Michigan and has successfully served as an invaluable resource for project managers and concerned citizens alike. The need for an updated manual is driven by the continued significant decline in amphibian and reptile populations in Michigan and the need for increased conservation actions. At the time of publishing, approximately 60% of Michigan herpetofauna are considered rare or Species of Greatest Conservation Need (SGCN), as identified by the MDNR Michigan's Wildlife Action Plan (Clark-Eagle et al. 2005, Derosier et al. 2015). Most of these species are wetland dependent at some phase in their lives. Habitat destruction, degradation, and fragmentation are the

1. Despite increasing rarity, the Butler's Garter Snake, a State Special Concern species, can be found within urban environments indicating the species' resilience to human and industrial activities.

main factors for decline of many amphibian and reptile species in Michigan and the United States (Dodd et al. 2003, Marchand and Litvaitis 2004, Weyrauch and Grubb 2004, Cushman 2006, Gardner et al. 2007). Decreases in water quality, habitat patch size, and connectivity coupled with invasive species, environmental contaminants, pathogens, illegal collection, and high densities of subsidized mesopredators pose a significant threat to many species in Michigan (Roe et al. 2003, Bell 2005, Moore and Gillingham 2006, Ryan et al. 2008, Michigan Natural Features Inventory 2012, Harding and Mifsud 2017). The unique natural histories and biological characteristics of amphibians and reptiles make these animals vulnerable to both aquatic and terrestrial disturbances. The guidelines proposed in this manual have the potential to reduce negative pressures on herpetofauna populations in Michigan and contribute to their protection and preservation.

This manual is to be used as a quick-reference guide throughout all phases of site development and construction, mitigation, restoration, and management. Specific laws and applicable BMPs for the mitigation of potential impacts to amphibians and reptiles are provided. These are listed and described within the appropriate BMP section to best address specific concerns as they are encountered while a project moves into implementation. It is our hope that this resource will be a living document and work in progress. As new threats, technologies, and management techniques arise, revisions will continue to be made to help best manage and protect Michigan's herpetofauna.

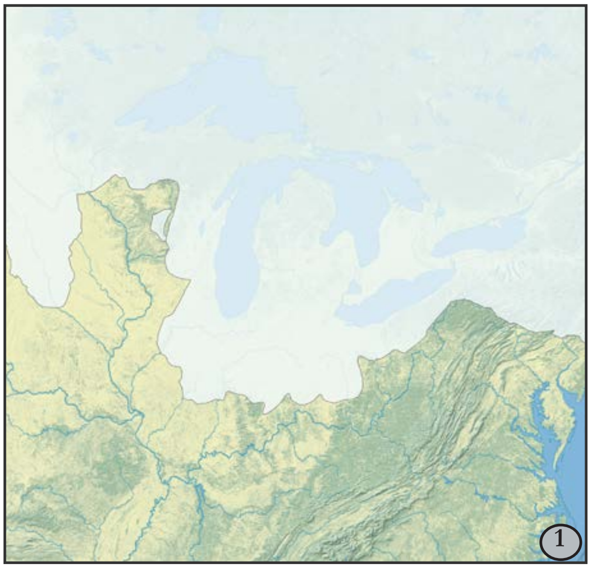
2. Engaging the public can help foster a stewardship attitude and support long-term conservation.

2. Amphibians and Reptiles of Michigan

Amphibians (frogs, toads, and salamanders) and reptiles (turtles, snakes, and lizards) are two diverse groups of animals which, though not closely related, are traditionally studied under the biological discipline of herpetology due to their similar ecological limitations and ectothermic life-histories. These two taxa are incredibly diverse as over 7,200 amphibian species and over 9,800 non-avian reptiles occur globally. In contrast, only 5,500 mammal species occur globally yet this group is disproportionally overrepresented in public conservation efforts. Despite the lack of public awareness and conservation efforts, herpetofauna are incredibly ecologically important as they mobilize energy through multiple trophic cascades due to their amphibious life cycles. Amphibians exhibit a biphasic lifestyle which is particularly important for the transfer of energy through the food web. As tadpoles in aquatic habitats, they are herbivorous, before transferring these resources to land in their adult phase where they are both a carnivorous predator and prey for other wildlife. Michigan's herpetofauna are ecologically important as they fulfill an essential mid-level position in food webs (as predators, scavengers, and an important prey base for other animals) and help maintain a balance of invertebrate and rodent populations and aquatic vegetation as mid-level consumers (Lagler 1943, Klimstra and Newsome 1960, Rowe 1992, Walls and Williams 2001, Congdon and Keinath 2006, Harding and Mifsud 2017). Amphibians and reptiles are also important as they are key bioindicators of environmental health and habitat quality (Cooperrider et al. 1986, Adamus and Brandt 1990, Welsh Jr. and Ollivier 1998, Shear et al. 2003, Guilfoyle 2010).

1. Amphibians and reptiles, such as this hatchling Eastern Snapping Turtle (left) and adult Green Frog (right), form an essential mid-level position in the food web, serving as both prey and predator depending upon the species and life stage.

Despite the ecological importance of the state's herpetofauna, these groups have not been as comprehensively surveyed or studied as compared to other vertebrate groups such as birds, mammals, or game fish. This may be partly due to a historical neglect for non-game species in Michigan by biologists and state agencies (Mangun and Shaw 1984) and a general apathy or even antagonism towards certain herpetofauna (i.e. snakes) by the public. Confounding the problem is that many amphibian and reptile species are cryptic and inconspicuous and thus difficult to survey. Other species are deceptively seasonally abundant (i.e., loud frog calls and turtles crossing roads) which may present the appearance of thriving populations that are of no conservation concern when these populations are actually declining. As a result, gaps in knowledge have left Michigan herpetofauna poorly understood and the true status of many species remains undetermined. The limited number of herpetological studies that have been conducted in Michigan indicate significant population declines for approximately 60% of species (Clark-Eagle et al. 2005, Derosier et al. 2015), and there is plentiful anecdotal evidence that the abundance and distribution of many (even formerly common) amphibian and reptile species have declined significantly. It is well documented that amphibians and reptiles are sensitive to ecological degradation and to impacts associated with wetland conversion, upland commercial, residential, and recreational development, and maintenance (Knutson et al. 1999, McKinney 2002, Dodd et al. 2003, Marchand and Litvaitis 2004, Weyrauch and Grubb 2004, Saumure et al. 2007, Skidds et al. 2007, Humbert et al. 2009, Böhm et al. 2012). It is clear that additional protections, education measures, and management are necessary to ensure the continued existence and possible recovery of amphibian and reptile populations on a landscape shared with humans.



1. The extent of North American ice sheets at the last glacial maximum approximately 18,000 years ago.

The Ice Age and Herpetofauna in Michigan

Michigan's chaotic climatic and geologic history attributed to the succession and recession of glacial ice sheets within the region has dramatically influenced the herpetofauna present and their abundance across the state today.

Before the most recent Ice Age, the Pleistocene Epoch, which lasted from 1.8 million years ago to 10,000 years ago, Michigan was a warm, dry, upland area, and was likely home to many amphibian and reptile species (Palmer and Geissman 1999, Holman 2012). During the Pleistocene, huge ice sheets advanced southward and retreated northward many times over thousands of years. As these massive ice sheets advanced southward on the landscape, they eliminated vegetation and wildlife communities and covered the land in a thick layer of ice for thousands of years at a time (Holman 2012). During northward retreats, vegetation and wildlife would push northward to colonize the newly exposed barren and sterile landscape. With the advancement and retreat of glacial ice sheets, sea and lake levels would rise and fall, covering and exposing the land (Holman 2001). With the stress, destruction, and climatic alterations experienced during the Pleistocene, 191 mammal species became extinct, though herpetofauna were much more resilient due to their ectothermic physiology, small bodies, behaviors, and adaptability (Clausen et al. 1979, Holman 1991). Only giant tortoises of the *Hesperotestudo* genus became extinct, and it is hypothesized that it may be because they were a desirable food source for Paleo-Indian people who lived during this time period (Clausen et al. 1979, Holman 1991).

Scott Gillingwater

2. Mink Frogs are extremely cold-adapted and likely were more abundant during cooler glacial and postglacial periods.

The herpetological re-colonization of Michigan following the recession of the most recent glacial period of North America, the Wisconsin (14,800 years ago to present day), occurred in three waves of primary, secondary, and tertiary invaders. Determination of what and when species made their way into Michigan is based on the paleobotanical records, geological record, herpetofauna fossil records, archeological finds, and ecological tolerances (cold-hardiness) of present day herpetofauna

1. Primary invader, the Eastern Garter Snake.

2. Secondary invader, the Fowler's Toad.

3. Tertiary Invader, the Marbled Salamander.

(Holman 2004, Holman 2012). Primary invaders dispersed into mostly coniferous forest and swamp habitats and could tolerate the cold tundra landscape that followed the recession of ice sheets (Holman 2004). Primary invaders included salamanders, mudpuppies and newts such as the Blue-spotted Salamander (*Ambystoma laterale*), Spotted Salamander (*Ambystoma maculatum*), and Eastern Tiger Salamander (*Ambystoma tigrinum*); frog and toad species such as the American Toad (*Bufo americanus*), Eastern Gray Treefrog (*Hyla versicolor*), and Green Frog (*Rana clamitans*); turtle species such as the Eastern Snapping Turtle (*Chelydra serpentina*), Midland Painted Turtle (*Chrysemys picta*), and Blanding's Turtle (*Emydoidea blandingii*); and snake and lizard species including the Five-lined Skink (*Plestiodon fasciatus*), Northern Watersnake (*Nerodia sipedon*), Northern Ribbon Snake (*Thamnophis sauritus*), and Eastern Garter Snake (*Thamnophis sirtalis*) (Holman 2012).

Secondary invaders dispersed into mixed conifer-broadleaf areas in the Lower Peninsula of Michigan. Secondary invader amphibian species included the Fowler's Toad (*Bufo fowleri*), and Blanchard's Cricket Frog (*Acris crepitans blanchardi*) (Holman 2012). Secondary invader turtle species included the Spotted Turtle (*Clemmys guttata*), Eastern Box Turtle (*Terrapene carolina*), and Red-eared Slider (*Trachemys scripta elegans*). Snake species considered to be secondary invaders included the Blue Racer (*Coluber constrictor*), Eastern Hog-nosed Snake (*Heterodon platirhinos*), and Eastern Massasauga Rattlesnake (*Sistrurus catenatus*), commonly abbreviated as EMR (Holman 2012).

Lastly, tertiary invaders dispersed into broadleaf (deciduous) areas in the state. Tertiary invaders included three amphibian species, the Marbled Salamander (*Ambystoma opacum*), Small-mouthed Salamander (*Ambystoma texanum*), and Western Lesser Siren (*Siren intermedia*). Reptile tertiary invaders included the Six-lined Racerunner (*Aspidoscelis sexlineata*), Kirtland's Snake (*Clonophis kirtlandii*), and Copper-bellied Watersnake (*Nerodia erythrogaster*) (Holman 2012).

Climatic events of the Holocene Epoch (10,000 years ago to present day) were also quite influential in the distribution of modern herpetofauna across the state of Michigan. From 9,000 to 5,000 years ago, a global climatic temperature increase, known as the Hypsithermal Interval, allowed many herpetofauna species to make their way further north into Michigan than what was previously possible (Holman 2012). These herpetofauna invaders came from Indiana and Ohio migrating up the Lower Peninsula in a random fashion, dispersing into coniferous forest and swamp habitats. The Upper Peninsula of Michigan was colonized by herpetofauna coming through the state of Wisconsin (Holman 2012). Additionally, a few species may have been able to disperse across the Straits of Mackinac. Following the Hypsithermal Interval, a cooling period that began around 1,200 years ago known as the "Little Ice Age" caused the withdrawal of some herpetofauna species across the state (Kapp 1999). From the year 1750 to present day, Michigan has once again warmed. The warming and cooling of Michigan, structured the dispersal of herpetofauna species before European settlement in the Americas during the Holocene Epoch.

1. The Eastern Red-backed Salamander and other Michigan salamander species frequently utilize fallen trees and logs as shelter within forested habitats.

Relic populations may still remain from the Hypsithermal Interval (warming period) of the Holocene (Bernabo 1981, Kapp 1999, Holman et al. 2003). These species may survive in populations isolated from the rest of their range due to the lake-influenced climate in the state, that is, the warming effect of the Great Lakes. For example, the Western Lesser Siren is found in only two counties in Michigan, Van Buren and Allegan County. Here they are separated from the rest of their range which occurs mainly in the southeastern United States, ranging from Indiana down through Kentucky and Tennessee to the eastern coasts of Virginia, North and South Carolina, Georgia, and Florida, and the southern coasts of Alabama, Mississippi, Louisiana, and Texas, and into Mexico (Minton 2001). Additionally, some "slower colonizers" may still be making their way northward into new habitats (Holman 1992). The southern half of Michigan's Lower Peninsula has nearly twice as many reptile species as all other areas above the mid-point of the state. This bottom half also has tertiary invader species that do not occur anywhere else in the state. The Upper Peninsula of Michigan also contains mostly primary invaders. The islands that speckle the Great Lakes surrounding Michigan are also home to predominantly primary invading species who likely made their way onto these islands 8,000 to 4,000 years ago when lake levels were lower and these islands were connected to the mainland (Hatt et al. 1948, Holman 1992).

Distinct glacially derived landforms now form the mosaic of habitats across the landscape in which herpetofauna in Michigan are dispersed. Many other states located within the southern and eastern United States have flat, flakey bedrock shales, offering the perfect shelter and hibernacula for many species of salamanders and snakes. Due to the grinding, tilling, and erosion of Michigan's geologic layers during glacial periods, the state possess more rounded boulders, cobbles, pebbles, and sand, limiting the availability of habitat (Holman 2012). However, some Michigan herpetofauna have adapted to this geologic disposition and seek out alternative microhabitats (Holman 2012, Harding

2. The Eastern Hog-nosed snake is often found within xeric, dry upland habitats within Michigan, such as dune ecosystems.

1. Vernal pools such as this can seasonally support a dozen or more species of herpetofauna. Preserving these wetlands is key to the survival of many amphibian and reptile species.

and Mifsud 2017, Mifsud personal observation 2022). Deposits of sand and silt concentrated within historic glacial outwash locations within the southwestern region of the state provide sandy soils ideal for turtle nesting and habitat for 'sand-loving' species such as the Fowler's Toad and Eastern Hog-nosed Snake (Holman 2012, Harding and Mifsud 2017).

Natural History of Herpetofauna in Michigan

Amphibians and reptiles have unique physiological (functional) and morphological (physical) characteristics that allow them to fill niche roles in ecosystems that are essential to the maintenance of biodiversity and ecological functionality. Some of these biological traits include behavioral thermoregulation by exchanging heat with their surroundings, hibernation (or more technically, brumation: a hibernation-like state), biphasic (aquatic and terrestrial) life cycles, and metamorphosis (Heath 1964, Semlitsch 2008, Harding and Mifsud 2017). Amphibians and reptiles are ectothermic, meaning that their body temperature is largely dependent on the ambient temperature of the surrounding environment.

2. Turtle eggs, like the Eastern Snapping Turtle eggs pictured above, require specific nest conditions in order for eggs to develop. Creating and maintaining nesting sites is vital for long-term turtle population viability.

Most species of amphibian and many reptiles in Michigan rely on the presence of water for at least one or more life cycle stage (e.g., larval stage, breeding) (Holman 2012, Harding and Mifsud 2017). Amphibians have moist, highly-permeable skin and generally require close proximity to a water source (Hecnar 2004). They typically also lay their eggs in water, and larvae are completely dependent on aquatic habitats. Reptiles generally have less permeable skin covered with keratinaceous scales. These animals may also require high levels of moisture in their preferred habitats, and several species (e.g., Eastern Massasauga Rattlesnakes, Spotted Turtles, Blanding's Turtles) live in wetlands for at least part of the year (Lee 1999, Lee and Legge 2000, Moore and Gillingham 2006, Beaudry et al. 2009, Smith 2009, Harding and Mifsud 2017). Since many amphibians and reptiles have extensive contact with water, high water quality is imperative for viability of diverse amphibian and reptile communities.

3. Hibernacula provide overwintering habitat for a variety of herpetofauna and other wildlife species. These structures can be man-made or natural.

Many species of amphibians and reptiles are seasonally wetland dependent and rely on uplands adjacent to wetlands during the remainder of their annual cycle (Porej et al. 2004, Attum et al. 2008, Attum et al. 2009). Many species, such as Copper-bellied Water Snakes, Wood Frogs (*Rana sylvatica*), and Eastern Tiger Salamanders seasonally migrate between wetland and upland areas for breeding, nesting, and foraging. These species require a mosaic of wetland types with intact upland habitat communities adjoining them. These species rely on linkages between uplands and wetlands to maintain population stability.

1. Fallen trees and old logs can be repurposed as basking structures for turtles.

2. Evidence of recruitment, such as this young of year Northern Spring Peeper, is an indicator of community health.

3. Salamanders require submerged vegetation, such as this branch, to attach their egg masses to.

This chapter describes the herpetofauna of Michigan and their habitats. Understanding the ecology, life cycles, and specific habitat requirements of reptiles and amphibians is critical to developing and managing landscapes in ways that support and promote biodiversity.

At present, Michigan is comprised of 59 species of native herpetofauna including:

- 18 species of snakes
- 11 species of turtles
- 2 species of lizards
- 14 species of frogs and toads
- 14 species of salamanders

Michigan Herpetofauna: Ecological and Habitat Requirements

Amphibians and reptiles in Michigan live in a variety of community types with supporting habitat features (Appendix A). These animals are constrained by their physiology to occupy specific areas that provide these key features. These usually include:

Basking structures - Areas where amphibians and reptiles can warm themselves to regulate their body temperature. Amphibians and reptiles can warm themselves on or under sun-exposed rocks and logs or in gaps in the vegetation canopy where the sun shines. It is equally important that structurally diverse areas of vegetation and substrates that provide shade or cooler temperatures are adjacent to basking areas. Amphibians and reptiles can regulate their body temperature behaviorally by moving between these microclimates.

Shelter - Spaces that provide protection from predators and the elements include areas of dense vegetation, rocks, logs, tree roots, subterranean structures (e.g., burrows, or soils where burrows can be made), and suitable water bodies.

Foraging areas - Areas that contain a suitable food source. Depending on the life stages present, these areas can vary among a species.

Hibernacula - Places to hibernate in the winter, typically a protected area. Depending on the species, a hibernaculum can range from a dry, abandoned mammal burrow, to a burrow under thick leaf litter on the forest floor, to a submerged substrate in a pond, lake, or stream.

Nesting and egg laying sites - Lizards, turtles, and many snakes lay shelled eggs and typically require well-drained, moist soils on a south-facing slope for their nests. Frogs and most salamanders typically require submerged vegetation, rocks, branches, or other structures for egg attachment.

Several resources on the natural history and distribution of Michigan herpetofauna are available online. You can also learn more about Michigan amphibians and reptiles by visiting the Michigan Herp Atlas (www.MIHerpatlas.org). The Michigan Herp Atlas is the most comprehensive and continuously updated database of herpetofauna observations in Michigan. The Herpetological Resource and Management website (HerpRMan.com) provides information regarding Michigan amphibian and reptile species. The University of Michigan Animal Diversity Web and the MDNR websites also provide useful information relating to amphibians and reptiles natural history, range, and conservation status.

1. Midland Painted Turtles require well-drained soils for their nesting sites. Turtles construct nests by touch, never seeing the eggs.

This manual utilizes commonly accepted and used nomenclature for Michigan herpetofauna (Holman 2012). Taxonomic reclassification continues as more genetic information is obtained and the naming used within this document may be revised in the future. For a complete list of North American herpetofauna nomenclature, see Crother et al. 2012.

2. The Eastern Newt is unique in that aquatic larvae metamorphose into a terrestrial form called an eft. Efts subsequently metamorphose again into an aquatic breeding adult.

3. Strings of Eastern American Toad eggs are laid amongst submerged vegetation and will hatch in 2-14 days.

4. Male Midland Chorus Frogs call in early spring to attract females to mate with.

Amphibians

Some of the characteristics that typically define the amphibian group include aquatic eggs, a gilled larval stage (in most but not all species), glandular skin that is variably permeable to water, and a lack of claws and keratinaceous scales. Since all amphibians in Michigan rely on the presence of water to fulfill their basic needs, they must live in damp or aquatic habitats. Michigan amphibians include the following groups:

Salamanders

Salamanders are most abundant in temperate zones and have peak diversity in the U.S. All salamanders are carnivores, feeding largely on invertebrates in aquatic and terrestrial ecosystems. Michigan is home to several species of salamanders, including a unique hybrid complex of unisexual polyploid salamanders (*Ambystoma sp.*), which incorporates the genetic material of several species.

Frogs and Toads

Frogs and toads (frogs with warty skin and hopping gait) are defined by their elongated hind limbs that are adapted for swimming and jumping, buccopharyngeal respiration (gas exchange facilitated by rapid pulsing of the throat), and distinct breeding calls that can be used for field identification (Harding and Mifsud 2017). They are mainly herbivorous or omnivorous as larvae (tadpoles), and fully carnivorous as adults, feeding largely on invertebrates. Frogs and toads are mid-level consumers in both aquatic and terrestrial food webs, as they eat vegetation (as larvae), invertebrates, small vertebrates and also provide food for other animals at higher trophic levels.

1. Butler's Garter Snakes primarily eat earthworms, but will also feed on slugs, leeches, salamanders, and small frogs. In Canada, the presence of earthworms is used as an indicator for potential presence of this declining and cryptic species.

2. The upper and lower portions of the shell, the carapace and plastron, help protect turtles from predation. This simple but effective design has been in use by turtles for 200 million years.

Adults often lay masses or strings of hundreds to thousands of eggs, however, in most instances the majority of their eggs and the resulting tadpoles become a meal for another animal before they can complete metamorphosis.

Reptiles

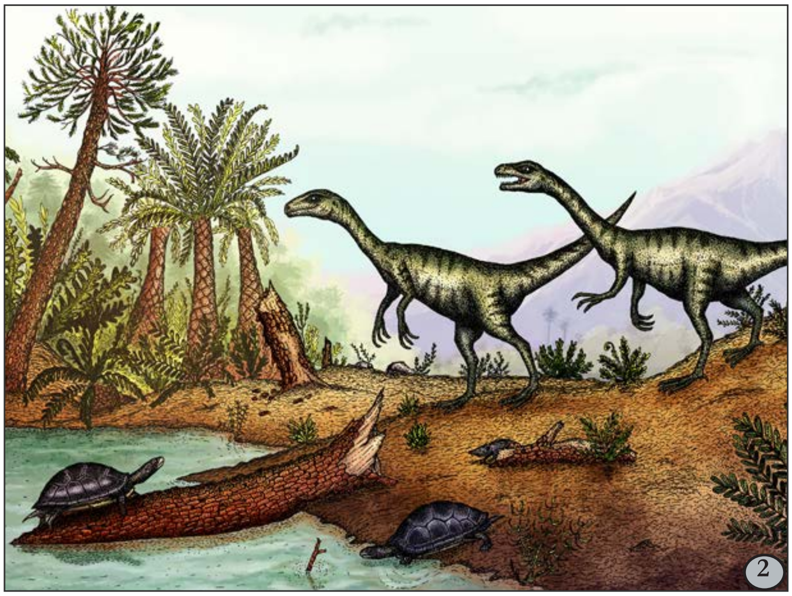
Some of the characteristics that traditionally define reptiles include claws and a body covering of keratinaceous scales or scutes (in turtles). Most reptiles produce shelled (amniotic) eggs that are laid in a variety of environments; however, some reptiles (e.g., Eastern Massasauga Rattlesnakes, Garter Snakes and Water Snakes) give birth to fully formed live young. Reptiles in Michigan rely on a variety of natural communities within both uplands and wetlands to fulfill their life requisites, but are often closely associated with wetland communities at least seasonally. Michigan reptiles include the following groups:

Snakes

Snakes are defined by elongated legless bodies and skeletal structure that contains from 150 to over 400 ribs. Some lizards are also legless and possess eyelids and external ears that snakes lack. Snakes are entirely carnivorous, eating rodents, birds, eggs, amphibians, and insects. Most snakes in Michigan hibernate in holes, old mammal burrows, and crevices in the ground during winter. Snakes have either smooth or somewhat rough, dry skin, the outer layer of which is molted in a single piece. A shed skin will remain in the environment for a week or two and occasionally up to a month (Gray 2012). Sheds can sometimes be identified to species and indicate the presence of a snake even if the snake is not observed.

Turtles

Turtles are characterized by a hard outer shell that consists of two parts, the upper shell (carapace) and the lower shell (plastron). The shell is reduced in some species for extra mobility (e.g., Snapping and Softshell Turtles) while other species possess a hinged plastron that allows them to withdraw and cover their limbs, head, and tail completely (e.g., Box and Blanding's Turtles). All turtles are toothless with sharp, beak-like jaws that can slice through food items. Some species in Michigan are mostly carnivorous while others are omnivorous. Turtles are generally long-lived animals and the typical lifespan for most turtle species is at least several decades, though some species are known to surpass the century mark. Longevity is necessary to make up for the naturally high mortality of turtle eggs and hatchlings, as well as the long time periods needed for young turtles to reach sexual maturity.



Jim Harding & Hailey Brown

1. Six-lined Racerunners are a State Threatened species, with only one known isolated colony occurring in Tuscola County. These lizards prefer sandy, sunny sites. Observations of this species should be reported to the Michigan Herp Atlas.

For example, the minimum age of sexual maturity for female Blanding's Turtles is 14 years but is typically closer to 20 years (Congdon et al. 1993).

Lizards

Michigan has two species of lizards known to breed within the state. These species exist in isolated areas and are more abundant in southern Michigan. Lizards are characterized by having four limbs (though legless species exist in other states) and long tails that, in many species, can be detached as a defense mechanism. Michigan's lizards are predators and feed mostly on insects and other small invertebrates. While most species contribute no parental care after laying their eggs, one Michigan lizard species, the Five-lined Skink is known to guard its eggs until hatching. Lizards are generally short-lived compared to turtles and typically live less than 10 years.

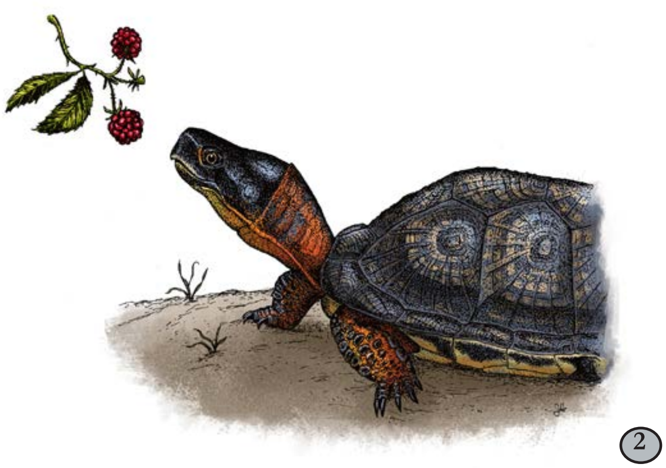
Michigan Herpetofauna Community Associations and Habitats

Identification of herpetofauna habitat is essential to the protection and conservation of Michigan's amphibians and reptiles. The potential habitats at a site largely depend on the number and size of natural communities that are present. Plants, animals, fungi, and detritus are all part of the natural community however the topography, water, soil, and rock are also important components of a habitat and should be surveyed for the potential features and functions they provide for amphibian and reptile species.

On larger sites that cannot easily be effectively surveyed on foot, general categories of natural communities often can be identified on aerial photographs. These photographs are available at no cost online (e.g., using Google Earth, Bing, etc.), and some sources provide historical images, which can enhance the understanding of the long-term ecological condition of the site. To a trained aerial interpreter, color differences in the images can be a good indication of what vegetation and hydrologic processes are present that could denote the presence of a particular community. Natural communities identified using aerial imagery must be field checked for accuracy confirmation.

Public and private natural resource professionals may be able to assist in identification of herpetofauna habitat and can work to create a strategic plan that balances primary objectives (development, maintenance, restoration, or ongoing stewardship activities) with the incorporation of wise natural resource management practices.

Refer to Appendix A for the community types where Michigan herpetofauna may usually be found.



Jim Harding & Hailey Brown

2. Everything that contributes to habitat for amphibians and reptiles, including other animals, shelter, water, and food, should be considered when working to conserve the herpetofauna of an area.

1. Eastern Massasauga Rattlesnakes live in wetlands for most of the year and are seldom seen by humans. This species is cryptic and in decline throughout their range.

Rare Species Showcase

Many amphibian and reptile species within Michigan are considered to be rare or in decline and are in need of focused conservation efforts. The Eastern Massasauga Rattlesnake and Blanding's Turtle are both representative species that illustrate the complexity of herpetofauna life history and the importance of formulating viable conservation strategies. Michigan is often considered to be the stronghold for both species and the widespread understanding of their biology, ecology, and conservation is crucial for their continued existence.

Eastern Massasauga Rattlesnake

The Eastern Massasauga Rattlesnake is a State Threatened species in Michigan and is Federally listed as Threatened under the Endangered Species Act (ESA) (U.S. Fish and Wildlife Service and National Marine Fisheries Service 1973, Michigan Natural Features Inventory 2022). Their range extends from western New York and southern Ontario to western Iowa and southern Missouri. Within Michigan the species is found only in the Lower Peninsula, where it is widely distributed yet uncommon (Harding and Mifsud 2017). Wetland communities including, fens, bogs, sedge meadows, and wet prairies are utilized from early fall until late spring where snakes hibernate underground in crayfish chimneys or small mammal burrows (Harding and Mifsud 2017). Studies have shown high fidelity toward overwintering sites and they will often return to the same location each year (Johnson et al. 2000, Smith 2009). Eastern Massasaugas and similar rattlesnakes are known to exhibit postpartum mother-offspring associations that may promote neonate survival (Reinert and Kodrich 1982, Butler et al. 1995, Greene et al. 2002, Hileman et al. 2015). Eastern Massasauga Rattlesnakes move to adjacent upland habitats that include shrubby fields and grasslands during the summer where they utilize the warm weather for foraging and development of young (Harding and Mifsud 2017). Within the upland habitats, this species typically avoids closed canopy forests and those that do enter these areas are found where sunlight penetrates the canopy (Center for Reptile and Amphibian Conservation and Management). Home range and movement patterns are often site dependent making it important for project managers to understand what populations they are working with. Typically, Eastern Massasauga Rattlesnakes have larger home ranges in populations located further north in the range (Harvey and Weatherhead 2006, Smith 2009, DeGregorio et al. 2011). Small mammals make up a majority of this snake's diet, but they will also feed on amphibians, other snakes, birds, and insects (Keenlyne and Beer 1973, Seigel 1986, Hallock 1991, Shepard et al. 2004, Harding and Mifsud 2017). Rattlesnake consumption of small mammals also controls tick populations, potentially benefitting humans by decrease risk of Lyme disease transmission (Kabay et al. 2013). Although the Eastern Massasauga Rattlesnake is a venomous snake, the first line of defense is their cryptic

1. Eastern Massasauga Rattlesnakes are ovoviviparous, meaning that eggs hatch within the mother and offspring are born alive.

coloration and behavior (Harvey and Weatherhead 2006). When encountered, they typically stop moving and remain undetected, however if a potential predator approaches and the snake does not flee, it will stand its ground and vibrate its rattle as a warning before striking. This species is generally shy and unaggressive yet they are heavily persecuted by humans and often killed unnecessarily (Harding and Mifsud 2017). Visual encounter surveys for this species should be conducted between the first week of April through the second week of September (Michigan Natural Features Inventory 2022). Additionally, detrimental land management practices, including timber harvesting, mowing, disking, and prescribed burning, should be conducted during the Eastern Massasauga Rattlesnake's inactive season of November through early March (Lee and Legge 2000, Cross et al. 2015).

Populations of this species have declined rapidly in recent decades mainly as a result of habitat loss and persecution. The wetlands Eastern Massasauga Rattlesnakes inhabit have largely been degraded or lost due to draining for agriculture, residential development, roads, and pollution (Lee and Legge 2000). Additionally, much of their upland habitat has also been destroyed or fragmented. As Eastern Massasauga Rattlesnakes require open upland habitat adjacent to wetlands, conservation and restoration efforts that focus solely on wetlands typically fail to preserve this species (Harding and Mifsud 2017). Vehicle-caused mortalities are also a significant threat to this species as is human persecution, particularly during their active and mating seasons (Lee and Legge 2000, Shepard et al. 2008a). Venomous species like the Eastern Massasauga Rattlesnake may be particularly vulnerable to vehicles as they often cross roads more slowly than nonvenomous species (Andrews and Gibbons 2005). Habitat fragmentation often forces these snakes to cross roads in order to maintain stable populations (Baker et al. 2016). Eastern Massasauga Rattlesnakes have been found to avoid road crossings, but road mortalities may introduce a selective pressure that favors individuals that avoid roads, thus reducing road mortalities but inhibiting gene flow (Shepard et al. 2008b). The most important management step for the conservation of Eastern Massasauga Rattlesnakes is the protection of existing populations and suitable wetland habitats that are adjacent to upland habitat (Lee and Legge 2000). Habitat loss, degradation, and fragmentation have a very high probability of causing quasi-extinction of Eastern Massasauga Rattlesnake populations after 25 years (Faust et al. 2011). Without the implementation of significant conservation action to address these risk factors, the Eastern Massasauga Rattlesnake will remain at risk of imminent extirpation throughout portions of its range (Szymanski et al. 2016).

1. Blanding's Turtles utilize a variety of habitats seasonally, including wetlands, vernal pools, and upland habitat, demonstrating the need for contiguous ecosystems.

Blanding's Turtle

The Blanding's Turtle is listed as a species of Special Concern in Michigan and is either Threatened or Endangered throughout most of its remaining range (Lee 1999). The Blanding's Turtle currently receives no federal protections, though the species' status is currently listed as Under Review to assess whether it warrants listing under the ESA (U.S. Fish & Wildlife Service 2022). The range of the Blanding's Turtle extends from southwestern Quebec and southern Ontario west to Minnesota and Nebraska and to southern Illinois (Lee 1999). In Michigan they can be found throughout the Lower Peninsula, including Washtenaw County, but are rarer in the Upper Peninsula. This turtle species requires a mosaic of habitat types for their survival. For much of the year, Blanding's Turtles prefer wetland community types such as marshes, ponds, swamps, lake shallows, slow moving rivers, oxbows, and pools adjacent to rivers. The species will utilize shallow water areas for basking and foraging while overwintering occurs in deep wetlands where the turtles burrow into the mud below the frost line (Van Dam 1993). Upland habitats are critical for activities such as mating, nesting, and dispersal. Females require well drained soils, usually with southern exposure for nesting during summer months. Blanding's Turtles exhibit high fidelity toward nesting sites, generally returning to the same nesting location each year (Congdon et al. 1983). Blanding's Turtles are known to move large distances to reach each of these habitats at different times of the year, and total seasonal distance traveled can reach as high as 6,760 meters (Joyal et al. 2001). Both male and female turtles will maintain a long-term (>40 years) fidelity to a single residence wetland but frequently utilize other habitats outside of this wetland, including mating with individuals from other residence wetlands (McGuire 2013). Additionally, females will sometimes make long migrations to nesting sites as they do not necessarily nest in proximity to their residence wetland. Females often use multiple nesting sites over their lifespan, which, in combination with repeat paternity, can facilitate gene flow across the landscape further than any individual turtle's movements (McGuire 2013, McGuire et al. 2015). For instance, a male Blanding's Turtle may move 2 km, but his genes may move over 6 km as a result of his female mate traveling with his stored sperm. The mating of individuals from separate residence wetlands,

2. Hatchling Blanding's Turtles will often select to overwinter within upland habitat during their first hibernation as opposed to aquatic environments.

as well as the dispersal of hatchlings away from their mother's residence wetland, contribute to the demographic and genetic connectivity between residence wetlands (McGuire 2013). The diet of this species consists mainly of crayfish, snails, insects, small fish, tadpoles, frogs, and some vegetation. Blanding's Turtles have a life span of at least 80 years and do not reach sexual maturity until around 20 years of age in some areas of Michigan (Congdon 2001, Harding and Mifsud 2017). Adult turtles have few natural predators, but hatchling and juvenile turtles suffer very high mortality rates from mammals such as raccoons, skunks, and foxes in addition to fish, frogs, snakes, and birds (Harding and Mifsud 2017). The ideal survey period for the Blanding's Turtle ranges from mid-April through mid-September and is typically conducted utilizing visual observation of basking sites as well as hoop and net traps (Harding and Mifsud 2017).

1. Blanding's Turtles control their body temperature by basking on sunny logs in a wetland. The logs also provide cover for the turtles when they dive into the water.

Destruction and degradation of wetlands is the leading cause of population declines throughout the species' range (Harding and Mifsud 2017). The primary drivers of this habitat loss stem from urbanization as well as various agricultural activities, including the drainage of wetlands, channelization of rivers, development of upland nesting areas, introduction of herbicides and pesticides, water impoundments, and agricultural activities adjacent to wetlands (Kofron and Schreiber 1985). These sources of habitat loss also limit movement between Blanding's Turtle habitats, fragmenting populations and disrupting the mechanisms that maintain genetic diversity (Rubin et al. 2001). Habitat fragmentation also increases mortality rates of individuals moving between habitats (Grgurovic and Sievert 2005). Road mortality can intensely decrease Blanding's Turtle populations as this turtle often migrates long distances, making it particularly vulnerable to this threat (Harding and Mifsud 2017). Lastly, increased populations of mesopredators that predate Blanding's Turtle nests, such as raccoons, poses a significant threat (Lee 1999, Mifsud 2014). The most important conservation need for Blanding's Turtles is the preservation of suitable habitat, including the mosaic of habitats it requires rather than wetlands alone (Lee 1999, Harding and Mifsud 2017). As Blanding's Turtles, particularly gravid females, exhibit large core habitats, maintaining corridors between permanent bodies of water is necessary to support genetic connectivity (Howes et al. 2009, Millar and Blouin-Demers 2011). Reducing or restricting certain activities near wetlands, including herbicide and pesticide use, timber harvesting, road construction, and agricultural operations, would benefit this turtle species (Lee 1999). Additionally, the use of predator exclusion devices and active predator control around key Blanding's Turtle nesting areas may increase successful population recruitment (Lee 1999, Mifsud 2014).

3. Threats to Amphibians and Reptiles

Shane DeSolla

1. Sea walls and other forms of shoreline hardening, limit adjacent terrestrial habitat for semi-aquatic species including a large portion of amphibians and reptiles.

2. This Snapping Turtle egg was incubated in asphalt. Pollutants in these materials may likely impact nest success.

Habitat Loss, Degradation, Fragmentation, and Urbanization

Habitat destruction, degradation, and fragmentation (secondary effect of habitat destruction and degradation) are among the most serious causes of current and future reptile and amphibian population declines and species extinctions (Knutson et al. 1999, Dodd et al. 2003, Marchand and Litvaitis 2004, Weyrauch and Grubb 2004, Böhm et al. 2012). Freshwater systems face significant reductions in biodiversity, which can be linked to overexploitation, water pollution, flow modification, destruction or degradation of habitat, and invasion by exotic species. North American freshwater species (including reptiles and amphibians) are currently experiencing pressures that will likely lead to several extinctions by the end of the century, with projected rates of 4% extinction per decade (Ricciardi and Rasmussen 2001). Herpetofauna in Michigan rely on wetland and adjacent upland communities for specific habitat features and frequently move between communities on a seasonal basis. Some amphibian species are known to experience high breeding site fidelity, travelling upwards of 10 km (Smith and Green 2005). Connectivity is therefore essential for long-term viability of amphibian and reptile populations on a landscape level. Habitat fragmentation occurs when existing populations become isolated because corridors between specific habitat features have been lost. Fragmentation can result in increased mortality, reduced genetic diversity, increased predation pressure, increased edge habitat, reduced habitat quality, reduced critical zones - areas that are critical for life function, and invasive species colonization (Fahrig and Merriam 1985, Petranka et al. 2007, Bennett et al. 2010, Bennett and Litzgus 2012, Row et al. 2012). The effects of fragmentation on herpetofauna populations may not present themselves for decades after the fragmentation event in what is known as a time lag (Löfvenhaft et al. 2004). Genetic variation has been suggested to experience detrimental impacts following this time lag (Richmond et al. 2009, Maigret et al. 2020).

Habitat fragmentation can also negatively impact herpetofauna metapopulations (Hels and Nachman 2002). A metapopulation is a collection of partially isolated subpopulations in breeding habitat patches, among which dispersal occasionally happens and the persistence of

1. Wetlands are significantly negatively impacted by habitat loss, urbanization, and pollution.

2. Roads (especially with curbs) can play a significant role in fragmenting landscapes. This female Northern Leopard Frog was migrating across the road to reach a breeding site.

3. It is important to monitor and take corrective measures to prevent mitigations from becoming dominated by invasives.

each patch is dependent upon the existence of the metapopulation. Metapopulations can have a source-sink structure in which source subpopulations provide all external recruits into sink subpopulations, which contribute a negligible amount of recruits to the source subpopulation. Fragmentation can exacerbate the isolation between subpopulations within a source-sink metapopulation, potentially extirpating the sink subpopulations by reducing dispersal from source subpopulations. Dispersal can be significantly reduced by high dispersal mortality or low dispersal rate. The persistence of corridors connecting wetland habitats has been shown to maintain necessary metapopulation processes in turtle species (Howeth et al. 2008).

Historically, Michigan had abundant wetlands, streams, lakes, and terrestrial areas that provided suitable communities for amphibians and reptiles (Holman 2012). However, Michigan lost approximately 50% of these important habitats between the 1780s and mid-1980s (Dahl 1990). Several wetland protection, loss mitigation, and restoration programs have been established through EGLE, United States Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), the USFWS, the MDNR, and several nonprofit conservation organizations including Ducks Unlimited. While the wetlands created through these programs provide some ecological services (e.g., flood control and waterfowl habitat), these wetlands are often open-water ponds that support predatory fish populations that threaten the survival of amphibian larvae (Ficetola and De Bernardi 2004, Porej et al. 2004, Cunningham et al. 2007). These open-water wetlands do not replace ecological functions and values of most destroyed and degraded vernal pools (seasonal forested pools that provide critical breeding habitat for several amphibian and reptile species), swamps, emergent marshes, fens, bogs, and wet prairies (Shulse et al. 2010). Mitigation wetlands seldom provide the appropriate food resources, cover, hydroperiods (– length of time surface water is present), sandy or gravel nesting areas with proper exposure, or hibernacula. Often, high-quality terrestrial areas necessary for survival and successful recruitment are lacking (Reinartz and Warne 1993, Zedler and Callaway 2002, Porej 2003b, Vasconcelos and Calhoun 2004, Petranka et al. 2007, Shulse et al. 2010). In addition, complete amphibian communities are generally absent from most created wetlands (Lehtinen and Galatowitsch 2001, Porej 2003a, Mack and Micacchion 2006) and many created wetlands are geographically separated from existing wetlands, which limits colonization by amphibians and reptiles (Lehtinen

1. Habitat conditions in degraded wetlands are typically not suitable for amphibians and reptiles. With restoration, these areas can serve as habitat again.

2. Roadways can impede amphibians and reptiles from moving through the landscape to nesting and hibernation areas.

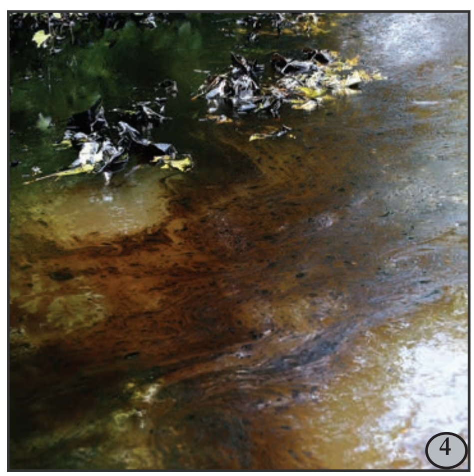
and Galatowitsch 2001).

Construction and development can also remove amphibian and reptile habitat features from the landscape. This impacts specific amphibian and reptile species in the destroyed community as well as those that relied on that area as a connection between other habitat features (Knutson et al. 1999, McKinney 2002, Skidds et al. 2007). Changing the natural contours and composition of a landscape can alter drainage patterns, thereby altering the hydroperiods, water depth, and overall community structure in wetlands and entirely alter the character of upland areas. Use of heavy equipment during construction can compact soil which can cause direct mortality to amphibians and reptiles in the project area (Bol 2007). Compacted soils also support only a limited variety of vegetation which may not provide the suitable canopy cover or duff layer required by various amphibian and reptile species (Gebauer et al. 2012).

Roads and other forms of transportation can have significant long-term effects on biodiversity and population sustainability (Findlay and Bourdages 1999). (Bartoszek and Greenwald 2009, Bulté et al. 2010, Hartzell 2015, Bilkovic et al. 2019, Dornas et al. 2019). Roads are a significant barrier for amphibian and reptile movement in the landscape, with tens of thousands of turtles, snakes, and frogs being killed along roadways every year (Steen and Gibbs 2004, Steen et al. 2006, Row et al. 2007, Patrick et al. 2011, Cosentino et al. 2014). In some places, roads are a significant source of mortality for herpetofauna and can threaten the existence of local populations (Beaudry et al. 2010, Gunson et al. 2012, Sarver and Walton 2012). Persistent mortality can reduce species abundance and diversity up to 2 miles away (Reh and Seitz 1990, Vos and Chardon 1998, DeMaynadier and Hunter Jr 2000). Frogs and some turtles can live in ditches created along roads and use these as movement corridors. Unfortunately, a short foray from the ditch can put these animals in the path of traffic. Roads built in areas of high quality communities or near reptile habitat features (e.g., snake hibernacula) have higher reptile mortality rates (Fortney et al. 2012). Often, animals are killed as they attempt to access seasonal habitat features, nest in the warm, dry soil on the shoulder of a road, or bask on the warm road surface (Ashley and Robinson 1996, Steen and Gibbs 2004, Steen and Smith 2006, Szerlag and McRobert 2006, Row et al. 2007, Shepard et al. 2008, Patrick et al. 2011, Fortney et al. 2012). Behaviors associated with road interactions such as avoidance and crossing speed can vary from species to species (Andrews and Gibbons 2005). Roads can also function as corridors for amphibian and reptile predators, which increases predator movement along roadsides (Trombulak and Frissell 2000, Frid and Dill 2002, Andrews and Gibbons 2005, Aresco 2005a, Barrientos and Bolonio 2009, Clark et al. 2010, Hawlena et al. 2010). These predators can increase negative pressure on herpetofauna populations, as they may eat turtle eggs or amphibians and reptiles attracted to the warm road surface (Boarman et al. 1997). Roads also create a barrier for those amphibians and reptiles that avoid roads, thus restricting these species' range of movement and use of habitat features (Andrews and Gibbons 2005, Jaeger et al. 2005, Andrews et al. 2008). Additionally, the presence of roads can alter microclimate

conditions (e.g., temperature, humidity, and evaporation), which can reduce the suitability of habitat for herpetofauna (Mader 1984). Railroads share many of the aforementioned negative impacts with roads, including their contribution to the decline of herpetofauna populations through fragmentation and direct mortality (Bartoszek and Greenwald 2009, Iosif 2012, Clauzel et al. 2013, Hartzell 2015, Dornas et al. 2019). Similarly, boat traffic is often responsible for the direct mortality of herpetofauna, primarily turtles (Bulté et al. 2010, Lester et al. 2013, Hollender et al. 2018), as well as the habitat degradation and erosion of shoreline habitat caused by boat wakes (Fonseca and Malhotra 2012, Bilkovic et al. 2019, Schafft et al. 2021).

Activities associated with urbanization can create a varied array of potential threats or problems for amphibians and reptiles. Mowing can cause direct mortality to amphibians and reptiles (Saumure et al. 2007, Humbert et al. 2009, Mifsud personal observation 2022). Snakes, frogs and toads, and turtles in the process of nesting are particularly vulnerable to mowing because of their low profile and cryptic coloring. In addition to the potential injury or mortality, mowing contributes to loss of habitat for amphibians and reptiles. In or near urban areas, excessive aquatic vegetation growth triggered by high nutrient levels in waterways is often addressed by mechanical harvest or herbicide application. This method is only a temporary fix, as it does not address the cause of the problem - excessive nutrient inputs - and unfortunately also harms amphibians and reptiles. Machines indiscriminately remove non-target flora and fauna, including amphibians and reptiles from the surface of the water and process them with the targeted vegetation, sometimes crushing the animals (Wile 1978, Haller et al. 1980, Mikol 1985, Engel 1990, Booms 1999). In a best case scenario, these animals are displaced to the area where the unwanted vegetation is disposed. Mechanical weed harvesting also can disturb the bottom, releasing sediments and toxins into the waters that amphibians and reptiles use as part of their habitat (Washington State Department of Ecology 2003). Urban lighting has also been identified as potentially harmful to amphibian and reptile communities (Perry et al. 2008). Many amphibians and reptiles respond to visual cues, and life processes such as migrations, mating, nesting, and hibernation may be influenced by light pollution.



1. Eastern Spiny Softshell Turtles are at risk for collisions with motorized watercraft and aquatic weed harvesters as they are camouflaged and often bask by floating at the surface of the water.

2. Creating no-mow zones like this one in Lake St. Clair Metropark can reduce direct mortality of herpetofauna.

3-4. Pollutants including fertilizer, herbicide, sewage, and stormwater runoff indirectly impact wildlife communities.

Joanna Gibson

1. This Eastern Box Turtle has suffered fatal injuries during a prescribed burn.

Although often used as a wildlife conservation and plant community restoration measure, controlled (prescribed) burns can cause injury and direct mortality to herpetofauna as well as alter habitat suitability (Durbian 2006, Woodley and Kingsbury 2011, Mifsud personal observation 2022). The success of burns is often focused on vegetation community development and often does not consider the short- and long-term impacts to wildlife unless directed specifically as a target animal species. Such actions often do not take into account the implications of a highly-fragmented landscape that may limit colonization after the burn program has completed (Cole and Landres 1996). The full ramifications of fire on herpetofauna in Michigan are currently largely unknown due to a lack of study and the wide range of effects. Considerations of the types of fire, life histories of non-target species, and potential impacts to herpetofauna, specifically appear not to be evaluated. As a result, fire management (e.g., change in litter, vegetation structure, response in various life stages, effect on food source, etc.) can alter the site in ways that may negatively affect some species. However, turtle and snake mortality has been documented at burn sites in Michigan (Cross 2009, Gibson 2009, Woodley and Kingsbury 2011, Mifsud personal observation). Fire can unevenly affect species based on their mobility, as highly mobile groups, such as lizards, have lower levels of mortality associated with fire compared to frogs, salamanders, snakes, and turtles, and the community composition post-burn may have fewer and more generalist species than pre-burn (Rochester et al. 2010). Use of fire alters percent canopy cover and the litter layer which offers cover for many amphibians and reptiles and is critical for maintaining humidity levels and provision of micro-habitats (McCleod and Gates 1998, Rochester et al. 2010). The temporary decrease in abundance of post-burn insect communities that live closest to the ground (in the "fuel" layer (Siemann et al. 1997, Tooker and Hanks 2004)) may decrease the food base available to amphibians and reptiles directly after a burn.

Chemical Use

Sean Zera

2. This male Spotted Turtle was impacted by the 2010 oil spill in Marshall, Michigan. Long-term effects from chemical exposure and loss of habitat from the spill are still not known.

Amphibians and some reptiles have highly permeable skin and typically have extensive contact with water or soils. These characteristics make them particularly sensitive to chemical use and pollution in soil and water and susceptible to bioaccumulation (biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment) of toxins and contaminants (Johnson et al. 1999, Unrine et al. 2007). Their sensitivity to chemicals and tendency towards bioaccumulation can result in decreased abundance and the extirpation of sensitive species (McNeely 1992). Other specialized physiological features of some amphibians and reptiles increase their sensitivity to toxins, as in the case of Eastern Spiny Softshells (*Apalone spinifera spinifera*) and Eastern Musk Turtles (*Sternotherus odoratus*), which can respire through specialized tissue in the cloaca and tongue (Heiss et al. 2010). Reptile and amphibian population declines have been linked to increased chemical use and pollution (Fontenot et al. 2000, Johansson et al. 2001), but relatively little work has been done to document the

1. A Northern Map Turtle receiving treatment for oil exposure. Chemical burns on exposed surfaces and consuming of hydrocarbon pollutants were the most commonly observed sights early in the spill response.

response of amphibian and reptile communities to various types of chemical contaminants (Egea-Serrano et al. 2012).

Development and land conversion for agriculture can result in several types of chemical pollution that have wide ranging, deleterious effects on amphibian and reptile populations. Industrial, commercial, transportation, and residential activities can also introduce high nutrient, pesticide, and herbicide levels and can result in acidification of the environment. All of these can adversely affect amphibian growth and development, and ultimately contribute to population declines (Bradford and Gordon 1995, Jung and Jagoe 1995, Mann and Bidwell 1997). Runoff from roads, parking lots, sidewalks, rooftops, lawns, and other surfaces has introduced high levels of road salts, de-icer chemicals, heavy metals, petroleum products and hydrocarbons from vehicle emissions into the local water supply and adjacent wetlands (Schueler 1994, Barnes 2001, Brabec et al. 2002, Schueler 2003). Chemical contaminants may weaken the immune system of amphibians and reptiles and increase their susceptibility to parasites, disease and ultraviolet (UV) radiation (Blaustein et al. 2003, Daszak et al. 2003, Gendron et al. 2003). However, these negative impacts to herpetofauna associated with chemical use can occur solely as a result of permissible, on-label, ubiquitous use by all, without ill intent.

2. Eastern Musk Turtles and several other reptile and amphibian species spend the majority of their life in contact with water and are extremely sensitive to chemical pollution.

Salts and Heavy Metals

Matt Smar

3. Storm water runoff carries road salt, pollutants from vehicles, and warm water into storm sewers, some of which lead directly to rivers and other water bodies.

Materials used for road maintenance include de-icers which can contain salts, sand, cinder, sodium ferrocyanide, and heavy metals (Oberts 1986). Hydrocarbons and heavy metals are also introduced from motor vehicle use. This suite of pollutants can affect water quality, which in turn can harm herpetofauna populations (Karraker 2006, Andrews et al. 2008, Bennett et al. 2011). These pollutants reduce water quality and degrade terrestrial resources on which amphibians and reptiles rely (Findlay and Kelly 2011). The full extent of the ecological ramifications of road salt and de-icer application is yet unknown; however, regulatory agencies such as the United States Environment Protection Agency (EPA) and Environment Canada have recognized the toxicity of road salt to ecosystems and wildlife and is actively working to reduce its use (United States Environmental Protection Agency 2005b, Karraker 2006, Karraker et al. 2008). Environmental salinity from application of road salts can make wetlands unsuitable for wildlife, but it can also degrade smaller areas of larger wetlands that will support invasive species, such as Eurasian common reed (*Phragmites australis*, hereafter referred to as *Phragmites*) (Karraker 2006). Although lower-impact alternatives to conventional road salts are used and recommended by the Michigan Department of Transportation (MDOT) (Michigan Department of Transportation 2006), in winter 2006/2007 road salt use on municipal roads in Michigan was applied at an average of 22.78 tons per lane-mile (Michigan Department of Transportation 2008). This salt in the environment runs into surface waters and percolates through the soil into the ground water, increasing the long term baseline salinity of water resources critical to most amphibians and reptiles (Judd 1970, Demers and Sage 1990, Rosenberry et al. 1999, Paul and Meyer 2001, Jackson and Jobbágy 2005, Kaushal et al. 2005).

Polycyclic Aromatic Hydrocarbons (PAHs) and Other Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) and other hydrocarbons are pollutants that are commonly detected in the environment as a result of natural occurrences such as volcanoes and fires, but also result from anthropogenic sources such as urban and industrial runoff, wastewater treatment effluent, petroleum spills, and atmospheric deposition from combustion (Albers 2002). PAHs are endocrine disrupting compounds (ATSDR 1995) that can cause lethal and sublethal effects and deformations in wildlife (Albers 2002, Douben and Wiley 2003). These compounds have also have been linked to immune suppression (Dickerson et al. 1994), hemolytic anemia (a condition in which red blood cells are destroyed), and cancer (Baumann and Harshbarger 1995). Relatively little work has been done to study the effects of PAHs in the environment on amphibians and reptiles (Pauli et al. 2000), but these compounds likely have similar impacts to those demonstrated for other wildlife groups. Demonstrated impacts in amphibian and reptile species from exposure to PAHs include deformities in Eastern Snapping Turtle hatchlings (Van Meter et al. 2006), reduced fertility and hatchling mortality in Eastern Snapping Turtles and Midland Painted Turtles and toxicity and cancer in amphibians (Balls 1964, Fernandez and L'Haridon 1992, Djomo et al. 1995, Bell 2005).

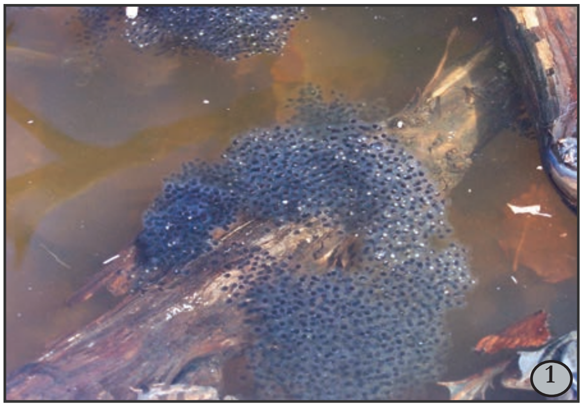
1-2. Stormwater runoff from agricultural and urban areas increase the nutrient levels in the Saginaw Bay and other Great Lake water bodies, which has resulted in algal blooms and excessive plant growth.

NASA

Shane DeSolla

Pharmaceuticals and Hormones

Pharmaceuticals and hormones (e.g., synthetic hormones, acetaminophen, triclosan [an antibacterial and antifungal agent common in soaps, toothpaste, cleaning supplies, and some plastics], and caffeine) are present in the environment and are increasing in human use. Pharmaceuticals are known to have endocrine disrupting properties with the potential to interfere with hormonal and developmental pathways in animals (Crump 2001). These chemicals have been detected in aquatic ecosystems around the world and are now commonly found in surface waters (Garric and Ferrari 2005) and in wastewater treatment plant effluent (Gross et al. 2009). The environmental contamination associated with pharmaceuticals are in part regulated by the Food and Drug Administration (FDA) that evaluates environmental impacts of drug use (U.S. Food and Drug Administration 2011) and the EPA that limits the discharge of pollutants into navigable waters of the United States and into wastewater treatment plants by existing and new pharmaceutical manufacturing facilities (United States Environmental Protection Agency 2006). The effect of these chemicals on amphibians and reptiles in aquatic systems is not well documented, however, there is evidence that these pollutants may be linked to developmental and behavioral abnormalities and lethality in amphibians (Sower et al. 2000). They potentially impact the



1-3. Eggs and larvae of amphibians, like Wood Frogs, are particularly sensitive to pesticides and herbicides.

metabolic processes of wildlife and other ecological processes (Länge and Dietrich 2002, Sumpter 2007, Williams and Cook 2007).

Excess Nutrients

Nutrients (e.g., nitrogren and phosphorous) found throughout the Great Lakes basin associated with runoff from agricultural fields, industrial water treatment, and waste water treatment have been linked to deformities and have both sublethal and lethal effects in amphibians (Rouse et al. 1999) and the expansion of Phragmites (King et al. 2007). The runoff of one type of organic fertilizer, poultry litter, can be particularly damaging to amphibian larvae and is lethal to eggs and damaging but sublethal to tadpoles (Curi et al. 2017). Chronic effects on amphibians (reduced feeding and swimming, disequilibrium of larvae, and developmental abnormalities) were observed in some species at nitrate concentrations well below the EPA Maximum Contaminant Level (MCL) for nitrate in drinking water (Rouse et al. 1999). Nitrates may affect amphibian populations by encouraging algal growth which can lead to increases in *Planorbella* spp. These snails are believed to be the exclusive primary intermediate host for Ribeiroia ondatrae, a species of trematode that parasitizes amphibians and causes deformities (Johnson and Chase 2004). Additionally, nitrates may increase predation risk in tadpoles by decreasing their overall activity level and predator detection ability (Ortiz-Santaliestra et al. 2010).

Pesticides

Pesticides, including herbicides and insecticides commonly applied to agricultural fields and manicured landscapes can cause developmental abnormalities, deformities, and altered behavior and have been documented as the impetus for declines in several amphibian species (Mann and Bidwell 1997). Several commonly used herbicides and pesticides (e.g., Roundup®, Sevin®, malathion, 2,4-D) also reduce the number of overall species in aquatic communities and could have indirect effects on amphibians and reptiles that rely on a stable food supply (Relyea 2005). Amphibians are particularly at risk from pesticide exposure due to the nature of their life histories: most species have an aquatic larval stage as well as some form of a terrestrial stage, exposing them to toxins in multiple environments at multiple life stages (Brühl et al. 2013).

Recent studies suggest that pesticides and fungicides may have extremely harmful effects on amphibians in terrestrial environments (Brühl et al. 2013). Reduced abundance of Mink Frogs (*Rana septentrionalis*) has been linked to large scale insecticide use (McAlpine et al. 1998). Acute and chronic mortality and deformations in salamander and frog communities have been observed after insecticide applications (Ingermann et al. 2002, Boone and James 2003). The historical use of Dichloro-Diphenyl-Trichloroethane (DDT) in the U.S. has been documented to cause


Scott Gillingwater

1. Shallow breeding sites used by amphibians, such as the Boreal Chorus Frog, are often filled by surface runoff and are vulnerable to contamination by pollutants.

2. Atrazine, the most widely used herbicide in the United States, has been demonstrated to inhibit reproductive development and suppress immune system response of Northern Leopard Frogs.

significant mortality to amphibians and reptiles (U.S. Fish and Wildlife Service 1945, Herald 1949). Insecticide use can reduce the prey base for amphibians and reptiles, and some insecticides have a variable effect on amphibian species and can alter the amphibian community compositions (Boone et al. 2004). Although not as widespread as in the past, chemical control of mosquitos is conducted as part of an integrated mosquito management strategy (MMCA 2013) through chemical applications to the surface of water bodies and by spraying into the air ("fogging"). Some of the chemicals used in fogging are to kill adult mosquitos (e.g., malathion), while organophosphates target mosquitos larvae stages, both are toxic to tadpoles (Berrill et al. 1994, Sparling et al. 1997, Relyea 2004) and may result in amphibian declines. Removal of larval and adult mosquitos from an ecosystem can also remove a significant food source for larval amphibians, fish, birds, and other wildlife (Blaustein and Kotler 1993, Blaustein et al. 1996, Kumar and Hwang 2006). Organochlorine pesticides, such as lindane, endosulfan, dicofol, methoxychlor and pentachlorophenol, break down slowly and can be retained in tissue for long periods of time. These substances and banned organochloride pesticides, such as DDT, have been detected in turtle organs and eggs at levels that have implications for human consumption of turtles and for development of turtles (Solla and Fernie 2004).

Herbicides move via groundwater and surface runoff into wetlands where amphibians are likely to be affected. As of 2003, the United States EPA has approved over 20,000 insecticides, fungicides, and herbicides (United States Environmental Protection Agency 2003). The most extensively used herbicide is atrazine, which is toxic to aquatic organisms (United States Environmental Protection Agency 2003), and for this reason has been banned by the European Union since 2004 (Sass and Colangelo 2006, Ackerman 2007). Atrazine has commonly been detected in surface waters, and concentrations generally peak following major storm events that occur within a few weeks of application. Atrazine has been linked to malformations, specifically in Northern Leopard Frogs (*Rana pipiens*), resulting in reproductively viable hermaphroditic transformations that skews sex ratios, disrupts population structure, and may reduce genetic diversity (Allran and Karasov 2000, Sower et al. 2000, Hayes et al. 2002a, Hayes et al. 2002b, Hayes et al. 2003, Coady et al. 2004, Hayes et al. 2010, Herpetological Resource and Management 2011b). Additionally, atrazine exposure can increase risk of desiccation for salamanders, even months after exposure likely due to the disruption of neuroendocrine processes associated with water-conserving behaviors (Rohr and Palmer 2009). Another herbicide, alachlor, has been shown by the EPA to cause skin and eye irritation; increased risk of renal, spleen and liver damage; and promotes cancer of the lining of nasal cavity and eyelids. This chemical has been banned in Europe since 2006 and in Canada since 1985 but continues to be used in the U.S. (United States Environmental Protection Agency 1998, Rotterdam Convention 2011). The pre-emergent herbicide, acetochlor, can have negative

1. Exposure of Green Frog tadpoles to glyphosate has been linked with decreased size at metamorphosis.

physiological effects and has been linked to hindered hind limb development for larvae and may lead to reduced population size for affected species including Northern Leopard Frog, Green Frog, and Bullfrog (*Lithobates catesbeianus*) (Cheek et al. 1999, Mann et al. 2009).

Glyphosate based herbicides (e.g., Roundup®, Rodeo®, Accord®) and surfactants (e.g., POEA, polyethoxylated tallowamine; NPE, nonlyphenol ethoxylates) are commonly used in land management (Dill et al. 2007). These herbicides have more severe negative effects and are moderately to highly toxic to amphibians. Larvae exposed to glyphosate and surfactants can produce smaller adults, mature slower, have deformations and abnormalities, and have higher mortality rates (Howe et al. 2009, Relyea and Jones 2009). There is evidence to suggest that the surfactant rather than the active ingredient (isopropylamine salt of glyphosate) in these herbicides is responsible for the toxic effects (Trumbo 2005). As surfactants are proprietary mixtures protected under trade-secret laws, manufacturers are not required to list the chemical composition of these compounds. Glyphosate and atrazine applied for weed and invasive plant control in agricultural fields have been detected in nearby water bodies at concentrations that exceeded the freshwater aquatic life standard for their respective chemical compositions (Battaglin et al. 2009). These measurements are identified in the Canadian Environmental Quality Guidelines and have been set to provide protection of freshwater life from anthropogenic stressors such as chemical inputs or changes to physical components (Canadian Council of Ministers of the Environment 1999). Although glyphosate herbicides are deemed safe in part because they supposedly quickly degrade in the environment, concentrations of glyphosate greater than the LC50 (lethal concentration for 50% of the population) value for many amphibians (between 10 and 1 mg acid equivalent/L) (Govindarajulu 2008) have been detected in nearby waterways one week after application (Battaglin et al. 2009). Additionally, some herbicides, such as triclopyr, can be detected in nearby aquatic systems up to 13 months after treatment (Battaglin et al. 2009). Impacts of these herbicides to aquatic ecosystems and specifically to amphibians and reptiles, is greatest when a buffer zone is not used and chemicals are used directly around aquatic systems (Trenham 2001, Trenham and Shaffer 2005, Battaglin et al. 2009). The deleterious impacts of multiple types of pesticides can combine to be even more damaging to amphibians, with a singular frog potentially containing a mixture of up to eight different herbicides in their tissue (Smalling et al. 2015).

Piscicides

Lampricide is used as a piscicide to kill invasive sea lamprey (*Petromyzon marinus*) in Michigan waters. Lampricide has deleterious effects on several non-target species (Boogaard et al. 2003, Dawson 2003, Hubert 2003). This chemical is toxic to many insects, including some beneficial insects (e.g., lady bugs), fish, and ticks, and slightly toxic to some bird species (Extoxnet 1996). Lampricide can be toxic to gill-breathing larval amphibians and adult amphibians, such as Mudpuppies (*Necturus maculosus*) and sometimes results in large-scale mortalities (Gilderhus and Johnson 1980, Kane et al. 1993, Boogaard et al. 2003, Dawson 2003, Hubert 2003, Billman et al. 2011, State of Vermont 2011). Several turtle species may be impacted by lampricide, particularly

1-2. Application of lampricides often results in mortality of Mudpuppies in areas where these fully aquatic salamanders live.

3. Dams not only affect hydrologic processes but can also serve as a form of habitat fragmentation for wildlife.

Eastern Spiny Softshells and Eastern Musk Turtles, as these species respire through specialized tissue in the cloaca and tongue which likely increases sensitivity to toxins (Heiss et al. 2010). Long-term accumulation of lamprey-killing chemicals in Mudpuppies may shorten the life span in these long-lived (~25 yrs.) amphibians and decrease their ability to reproduce (Parren and Hart 2012). Direct mortality sometimes in the hundreds of Mudpuppies in Michigan has been documented though efforts have been made to refine application techniques to reduce mortality. The full impact of lampricide on herpetofauna is largely unknown (State of Vermont 2011). Researchers have identified the need for further investigation on how non-target, non-fish vertebrate and invertebrate species (specifically larval amphibians, mollusks, and endangered species) are impacted (McDonald and Kolar 2007).

Rotenone is a broad spectrum pesticide used to treat a problematic fish community. The application of rotenone during the winter when amphibians are in hibernation has not shown adverse effects on amphibian populations (Walston and Mullin 2007). Since cold weather also lengthens the half-life of rotenone (Dawson et al. 1991), the desired management effect is likely to be more successful.

Alterations to Hydrologic Processes

Massive efforts through the 1800s and 1900s to drain Michigan's wetlands and saturated soils for agriculture directly reduced herpetofauna habitat and ultimately resulted in a loss of over 11 million acres and 50% of the States's wetland (Dahl 1990). Watershed level alterations in hydrologic processes can reduce habitat availability, connectivity, and suitability and recruitment success for various amphibians and reptiles (e.g., Eastern Massasauga Rattlesnake, Blanding's Turtle, Red-spotted Newt (*Notophthalmus viridescens viridescens*), Wood Frog, Spotted Salamander) (Chin 1996, Willson and Dorcas 2003, Faulkner 2004, Riley et al. 2005, Skidds et al. 2007, Hamer and McDonnell 2008).

As Michigan became more developed, roads, sidewalks, and roofs replaced areas of vegetation. Vegetation typically reduces the impact of rain events by providing physical a barrier that breaks large rain drops into smaller droplets, allowing soil to absorb water over time and slowing the velocity of runoff. As the velocity of runoff is reduced, the water infiltrates the soil and reduces soil surface erosion. As the water reduces in velocity and infiltrates the soil, sediment and pollutants drop out of the runoff and attach to the soil surface where they are either adsorbed (bound to) onto soil particles or infiltrate into the soil where they are either broken into inert compounds by soil microbes or leach downwards into the subsoil. Open fields that lack dense herbaceous vegetation are vulnerable to erosion and runoff during heavy rain events. Impermeable surfaces do not allow for the infiltration of water and thus increase the rate of stormwater runoff, which generally has increased sediment loads containing higher concentrations

Matt Smar

1. Impermeable surfaces increase runoff and decrease infiltration.

2-3. Not only is vegetation important for preventing runoff that leads to severe erosion, but it also provides habitat for amphibians and reptiles, such as the Pickerel Frog.

of adsorbed pollutants (due to increased sediment loading with adsorbed contaminants) and is warmer than surface waters.

In vegetated areas, rain water is filtered as it slowly percolates through the soil and is slowly released into nearby water bodies via groundwater flows, which help feed streams during dry times. This allows for water to be released into water bodies on a nearly continuous basis and moderates fluctuations in water levels throughout the year. In areas where impermeable surfaces dominate the landscape, water bodies experience flashiness - quick changes in water level, rate of flow, and volume. In addition to the growing percentage of impermeable surfaces, detention of water has been lost in many areas as a result of wetland degradation and loss. Large quantities of rainfall are discharged into nearby water bodies during and directly after a storm, at other times ground-water inputs are minimal as water does not have an opportunity to infiltrate into the soil. Stormwater runoff in urban areas is often channeled to municipal sewers or discharged directly into surface waters (Booth and C.R. 1997). Although these combined sewer systems are less common today due to sewer separation efforts (United States Environmental Protection Agency 1999), use of combined storm and sanitary sewer systems result in overflows of raw sewage into streams and rivers during large and sometimes relatively small storm events resulting in the accumulation of contaminants in water bodies (Eganhouse and Sherblom 2001, United States Environmental Protection Agency 2001, 2005a). These alterations to natural hydrologic patterns result in extreme changes in water level and temperature and increased erosion and pollution, which degrades aquatic communities that support amphibian and reptile populations (Murray and Hoing 2004, Massal et al. 2007).

Removal of vegetation and the litter layer decreases infiltration, increases runoff, and increases the rate of wind and water erosion (Ash 1997). Increased runoff and stream velocity increase the erosive action in upland areas along the banks and in the streambed. The resulting channel incision and steep banks limit connectivity for amphibians and reptiles in the floodplain. These deepened waterways have reduced frequency and duration of inundation (flooding) as the water level is not able to crest the banks and dissipate the energy of the waterway and deposit sediments (Buijse et al. 2002). Sediment from upland and streambank erosion suspended in surface waters results in increased turbidity and reduced dissolved oxygen. Turbidity reduces water clarity and quality decreasing amphibian and reptile aquatic habitat suitability (Roy et al. 2003, Sacerdote and King 2009). Reduced levels of dissolved oxygen create unsuitable conditions for larval amphibians and Mudpuppies (which use gills for respiration). These effects extend to, fish, and aquatic invertebrates which form the prey base for many aquatic and terrestrial amphibians and reptiles (Spieles and Mitsch 2000, Morley and Karr 2001, United States Environmental Protection Agency 2009).

Stream morphology is also altered as a result of anthropogenic actions. Channelization

1. Crayfish chimneys are frequently used by overwintering herpetofauna and can serve as critical microhabitat. These structures demonstrate the importance of maintaining overall community health to sustain viable ecosystems.

2. Channelization reduces the amount of available habitat and alters the flow of water and sediments.

(often in urban areas) has generally been achieved through use of concrete or rock construction. These structures typically remove macro- and micro-habitat features that amphibians and reptiles use for cover, hibernation, as foraging grounds, and for nesting (Bodie 2001). Hardening and straightening waterways alters the flow of water, changing the character of sediment transport and deposition, and decreases infiltration. Over 2,500 dams have been constructed throughout Michigan (Michigan Department of Natural Resources and Michigan Department of Environmental Quality 2004). Although dams were constructed to generate power, create impoundments for recreation and irrigation, to prevent flooding, they also dramatically impact native wildlife and fisheries resources. Dams often create barriers to amphibian and reptile movement and serve to fragment populations (Bennett et al. 2010). These barriers alter hydrologic and thermal conditions that impact breeding, nesting, basking, and hibernation opportunities of riverine herpetofauna, altering their spatial distribution (Lind et al. 1996, Ashton et al. 2011, Bettaso 2013). Dams reduce areas of suitable aquatic communities upstream and downstream (Eskew et al. 2012). For example, higher water levels upstream of a dam can inundate the sandy banks turtles use for nesting (Hunt et al. 2013).

Manipulating water-levels for waterfowl management, recreational use, or restoration efforts can impact amphibians and reptiles. Drawdowns – water removals – are performed to manage aquatic vegetation as well as increase habitat for waterfowl and wildlife in managed wetlands however this method can result in high mortality of amphibian larvae and young turtles if conducted at inappropriate times of the year (Kaltenecker et al. 1999). Late season drawdowns of lakes or other water bodies can result in significant mortality of hibernating animals using the lake shore and lake bottom as winter refugia (Bodie and Semlitsch 2000b, Bodie and Semlitsch 2000a). The lowered lake level exposes the shoreline and removes the insulating layer of ice resulting in frozen ground. Summer drawdowns for management can expose amphibians and reptiles to harsh, hot conditions and significant risk of predation. These individuals may attempt to wait for conditions to improve (i.e., estivate, burrow in the mud) and ultimately die, or individuals may travel overland to seek shelter elsewhere (Roe and Georges 2008). Traveling to suitable wetland areas has several risks, including road mortality, exposure to predators, and desiccation from heat exposure (Aresco 2005b, Spencer and Thompson 2005). Duration of inundation of wetlands is also an important consideration. If water is not present for enough time, this could result in a disruption of life processes resulting in population declines for pond-breeding amphibians (Paton and Crouch III 2002). Additionally, adding water to an emergent marsh in early spring can drown herpetofauna like Midland Painted Turtle hatchlings, which overwinter in terrestrial areas (Baker et al. 2007). Adding water during mid-spring to early summer in an area where turtles nest close to the shore may drown eggs of turtle species, like Eastern Spiny Softshell (Tucker et al. 1997, Galois et al. 2002). If water is added to shallow areas that support amphibian development, fish may become established. When fish are introduced to a water body

Anonymous

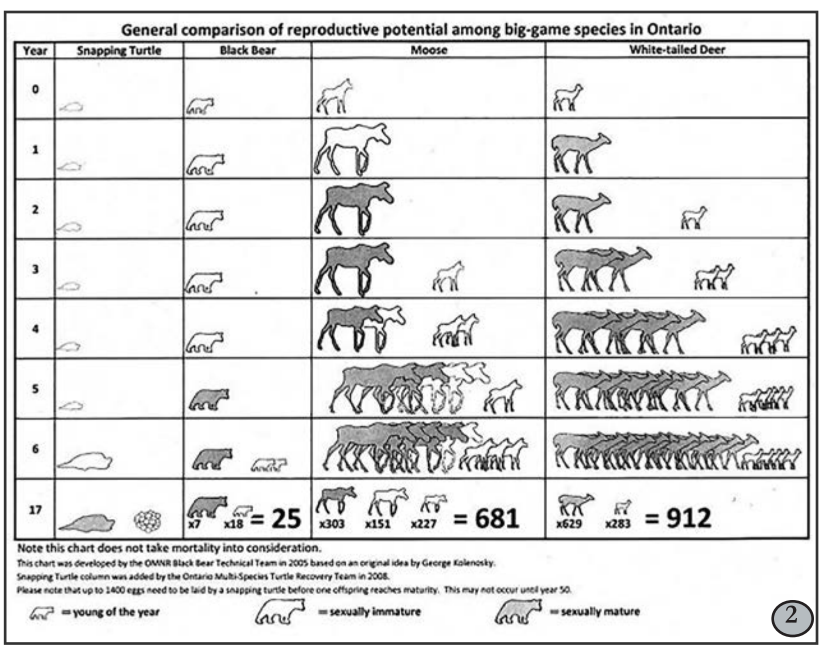
1. Populations of Spotted Turtle (1) as well as Blanding's Turtle, Eastern Box Turtle, and Wood Turtle have experienced significant pressure from illegal collection.

they will eat amphibian larvae and negatively affect amphibian reproduction (Snodgrass et al. 2000). Many amphibians can chemically detect the presence of fish within a water body and will actively avoid these sites for breeding, even if they had previously bred at that location for decades (Hecnar 1997).

Illegal Collection and Overharvesting

Illegal collection for the national and international pet trade has reduced the viable (breeding) populations for some species in Michigan, such as the Wood Turtle (*Glyptemys insculpta*), Spotted Turtle and possibly Blanding's Turtle and Eastern Box Turtle (Lannoo 1998, Harding and Mifsud 2017). Collection of adults and hatchlings of these long-lived animals can result in severe population declines as turtles have delayed sexual maturity and require high juvenile and adult survivorship to sustain populations (Congdon et al. 1993, Congdon 1994, Congdon and Keinath 2006, Harding and Mifsud 2017).

Poaching and illegal collection can be, and historically was, a problem for herpetofauna in Michigan (Harding and Mifsud 2017). In addition, the high demand in overseas Asian food markets for turtles has put pressure on the poaching of some Michigan turtle species for export (Hylton 2007). There have been multiple examples of arrests made for trafficking of turtles and other herpetofauna in Michigan. Just across the border in Canada, dead and alive Blanding's Turtles, Spotted Turtles, and Eastern Massasauga Rattlesnakes have been confiscated from people who have collected these animals for food or other purposes (Cota-Larson 2009, Harding 2013) and unexplained declines in populations of Spotted Turtles likely point to poaching (Litzgus 2012). Although far more turtles are killed annually on roads than through illegal collection, illegal take of animals is a real problem in Michigan and needs to be mitigated.



Ontario Multi-Species Recovery Team

2. This diagram illustrates Eastern Snapping Turtle reproductive potential compared to commonly managed big game species. Due to delayed sexual maturity and low reproductive potential of Eastern Snapping Turtles and other turtle species, high adult survivorship is required to achieve population stability and sufficient recruitment. It is critical for management actions to take into consideration the significance of a singular sexual mature female in terms of population viability.

Jim Harding

Sean Zera

While illegal collection and poaching pose a significant threat to Michigan herpetofauna, legal take can also unintentionally contribute to overharvest and declining populations of long-lived, slow to mature species. Regulations have been enacted to prevent overharvest of Eastern Snapping Turtles (Michigan Department of Natural Resources 2012), however enforcement is limited and difficult. The Eastern Spiny Softshell is also at risk of landscape-wide population declines due to the selective harvest of large, sexually mature females (Convention on International Trade in Endangered Species of Wild Fauna and Flora 2022).

Persecution

Herpetofauna are persecuted by humans for various reasons. Snakes are likely the most persecuted group, as people have misplaced social, religious, or cultural beliefs that snakes will harm them, are evil, reduce populations of game species, and are aggressive and venomous (Ceríaco 2012). It appears that larger snakes, such as the Black Rat Snake (*Pantherophis spiloides*) and Blue Racer, which mainly eat rodents, are more feared and therefore suffer greater persecution than smaller snakes. The Eastern Hog-nosed Snake and Eastern and Western Fox Snake (*Pantherophis gloydi* and *P. vulpinus*, respectively) are killed because they look similar to venomous copperheads or cobras. The only pit viper species in Michigan is the Eastern Massasauga Rattlesnake which, due to its secretive and non-confrontational habits, is not usually encountered by humans. Fatalities attributed to Eastern Massasauga Rattlesnakes are incredibly uncommon due to the species' non-aggressive nature and relatively short fangs that can only inject a small volume of venom (Klauber 1982).

Turtles and amphibians are also occasionally persecuted for eating game fish, waterfowl, and ornamental fish and are killed for "fun" or hit on roads in "sport". Accounts of people shooting turtles and frogs, dead turtles riddled with bullet holes, and purposefully hitting turtles and snakes with cars pose threats to these populations (Ashley et al. 2007). Eastern Snapping Turtles, particularly, are subject to threats as this species is aggressive when approached on land. The Mudpuppy and Eastern Snapping Turtle, in particular, are killed because people unjustifiably believe they affect fishing success and reduce the abundance of game species (Bosch 2003, Siebert 2008).

1-4. Unfortunately, reptiles and amphibians are often killed in the name of "sport". Wood Turtles (1,2) and other reptiles are shot or run over for fun throughout the state. Eastern Hog-nosed Snakes (3) are sometimes mistaken for a cobra or copperhead and are killed purposefully. However, these snakes are harmless to humans and often "play dead" when confronted. Black Rat Snakes (4) and other large species are also killed out of fear. It is illegal to shoot reptiles and amphibians in Michigan and such activities should be reported to the MDNR Report All Poaching (RAP) Hotline at 1-800-292-7800.

1. *Phragmites*, autumn olive, and other densely growing invasive plants often shade out critical habitat.

2. Where *Phragmites* grows in dense stands, turtles, like this Eastern Snapping Turtle, must travel farther distances to find nesting areas. This extra traveling can be exhausting to any animal, let alone a gravid turtle. These individuals are also more vulnerable to predation and persecution.

Invasive Species

Invasive plant and animal species typically are able to quickly become established, have high reproductive success, advantageous life history traits (e.g., short time until reproductive maturity, multiple forms of reproduction), few predators, and adaptive capabilities (Klocker and Strayer 2004, Whitney and Gabler 2008, Campbell et al. 2010). The combination of these and other ecological factors allows these species to dominate an area and outcompete native, non-invasive species (Devin and Beisel 2007). Since invasive species have characteristics that generally allow them to thrive in harsh environments, after invasive species have become established they are difficult to remove. The continued presence of invasive species and/or the dominance of invasive species can diminish biodiversity and reduce the diversity of native plant and animal communities, including herpetofauna (Brown et al. 2001, Brown and Blossey 2002, Kats and Ferrer 2003, Meyer 2003, Bolton and Brooks 2010). The introduction of non-native species can impact amphibians and reptiles through direct predation, competition for food, altered behavior, habitat structure, and disturbance cycles (e.g., fire regimes) (Gibbons et al. 2000). Unfortunately, methods to control invasive species can also have negative effects on herpetofauna (See Section 7).

Invasive species can be detrimental to native herpetofauna populations through habitat alteration, competition, and added predation pressure. The shade from dense stands of invasive plants can eliminate sunny basking areas and turtle nesting sites. Below is a subset of the current invasive species that threaten herpetofauna and their habitats.

Phragmites, **reed canary-grass** (*Phalaris arundinacea*), **glossy buckthorn** (*Frangula alnus*), **common buckthorn** (*Rhamnus cathartica*), and **purple loosestrife** (*Lythrum salicaria*) have dramatically altered wetlands and coastal areas throughout Michigan. These invasive plants grow in dense monocultures that do not provide necessary habitat components (basking areas, appropriate food base) for herpetofauna (Tesauro 2001; Bolton and Brooks 2010). Invasive plants can fragment herpetofauna habitat by creating physical barriers to movement across the landscape (Westbrooks 1998).

Phragmites typically grows in dense stands and currently dominates several wetland plant communities and threatens wetlands throughout Michigan (Lynch and Saltonstall 2002, Tulbure et al. 2007, Tulbure and Johnston 2010, Mifsud 2014). Although amphibians can occupy small patches of *Phragmites*, few individuals occupy larger stands (Meyer 2003). Dense stands of *Phragmites* degrade habitat for nesting, which reduces turtle nesting success and recruitment (Committee on the Status of Endangered Wildlife in Canada 2002, Bolton and Brooks 2010) and restricts movements of turtles to upland nesting areas, movements of frog species to and from open water, and movements of herpetofauna from optimal thermoregulation (Mifsud personal observation 2022). Shade from *Phragmites* cools the water which can slow the growth of amphibian eggs and larvae and reduce the proportion of larvae that survive to metamorphosis (Cohen et al. 2007). *Phragmites* is predicted to expand as Great Lake water levels recede related to

1. Amphibian larvae like these Western Chorus Frog eggs can experience deformities or mortality when developing in wetlands dominated by invasive buckthorn species.

climate change (Tulbure and Johnston 2010).

European buckthorn species grow aggressively in moist soils and wetland edges and affect microhabitats by reducing leaf litter, soil moisture, and wetland hydroperiod and increasing soil acidity. These species also produce the chemical emodin that can be found in nearby soil, pond sediment, and pond water. This metabolite is known to cause mortality and deformities in larval amphibians (Sacerdote and King 2014). Due to the low naturally low survival rate of larval stage amphibians, local populations may experience significant declines in areas heavily invaded by buckthorn species. Removal and long-term control of these aggressive growing invasives is strongly recommended. To reduce risk of continued contamination, cut material should be taken offsite.

Autumn olive (*Elaeagnus umbellata*), **honeysuckle** (*Lonicera* spp.), **garlic mustard**, **Japanese barberry** (*Berberis thunbergii*), and **multiflora rose (***Rosa multiflora***)** are common invasive plants in upland areas (Borland, Campbell et al. 2009). These dense invasive plants shade the ground, thus interfering with the thermoregulatory behavior of herpetofauna and reducing the suitability of these areas as basking sites for snakes or nesting sites for turtles.

Goldfish (*Carassius auratus*), are a non-native species that, when released into the 'wild' in Michigan, alters the ecosystem and increases competition for food and resources for native herpetofauna species. Goldfish also increase the turbidity of water and feed on eggs and larvae of amphibians (Wilson 2005).

Raccoon (*Procyon lotor*), while a species native to Michigan, has become overabundant due to the alteration of available resources by humans. These unnaturally high densities of raccoons can result in 100% turtle nest mortality at some sites (Herpetological Resource and Management 2011a). Raccoons often destroy most, if not all, turtle nests in areas of high raccoon density (Oldfield 1994, Geller 2012), which leads to low or no recruitment for turtle populations (Christiansen and Gallaway 1984, Browne and Hecnar 2007). Because many turtle species are long-lived with a slow rate to maturity and low reproductive capacity, mortality exceeding the normal rate of loss could lead to population declines and possible long-term population or species extirpation.

Wild turkey (*Meleagris gallopavo*), another species native to Michigan, has recovered from its

Jim Harding & Hailey Brown

2. Artificially high densities of raccoons add significant pressure to turtle populations. In many parts of Michigan, annual nest mortality reaches an unsustainable 100%.

3. Small steps like properly disposing of refuse and locking bin covers can reduce subsidized predator impacts.

1. Mute Swans alter vegetation composition and make aquatic habitats unsuitable for some amphibian and reptile species.

extirpation in the state to where the current population is higher than known historical levels (Bump 2022). Wild turkey have a varied diet and are known to prey upon amphibians and reptiles (Fleenor 1976, Evans-Peters 2013). In areas of high turkey density, this bird may be deleterious to herpetofauna populations.

Mute swan (*Cygnus olor*) are aggressive exotic birds that may force native waterfowl off of water bodies and attack, injure, or kill wetland birds (Petrie 2002, Perry et al. 2004). Mute swans may also displace turtles from optimal basking sites. These swans heavily forage on aquatic vegetation year-round, thus altering the vegetation composition and structure (Søndergaard et al. 1996, Bortolus et al. 1998, Allin and Husband 2003, Perry et al. 2004) and reducing water quality with the large quantity of feces they produce (Reese 1975, Weisner et al. 1997, Czeczuga and Mazalska 2000, Perry et al. 2004, Bailey et al. 2008). Alterations of vegetation may make these water bodies unsuitable for omnivorous amphibians and reptiles.

Feral swine (*Sus scrofa*) have been known to damage native plant communities and wetland structure by digging, rooting, and wallowing (Campbell and Long 2009). Wallowing and rooting can lead to increased concentrations of phosphorus, nitrates, and total suspended solids, as well as a reduction in pH (Brown et al. 2015). These wetland alterations could make conditions unsuitable for wetland-dwelling amphibian and reptile species. Feral swine also have been known to consume snakes, frogs and toads, lizards, and turtles and turtle eggs in large numbers (Lowe et al. 2000, Fordham et al. 2006, Jolley et al. 2010).

Zebra mussels (*Dreissena polymorpha*) and other aquatic invasive animals transported via ballast water, boats, and bait dumping have altered habitat for native species (Glassner-Shwayder 2000). Rusty crayfish (*Orconectes rusticus*), round gobies (*Neogobius melanostomus*), and Eurasian ruffe (*Gymnocephalus cernuus*) consume eggs of native fish. Spiny waterfleas (*Bythotrephes longimanus*), fish hook waterfleas (*Cercopagis pengoi*), and round gobies compete with young native fishes for food. Rusty crayfish are a large aggressive species that consume large amounts of aquatic vegetation and outcompete native crayfish which are a primary food source for Queen Snakes (*Regina septemvittata*) (Ontario's Invading Species Awareness Program 2013)

Other invasives such as **quagga mussels** (*Dreissena rostriformis bugensis*) and **sea lamprey** alter food web and ecosystem functions which can indirectly impact herpetofauna (Gibbons et al. 2000). However, some reptile species, such as the Northern Map Turtle (*Graptemys geographica*), capitalize on the presence of these abundant invasives as a food source and help control these undesirable species (Lindeman 2006).

2. Rusty Crayfish outcompete amphibian and reptile native food sources.

Doug Watkinson

Emerald ash borer (*Agrilus planipennis*) and other invasive insects alter the composition of wetland and upland plant communities and the quality of habitat for salamanders, Eastern Box Turtles, and other upland-dependent herpetofauna that rely on appropriate levels of canopy cover, microclimate, and amount of understory vegetation (Poland and McCullough 2006).

Some non-native, invasive species, such as **earthworms**, have become

1. Invasive insects like the emerald ash borer alter upland conditions that species like the Spotted Salamander require for survival.

incorporated into the diet of several amphibians and reptiles. Over time, these species adapted to consume earthworms and now earthworms comprise a major portion of their diet (Ransom 2012). Though they can negatively impact landscapes, they have also become an important food resource. For species such as the Butler's Garter Snake (*Thamnophis butleri*), a declining species in Michigan, earthworms are a primary food source and a critical resource for this and other species of herpetofauna.

2. Feral and outdoor cats are among the most efficient and devastating invasive species in the United States and across the globe.

Feral and outdoor pet cats (*Felis catus*) **and dogs** (*Canis lupus familiaris*), have been estimated to kill one billion birds per year in the United States (Dauphiné and Cooper 2009) and it is suggested that even more amphibians, reptiles, and small mammals are killed (Coleman et al. 1997, Calver et al. 2007). Cats in Great Britain killed an estimated 5 million reptiles and amphibians in only a five-month span in 1997 (Woods et al. 2003). In Canberra, Australia, house cats were estimated to annually kill 29,700 reptiles and 5,940 amphibians (Barratt 1998). Cats may also impact the behavior of herpetofauna, increasing wariness and refuge-seeking behavior (Stone et al. 1994).

The impact of dog predation on wildlife in the United States is not well studied. However, feral dogs were primary drivers of the extirpation of the Rock Iguana (*Cyclura carinata*) on Pine Cay Island in the Caicos archipelago (Iverson 1978) as well as the decline of Marine Iguanas (*Amblyrhynchus cristatus*) in the Galapagos Islands (Kruuk and Snell 1981). Further research is needed to assess their impact on herpetofauna in Michigan.

Non-Native Species

Non-native or exotic species, while not considered to be indigenous to the specific area or region, do not always qualify as an invasive species. If the non-native species does not possess the ecological or economic harmful traits, including high reproduction rates or the ability to outcompete native species to a significant degree, it is not considered to be invasive (National Park Service 2023). Currently, three species of turtle found within Michigan are considered to be non-native including the Eastern River Cooter (*Pseudemys concinna concinna*), Yellow-bellied Slider (*Trachemys scripta scripta*), and False Map Turtle (*Graptemys pseudogeographica*). While some urban Red-eared Slider populations within Michigan may be linked to individuals released as pets, the species most likely historically occurred throughout portions of the state and is to be considered native (Terry 2015, Harding and Mifsud 2017).

Non-native species within Michigan such as the Eastern River Cooter and Yellow-bellied Slider

1-2. Native Red-eared Sliders and non-native Eastern River Cooter (1) and Yellow-bellied Slider (2) basking together on fallen trees.

are of little concern due to very few individuals present on the landscape and limited successful recruitment. The Red-eared Slider, while commonly classified as invasive in areas outside of its historical range, may provide analogous ecological functions similar to that of native species (Dupuis-Désormeaux et al. 2022). Non-native species also typically occur within heavily urbanized environments oftentimes already lacking native species due to human disturbance (Dupuis-Désormeaux et al. 2022). Michigan's non-native turtle species may fulfil similar ecological roles within human-influenced landscapes currently lacking native species. However, it is also still possible for non-native species to outcompete native species that are present and transmit infectious diseases (Dupuis-Désormeaux et al. 2022).

Disease

Disease has been implicated as a factor in the decline of amphibian and reptile populations worldwide (Blaustein et al. 1994, Berger et al. 1998, Daszak et al. 1999, Kiesecker et al. 2001). Many of the previously mentioned factors that threaten herpetofauna populations can work synergistically, increasing stress on the animals and lowering their immune response, thereby causing them to become more susceptible to infectious diseases (Fellers et al. 2001, Blaustein et al. 2003).

Disease can be spread by anthropogenic vectors such as the collection and export of frogs for human consumption and use (Mazzoni et al. 2003, Schloegel et al. 2009, Bai et al. 2010, Schloegel et al. 2012), the pet trade (Une et al. 2008), and use as bait (Garner et al. 2009). Many of these pathogens are highly virulent and transmissible between vertebrate classes (Farnsworth and Seigel 2012, McGuire et al. 2012). Examples of infectious diseases in reptiles and amphibians include viruses, bacteria, mycoplasmas, fungi, protozoans, and trematodes. These agents are associated with varying levels of mortality and population decline in herpetofauna (Wright and Whitaker 2001). The impacts from disease can be direct or indirect. Many species of reptiles (particularly snakes) feed on amphibians. If amphibian populations decline as a result of disease, the success of snakes and other predatory species will be reduced.

Jim Harding

3. "Red-leg" and other diseases can have significant impacts to amphibian populations.

Some of the causes and vectors of these diseases in herpetofauna are known. Limb deformities in amphibians have been linked to trematode worms (Johnson et al. 2002). The disease known as "red-legged disease" is caused by the bacteria *Aeromonas hydrophila* and is believed to be responsible for massive seasonal die-offs in Northern Leopard Frogs (Harding and Mifsud 2017). Chytridiomycosis has been cited as "the largest infectious disease threat to biodiversity"

1. Emerging diseases such as Snake Fungal Disease (as shown on this Eastern Garter Snake) and Ranavirus can have significant impacts to herpetofauna populations.

and is a disease of amphibians caused by *Batrachochytrium dendrobatidis* (Kilpatrick et al. 2009, Voyles et al. 2009). This pathogenic fungus, which causes symptoms such as abnormal posture, lethargy and gross lesions, has been implicated in significant population decline of amphibians (Carey et al. 1999). Currently, 520 species of amphibians have been diagnosed with infectious *B. dendrobatidis* (Aanensen 2013).

Ranavirus is an emerging and dangerous pathogen, which is a potential significant threat to Michigan herpetofauna. This Emerging Infectious Disease (EID) infects multiple cell types, leading to organ necrosis and hemorrhaging, often leading to death from the ranavirus itself or from secondary invaders (Miller et al. 2011). Infection and subsequent die-offs have occurred in other states in species also common to Michigan (e.g., Marbled Salamanders, Small-mouthed Salamanders, Eastern Tiger Salamanders, Eastern Newts, Blanchard's Cricket Frogs, Gray Treefrogs, Green Frogs, Northern Leopard Frogs, Eastern Box Turtles) (Bollinger et al. 1999, Docherty et al. 2003, Snyder 2007, McGuire et al. 2012, United States Geological Survey 2012, Davis et al. 2019), potentially facilitating the transmission of this disease to Michigan populations. Indeed, the presence of ranavirus was recently detected in Wood Frogs in Michigan (Sauer et al. 2019), though testing for this pathogen is limited in the state as the procedure is expensive and time consuming (Stephens and McCurdy 2008). More tests are needed to determine the prevalence of ranavirus within Michigan herpetofauna. Transmission can occur between individuals of the same species, different species, and even between reptiles and amphibians, making this pathogen particularly dangerous (Brenes et al. 2014). Since this disease is easily transferred and typically effects the entire herpetofauna population at an infected site, if strict preventative measures are not implemented it is likely Michigan herpetofauna will suffer this disease (Jancovich et al. 2010).

Snake Fungal Disease (**SFD**) is an EID known to cause mortality in snakes, however population level impacts are not well known due to the cryptic nature of many snake species and a lack of long-term data. This disease, caused by the *Ophidiomyces ophiodiicola* fungus, creates skin lesions that, in severe cases directly kill the host, or can lead to death indirectly through complications (Lorch et al. 2016, Hileman et al. 2018). Recently, a relatively high prevalence of SFD in Michigan populations of the Federally Threatened Eastern Massasauga Rattlesnake has been observed (Tetzlaff et al. 2015, Allender et al. 2016, Allender et al. 2018). Additionally, SFD was detected in an Eastern Milksnake (*Lampropeltis triangulum triangulum*) in Michigan (Ravesi et al. 2016). This disease has also been found in neighboring states and provinces in species also common to Michigan (e.g., Northern Ring-necked Snake [*Diadophis punctatus edwardsii*], Northern Water Snake, Eastern Fox Snake, Black Rat Snake, Western Fox Snake, Queen Snake, Northern Brown Snake [*Storeria dekayi dekayi*], Northern Red-bellied Snake [*Storeria occipitomaculata occipitomaculata*], Northern Ribbon Snake, and Eastern Garter Snake) (Lorch et al. 2016, Davy et al. 2021). As such, it is likely that this pathogen has already, or will in the near future, spread to Michigan populations of these species. The prevalence of SFD in the Midwest region is rapidly growing and this disease poses a significant threat to Michigan snake populations.

Turtle Shell Disease, also known as Pond Turtle Shell Disease, is a new EID caused by the fungus *Emydomyces testavorans* that afflicts chelonians with ulcerative skin and shell disease (Woodburn 2019, Adamovicz et al. 2020). This disease was only recently discovered and has primarily been observed in freshwater aquatic turtles within the western United States and Illinois (Woodburn 2019, Adamovicz et al. 2020, Lambert et al. 2021). This fungus often proliferates in captive environments which can lead to infections of wild populations when captive turtles are released as a part of headstarting programs (Woodburn 2019, Hazemi 2020). The detection of this disease in Illinois Blanding's Turtles poses a risk to Michigan's population of this species given the close proximity of the two states (DeVore 2022). In addition to Blanding's Turtles, Michigan turtle species that have been infected with *Emydomyces testavorans* in other states include the Eastern Spiny Softshell and Red-eared Slider (Woodburn et al. 2019, Adamovicz et al. 2020). The conservation concerns posed by this disease in the regions of its proliferation (Lambert et al. 2021) are likely to recur in Michigan unless strict preventative steps are taken.

Climate Change

Climate projections from multiple sources closely agree on temperatures and wind predictions for Michigan into the middle of the 21st century, but there is still great uncertainty in projected precipitation totals and intensity trends (Winkler et al. 2012). As a general comparison, by the end of this century, the climate of Michigan is predicted to resemble the current climate of central Missouri and northern Arkansas (Union of Concerned Scientists). The predictions of various proposed climate change models show potentially significant shifts in plant communities and wetland conditions in Michigan and the United States (Hellmann et al. 2010, Nelson et al. 2011) which would affect amphibian and reptile populations. EGLE has acknowledged that wetland communities will play an important role in counteracting the negative effects of climate change, making it critical to protect and restore these ecosystems (Christie and Bostwick 2012). Changes in habitat availability may affect amphibian survival, growth, reproduction, dispersal, and access to food (Blaustein et al. 2010). Due to variation in their capacity to adapt to sudden changes, some species may benefit from changes in the environment, while other groups may be negatively affected (Hoving et

1. Climate change will likely result in increasingly frequent draughts, storms, and other weather extremes, negatively impacting herpetofauna and other wildlife populations.

Chris Hoving

David Dortman

1. Roads present a barrier to amphibian and reptile species that will seek new ranges due to climate change. Creating and restoring habitat connectivity will be a key factor in the expansion of Michigan's herpetofauna distribution.

2. Thousands of Mudpuppies died along Lake Huron in the 2012 Superstorm Sandy. It is likely that as climate change progresses, large intense storms will become more frequent.

al. 2013). For example, amphibian eggs and larvae may desiccate or drown as a result of altered local climate patterns. Kiesecker et al. (2001) found that in extreme dry years, reduced pond depth increases exposure of amphibian embryos to UV radiation, which could lead to pathogen outbreaks and population declines. Climate change may also threaten the long-term viability of reptile and amphibian populations (Pounds et al. 1999, Kiesecker et al. 2001) as it may alter their development, spatial distribution, abundance, and species interactions (Pounds et al. 1999, Walther et al. 2002). Amphibians have been observed to call and breed earlier in years with warmer temperatures (Walther et al. 2002, Mifsud personal observation 2022). In the case of reptiles, shifting climates may affect nesting success and timing. Insufficient time for incubation prior to cold weather can result in reduced productivity of reptile nests (Sommer et al. 2009). Also, species for which the sex of individuals is determined by the temperature of incubation (e.g., Eastern Snapping Turtle) could experience skewed sex ratios (Janzen 1994, Ewert et al. 2004). However, analysis of long-term data reveals various responses among species (Blaustein et al. 2001).

Climate change is expected to amplify current threats to wildlife populations and the communities that support them. As environmental conditions change, previously occupied habitats will become unsuitable. The potential for dispersal is limited in areas with significant habitat fragmentation, thus making populations vulnerable to extirpation. Herpetofauna and the community types they inhabit will be more sensitive to change in precipitation and hydroperiods in ranges where hydrologic processes have been altered by the addition of impermeable surfaces, stream channelization, and water level manipulations (Hall 2012, Angel et al. 2018). Impacts to amphibians caused by chemical pollution may increase in altered climates due to increased contaminate exposure time and mobility (Rohr and Palmer 2009). Climatic regimes often determine species ranges and warming trends will likely result in northern range shifts for both floral and faunal communities. These climate-linked expansions will result in the establishment of new species, which may benefit some taxa whose range will expand and increase northward. New species may also include invasives that have the potential to dramatically change existing community dynamics by increasing resource competition, and introducing new diseases (Walther et al. 2002). Climate-driven species expansion will also be significantly limited and resultantly dangerous for a variety of taxa, especially herpetofauna, due to habitat fragmentation and bisection by roads (Coombs 2016).

1. Documenting amphibian and reptile communities within wetlands and other natural areas provides a foundation for their management and conservation.

Insufficient Assessment

Despite numerous threats to herpetofauna and the identified need for conservation, insufficient resources have been allocated to conduct species, population, and herpetofauna habitat status assessments. The unique natural history and biological characteristics of amphibians and reptiles make these animals vulnerable to habitat disturbances, degradation in water quality, alterations to hydrologic processes, climate change, and to the introduction of invasive species. The impacts of identified and potential threats are difficult to disentangle and many of these threats act synergistically such that components of the observed effect can be difficult to attribute to specific factors. Understanding the true effects of anthropogenic forces is further confounded by the natural ebb and flow of population and community dynamics, which is often not well understood. The need for greater data collection and conservation efforts focused on herpetofauna in Michigan is well documented and the State of Michigan, other non-governmental organizations, and individual citizens are making strides to align with these needs (PARC 2011, Derosier et al. 2015, Michigan Herp Atlas 2022). Additionally, there is a great need to assess the implementation of conservation and restoration techniques in a variety of natural communities and settings in Michigan. By evaluating the implementation and success of these techniques, future implementation can better enhance amphibian and reptile populations.

2-4. Various sampling techniques (dip net surveys, funnel traps, and artificial cover objects as illustrated here) and other methods are critical in assessing habitat and restoration success.

4. Conservation Efforts

Over the past several decades, even some of the most common species have become rare in many parts of Michigan. Conservation and protection must strive to **keep common species common** and to recover State and Federally Threatened and Endangered species and protect their habitats. Although traditional management and development activities have contributed to the decline of amphibians and reptiles, opportunities exist to mitigate impacts from these activities. Protection and restoration of landscape-level processes as well as of individual terrestrial and aquatic communities can have profound effects on the conservation of amphibians and reptiles. These opportunities to conserve and protect herpetofauna can only be realized if effective, science-based mitigation and management tools are available to developers, land managers, local governments, and the public.

1-2. Though locally common, Blue-spotted Salamanders and Black Rat Snakes are listed as Species of Greatest Conservation Need. The Black Rat Snake is also a species of Special Concern. Habitat loss and fragmentation can greatly alter these populations.

Pre-construction planning that considers wildlife can maximize benefits for wildlife and expedite the permitting process and project completion. Post-construction management for herpetofauna can consist of simple changes in routine maintenance (e.g., mowing less frequently) that can even save money while benefiting herpetofauna. Other small changes to an existing developed site, such as removing curbs, can have minimal financial cost and tremendous gain for herpetofauna. Restoration of degraded aquatic and terrestrial habitat and protection of landscape-level processes can facilitate all species requirements (e.g. nesting, hibernation) for herpetofauna.

Chris Hoving

1-3. The Small-mouthed Salamander (1), Marbled Salamander (2), and Kirtland's Snake (3) are State Endangered species.

Using the techniques described in this BMP manual, all landscapes, from rural to highly-modified urban areas can provide important herpetofauna habitat.

The general goals of the restoration, management, and development practices are to:

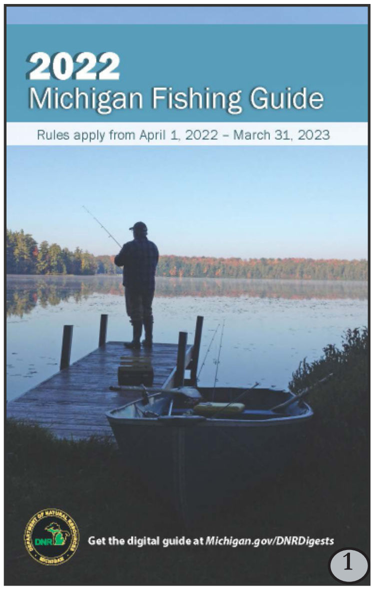
- Maintain and enhance healthy environments that support a diverse assemblage of amphibians and reptiles
- Protect and create sufficient habitat and area essential for project activities
- Maintain and improve habitat quality and connectivity
- Maintain natural processes and develop methods for improvement and restoration

Existing Conservation Guidelines

The original Michigan Amphibian and Reptile BMP manual currently serves as an effective all-encompassing document regarding the conservation of amphibian and reptile species in Michigan. The manual provides important information regarding the challenges Michigan's herpetofauna communities' face and extensive guidelines to be implemented for a wide variety of restoration, management, and development projects to promote their conservation.

The MDNR created the Michigan's Wildlife Action Plan to provide a comprehensive framework and information source to coordinate statewide wildlife management and conservation efforts (Clark-Eagle et al. 2005, Derosier et al. 2015). Wildlife Action Plans cite the need to prioritize conservation actions for wildlife with "low or declining populations." These documents support the urgency to conserve Michigan herpetofauna as they identify approximately 60% of Michigan's species as Threatened, Endangered, Special Concern, or as Species of Greatest Conservation Need.

Several publications provide recommendations for how Michigan can adapt quickly to potential climate change scenarios while maintaining the integrity of our natural resources base. The Climate Change Adaptation Plan for Coastal and Inland Wetlands in the State of Michigan (Christie and Bostwick 2012) is a whitepaper that was developed for the former MDEQ now EGLE. This document includes recommendations for strategic planning; monitoring and assessment; voluntary restoration, conservation, and management; revisions to current regulations; and integration with other water programs for watershed management. The report, "Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II", prepared by the U.S. Global Change Research Program, aims to help inform decision-makers, public health officials, emergency planners, and other stakeholders by providing a thorough examination of the effects of climate change on the United States (Angel et al. 2018). "Changing Climate, Changing Wildlife: A Vulnerability Assessment of 400 Species of Greatest Conservation Need and Game Species in Michigan" (Hoving et al. 2013) was developed by the MDNR Wildlife Division and assesses the potential degree of vulnerability that Michigan wildlife faces due to climate change. The recommendations in these publications include wildlife, habitat, and environmental goals and recommendations that can help to enhance and increase the long-term viability of Michigan's herpetofauna populations.



1. Refer to the yearly Michigan Fishing Guide for current limits and regulations regarding the take of amphibians and reptiles.

Partners in Amphibian and Reptile Conservation (PARC) created a handbook entitled "Habitat Management Guidelines for Amphibians and Reptiles of the Midwestern United States" (Kingsbury and Gibson 2012). This publication has a broad audience of landowners, state and federal agencies, and other stakeholders from across the nation and provides information and recommendations about land management to benefit United States herpetofauna.

State, Federal, and International Regulations

Several laws and regulations offer protection to the environment, herpetofauna, and other wildlife in Michigan, the United States, and the world. The MDNR regulates impacts on amphibians and reptiles and their habitats through two regulations: the MDNR Fisheries Division Order (224.16) and Part 365, Endangered Species Protection, of the Natural Resources and Environmental Protection Act.

The MDNR Fisheries Division Order (224.16) sets limits and regulations regarding take methods, acceptable species, seasons, minimum size, daily possession limit, and total possession limit for all herpetofauna within Michigan (Michigan Department of Natural Resources 2016). All State Special Concern, Threatened, and Endangered herpetofauna species are protected from take in accordance with MDNR fisheries Division Order (224.16). An all-species fishing license is required to take non-protected amphibians and reptiles, and take must abide by the limitations outlined by the MDNR in the latest Michigan Fishing Guide (Michigan Department of Natural Resources 2022). Sale, including commercial trade, of amphibians and reptiles is not permitted. Eastern Snapping Turtles could be commercially harvested in Michigan until 2008 when commercial harvest was ended. Cultural or Scientific Collector's Permits can be applied for through the MDNR Fisheries Division to allow for collection of amphibians and reptiles not covered under a State of Michigan Fishing License.

2. The Bullfrog is a commonly harvested herpetofauna species. Maintaining stable amphibian and reptile populations is critical for continued recreation opportunities.

Part 365, Endangered Species Protection, of The Natural Resources and Environmental Protection Act (NREPA Public Act 451 of 1994 as amended), administered by the MDNR Wildlife Division, provides for the conservation and protection of State Threatened and Endangered species (Michigan Department of Natural Resources 1994). This law prohibits the collection or take of Threatened and Endangered species, including Spotted Turtles, Eastern Box Turtles, Wood Turtles, Eastern Fox Snakes, Eastern Massasauga Rattlesnakes, Copper-bellied Water Snakes, Kirtland's Snakes, Six-lined Racerunners, Blanchard's Cricket Frogs, Small-mouthed Salamanders, Marbled Salamanders, and Western Lesser Sirens. Threatened and Endangered Species monitoring permits are required whenever listed species might be harmed, handled, or disturbed, even if conservation activity is likely to benefit those species long-term and can be applied for through the MDNR Wildlife Division. Most Special Concern species in Michigan are not afforded protection under this legislation; however, Special Concern amphibians and reptiles are protected from take in accordance with MDNR Fisheries Division Order (224.16).

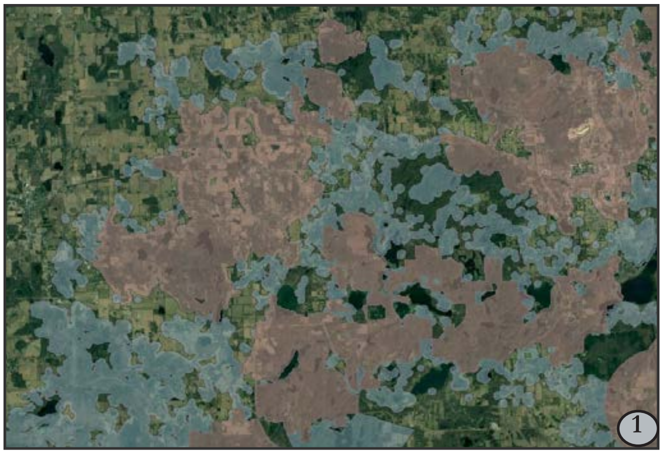
1. It is illegal to kill or harm Eastern Fox Snakes or any other Threatened, Endagered, or Special Concern species.

2-3. Both the Eastern Massasauga Rattlesnake (1) and the Copper-bellied Watersnake (2) are Federally protected species. Observations of these species should be reported to the Michigan Herp Atlas.

Jim Harding

The ESA, administered by the United States Fish and Wildlife Serve (USFWS) and the National Marine Fisheries Service (NMFS), protects all Federally Threatened and Endangered species by prohibiting take including harassing, harming, hunting, shooting, wounding, killing, trapping, capturing, or collecting individuals (U.S. Fish and Wildlife Service and National Marine Fisheries Service 1973). The ESA also provides protection for any Critical Habitats of listed species on public and private lands (U.S. Fish and Wildlife Service and National Marine Fisheries Service 1973). Critical Habitat is defined by the USFWS as specific areas within the species' range, occupied by the species at the time it was listed, that contain the physical or biological features that are essential to the conservation of the species and that may warrant special management or protection (U.S. Fish & Wildlife Service 2017). There is currently no Critical Habitat designated for the two species of federally protected Michigan herpetofauna: the Eastern Massasauga Rattlesnake and Copper-bellied Watersnake. While there is no defined Critical Habitat for either species, the USFWS Information for Planning and Conservation (IPaC) developed

Tier 1 and Tier 2 habitat areas for use as screening tools for the Eastern Massasauga Rattlesnake in Michigan (U.S. Fish and Wildlife Service 2017). Tier 1 habitat is defined as habitat that is known to support the species; Tier 2 habitat is defined as areas that have landscape features known to be present in habitats suitable for the species.



1. USFWS Eastern Massasauga Tier 1 and Tier 2 habitat screening tools help to inform project managers if the species' habitat is potentially present on-site.

The ESA also mandates that a recovery plan for each Endangered and Threatened species be created and that post-recovery monitoring be conducted for de-listed species. Although it is illegal to destroy these protected species and their habitats according to the ESA, enforcement can be difficult since many individuals and habitats occur on private lands. Also, the ESA remains a contentious piece of legislation concerning the quality of protection for listed species, the economic repercussions of these actions, and government involvement in natural resource management (Brown and Shogren 1998). Although the ESA is a good starting point for conservation, several amphibian and reptile species not listed under the ESA are vulnerable to habitat loss and degradation, illegal collection, and persecution (See Section 3).

International regulations regarding herpetofauna include the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), an international agreement between governments to protect endangered species by trade restrictions. The CITES agreement does not provide in-country habitat or management regulations and restrictions (CITES 2022). Eastern Box Turtles, Blanding's Turtles, and Spotted Turtles, actively exploited for the international pet trade, are currently listed in CITES Appendix II, meaning that there are population level concerns for these species, but that regulated commercial trade is still allowed with proper permitting.

2. Spotted Turtles are listed as State Threatened and regulated in commercial trade by CITES. It is illegal to collect this species without appropriate permits.

Although these regulations provide a good regulatory framework for conservation, several amphibian and reptile species continue to be threatened by habitat loss and degradation, illegal collection, and persecution (See Section 3).

See Appendix A for more information regarding current State and Federal status designations for each species of Michigan herpetofauna.

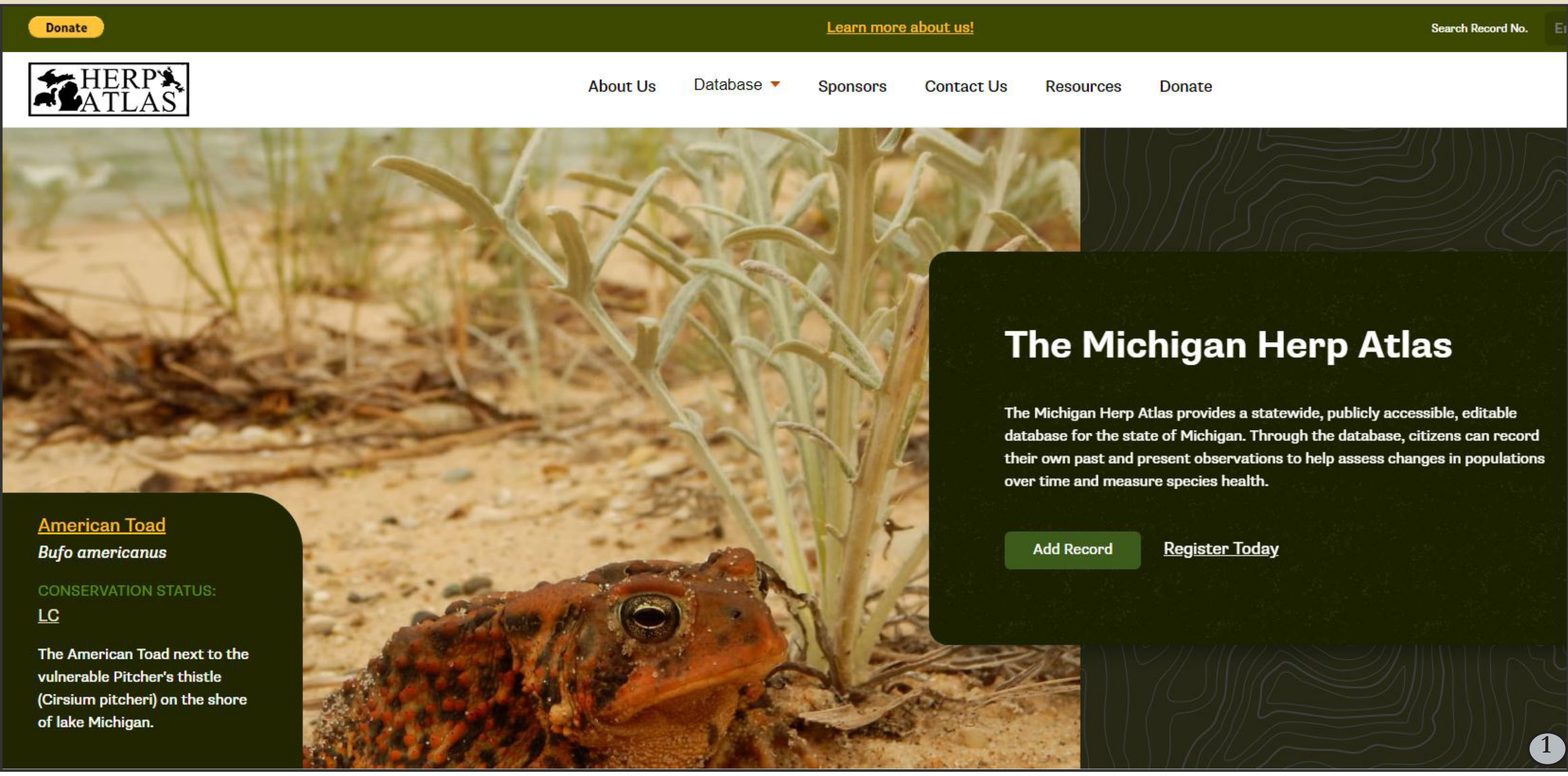
1. Herpetofauna-focused surveys often utilize visual encounter, meander transects to document amphibian and reptile presence in addition to other methodologies.

Herp HAT: the Herpetofauna Habitat Assessment Tool for Michigan

The need for the development of indicators of ecosystem health for the Great Lakes region was recognized at the State-of-the-Lakes Ecosystem Conference in 1998. Following this recognition, ecosystem health monitoring protocols have been developed to evaluate wetland integrity, including bioassessments of fish, crayfish, anurans, plants, macrophytes, macroinvertebrates, zooplankton, and birds. EGLE also created the Michigan Rapid Assessment Method for Wetlands (MiRAM) to quantify wetland integrity by surveyors with significant knowledge of wetland plant, fish, and wildlife species and their ecological wetland roles. However, no methods have yet been developed that incorporate reptiles or non-vernal pool associated amphibians. As recognized indicators of environmental health, herpetofauna are ideal candidates for incorporation into a wetland functional assessment tool. Incorporating a system that considers reptile and amphibian communities provides a stronger holistic approach to quantifying wetland value and function.

The Herpetology Habitat Assessment Tool (Herp HAT) incorporates species-specific Coefficient of Conservativism Scores (C-Scores) developed by Michigan herpetologists with expertise in their field and species, observational herpetofauna data, and MiRAM Scores to create an overall Wetland Score. C-Scores for species are calculated based on a list of metrics that attempts to consider all associations that might be correlated with wetland functional value including: (1) Current State Regulatory Status; (2) Rarity; (3) Fragmentation Tolerance; (4) Generalist or Specialist; (5) Life History Traits; (6) Probability of Detection; (7) Required Hydroperiod; and finally, (8) Need for Fishless Wetlands. The Herp HAT Score represents the conservation value of a wetland to herpetofauna, and when combined with the MiRAM Score, it creates a well-rounded Wetland Score that considers several bioindicators in assessing wetland health.

Herp HAT is a valuable resource for regulators, natural resource practitioners, private sector biological and natural resource organizations, and environmental stewards on projects that encompass Michigan wetlands. Herp HAT allows users to determine the functional value of wetlands for herpetofauna in an accurate, rapid manner.



The Michigan Herp Atlas

The Michigan Herp Atlas is a comprehensive, inclusive, publicly accessible database of herpetofauna observations within the state of Michigan with nearly 350,000 records to date. This valuable resource provides evidence of changes in species distributions and population health over time, and can be used to demonstrate declines in herpetofauna populations and potential recovery resulting from conservation efforts. The comprehensive data collected through the Michigan Herp Atlas allows for future evaluation of Michigan's herpetofauna status to be made based on science. The Herp Atlas is the primary source for the most comprehensive and up-to-date accounts for Michigan herpetofauna.

The Michigan Herp Atlas presents an opportunity for everyone to contribute to conservation of amphibians and reptiles. Observations of a frog at a construction site, a dead snake on the road, a turtle at a restoration site, and all other herpetofauna observations are valuable and should be submitted to the Michigan Herp Atlas.

Please visit and contribute to the Michigan Herp Atlas at:

www.MiHerpAtlas.org.

1-2. Everyone can submit observations of amphibians and reptiles to the Michigan Herp Atlas.

5. Project Planning

1-3. Before beginning any project, it is important to determine what amphibian or reptile species may be present and plan to avoid any negative impacts.

This section provides information for land managers, planners, designers, and contractors about how the initial planning phases of a project can help protect amphibians, reptiles and other wildlife throughout the entire life-cycle of a project. Whether actively managing natural resources or developing a new construction, your decisions and actions have an effect on amphibians, reptiles, and other wildlife. Amphibians and reptiles are sensitive to disturbance, pollution, and land degradation. Everyone involved in land use decisions can help minimize these threats and help conserve sensitive herpetofauna as well as natural communities. See Appendix B for a recommended project action timeline to minimize impacts to herpetofauna.

Obtain the Appropriate Permits

Before any construction or other activities can begin on a site, permits from government agencies may be required. Permits are issued by a number of different agencies and may be needed regardless of whether the land is owned by an individual, business, or government agency. Information to determine what permits may be necessary to continue a project can be found by reviewing the USFWS, EGLE and MDNR websites. Ensure to apply for permitting well in advance of the proposed work to account for delays in the permitting process.

Evaluating the Site

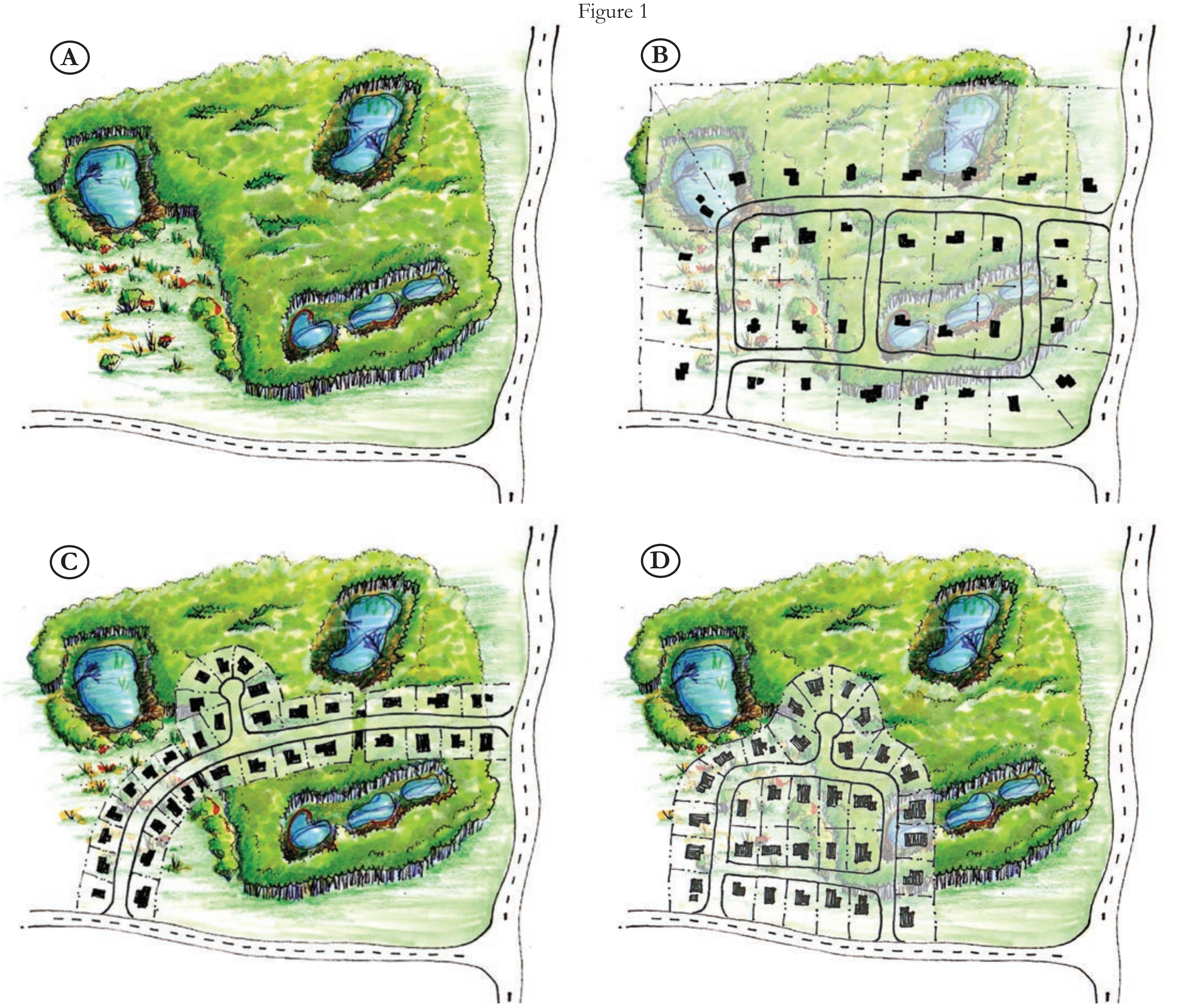
Although habitat destruction, degradation, and fragmentation are the main reasons for decline of amphibians and reptiles (Dodd et al. 2003, Marchand and Litvaitis 2004, Weyrauch and Grubb 2004), land use planning and pre-construction planning can help mitigate these problems (Calhoun et al. 2005). As part of this process, a professional wildlife biologist with demonstrated experience and expertise in working with amphibians and reptiles should be consulted to minimize negative impacts to wildlife communities.

Figure 1. Thoughtful and creative design approaches can significantly minimize impacts while still meeting project objectives. Homes adjacent to natural areas also have higher values. Pre-development (A). Typical development (B). Fragmented site (C). Loss of some high quality wetland to maintain greater connectivity (D).

Identify natural resources - Natural community type and wildlife communities potentially present should be identified. During this process, amphibian and reptile habitat and potential annual movement corridors should be identified. Even if a specific species is not observed on site, the species may be present. Several Michigan species are cryptic and it is highly unlikely that all species present will be detected during surveys. Site visits, when possible should be timed to coincide with optimal observation windows based on the species natural histories.

Assess habitat connectivity - All areas of wildlife habitat cannot be preserved, thus the importance of preservation of habitat areas should be ranked according to ecological value. Quality of habitat and connectivity should be considered when assessing ecological value, as an isolated area of high-quality habitat may not be able to support wide-ranging animals that require large contiguous areas for food, seasonal migrations, and reproduction. When

Figure 1



1. Even the Red-backed Salamander, a terrestrial species, relies on moisture in the environment under logs and in the duff layer on the forest floor.

2. Buffer zones minimize the impact of human disturbances on herpetofauna, like Four-toed Salamander populations.

3. Floodplains and wetlands alleviate threats of flooding and provide critical amphibian and reptile habitat.

such areas are preserved as part of development and management, they can degrade and become low-quality habitat often supporting invasive species. Conversely, areas of lower quality habitat that connect areas of high-quality habitat may be critical to facilitate species movements necessary for breeding and long-term population viability – the ability for a population to persist and avoid extinction. Habitat assessments should include a review of any threats facing the site including those that may occur as a result of the project. These threats should be addressed and mitigated when possible.

The presence of rare and protected species, breeding species, and the ability of the area to support reproduction should be considered when evaluating ecological value of a site (Calhoun et al. 2005). The presence of a variety of wetlands and uplands also has great ecological value. The presence of high-quality upland areas adjacent to wetlands is an important habitat component for several amphibians and reptiles. Some snakes and turtles migrate seasonally between wetlands and uplands (e.g., Eastern Massasauga Rattlesnake, Copper-bellied Water Snake, Blanding's Turtle). Several salamander and frog species require vernal pools for breeding and larval phases and the associated uplands for foraging during adult life stages. However, it is important to keep in mind that just because a site may be degraded or not as natural as desired, it may still provide important ecological function and value as well as support a rich diversity of herpetofauna.

Prioritize areas to protect - Overlaying maps of various features (e.g., land cover, topography, species distribution or home ranges) can reveal areas that are critical to ecological function, such as vernal pools and the adjacent uplands, which development plans should avoid. Construction, linkages (e.g., utilities and roads), and associated impacts should be planned to avoid or minimize impact to these areas. Also, corridors and areas that provide connectivity should be identified for protection to minimize barriers to movement. Use of Geographic Information Systems (GIS), or a spatial data analysis and mapping software, by a wildlife or environmental professional may be helpful in this process.

Several maps and GIS layers are available through various government and nonprofit organizations. The USDA NRCS Geospatial Data Gateway is a large, online database of spatial environmental and natural resource data provided through a partnership between the three Service Center Agencies (SCA); NRCS, Farm Service Agency (FSA), and Rural Development (RD). The USFWS IPaC website

1. Wetland restoration is complex, and contacting a wetland restoration specialist is recommended.

provides Tier 1 and Tier 2 habitat areas for use as screening tools to determine if a project occurs within habitat that is protected for the Eastern Massasauga Rattlesnake. Ducks Unlimited provides the Conservation and Recreation Lands (CARL) database online, which maps and describes public and private lands involved in conservation or which are protected. These maps were created to aid in the development of landscape and long-term planning perspectives for conservation activities. United States Geological Survey (USGS) supports Earth Explorer, an online database that allows the user to query and order or download satellite images, aerial photographs, and cartographic products. The State of Michigan provides public access to several online GIS databases (e.g., potential wetland restoration areas, land cover, aerial photographs, hydrologic and hydrographic mapping) through the Geographic Data Library catalogs. All of this information can be used to develop models of where the optimal habitat for any given species is distributed. If field visits confirm the reliability of the model it can then be used to prioritize protection and restoration efforts (Gara and Micacchion 2010).

Plan to Maintain Ecologically Functional Landscapes

Land planning focused on maintaining the ecological function of a site can help to direct the smaller scale, site-design components and management activities. Ecosystem function defined as the interaction between organisms and the physical environment (e.g., nutrient cycling) is an important component to consider when restoring a site. Maintaining ecological function of a landscape can also benefit the conservation of amphibians and reptiles. Large-scale decisions and general guidelines regarding management activities, earth moving, siting developments, and construction materials can affect habitat quality and connectivity, hydrologic processes, and wildlife conservation.

Weigh potential costs and benefits of various restoration, management, and development scenarios and develop a long-term adaptive management plan - By considering the social, economic, and environmental consequences and the role of all stakeholders, long-term, sustainable solutions can be achieved. Habitat quality, overall area, level of landscape connectivity, and other relevant factors should be considered when weighing environmental outcomes. It is important to consider preserving areas that help to maintain contiguous habitat areas and maximize site connectivity and landscape connectivity. Careful consideration of the overall functions and values and the cost- benefit analysis is necessary, especially on larger projects.

Maintain natural drainage systems, hydrologic processes, and water quality - For most species of Michigan herpetofauna, the presence of high-quality water is imperative for survival.

1. In some cases, the highest quality wetland is not the most important site to save if it results in physical isolation and loss of a large continuous habitat. Consider context when evaluating habitat impacts.

Amphibians are especially affected because their permeable skin requires moisture. Hydraulic connectivity can greatly influence herpetofauna population stability. Even the hydrologic connections through ditch systems can increase genetic diversity within amphibian communities (Reh and Seitz 1990), although creation of narrow corridors is not recommended as a conservation strategy, due to potential increased predation pressure (Mazanti 2003). However, this is a situation where working with the landowner to protect areas adjacent to the waterway through the Conservation Resource Program (CRP) may be a viable avenue.

Avoid wetland alterations/Maintain functional wetlands - Filling or draining wetlands displaces amphibians and reptiles and destroys their habitat. Displaced animals are less likely to find new home ranges and they experience increased predation pressure, risk of exposure, and possibly desiccation. Suitable habitat may not be nearby or if suitable habitat is available, other individuals may already have filled the same niche. The structure, hydroperiod, vegetative cover, microtopography, slope, and adjacent upland buffer areas of high-quality wetlands contribute to maintaining high-quality amphibian and reptile habitat and ecological function and should all be maintained (Semlitsch and Bodie 2003, Rittenhouse and Semlitsch 2007). Development and disturbances in wetlands, wetland critical zones and buffers, and habitats hydrologically and ecologically connected to wetlands should be avoided whenever possible.

2. Protecting hydrologic connections between landscapes is critical for ecosystem health and maintaining viable herpetofauna populations.

Maintain watercourse function – Streams and rivers naturally move on the landscape and development and management activities should account for this natural process. Constructed features such as bridges, buildings, and roads should be located in areas where they will not restrict the flow of a waterway as it naturally changes its meander. Fluctuations in streambed topography, structure, stream flow dynamics, bank slope, and floodplain areas should be considered in determining where development can be placed. Planning for these natural processes can help avoid costly damage to constructed features and avoid degradation of wildlife habitat in riverine areas.

Conservation Resource Alliance

Avoid essential habitat – Essential habitat includes areas such as vernal pools, wetlands, adjacent uplands, potential hibernacula, and identified breeding areas. Construction and management activities should be planned to preserve essential habitat for species potentially present on site and avoid possibly killing large numbers of amphibians and reptiles with earth-moving equipment and machinery. Heavy equipment may also entomb salamanders in burrows and compact loose soils, negatively impacting diverse vegetation growth and invertebrate communities, which serve as a critical food source for herpetofauna. For development projects such as natural gas pipelines or transmission lines, consider utilizing horizontal directional drilling (HDD) or boring installation when possible to avoid direct impacts to essential habitat areas.

1. Fragmenting large contiguous habitat with roads, as shown, here can not only impact hydrology but also increase mortality of migrating wildlife.

Reduce habitat fragmentation - Creating wildlife habitat corridors and buffers around essential habitat areas and reducing the number of roads, fences, or other barriers can help to increase and/or maintain genetic diversity and a more robust population of animals. Clearly defining the extent of disturbance around a building can preserve natural areas that are used by amphibians, reptiles, and other wildlife. By only disturbing the natural areas directly around a building within the areas actively used by people (e.g., the space between a house and garage and a small outdoor picnic area) the native flora and fauna and landscape connectivity for wildlife can be preserved (Thompson and Sorvig 2007). Preserving a greater proportion of natural areas also allows people to interact more closely with the ecosystem in which they live and become better stewards of their resources.

Maintain landscape mosaic - A diversity of natural communities including wetlands and associated uplands helps to sustain a diversity of species including those which rely on linkages between uplands and wetlands, such as Wood Frogs, Blue-spotted Salamanders, Spotted Salamanders, and Marbled Salamanders. Maintenance of a contiguous landscape mosaic allows for several subpopulations to exchange individuals, which enhances genetic diversity and sustains the metapopulation in the event of the extinction of one subpopulation.

Cluster development and disturbances - Where possible, focusing work in areas far from wetlands and high-quality herpetofauna habitat minimizes habitat fragmentation. Clustering development and disturbances in lower quality habitat areas, which do not impact landscape connectivity can preserve ecological function and healthy herpetofauna communities, as well as other wildlife (Milder 2006, Baldwin et al. 2007, Milder 2007). These types of development conserve open space, reduce impervious surfaces, minimize habitat fragmentation by roads, reduce road mortality of amphibians and reptiles, and decrease road-related pollution.

Clustering development is also economical. Some communities give incentives for clustering and allow for smaller lot sizes or greater unit density in certain areas that avoid impacting habitat (Bengston et al. 2004). Fewer roads and reduced infrastructure typically reduce the initial construction costs, increase the selling price, and reduce overall long-term maintenance (Arendt 1996, City of Novi 2021). Preserved green space is considered an asset by many potential property owners who are willing to pay a higher price for this valuable amenity. This development strategy also reduces cleared areas which are susceptible to the establishment of invasive plants, and it reduces the movement of herpetofauna predators (e.g., raccoons) into forested areas.

Reduce impervious surface - Large-scale implementation of pervious surfaces or reductions in impervious surfaces can reduce surface flow and increase infiltration. Increases in water quality (on which several amphibians and reptiles rely) can result from increased infiltration. Techniques to reduce runoff and increase infiltration include use of porous paving, green roofs, vegetated swales, and rain gardens. Retaining and planting large street trees and other vegetation, reducing the width of residential streets, and clustering developments can also reduce the proportion of impervious surface covering the landscape.

Provide appropriate habitat structure - Each herpetofauna species has specific requirements for vegetation types, water sources, nesting sites, overwintering sites (hibernacula), basking sites, and feeding grounds/food sources that compose suitable habitat. In some cases this can include human made or modified structures. Planning to provide for species' needs at all life stages for restoration can significantly influence community health and diversity.

Engage the public and site users - Conservation success relies on public support and compliance by the people who use a site. The greatest tool we have is the group of educated constituents who are positively engaged in the conservation and preservation of amphibians and reptiles. Consider implementing signage at restoration sites to inform and engage patrons on the sites' importance to wildlife and the environment.

Plant native and diverse vegetation communities - Select native flora seed mixes appropriate for the habitat community type to provide forage, shelter, and habitat for herpetofauna in addition to insects and other wildlife.

Control subsidized predators and invasive species - Maintaining the balance of native predators and prey in an ecosystem helps to conserve amphibians, reptiles, and other native wildlife. Much of Michigan has been altered and the current landscape represents a new shift in community composition. Though eradication of invasive species can be a target, healthy communities should be the overall goal.

Plan for post-implementation monitoring - Monitoring amphibian and reptile richness and distribution post-construction or after a site has been restored is useful in determining the success of a project as a metric. Monitoring efforts may target the following:

- Target species, such as sensitive species or those that require specific habitat types, as indicators.
- The presence of plants or objects that provide the necessary structure and services to meet the species' needs.
- Species distribution and presence of multiple life stages indicating the successful recruitment of new individuals into the population.

1. On-site materials can be repurposed to provide ecological function and habitat for herpetofauna, such as this hibernaculum constructed from concrete rubble.

2. Signage can help to engage patrons regarding the site's importance to wildlife and the environment.

1. Post-implementation monitoring is an effective way to gauge the success of restoration and help to better inform future management actions.

Implement Herp-Friendly Work

Construction activities can have long-term impacts on wildlife communities and habitat and should be planned to minimize impacts to herpetofauna and other wildlife.

Avoid indirect habitat alterations - Indirect alterations include activities such as removal of shade trees, which can affect the microclimate and change habitat suitability for herpetofauna, changes in topography that alters runoff inflows into a wetland, or the alteration of ground flow by creating ponds in uplands adjacent to spring fed wetlands.

Conduct work when risk to wildlife is less - By evaluating which species are present at and near a work site and their annual movements and habitat needs, specific construction tasks can be timed to reduce impacts to these animals. Construction should be timed to avoid active seasons, migrations, and management activities such as herbicide application should be timed to avoid sensitive larval stages of amphibians in nearby wetlands. See Appendix B for more information regarding generalized project timing recommendations.

Engage work crews - Work crews should be alerted to the potential presence of listed and non-listed wildlife species on site that are to be the target of conservation efforts. Workers should be trained to identify these species and should be informed of protocol to follow upon observing one of these animals, including who to contact, their contact information, the place and time of a sighting, and whether or not positive identification was possible (to the best of worker abilities). When State or Federally Threatened or Endangered species are sighted, workers must stop all activities that could endanger the animal until it has cleared the area and is out of danger.

2. Engaging those involved with the project on a day-to-day, boots-on-the-ground perspective can have a tremendous impact on the conservation of wildlife.

Rescue and relocate wildlife - If the proposed project activities are deemed to directly impact herpetofauna populations within essential habitat areas, professional wildlife biologists with demonstrated experience and expertise working with herpetofauna should be present on-site to conduct relocation or translocation efforts. Relocation and translocation often referred to as 'wildlife clearance' or 'site walk-downs', is the act of rescuing or removing wildlife from the area of impact before and/or during project activities and relocating the individuals to nearby suitable habitat outside of the project area.

Prevent wildlife from entering the workspace - Soil erosion control silt fencing or dedicated wildlife barrier fencing (WBF), when properly utilized, can be an effective proactive measure for protecting herpetofauna and other wildlife through reducing the risk for species to be physically injured or killed by excluding animals from active impact areas.

Avoid creation of wildlife traps - Synthetic soil erosion control mesh should never be used as it can fatally entangle herpetofauna and other wildlife. Photodegradable varieties do not degrade when shaded by newly sprouted vegetation and must also be avoided. Several wildlife-friendly, natural products are available and should be used as the standard soil erosion control product.

1. Synthetic soil erosion mesh can entangle amphibians and reptiles, such as this Northern Water Snake, leaving them exposed to the elements and predators.

Perc test holes, uncapped vertical pipes, drain pipes, stand-pipes, head gates, and other open holes also act as pitfall traps that collect herpetofauna and other small animals. Because these animals cannot climb vertical walls, they often perish within these unintentional traps. Pipes should be removed, capped, or covered with screen and holes should be filled in to grade after use. Other traps include the creation of areas that are attractive to herpetofauna but do not provide the resources for these animals to thrive (e.g., a small pool of water in the spring that will dry before eggs can hatch or larvae metamorphose).

Soil erosion control fences, when not removed after final site cleanup can be unintended barriers for herpetofauna, sometimes trapping them on a construction site. These barriers should be removed after the site has been vegetated and equipment or vehicle use within the workspace has commenced to reduce mortality. Owners and owner representatives may choose to hold bond until these and other potentially hazardous soil erosion control measures have been removed.

2. Wildlife barrier fencing is an effective tool for minimizing construction-related mortality of amphibians and reptiles when paired with focused rescue and relocation efforts.

Herpetofauna-Safe Construction Along a Linear Corridor

From 2017 to 2020, Consumers Energy, Inc. replaced an aging natural gas pipeline, the Saginaw Trail pipeline, to ensure the proper delivery of natural gas and overall safety of the system. The pipeline corridor consisted of approximately 95 miles and extended through Saginaw, Genesee, and Oakland counties, Michigan. Pre-construction inventory surveys documented multiple areas within the pipeline corridor that possessed potential suitable habitat for a number of rare herpetofauna species, including the Federally Threatened Eastern Massasauga Rattlesnake. Working with Consumers Energy, USFWS, and EGLE, HRM developed Best Management Practice recommendations for the Saginaw Trail pipeline. The emphasis of the BMPs were placed on the Eastern Massasauga Rattlesnake and avoidance of take or harm to this species during construction. BMPs included the use of HDD installation within sensitive habitats, wildlife barrier fencing, rare species signage, environmental training, and focused rescue and relocation of herpetofauna and other wildlife.

Several collection methods were used to aid in the rescue and relocation efforts to optimize efficiency and success including artificial cover objects (1), dip nets, and aquatic turtle traps (2). Over 29,000 amphibians and reptiles, comprised of 29 species, were rescued and relocated by HRM biologists including the State Special Concern Blanding's Turtle (3), Butler's Garter Snake, and Eastern Fox Snake. In addition, HRM successfully incubated, and released 51 Blanding's Turtle hatchlings (4), 183 Eastern Snapping Turtle hatchlings, 11 Midland Painted Turtle hatchlings, and 9 Blue Racer hatchlings (5) from nests located within the construction workspace. These individuals were released back into suitable habitat within previously restored areas of the pipeline corridor.

The conservation measures implemented by Consumers Energy directly minimized the potential risk to herpetofauna. As a result of the innovative and detailed BMPs, the project was successful in the avoidance of harm to EMR and other protected species of herpetofauna. Throughout the four years of effort, a community mindset geared towards natural resource protection was created and fostered (6). Methods and BMPs developed as part of Saginaw Trail pipeline will serve as a template for future natural gas and other energy transportation projects. This project exemplified that it is possible to balance the needs of energy use with the needs of the natural resource protection.

6. Ecological Restoration and Mitigation and Habitat Design

This section highlights opportunities for planners, designers, and contractors to incorporate herpetofauna habitat in ecological restoration and mitigation projects. Several of the management and development techniques described in Sections 7 and 8 are also applicable to restoration and mitigation projects. Consult Section 5 to minimize potential impacts to amphibians and reptiles at the planning phase of site restoration, development, and management. There are also several voluntary programs available through NRCS and the USFWS that provide support for protection and restoration of wildlife habitat. These programs often provide technical and financial assistance and can help to enhance amphibian and reptile habitat. For more information on these programs, please contact NRCS about the 2018 Farm Bill, financial and technical assistance, easement, and landscape planning programs.

1. It is important to engage stakeholders early and identify the needs, goals, and protection strategies necessary to maximize success. Education is a key component in effectively developing realistic and achievable project goals.

Planning Restoration and Mitigation

Regardless of whether the focus of an ecological restoration or mitigation project is amphibians and reptiles, a successful project will have more sustainable outcomes through good planning. To help a project be as successful as possible, the following recommendations specific to the restoration and mitigation planning process should be considered.

Identify restoration needs at large and small scales - Watershed assessments can be useful to identify which restoration activities will most benefit landscape processes. Large-scale natural resource mapping and species surveys help quantify the available resources, the status of herpetofauna and wildlife communities, and how large- and small-scale management decisions will affect local and regional ecosystems. This more holistic approach can help to guide restoration design to address the actual problems instead of attempting to create small-scale temporary solutions.

Involve stakeholders - Government, non-governmental, private sector, academic, and local citizen groups should be

Large-scale Conservation Success for Lake Erie Water Snake

Population declines of Lake Erie Water Snakes (*Nerodia sipedon insularum*) had become so severe that this species was listed as Federally Threatened as of August 30, 1999. Local community members became involved in planning and conservation efforts to conserve their quickly disappearing snake. Some shorelines were permanently designated as natural areas to protect snake habitat, and new developments within the range of these snakes incorporated habitat features and reduced habitat loss. Through implementation and strong local support of a recovery plan to prioritize actions for snake survival, Lake Erie Water Snakes were delisted in 2011.


Kristen Stanford

1. Thanks to adaptive management and dedicated conservation efforts by herpetologists like Dr. Kristin Stanford and Dr. Rich King, this species was delisted as federally protected.

One such development (residential lots) included the establishment of a buffer area with no construction along each lot, allowing old stone foundations that the snakes would use as habitat structures to remain, construction of artificial hibernacula structures, closure of an existing access road in a kill zone, posting road signs to promote lower vehicle speeds and alerting community members to the presence of these snakes. Major earth moving was conducted between May 1 and November 1 to reduce mortality of hibernating snakes, and construction activities were conducted to maximize conserved habitat area. Activities such as these also facilitated research to aid in future recovery and management plans.

invited to contribute knowledge and resources needed to create an ecologically, economically, and socially sustainable project. Involving these groups early on is often necessary to gain community support important in long-term success.

Set measurable goals - Goals can help to gain support for a project and provide direction for smaller decisions that will be made along the way. By clearly defining goals in a measurable way, the success of a project can be determined when the project is complete.

Consider long-term goals and outcomes - Most restoration or mitigation sites require some level of continued management to provide ecological function or accomplish other goals. Funding sources may not be apparent or available for long-term management needed for simple tasks like periodic removal of invasive plants. Long-term success may need to be supported by stable government or non-governmental organizations or have considerable local community support.

2-3. During a coastal wetland restoration project, fill and a bike path were removed and coastal wetland substrate and plants were restored. The restored coastal wetland naturally buffers wave action and provides amphibian and reptile habitat.


Kathy Evans


Kathy Evans

1-2. Salamanders, such as the Southern Two-lined Salamander (1) and the Northern Dusky Salamander (2), can only live in areas with high humidity, like under logs, and leaf litter and near wetlands. Maintaining moist, forested upland areas and creating wetlands can help maintain salamander populations.

3. When practicing adaptive management, effects of climate change on species' seasonal habitat and natural history should be considered. Changes in hydroperiod can influence species and community success. Planning for such changes can impact overall success and utilization of a site as habitat.

Prioritize restoration elements - Identification of which elements will have the most impact or must be created first can be used to create a plan of construction and restoration activity phases. Phasing plans should also account for seasonal conditions, wildlife movements and life stages, economic feasibility, and regulatory conditions.

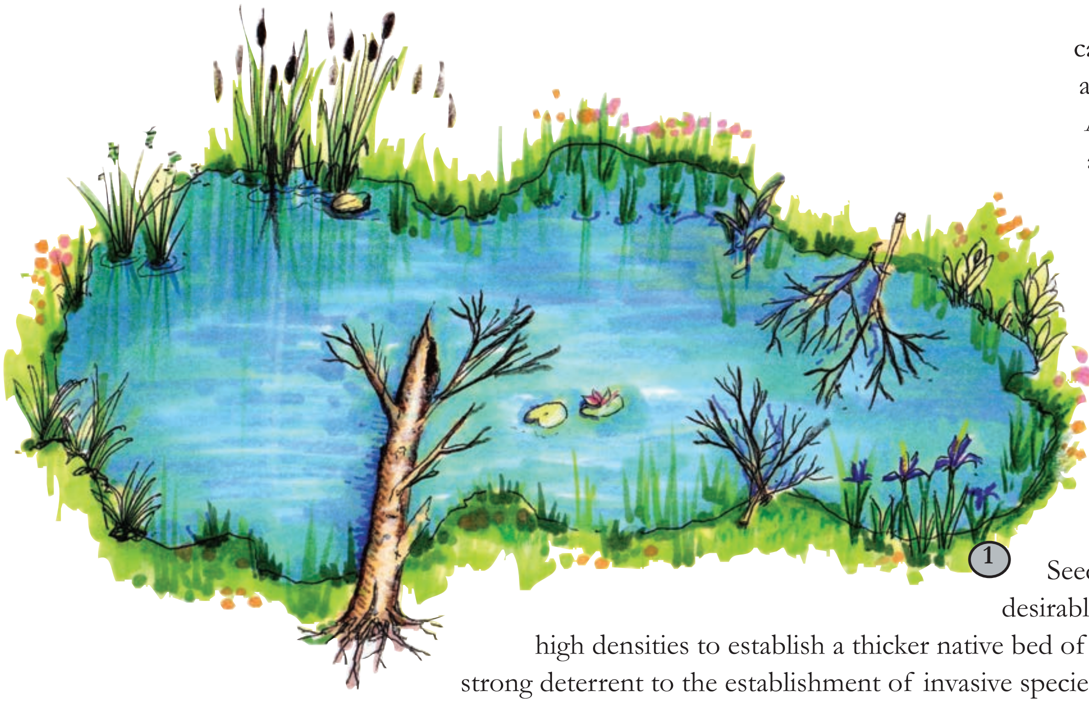
Practice adaptive management - For the project to be successful in the long term, it needs to be flexible to changing environmental, economic, and social conditions. Adaptive management uses a feedback cycle where setting goals and priorities lead to developing strategies. These strategies are realized by taking action, after which results are compared to the original goals and priorities to measure success and find ways to improve the project (The Nature Conservancy 2011). It is important to share the knowledge gained through adaptive management implementation with the broader community of restoration practitioners and land managers to advance restoration techniques.

Wetland Mitigation and Restoration

Over half of the wetlands in Michigan have been destroyed or degraded from their pre-settlement condition (Dahl et al. 1991) (See Section 3). Wetland restoration and creation can have large-scale benefits – including improved social welfare, greenhouse gas mitigation, waterfowl recreation (Jenkins et al. 2010) and can enhance population sustainability and connectivity of wildlife habitat (Petranka et al. 2007). Although there are substantial gains associated with wetland restoration, the exact outcome of any wetland restoration is difficult to predict (Zedler 2000). Following some basic guidelines/principles in wetland restoration planning can help to ensure the restored wetland becomes a functional and valuable part of the ecosystem and provides habitat function and conservation value for herpetofauna and other wildlife.

Ensure hydrologic processes can support the wetland - Siting wetland mitigation or restoration activities should take water inputs and outflows into consideration. A hydrogeomorphic approach to locating a wetland restoration project will greatly enhance the potential of its success.

Restore historical wetlands - Existing hydrologic processes, landscape position, and soil types usually make wetland restoration easier and more likely to succeed than a created wetland. Often native plant stock remains and high-quality wetland habitats



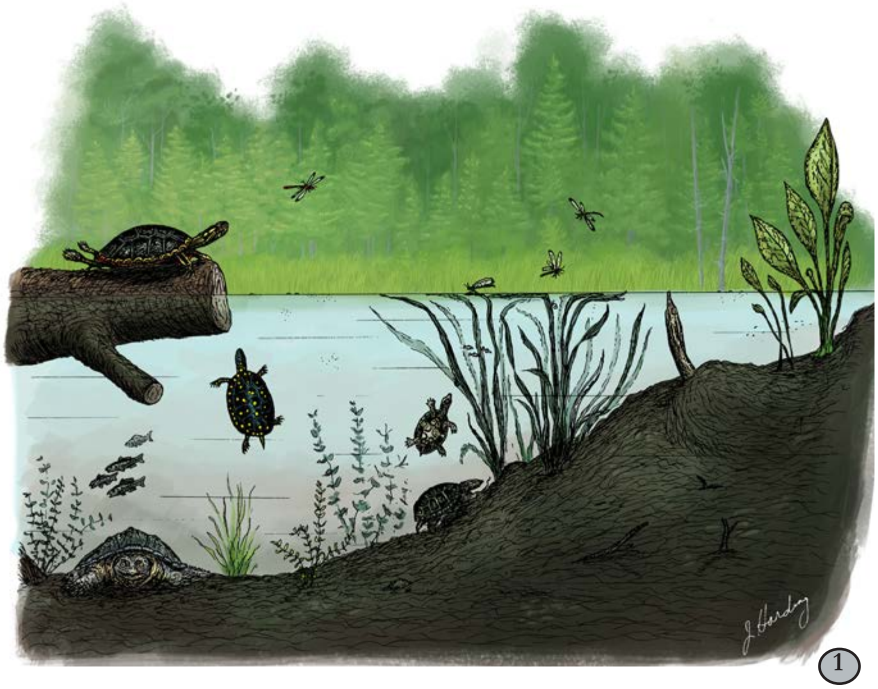
can be established quicker and more cost effectively. A major problem often associated with this type of restoration is the establishment and domination of the site by invasive species. To counteract this, soil types should be tested and amended if they are lacking sufficient nutrients to support healthy native vegetation. Seeding and planting of desirable wetland plant species at high densities to establish a thicker native bed of vegetation will be a strong deterrent to the establishment of invasive species.

1. A diversity of vegetation and structure will contribute to habitat for amphibians and reptiles as well as other wildlife.

Locate the restored or enhanced wetlands to increase connectivity - Several herpetofauna rely on a variety of wetlands in a complex. Restoring or creating a wetland complex with several wetlands of different configuration and depth within a few hundred feet of each other can provide dispersal opportunities for juveniles, migratory adults, or herpetofauna displaced by drought (Mazanti 2003). For animals such as salamanders, terrestrial travel can be risky due to a high risk of desiccation and predation (Ash 1997). Many of these species have extremely small home ranges and do not migrate far in search of additional habitat. By creating a wetland within close proximity between two existing wetlands, the distance that herpetofauna must travel to reach the nearest wetland will be reduced, and assures the potential for natural repopulations of the restored wetlands, thus reducing risk to amphibians and reptiles.

Bruce Kerr & EGLE

2. Placement of unassuming habitat structures, such as a tree limb along a shoreline, provides countless ecological functions for herpetofauna and other wildlife, including basking opportunities, shelter, and adhesion points for amphibian eggs.



Jim Harding & Hailey Brown

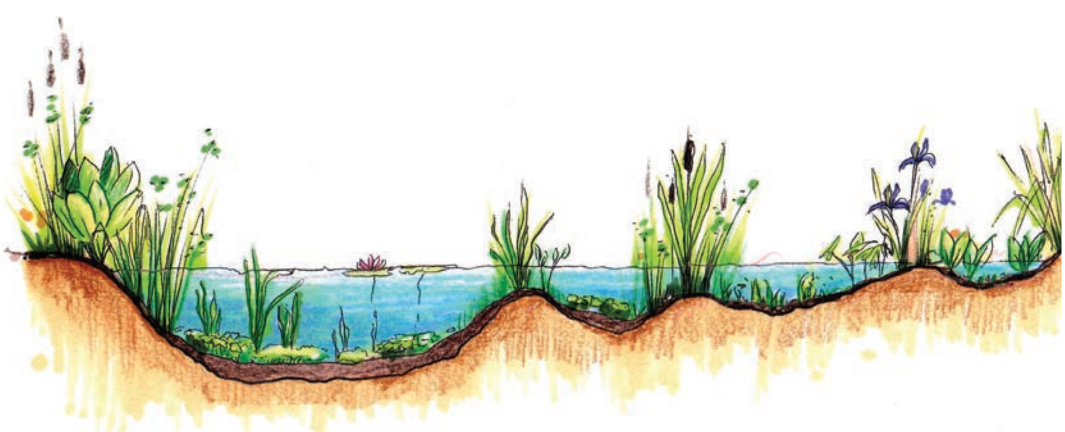
Create several wetlands with a variety of hydroperiods and conditions - The conditions created by depressions and pools of various depths and sizes can provide habitat suitable for several amphibians and reptiles during all seasons; however, they should provide similar conditions as nearby naturally occurring pools (Mazanti 2003). For example, within a body of water species such as Northern Map Turtles and Eastern Spiny Softshells will utilize deeper waters while Midland Painted Turtles and Blanding's Turtles occupy shallow zones. A diverse wetland complex or landscape matrix will have variable predator pressures, which is likely to provide long-term persistence of herpetofauna populations (Petranka and Holbrook 2006).

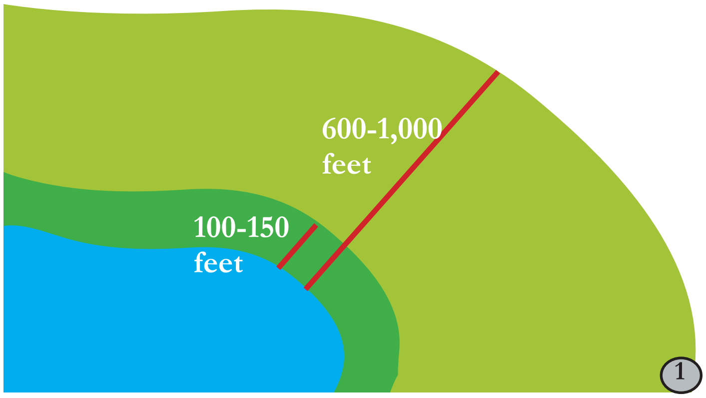
Restore and protect a buffer around a wetland - Strive to protect the first 600-1,000 feet (depending on which species are present) of upland area adjacent to a wetland to protect core habitat areas for amphibians and reptiles (Semlitsch 1998, Mazanti 2003, Semlitsch and Bodie 2003, Calhoun et al. 2005). Management or development actions within this buffer should not impact greater than 25% of the area to reduce risk of local population declines (Calhoun and Klemens 2002). This 25% should also be selected based on relative

1. A variety of habitat structures serve multiple purposes, including basking logs which can also provide valuable cover for amphibians and reptiles.

2. Maintaining a mosaic of habitat within a wetland is critical for herpetofauna population viability.

3. Wetlands with several depths, even if only varying by a few inches, can provide habitat for a wider variety of species.





1. Disturbance within 1.25 miles of a wetland can impact amphibians and reptiles associated with the wetland, although the closest 500 feet surrounding a wetland provide the most critical habitat. It is important to protect an upland buffer around wetlands to preserve habitat integrity and quality.

quality and proximity to contiguous habitat. If this amount of buffer cannot be protected, at least the first 100-150 feet of upland area adjacent to a wetland should be preserved as a buffer as this is where most pool breeding amphibians live their first year and where many species of freshwater turtles occur (Bodie 2001). Land conversion and habitat disturbances within 1.25 miles of a wetland can have a significant effect on the biodiversity of the respective wetland, and protection of this land should be included in wetland policies in "herp hot spots" and where essential habitat is present (Findlay and Houlahan 1997). If creating a wetland buffer, plant native species that provide cover, foraging and hunting areas, and safe breeding habitat for amphibians and reptiles while maintaining interstitial spaces for basking and herpetofauna movement. Establishment of dense vegetation and tall grasses should be avoided.

Design for a diversity of animals - Creation and restoration must take into consideration the needs of all wildlife including herpetofauna, birds, mammals, and macroinvertebrates. A diversity of native plants can contribute to habitat structure for several wildlife species. In general, a design based on herpetofauna and aquatic macroinvertebrates will have ecosystem benefits for other taxa (e.g., waterfowl, mammals, and fish).

2. Time construction and operation of machinery for times when amphibians and reptiles are less likely to be present.

Time construction and earth moving for the warm season - Grading and earthmoving should be conducted when animals are active during the warm seasons. Be aware that many amphibians and reptiles are slow-moving and may not be able to avoid equipment moving at seemingly slow speeds. Before beginning work, establish wildlife barrier fences around areas to minimize use of these areas by herpetofauna during construction activities and concurrently relocate animals out of construction zones. See Section 8 for more information on wildlife barrier fencing. This should be done under the guidance of an experienced professional wildlife biologist with demonstrated expertise in working with amphibians and reptiles and experience in conducting translocations. When using large equipment, start work at a central point and move outwards from that point to allow any remaining animals to flee in all directions.

Create gradual slopes - Studies have shown gradients as shallow as 1:15 (rise to run ratio) to 1:20 are much more ideal for supporting a variety of herpetofauna and their prey items. Whenever possible, wetland slopes should have no more than a 30% grade to support target species. Steep banks can prevent herpetofauna from coming ashore to bask, pursue prey, and nest (Reese 1986, Mack and Micacchion 2006).

1. Branches and old logs provide important refugia following tree removal. These materials can also be repurposed as basking logs or substrate for amphibian eggs in ponds.

Repurpose cleared vegetation as habitat structures - Trees, shrubs, stumps, rocks, and rubble removed as part of clearing and grading may be placed throughout the site to provide basking structure, cover, and hibernacula for herpetofauna (Mazanti 2003). This not only prevents much of this material from being landfilled, but can save a significant amount of money on the project while maximizing the habitat value.

Establish native emergent and submergent vegetation in the littoral zone and in vernal pools - This vegetation will provide refuge for small amphibians and reptiles and substrate for amphibians to attach egg masses (Mazanti 2003). These plants can also improve water quality, foraging sites, and help increase dissolved oxygen in the water.

Translocate animals from construction areas - Trapping and relocation efforts are important especially in restoration of existing wetlands where some herpetofauna may already live. This is not only at times a permitted requirement, but more importantly an opportunity to help minimize loss of populations. This activity should only be conducted under the guidance of a trained herpetologist with experience conducting such efforts and with appropriate permits. Further details on translocation are discussed later in this section.

2. Restoration should consider natural water hydrodynamics and presence of oxbows and meander scars as important backwater habitats and when possible incorporate natural channel design principles.

Monitor to gauge success - Evaluation of project outcomes, including flora and fauna communities, can indicate which methods were the most successful and which can further be improved on to increase future project success. Measures of project success should include objective, quantitative, and repeatable data in order to provide reliable feedback. This feedback cycle helps to improve techniques used for sites with a specific set of conditions and drives better habitat restoration and management. Herpetofauna should be monitored during times when species are most active to accurately gauge restoration success. Ideally at a minimum sampling would be conducted in late spring and late summer/early fall to maximize species and life stage detection.

Stream and River Restoration and Mitigation

Many of Michigan's streams and rivers have been physically altered through channelization, bank stabilization, dredging, culverts, and impoundments. These alterations have reduced the habitat structures and niches that herpetofauna, such as Wood Turtles, Northern Map Turtles, and Queen Snakes use in the channel and riparian zones. Disturbances that contribute to the imbalance in stream function can be gradually removed, or in some cases, quickly removed in active restoration and mitigation activities. Due to the complex nature of stream restoration and the unique conditions surrounding each waterway, a stream restoration specialist, preferably one familiar with the Rosgen Natural Channel Design Method (e.g., (Rosgen 2011)) or George

1. Species like the Queen Snake (1), Northern Water Snake (2), and Northern Map Turtle (3) can benefit from installing a variety of habitat features during stream restoration. Materials removed during a project such as logs or large rocks can be utilized for basking or cover. Reusing these materials can also reduce the cost of a project.

Palmeter river restoration techniques (e.g., (Herbkersman 1982)), should be contacted to lead restoration. The Natural Channel Design should be utilized when appropriate to allow for natural stream processes and biological lift, however this is not always possible due to infrastructure limitations. General guidelines to follow in planning for stream restorations that provide conservation value to herpetofauna are listed below.

Create a variety of habitat structures - Creation of sand and gravel bars, overhanging vegetation, and natural cutbanks provide cover and foraging grounds for a variety of species of herpetofauna and other wildlife. In-stream habitat structures for herpetofauna include woody debris, snags, leaf litter, boulders, clean sand, gravel, or cobble substrate. Small pools can also be excavated to the side of a river channel to provide additional protected areas to facilitate breeding, nesting, feeding, and basking.

Place culverts on straight parts of a stream or river - Straight stream sections can accommodate straight culverts or pipes and are less likely to dramatically move over time.

Culverts should be slightly wider than bankfull width - By placing a culvert wider than the bankfull width of a stream or river – the width a stream or river reaches just before spilling onto the floodplain - a flood-plain area can be created along the sides by placing rocks. It is important that if culverts larger than bankfull are installed that banks are created within the culvert that may not be mobilized out of the culvert. This is not only important for animal passage but it is necessary in order for the stream to continue to transport sediment through the system and allow for unimpeded fish passage. Sediment fills in between the rocks and creates an area that wildlife can also cross. Using a culvert to maintain bankfull width allows water, sediment, and debris to move downstream without blocking the culvert, creating scour pools, or perched culverts.

Select the appropriate type of stream crossing structures - Each stream crossing site varies but bridges are always the preferred alternative for animal passage and then typically are, in descending order of preference, open-bottom arch culverts, box culverts, elliptical culverts, and circular culverts. Larger culverts can provide more natural conditions - such as ambient light and temperature – which facilitate movement for a greater number of

Figure 2

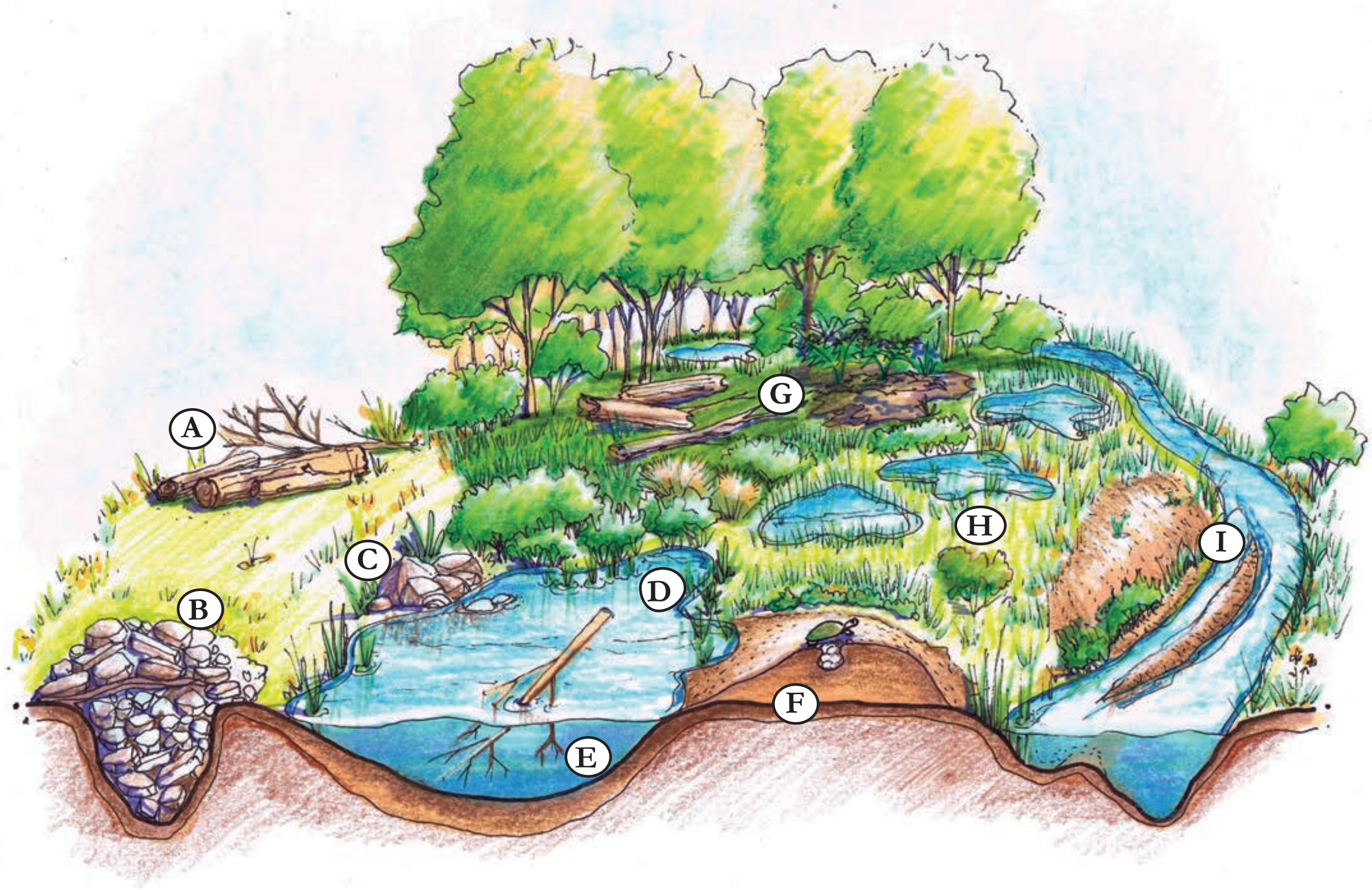


Figure 2. This figure illustrates an ideal landscape that can be managed or created to support herpetofauna richness and density.

Logs in a sunny/partly sunny location. Cover, basking, nesting and hibernation (A).

Depression filled with rocks, rubble, and/or rootballs. Reptile basking and hibernation (B).

Rocks along shoreline. Shelter and basking (C)

Emergent and submergent vegetation. Basking and foraging (D).

Finely branched brush and trees. Amphibian egg attachment and cover (E).

Sunny areas of loose, well drained soil. Turtle nesting and basking (F).

Logs and leaf litter in the forest understory. Salamander cover, nesting, foraging, and hibernation (G).

A variety of wetland types to support migrations, breeding, foraging, hibernation, and development of various amphibians and reptiles (H).

Sandy banks and sand bar. Turtle nesting and reptile basking (I).

amphibians, reptiles, and other wildlife. Wing walls or barrier fences leading to both openings of crossing structures can direct wildlife through a structure and prevent their movement onto a road. Consult a professional herpetologist or wildlife biologist to provide conditions the target species will need. Refer to Road Crossing Structures (Section 8) for more information on implementing crossing structures that best accommodate amphibian and reptile movement.

Consider the flow of water when placing culverts - Typically, a culvert should be placed with the invert elevations of both ends of the culvert buried at 1/6th of the riffle bankfull width of the stream up to a maximum of two feet at the same slope as the streambed measured from a riffle upstream and downstream of the existing culvert. If the upstream

Conservation Resource Alliance

1. This open-bottom arch culvert allows species like the Wood Turtle to follow stream corridors safely while reducing the risk of road mortality. For an additional illustration of this structure, see Figure 10 in development techniques.

flowline - the general path that water follows - is raised, scour near the culvert could result, and if the downstream flowline is raised the water velocity could be reduced and reduce the downstream scour. Maintaining a continuous slope allows amphibians and reptiles to traverse culverts and access upstream and downstream river areas.

Incorporate floodplain shelves - Floodplains provide an area for a stream to dissipate energy during flood events. Flooding reduces the velocity of the water in the channel and prevents unnaturally severe erosion downstream. During flooding, sediment is deposited on the floodplain, enriching the soil. Rocks, branches, and vegetation in the floodplain also provide wildlife habitat structures near to the water. Seasonally, floodplains can provide important habitat for herpetofauna and serve as critical corridors between habitats. In culverts that are large enough, floodplain shelves should be constructed from material that is not mobile during high flow events. These shelves should be created at the bankfull elevation and meet the bankfull width upstream and downstream to the culvert. If culverts are too small to construct a floodplain bench, smaller diameter culverts should be installed higher than the channel culvert and at the bankfull elevation. Another method of floodplain maintenance includes the two-stage ditch developed by The Nature Conservancy. This design introduces a floodplain zone called a bench into a ditch by removing the banks roughly 2-3 feet above the bottom for a width of about 10 feet on each side (The Nature Conservancy 2013). These various methods allow for improved hydraulics, reduced velocities, organism passage, woody debris transport, and reduced long-term maintenance costs.

Figure 3

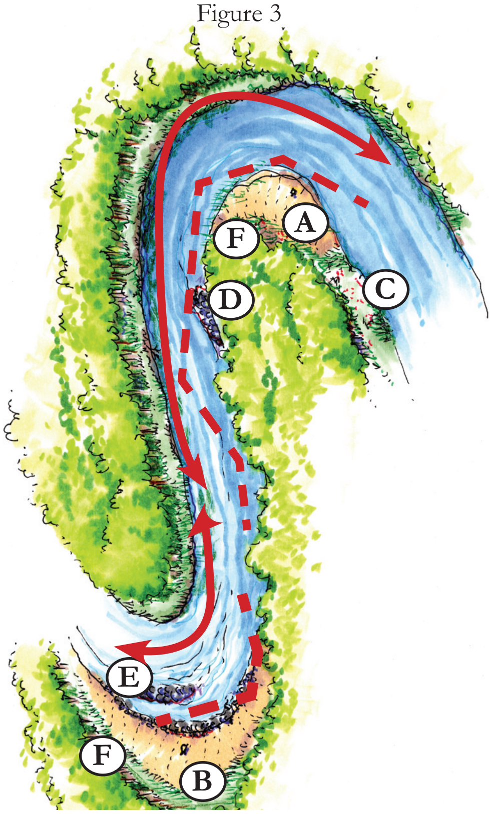


Figure 3. Sandy, sparsely vegetated banks along a river provide turtle nesting habitat (A and B).

Cutbanks which are prone to erosion (A) can be protected while maintaining access for turtle nesting. Rocks in the channel deflect stream velocity (C) and the toe of the slope is stabilized by small rocks filled-in with gravel or sand (D).

Sandbars prone to erosion (B) can be protected by rocks or riprap placed as a wing deflector (E).

Protect nest areas from predators by placing fencing (F). Predators following along this fence will be deflected away from the nesting area.

Restore riffle, run, and pool sequences - These natural stream features are often degraded in streams with significant anthropogenic influence. These sequences also give rise to point bars, beaches, and bank habitats important to riverine herpetofauna. These features also help oxygenate the water while also providing deeper pools where many riverine turtle species and some amphibians overwinter. If changes are made in stream features to improve habitat it is important to consult a stream restoration specialist since perturbations in the system can

1. A professional herpetologist uncovers a recently constructed Wood Turtle nest in a river sandbar to prevent raccoon predation. Upon hatching, the turtles were safely returned. Such activities require permits by the DNR.

2. A female Wood Turtle makes its way on land during the nesting season looking for nesting sites. This species can benefit from restoration activities that enhance riverine features and increase nesting opportunities. Education is also critical to discourage people from collecting this increasingly rare and long-lived turtle.

have significant effects of stream geomorphology and stability.

Stabilize slopes - In areas prone to erosion, use of vegetation as bank and toe of slope stabilization may be the best option, as it allows for the stream to move over time without scouring effects from stone placement and also enhances water infiltration through root penetration. However, in areas where Wood Turtles potentially occur, exposed sandy areas provide critical breeding sites. Strategically placed vegetation, rock, and wood structure may be needed to protect these sandy areas in degraded systems where erosion threatens these features. Placing sand, clay stone, and riprap can be added to stream banks, but should not constrict the stream more than its natural bank-full width.

Depending on which species use an area, various techniques should be incorporated into slope stabilization. In areas where turtles nest, large gaps between rocks can trap female turtles attempting to nest on the banks or hatchlings emerging from a nest. These scenarios often result in death to the animal. Filling in the gaps with smaller gravel, sand or other stable materials will help reduce the risk in turtle nesting areas. However, in areas where turtles are unlikely to nest (e.g., a north facing bank), snakes will seek cover in large gaps between rocks. Identification of the target species and providing a mosaic of conditions can help enhance amphibian and reptile populations.

Habitat Design

Wildlife habitat is comprised of everything that contributes to the presence or abundance of wildlife (Cooperrider et al. 1986, Hall et al. 1997). This means that floral, faunal, physical and chemical components as well as the spatial and temporal interactions among these components contribute to wildlife habitat and should all be considered in a restoration plan. Ecological restoration and mitigation often focus on habitat quality, connectivity, and reduction of fragmentation as a means to benefit wildlife communities. Creation of features, such as breeding, nesting, or hibernation structures, further supports herpetofauna by providing them an opportunity to carry out necessary life processes (Gillingham and Carpenter 1978). These structures enhance herpetofauna habitat quality and population viability when integrated into a plan that also accounts


1


2

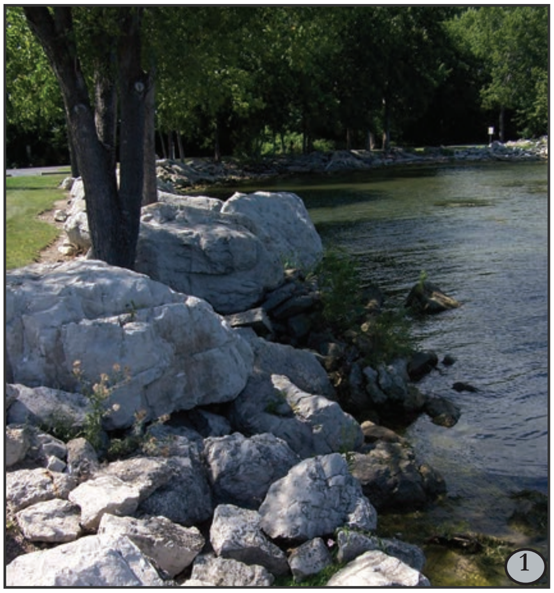

3

for restoration of large-scale landscape process. Oftentimes, small changes to conventional designs can result in large wildlife habitat improvements and monetary savings. A certified wildlife biologist or professional herpetologist should be consulted to design herpetofauna habitat and to integrate these components into a master plan. They can help coordinate efforts in the best interest of wildlife species on site while helping construction and management plans move through regulatory approval. General amphibian and reptile habitat design considerations are listed below and followed by details about the creation of habitat structures that benefit specific groups of herpetofauna.

Create complexes of wetlands connected by high quality upland areas - Several Michigan herpetofauna species rely on high-quality wetland and upland areas to complete their lifecycle (Porej et al. 2004, Attum et al. 2008, Attum et al. 2009, Harding and Mifsud 2017). Developing a mosaic of different vegetation types and providing connections between features of value enhances landscape connectivity for herpetofauna species. Creating ample upland corridors (>100 feet in width, e.g., (Mazanti 2003) between high-quality wetland features may provide appropriate landscape connectivity.

Maintain a variety of hydroperiods - Create an uneven surface with both large (approximately 3 feet) and small (approximately 6 inches) depressions to provide a variety of hydroperiods that various herpetofauna can utilize throughout the year. Maintaining clusters of pools that support a variety of hydroperiods help to support populations of vernal-pool dependent amphibians (Nagel et al. 2021). Larger pools within a wetland will make the system less vulnerable to drying, and combined with small pools that form in these microtopographic depressions can provide sources of water over a larger portion of the landscape and better accessibility for herpetofauna. The irregular topography also allows for greater variety in community types and allows for greater species colonization and densities.

1-3. Concrete/limestone rubble can be repurposed to provide critical reptile habitat such as hibernacula shown at these three project sites located throughout Michigan. When incorporating sand, these structures can also provide important nesting sites for reptiles. These systems are becoming increasingly used in Michigan as an inexpensive and effective way to create critical habitat while repurposing onsite resources.



1. These large rocks provide useful habitat for snakes that bask at this site. However, at a site with valuable turtle nesting habitat on land, these rocks could be a barrier for females going ashore or hatchling turtles attempting to return to the water. Incorporating areas with small rocks which fill in gaps will help improve turtle movement and reduces risk of babies getting trapped in gaps.

Look for opportunities to incorporate features at low cost - Byproducts of site alterations or on-site resources may present opportunities to create no-cost or low-cost habitat features. Rebar free concrete, rocks, trees, stumps, and rubble, which would otherwise be removed from a site for a cost, may be reused in hibernacula, refuges, basking sites, or nesting sites. The money is saved when removal costs are eliminated and no materials are purchased to create habitat features. Care should be taken to reduce the amount of crushed concrete material that enters aquatic systems as pH can increase from concrete leachates (Van Dam et al. 2011).

Create habitat for prey species - Providing habitat for the food source of the target amphibians and reptiles is essential to supporting and maintaining a rich assemblage of herpetofauna at a site. This is often accomplished while creating habitat or landscape features intended for use by herpetofauna. These restoration features provide habitat for the macroinvertebrates, mussels, small mammals, fish, and the other fauna that herpetofauna eat. However, the food source and the habitat requirements of the food source of each target species should be identified and checked for inclusion in restoration plans. This 'double-check' can be especially important for species, such as Queen Snakes, which have a specialized food source, feeding almost exclusively on crayfish (Wood 1949, Harding and Mifsud 2017). In this case, meeting the habitat requirements for maintaining a healthy population of crayfish is necessary to ensure a food source for Queen Snakes.

2. Sand can be used in restoration sites to create nesting areas. Knowing the species found locally will also guide what type of substrate is best.

Turtle Nesting

Nesting sites can be on a sunny riverbank or lakeshore, in a sandy field near a wetland, on an island or sandbar of a main channel, or even the dangerous gravel shoulder of a highway. Turtles typically nest between mid-May and early July, and species such as Blanding's Turtles will travel extensively (sometimes >1 mile) in upland areas to locate an acceptable nesting site (Standing et al. 1999, Mifsud 2004). Other turtles, like the Eastern Spiny Softshell, nest directly adjacent to the water, with most nests approximately 10-30 feet from the edge of the water. Always assess which turtle species are likely present and their nesting requirements when creating turtle nesting areas. Various turtle nesting area creation and maintenance techniques are listed below.

Locate a site - Turtle nesting areas are typically on south facing slopes to warm the nest to an appropriate temperature for incubation. Turtles typically nest in areas of sandy or loose, friable soils. Nesting areas should be approximately 3 feet or

1-2. This turtle nesting area is covered by a fenced structure designed to keep raccoons and other potential predators out. The fence attached to the sides of the structure is embedded in the ground. Turtles can access the nesting area under this structure from the water. This system has been successful, though each project is unique and consulting with a professional is encouraged.

more above summer water levels to reduce potential flood damage. When possible, locate nesting areas isolated from egg predators (e.g., raccoons, chipmunks, and skunks) and human disturbance. Small islands without predator populations are ideal areas for nesting sites. If constructing turtle nesting sites along the shoreline of a lake or the banks of a river, space nesting areas at 1-2 mile intervals (Buech and Nelson 1991).

Place sand or wood chips - A pile of sand or wood chips or an excavation filled with sand near to the water on a south-facing slope can provide a turtle nesting area. Avoid creating nesting areas on steep slopes to minimize erosion. If placing sand, select washed sand to reduce vegetation colonization. These types of nesting areas can be easily and quickly created with earth-moving equipment. A caution about using wood chips: when fresh these produce heat through the decomposition process and when exposed to full sun can become hot enough to bake turtle eggs. Use old mulch or place mulch at site well before nesting season (e.g., the fall of the previous season) to allow for sufficient decomposition to take place. These areas can also provide snake nesting sites.

Nesting area maintenance - Till sandy nesting sites in late spring after any potentially overwintering hatchling Painted Turtles have emerged, but well before nesting season begins. This

3. Sand bars such as this are critical nesting sites for many turtle species in northern Michigan. Armoring or stabilizing to encourage vegetation can eliminate this habitat locally.

1. Nesting areas should be maintained to reduce the growth of vegetation.

2. Protecting nests from predators will increase nest and hatchling success as observed with these emerging Wood Turtles.

Jim Harding

method of maintenance is less time intensive than hand weeding, poses less threat of water contamination than herbicide treatment, and maintains loose soil ideal for nesting (Dowling et al. 2010).

Mitigate predator damage - In several areas throughout Michigan, artificially high populations of subsidized mesopredators (a medium size predator that often increases in abundance when larger predators are eliminated), like raccoons, can result in devastatingly high turtle nest mortality (See Section 3). Individual turtle nests can be protected, or fenced covers can be placed over an entire nesting area, to increase chances of nest and hatchling success; however, raccoons (and even chipmunks) have been known to destroy or dig under these covers to reach eggs (Herpetological Resource and Management 2011, 2012). Use of techniques, such as electric fences or construction of islands (e.g., digging a moat at the base of a peninsula) may be implemented to protect ideal turtle nesting areas, as this has been a technique to successfully reduce mammalian predation on ground nesting birds and on sea turtles (Lokemoen et al. 1982, Bennett et al. 2009). Control of these predators on islands where turtles nests has been effective at reducing predation pressures (Garmestani and Percival 2005, Engeman et al. 2010) but to date there has been limited effort and success conducting similar control measures in inland areas.

Chris Hoving

3. Eastern Box Turtles burrow into the soft forest floor under leaf litter and debris to thermoregulate over winter.

Turtle Hibernacula

Some aquatic turtles remain semi-active during the winter, but most turtles in Michigan hibernate during cold seasons. As the weather begins to cool, the body temperature of turtles gradually decreases, preparing them for hibernation. During hibernation some species of hatchling turtles produce proteins that act like antifreeze and prevent ice crystals from forming in their cells which would cause death (Packard and Packard 1993). Aquatic turtles and terrestrial turtles have different hibernation

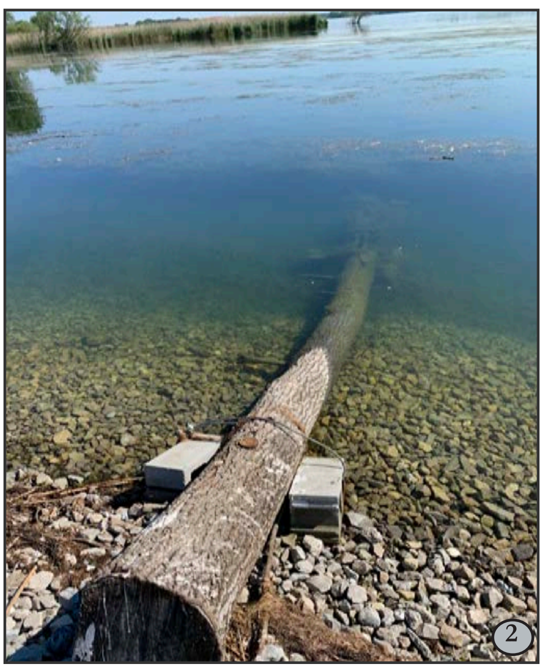
Jan Storey

1. Thanks to their ability to withstand below freezing temperatures, Wood Frogs can overwinter on the soil surface.

requirements, both of which can be provided for in restoration projects.

Terrestrial turtles - Michigan's only truly terrestrial turtle, the Eastern Box Turtle, hibernates in burrows in sandy or friable soil in forested areas. Hibernation of these turtles can be supported by ensuring that soils are not heavily compacted and that leaf litter and duff layer are maintained on the forest floor throughout the winter as these provide an important insulating layer. Providing areas of leaf litter at least one foot deep is ideal to ensure Eastern Box Turtle can survive the winter.

Aquatic turtles - Aquatic turtles that hibernate use fine silts, mud, and detritus at the bottom of water bodies or in submerged banks. In areas where turtle species hibernate on the bottom, wetlands should be the appropriate depth to avoid the entire water column from freezing solid and to ensure that the water does not become anoxic as turtles and other submerged fauna consume dissolved oxygen in the water. Some species that spend the winter on the bottom, such as Blanding's Turtle, may not truly hibernate the entire winter and have been observed moving slowly on the bottom under the ice. Hibernacula structures can be created as hollowed out areas under the banks. These structures must remain submerged or at a constant water level from early fall until emergence in the spring.



2. Logs and fallen trees already present at a site can be used to create basking structures. This helps reduce disposal costs while finding use for the material.

Turtle Basking

Several aquatic turtle species, such as Wood Turtles, Blanding's Turtles, and Spotted Turtles, need to bask to thermoregulate. These turtles climb out of the water to dry off and warm themselves in the sun. Basking helps fend off parasites, infections, and provides warmth and energy needed for digestion and other metabolic processes. They typically bask on logs or other structures in the water, as they are difficult for predators to access and can quickly dive into the water at the first sign of danger. When adequate basking sites are not present, turtles will use shorelines and banks where the risk to predation is greater.

Basking Structures - Felling trees on site, using existing logs, or bringing in logs can provide basking habitat. These elements should be placed roughly horizontally and in shallow waters. The branching and irregular shape of trees allows some surfaces of the tree to be above water even during times of high water. They may or may not connect to the shore. In fast moving waters these structures may need to be anchored in place and angled to reduce drag. Snakes will use these structures for basking and, depending on locations, amphibians may attach their eggs to the submerged fine branching. These structures also serve as habitat for some fish species that can provide an important food source for amphibians and reptiles.

Figure 4

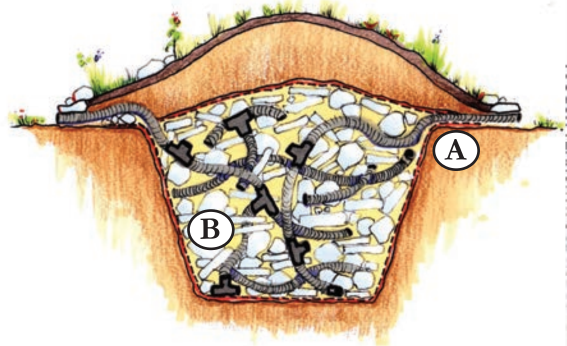


Figure 5

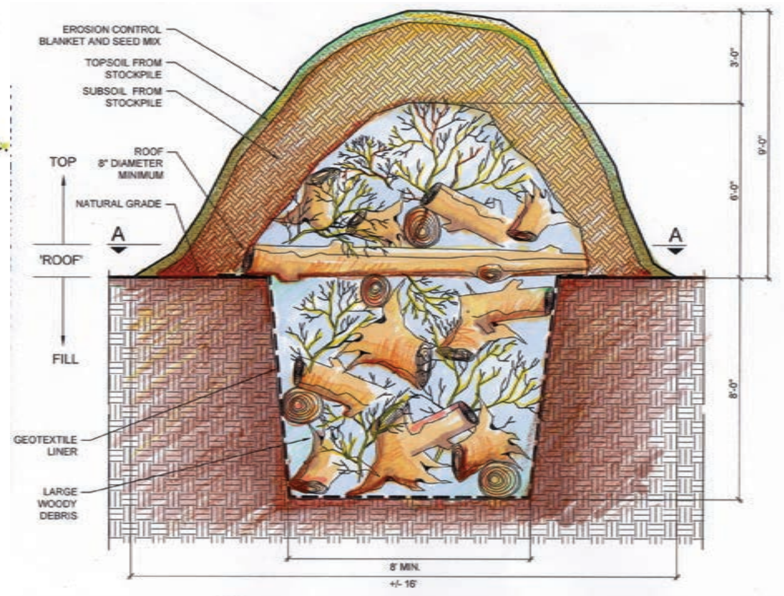


Figure 4.
Hibernacula structures containing pipes and tubes should have a "trap" (A) in the pipe to prevent cold air from traveling to the bottom of the hibernacula and freezing the hibernating animals in the winter. Several openings allow snakes and other animals to find an ideal niche in the hibernacula (B).

Figure 5.
Logs and stumps can be used to create a hibernaculum and provide tens or even hundreds of snakes and other wildlife protection from the cold. Both are reasonably priced and in many cases incorporating them can save money on projects.

Snake Hibernacula

Michigan snakes hibernate during cold seasons in crevices, holes, abandoned animal burrows, and crayfish chimneys (Carpenter 1953, Gillingham and Carpenter 1978, Smith 2009). Snakes may hibernate in large groups due to the scarcity of ideal hibernation areas and the benefits of warmth and protection from predators derived from a large group.

1-2. Logs along the edge of the forest can serve as important habitat for a variety of herpetofauna including Eastern Milk Snakes (2).

Hibernacula Structures - Created hibernacula are typically mostly below grade. Hibernacula are prepared by excavating a pit to a depth of at least 8', and then rocks, logs, tubing, pipes, concrete rubble, and/or other objects are placed in the pit that create interstitial gaps. The snakes are able to traverse these gaps and are protected from cold and predation. Once filled, the pit is covered with soil with only small openings remaining as a 'door' to the structure below. The rock and/or log

1. Northern Ribbon Snakes and other reptiles utilize branches and snags as basking sites.

2-3. Rock Structures such as this natural formation and created structure provide opportunities for thermoregulation as well as refugia, nesting, and overwintering habitat.

structure exposed in this 'door' can also provide a secondary basking site. If incorporating corrugated plastic tiles into the design, it is recommended that air traps be incorporated to prevent cold air from traveling to the bottom of the enclosure.

Snake and Lizard Basking and Cover

Like all herpetofauna, snakes and lizards are ectothermic and rely on the warmth of the sun to provide the heat energy needed for quick movements, digestion, and other metabolic activities. A suitable basking site is especially important during cooler periods in the spring, early fall, or on cool summer mornings. When snakes bask they are exposed to predators, including predatory birds, and prefer to have cover nearby if a quick get-away is necessary. Basking sites with a rough surface can help snakes shed their skins.

Snake Basking and Cover Structures - Basking structures are typically made of rock or wood. Gaps between stones and logs are important to provide places where snakes can quickly escape a predator. Hibernacula, as described above, can double as basking and cover areas. Stumps can also serve as cover and basking sites, as small snakes can hide under bark or in rotted holes in the stump.

Lizard Basking and Cover Structures - Similar to snakes, lizards will use logs and stumps for basking and cover. However, Five-lined Skinks prefer these structures along the edge of moist (not dry or wet) forests. Six-lined Racerunners, another Michigan lizard, prefer drier open forests and open fields, and will use woody debris, stones, logs, burrows, and leaf litter in these areas for cover and/or basking sites. Placement of these structures can attract and help support a healthy population of lizards if a nearby source population exists.

Snake and Lizard Nesting Sites

Some Michigan snakes give birth to live young, but a portion of snakes and all Michigan lizards lay eggs in a nest depression or a cavity that they excavate. Five-lined Skinks lay eggs in a cavity excavated in moist soil, sand, rotting wood, or leaf litter or under a log, rock, or other object (Harding and Mifsud 2017). Six-lined Racerunners lay eggs in burrows in the ground. Logs and rocks placed as hibernacula, cover, and basking structures for snakes and lizards can also provide ideal conditions for nesting. These structures may also provide the cover and protection from threats needed by a female snake giving birth to live young.

Amphibian Egg Laying Sites

The first step to create a successful amphibian egg laying site is to ensure a source

1. Rotting wood is often utilized by Five-line Skinks and many snake species to lay their eggs.

2. Finely branched limbs and trees dropped in the water can provide attachment sites for amphibian eggs and refugia from potential predators.

3. Spotted Salamander egg masses attached to vegetation and branches in shallow water.

of standing water in the spring that will last at least into early or mid-summer. Most species of salamanders and frogs and toads in Michigan (with the exception of the Eastern Red-backed Salamanders; *Plethodon cinereus*) lay their eggs in water or over water, and several species mate in water. Some amphibians deposit their eggs on sticks, branches, and plant leaves and stems in the water. These features can also help cover eggs and protect them from would-be predators. Once eggs hatch, the live and dead plant structures also offer protection to larvae.

Egg Laying Ponds - Ensure ponds hold areas of <30" water for at least four consecutive months. Irregular shorelines can help to increase the shoreline length, which provides greater habitat area. If areas of the pond are >30", these areas will not freeze solid and can provide hibernation opportunities for herpetofauna.

Amphibian Egg Laying Structures - Trees with fine branching can be felled into wetlands or brush removed from elsewhere on site can be placed in the water. The fine branching will decompose over a couple of years, and replacement structures will need to be placed. These sites can often double as reptile basking areas.

Plant Communities for Eggs and Larvae - Native, emergent and submergent wetland vegetation can provide ideal structures for amphibian egg placement, larvae foraging, and cover from predators. Protect this type of existing vegetation, or if conducting a wetland restoration, be sure to provide this vegetation as a component of wildlife habitat. Care should be made to limit the amount and type of plants within wetlands and allow for portions to remain as open water with sun exposure to help egg and larval development.

Frog and Toad Cover and Basking Sites

Frogs and toads need to bask to raise their body temperature above the ambient air temperature. Warmer body temperatures facilitate movement necessary for catching food and escaping predators. These amphibians are a desirable food source for many other animals and need cover nearby where they can hide from attack.

Vegetation - Sunny areas in shallow water or at the edge of a water body are ideal for basking. South facing slopes have more direct sun exposure, and the shadow pattern of nearby trees and vegetation should be considered

1-2. Frogs, such as the Blanchard's Cricket Frog (1) and Gray Treefrog (2), prefer to bask and vocalize to call mates in areas that also provide vegetation for protection.

when creating areas for frog and toad basking. The mottled shadow pattern of sparse herbaceous vegetation or deciduous trees in the spring can provide small areas of sun interspersed amongst shadows where frogs can quickly hide.

Logs and Submerged Objects - Logs and partially submerged vegetation also provide good thermoregulation areas where a frog can jump into the safety of water at the first sign of a threat.

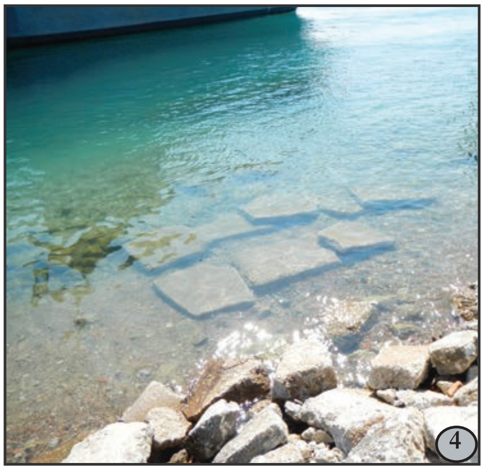
Salamander Cover and Foraging Sites

Salamanders do not bask as their skin is highly permeable and they would quickly desiccate in the sun and wind. To prevent desiccation, most salamanders need cool, moist, shadowed areas to live and hunt. Providing cover and foraging sites in the water is important for salamanders. Most salamanders live in water during their larval stage and some species with gilled adult phases (neotenic salamanders), such as Mudpuppies and breeding phase Red-spotted Newts, live in the water during their adult life.

Logs and Cover Objects - Areas near vernal pools or in moist forest areas are ideal for salamanders, and providing logs and leaf litter gives salamanders places to hide, attracts the invertebrates they eat, and helps retain moisture.

Aquatic Structures - Providing submergent and emergent vegetation and/or finely branched brush in water can enhance cover opportunities for salamander larvae and provide conditions ideal for the invertebrates and vegetation that salamanders eat. Additionally, placing logs or rocks in shallow waters can provide gaps and spaces for neotenic salamanders to take cover and hunt for fish, mollusks, and other invertebrates. The creation of rocky shoals in rivers and lakes can provide excellent habitat for Mudpuppies.

Trish Brockman & Hailey Brown



3-4. Simple structures, such as repurposed segments of concrete or sidewalk, mimic natural Mudpuppy habitat in addition to habitat for aquatic invertebrates and fish.

1. Many species of amphibians and reptiles require a mosaic of habitat with intact uplands between wetlands. Maintaining such landscape allows for greater ecosystem resilience and overall community function and health.

Upland Conditions for Amphibians

Upland areas that are suitable for amphibians are generally shaded, cooler, moist environments. Promoting or preserving dense canopy cover, little understory vegetation, and a high amount of leaf litter and duff can provide suitable conditions for salamanders, frogs, and toads. If designing for salamanders, try to minimize the ratio of edge to area of forest. Vernal pools throughout upland areas can provide a water source valuable to many amphibian species as well as other wildlife.

Upland Conditions for Reptiles

Upland areas managed for reptiles or those suitable for reptiles are generally dry and relatively open with gaps in forest and shrub canopy. These open conditions can be maintained through tree thinning or occasional use of fire (Iowa NRCS 2005). Prior to engaging in any invasive species management always assess the species of amphibians and reptiles present. Wooded areas may also be enhanced by the establishment of fruiting plant species, such as strawberry, raspberry, and grapes, in areas where Eastern Box Turtles likely occur. When possible, encourage the development of healthy fungal colonies in woodland environments. Various mushrooms are an important food source for Eastern Box Turtles and for prey items of herpetofauna. They also help maintain healthy forest ecosystems.

2-3. Reptiles like Northern Brown Snakes (2) and Blue Racers (3) require upland communities for survival. Incorporating techniques discussed in this BMP will benefit them and other regional herpetofauna.

Captive Breeding and Rare Species Headstarting

Establishment of an animal population can be part of the restoration process similar to the placement of plants from a nursery or dispersal of collected seeds from a reference site. Michigan turtle populations are in decline, with 40% of the native species listed as SGCN in the MDNR Michigan's Wildlife Action Plan and Special Concern or Threatened by the MDNR (Derosier et al. 2015, Michigan Department of Natural Resources 2016). The species listed as Special Concern, (Spotted Turtle, Blanding's Turtle, Wood Turtle, and Eastern Box Turtle) are all rare in Michigan and throughout their ranges. In addition, Blanding's Turtles, Spotted Turtles, and Wood Turtles are currently being evaluated for Federal protection under the ESA (U.S. Fish & Wildlife Service 2015). Given the current habitat conditions and population trends for these species in Michigan, human intervention is increasingly necessary to ensure populations of these species exist in perpetuity.

For rare species, pressure on populations can be offset through headstarting programs, where eggs are collected and the hatchlings are released once they have reached a larger, less vulnerable body size. Turtles are generally long-lived animals, with some species known to surpass the century mark, and must live long lives to successfully reproduce and replace themselves in the population. Longevity and reproductive opportunities are necessary to make up for the naturally high mortality of turtle eggs and hatchlings, as well as the typically long time periods needed for young turtles to reach sexual maturity.

1. Headstarting programs can benefit rare and declining long-lived species such as Wood Turtle and Blanding's Turtle. These activities should be conducted in coordination with the MDNR and a herpetologist with experience headstarting the target species.

2. Comparison in size between a natural Wood Turtle (left) at three years and a headstarted Wood Turtle (right) at one year. This can be an effective conservation strategy when conducted as part of an overall management approach.

Headstarting is a time intensive yet necessary part of turtle conservation to ensure at-risk turtle species persist in Michigan. Although headstarting does not reduce threats from habitat destruction, road mortality, and unsustainable collection, headstarting does improve chances of hatchling survival to maturity. In fact, there is strong evidence to suggest that some northern Michigan Wood Turtle populations have only experienced recruitment through the release of head-started individuals over the last decade (Harding 2013). Additionally, Blanding's Turtle nine-month headstarted hatchlings may survive at six times the rate of direct-released hatchlings (Green 2015). Headstarting increases the likelihood of hatchling turtles reaching sexual maturity, which is essential to maintaining the population while other conservation efforts advance. Wood Turtles exhibit higher survivorship as the length of time they are headstarted for increases, before experiencing diminishing returns after about one-year. Given limited funds and resources, headstarting turtles for one year may be the most efficient time period (Mullin et al. in press).

Headstarting efforts should only be conducted as part of a well thought and justified program by trained professionals with expertise in captive husbandry or headstarting turtles or other target organisms. Headstarting can potentially induce the spread of disease between headstarted turtles and wild populations (Alberts et al. 1998). However, this risk can largely be eliminated by following biological controls with captive animals and

1-2. Relocation of herpetofauna can be a useful tool when conducting a restoration. During these activities it is vital to include a professional herpetologist to ensure the safety of the animals and the effectiveness of the movement. Permits are required to conduct any rescue and relocation activities.

assessing disease risk in these individuals prior to releasing them to the wild (Jakob-Hoff et al. 2014, Calle et al. 2018). Though headstarting can play an important role in the recovery of a species, these efforts may not effectively bolster turtle populations unless the initial cause for decline is addressed (Smeenk 2010, Burke 2015). The higher adult survivorship is, the more effective headstarting efforts will be (Heppell et al. 1996). As such, headstarting is a management technique that must be employed alongside other methods aimed to address other challenges facing turtle populations.

Relocation, Translocation, and Rescue

When conducting a restoration or any other management or development activity that may disturb or threaten wildlife communities temporarily or permanently, relocation or translocation often referred to as 'wildlife clearance' or 'site walk-downs', should be considered. Relocation is defined as any movement of an animal, which can be within the same site; however translocation occurs when an animal is moved to an entirely new area usually some distance away from where it was found. Other situations where wildlife communities are imperiled may also require some level of 'rescue' to maintain viable populations, especially for rare or threatened species. Capture techniques, interim care, and release techniques should be appropriate to species' needs. This process requires that measures be taken to reduce the potential negative effects of donor and recipient sites. Do not attempt without consulting the proper authorities as rescue and translocation are regulated activities. A professional wildlife biologist with demonstrated experience and expertise in conducting these activities for amphibians and reptiles should be consulted to coordinate and conduct any effort that involves collecting, relocating, or holding an animal. Their skill and knowledge will help to ensure the safety of the animals and that all animals are moved and held legally and according to required permits. They also likely have knowledge of local areas and capture techniques that will make the rescue process more effective and rewarding. Due to many herpetofauna species' limited mobility and likelihood of being injured or killed during project activities, amphibians and reptiles greatly benefit from wildlife clearance efforts.(Griffiths and Pavajeau 2008, Germano and Bishop 2009, Bodinof 2010).

Receptor sites should be carefully selected and, if necessary, prepared for the wildlife to be released. Appropriate receptor sites depend largely upon the numbers of animals and the species to be released. The likelihood of long-term success of a relocation project is affected by the following criteria.

Location - The best options are sites that are close to the donor site and have good connections to other herpetofauna habitat. Because of the number of known and emerging diseases, care must be taken when considering a site. Potential pathogens should be evaluated when moving animals to new sites. Various veterinary labs and clinics can provide the necessary pathologic analysis to determine if a site is safe.

1-2. Even relatively inconspicuous and easy to create microhabitat, such as a small log, can provide ideal conditions to support amphibians and reptiles. These salamanders represent the animals observed under just one log. Simple steps such as this can have lasting effects on presence and density of amphibians and reptiles at a site.

Habitat - The conditions should be similar to donor site and have features necessary to support all aspects of the relocated animals' life cycles. Prior to any work, a receptor site should be evaluated for quality, structure, and functional similarity. If a site does not meet these criteria it should not be considered.

Size - Receptor sites should be at least equal if not larger than the donor site.

Season/Timing - Movement of animals should occur during the active season preferably in early spring to maximize the potential for adaptation and establishment. Alternatively if this is not possible, relocation can be done in late summer when conditions are cooler and when there is still sufficient warm weather to allow animals time to acclimate to new conditions and find suitable overwintering sites.

Pre-existing populations - If many animals are to be relocated, the receptor site should not already support those species to be relocated or an evaluation should be conducted to make sure the established population would not experience negative effects as a result of the relocation. If only a few animals are to be relocated, a pre-existing population of the species to be relocated should be present at the receptor site. This will incorporate relocated animals into a viable, breeding population. Pathological assessment is necessary when relocating animals to sites that support the same or similar species. In addition, the existing food chain dynamics should be taken into consideration. Releases should not occur at sites that have an abundance of predators or vulnerable prey populations.

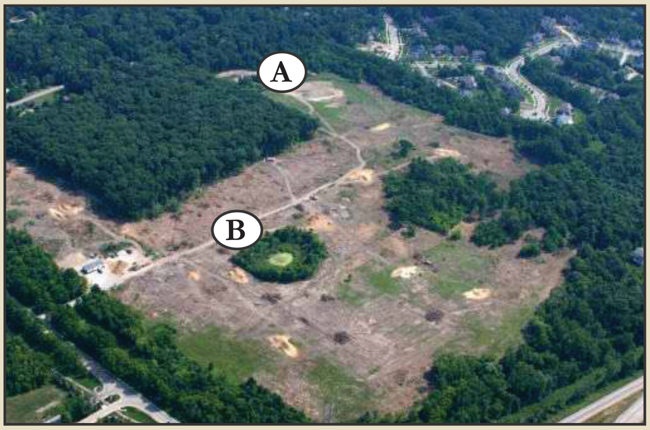
Founder population structure - The age structure, proportion of males and females, and size of a relocated population will contribute to the long-term viability of a population. These aspects should be included in analysis of the likelihood of long-term success.

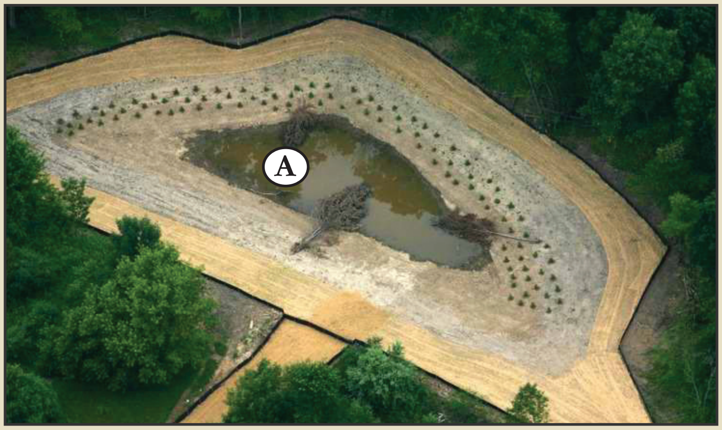
Prevent return to the donor site - Many herpetofauna have a 'homing' instinct and will return to a site after they have been moved (Farnsworth and Seigal 2012). Measures such as the placement of wildlife barrier fencing may be necessary to contain relocated animals to the receptor site during an adjustment period. In the case of "homing species" additional measures including the use of soft release are necessary. These cases involve a process where animals are partially contained in the new environment before being fully released. Studies have shown increased success when animals are allowed to slowly acclimate to their new environment (Tuberville et al. 2005, Alberts 2007, Parker et al. 2008, Attum et al. 2010).

Long-term management - After animals have been relocated, monitoring of the population and possible maintenance of habitat suitability may be necessary, depending on the site.

Multiple receptor sites - Having multiple sites that are linked may be useful in establishing a population. This can foster population connectivity and reduce the chance of a catastrophic event eliminating the entire relocated population.

Skyline High School Herpetofauna Rescue and Relocation





Ann Arbor Public Schools

In 2005, an intensive amphibian and reptile rescue was conducted in Ann Arbor, MI through a partnership between Ann Arbor Public Schools and City of Ann Arbor Natural Area Preservation (NAP). Important to the success of this effort was the involvement of a qualified herpetologist to approve mitigation design and placement, identification of recipient sites, as well as ensure that animals were handled appropriately. Translocation required permits and approval from the state.

Construction of the city's new Skyline High School resulted in the removal of the largest wetland on this site, a 0.5 acre vernal pool known as the "frog pond" (B) to neighbors. Located in an old field adjacent to an oak-hickory forest, this buttonbush dominated vernal wetland supported a diverse community of herpetofauna including at least nine amphibian species. A mitigation (A), designed to replace this wetland as best as possible and serve as a translocation site, was constructed prior to the rescue. Between March and August, approximately 5,000 reptiles and amphibians were moved from the impacted portion of the site to the mitigation, including common species which are often overlooked in conservation efforts. To date, the project has been successful as nearly all amphibian species known from the frog pond currently breed in the mitigation, and none were extirpated from the site.

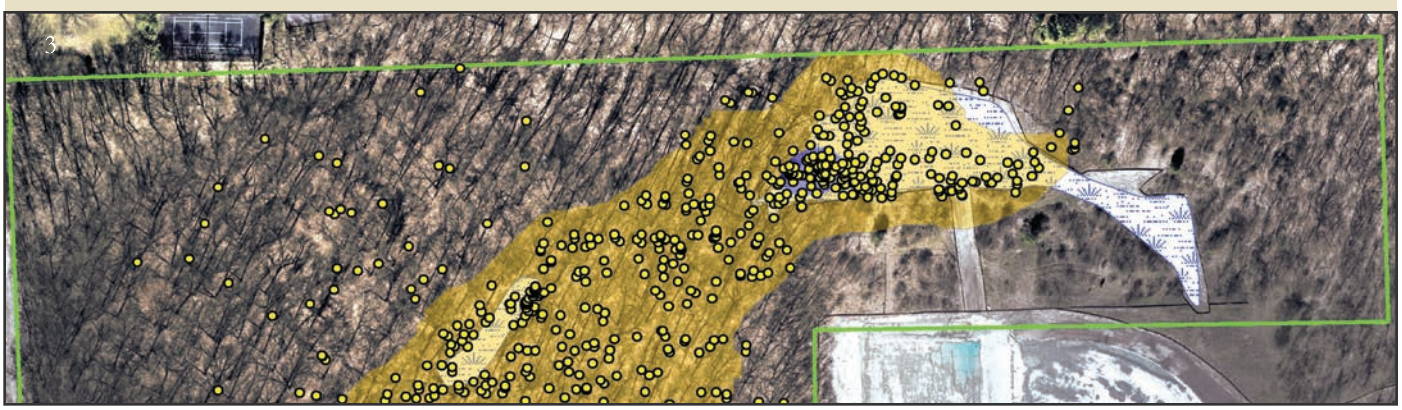
An important first step was installation of a wildlife barrier along the edge of the woodland, separating it and the mitigation from the frog pond to prevent herpetofauna from migrating to the frog pond in early spring. A three foot silt fence was used to maximize the likelihood of keeping amphibians and reptiles within the protected area and out of the construction zone, and was left in place and maintained for four years.

The mitigation was constructed in a section of old field immediately adjacent to the woodland. This allowed the species involved, which use forests for part or much of the year, to easily migrate to the new wetland without having to cross the lawns or roads being built on the rest of the site. Importantly, the mitigation was constructed before the frog pond was destroyed. This allowed for water to be pumped directly from the original wetland to the mitigation, resulting in the translocation and immediate establishment of macroinvertebrates and microscopic life. Mature buttonbushes (*Cephalanthus occidentalis*) were successfully transplanted from the frog pond as well. A seed bank was incidentally transferred along with the water and shrubs, and native plants established quickly. Since the water chemistry and food sources were identical to the source, the mitigation was immediately able to serve as a translocation site for breeding amphibians and their larvae.

Before translocation began, samples were collected and submitted for pathology testing to reduce the risk of disease transmission between the donor and recipient sites. The amphibians and reptiles rescued were released to the mitigated wetland or to the adjacent woodland, which included a much smaller vernal pool that was also a breeding site. Animals were collected from within the frog pond and elsewhere in the construction zone, but

also were removed from along the inside of the fence as they attempted to migrate. Breeding activity was noticed almost immediately among frogs and some salamanders released to the mitigation. Calling from translocated male frogs helped to draw others to the mitigation. Where large numbers of a species were translocated, portions were released to other suitable habitats within the city. These sites were selected for the occurrence of appropriate habitat and data indicating the historical presence of the species.

Intensive monitoring was conducted for four years following translocation. Coverboards and pitfall traps were used in conjunction with frog call and visual encounter surveys. During the first year after the destruction of the frog pond, a large number of amphibians and reptiles continued to migrate to the barrier fence, attempting to return to their historical breeding site. Over several years, migration activity shifted, with frogs and toads abandoning the original migration route completely and thriving in the mitigation. Even Midland Chorus Frogs (*Pseudacris triseriata*), previously referred to as Western Chorus Frogs, few of which were translocated due to difficulties stemming from their natural history, slowly recovered. Due to many salamanders being long lived some continued to attempt to migrate toward the frog pond. A decision was made to replace the temporary barrier made of silt fence with a more permanent fence designed to prevent species (especially salamanders) from wandering out of appropriate habitat. Novel projects like Skyline which utilize a well-designed and monitored approach are good examples of how projects can be successful when incorporating baseline data and a planning team with demonstrated expertise.



7. Management Techniques

1. Rare and sensitive species, like the Eastern Fox Snake, should be removed from areas being treated with chemicals during a species' active season.

This section provides information for land managers and those maintaining created and natural environments. This information can also be applied by others interested in conducting management that will minimize the negative impacts to herpetofauna. Several common land management techniques are harmful to amphibian and reptile communities, however, alternative strategies and practices and careful timing can be used to reduce negative impacts to herpetofauna and, in some cases, improve habitat quality for amphibians and reptiles.

Chemical Applications and Management

Chemicals are applied purposefully as well as unintentionally to a wide range of landscapes. Fertilizer, herbicide, and pesticide use is common in agricultural and residential areas. Accidental chemical spills or toxic contamination is associated with industrial land use, but due to the need to transport chemicals and the mobility of some chemicals in the environment, these events can even impact wilderness areas. Conventional management of agricultural lands, golf courses, swimming areas, and manicured landscapes often uses chemicals to control pests or weeds and in fertilizer applications (Ingram 1999). Additionally, the introduction of pharmaceutical byproducts into sewage water results in treated waste water discharge that contains hormones and other chemicals (Garric and Ferrari 2005, Gross et al. 2009). Chemical and hazardous spills and non-point discharge events can introduce harmful chemicals into aquatic and terrestrial biomes that can have public and wildlife health concerns (Andrews and Gibbons 2005). The introduction of chemicals to aquatic and terrestrial ecosystems can alter water chemistry, which can trigger physiological and morphological responses in organisms present (Hopkins et al. 2005, Brühl et al. 2013).

Pesticides, Nutrients, and Fertilizers

Herbicides, insecticides, pesticides, nutrients, and fertilizers contain chemical compounds that are meant to alter ecosystem function (e.g., kill pests, encourage growth). These chemicals can also have non-target impacts on amphibians and reptiles and should be avoided when used in proximity to these species whenever possible (See Section 3). Glyphosate based herbicides (e.g., Roundup®,

Figure 6. Spot-treat invasive plants and problematic weeds with quickly degrading, low toxicity herbicides during dry times or in the fall or winter when amphibians and reptiles are hibernating (A).

A 100-400 foot (min.) no-mow buffer adjacent to water bodies will help intercept chemicals in runoff and reduce erosion (B).

Use low toxicity substances inside as well as outside (C).

A diversity of native plant species can encourage a variety of predatory insects and wildlife that will reduce the need for pesticides (D).

Rodeo®, Accord®) that contain surfactants such as polyethoxylated tallowamine, which are commonly used to treat invasive plants, can severely impact amphibian species and cause population declines (Trumbo 2005, Howe et al. 2009, Relyea and Jones 2009).

The fertilizers applied in agricultural fields and residential areas and the nutrients that are sometimes byproducts of industrial and urban areas can be carried via stormwater runoff to aquatic ecosystems, sometimes up to 4,000 meters away (Houlahan and Findlay 2004). Added nutrients, specifically the introduction of phosphorous and nitrogen, can result in eutrophication, or the over-enrichment of water with nutrients that can stimulate excessive plant growth, of aquatic systems, which can facilitate shifts in plant and animal communities and decreased water quality (Smith 2003, Howarth et al. 2011, Chambers et al. 2012). Such shifts in aquatic macroinvertebrate communities may lead to a rise in parasitic infections and malformations in amphibians (Johnson and Chase 2004). Elevated levels of nitrogen (N) can also result in deformities in amphibians (Rouse et al 1999), and increased levels of nitrogen (N) and phosphorous (P) may reduce hatching success, increase deformity rates, and lower survivorship of frogs and salamanders (De Solla et al. 2002).

To reduce chemical applications, an ecosystem approach to management can be developed, which includes biopesticides, biological agents, integrated pest management, and site-specific cropping systems that limit pest influence (Lewis et al. 1997). Also, be sure necessary herbicide application permits are obtained, all other pertinent regulations are followed, and anyone who applies herbicides as part of their employment becomes a certified pesticide applicator before herbicide application. In addition, a permit from EGLE is usually required to apply herbicide where standing water is present. Several strategies can be used to reduce chemical impacts on the environment. Recommendations to reduce the impact of these chemicals on herpetofauna are described below.

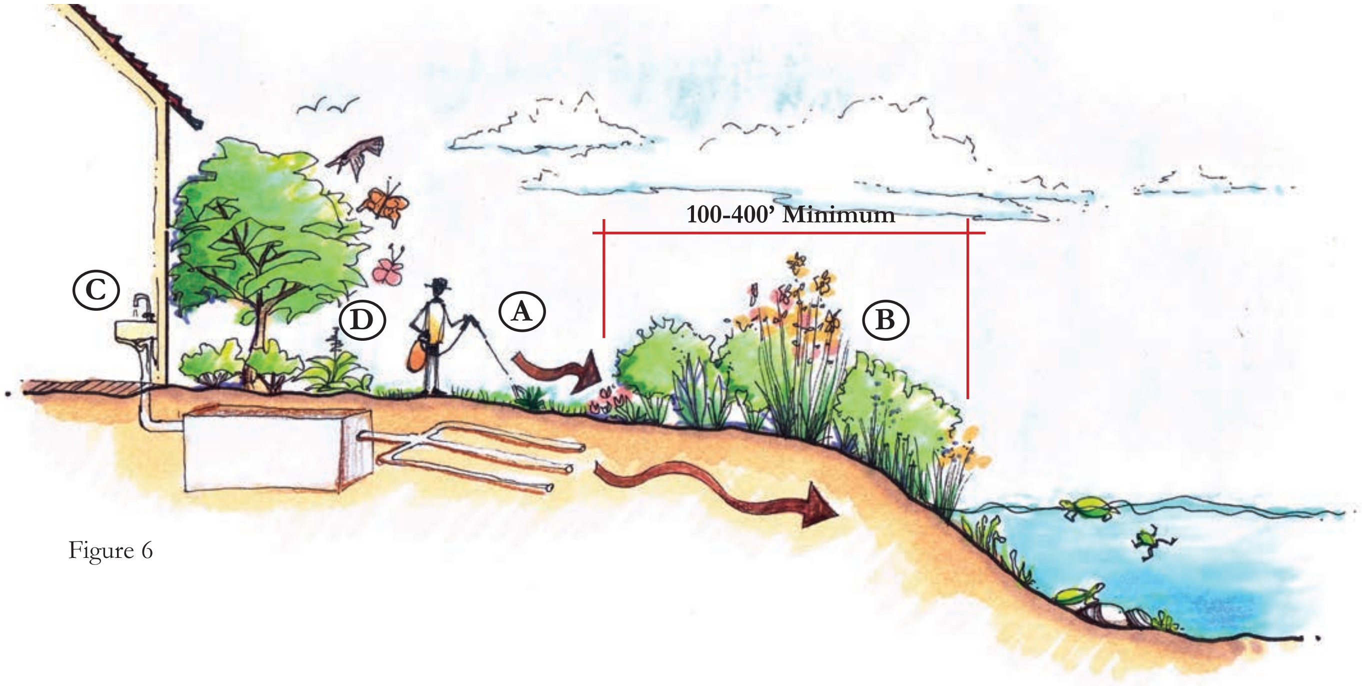


Figure 6

Sean Zera

1-4. Purple cone flower, bee-balm, arrowhead, and cardinal flower (clockwise from upper left) are native plants which can be used in buffer areas to enhance water quality and contribute to amphibian and reptile habitat.

Educate about techniques to reduce chemical, fertilizer, and nutrient inputs - Education about environmental side-effects of chemical applications, non-point sources of chemical contamination (stormwater runoff, lawn fertilization, and failing septic systems), and alternative practices can enable people to maintain their lands and homes in an environmentally responsible way. Simple, yet wide-reaching changes, such as reductions in lawn fertilization and the creation of un-mowed buffers (or no-mow zones) near water bodies (e.g., ideally 600-1,000 feet from a wetland, but at least 100-150 feet (Semlitsch 1998, Bodie 2001, Semlitsch and Bodie 2003, Calhoun et al. 2005) can help to reduce impacts of chemicals on herpetofauna. Changes in attitudes can also be as simple as the adoption of a "mixed plant" lawn which reduces the need to treat "weeds" and insects with herbicide and pesticide.

Implement alternative strategies to prevent the need for chemical applications - Prevention of weeds and other pests is the best and most effective strategy for eliminating the need for chemical applications. Changing maintenance practices to support a diversity of native plants and those that provide for beneficial insects and bugs (e.g., ladybugs, bees, dragonflies, predacious wasps, and spiders) can result in a diversity of birds, insects, reptiles, and amphibians to keep "pest" (e.g., aphids, slugs) populations in check. Also, use of companion planting (the ability of some plants to repel pests) can help to reduce pest populations. To prevent pest infestations, use barriers such as paper collars around the base of a plant to prevent burrowing pests, fine netting over plants, or sticky traps that deter and capture pests. Cutting, pulling, or digging up pest plants are often good alternatives to herbicide. Additionally, several amphibians and reptiles eat garden pests (e.g.., insects and rodents) and maintaining habitat that support these species can help control pest populations.

Use vegetated buffer zones between areas of chemical application and aquatic systems - Vegetated buffers, such as rain gardens, planted swales, and un-mowed areas, can intercept chemical runoff. Once stormwater runoff is intercepted, chemicals can be adsorbed to soil particles, intercepted by plant roots, and degraded by soil microbes (Pivetz 2001, Nannipieri et al. 2003). Some plant species also sequester chemicals and convert them into inert compounds, thus these plants may be beneficial to establish in these areas (Hinchman et al. 1996, Adesodun et al. 2010, Díaz et al. 2011, Murphy and Coats 2011). Wider buffer zones typically result in lower concentrations of herbicides entering the water. These lower chemical concentrations in the water bodies on which common and threatened amphibians and reptiles rely result in healthier herpetofaunal communities. When used in close proximity to streams, a buffer zone, ideally 600-

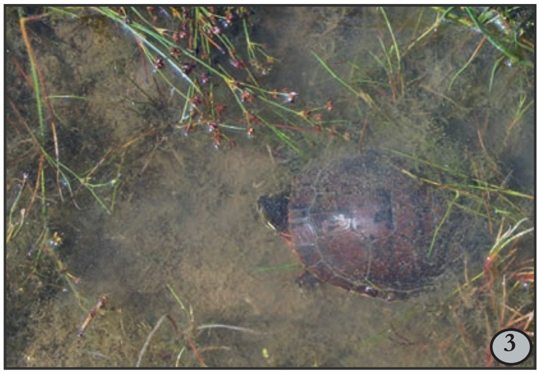
1,000 feet but at least 100-150 feet, with no chemical application, should be established to protect amphibian and reptile communities (Calhoun and Demaynadier 2004).

Apply chemicals during late summer and fall - If chemicals must be applied, application should be carefully timed to reduce contact with herpetofauna and other sensitive wildlife. Conduct management during times of the year when resident animals may not be present at the treatment location (i.e., treating a wetland when animals have seasonally migrated to upland areas) or when animals may be inactive (i.e., during times when they are burrowed in substrate, estivating, hibernating). Avoid application during times when amphibian larvae are present. Herbicides applied during times when amphibian eggs and larvae are not present will help to reduce negative side-effects to herpetofauna. However, tadpoles of frog species such as Bullfrogs and Green Frogs overwinter and are still present as tadpoles in late summer and fall (Harding and Mifsud 2017). Applying chemical in late summer and fall application will reduce exposure and potential negative affects to herpetofauna.

1-3. Spraying herbicide on *Phragmites* in fall when larvae have completed metamorphosis and animals have begun hibernation reduces direct exposure of species like Northern Leopard Frog (1), Eastern Gray Treefrog (2), and Midland Painted Turtle (3) to herbicide.

Apply chemicals in upland areas during "dry-spells" - The length of time between chemical applications and the next rainfall event affects the amount of chemicals entering nearby water bodies (Battaglin et al. 2009). To reduce the concentration of chemicals being washed into nearby water sources, the application of herbicides, insecticides, and pesticides in upland systems should be timed for the beginning of a 'dry-spell' when rain is not predicted. Reputable weather prediction sources, such as the National Oceanic and Atmospheric Administration (NOAA) National Weather Service, should be consulted to determine when drier conditions occur.

Apply quickly degrading chemicals during hibernation or estivation - Generally, herpetofauna are inactive when the temperatures are quite cold or very hot. Application of chemicals is likely most suitable in early spring prior to emergence, during mid- to late summer when herpetofauna are estivating or have moved to upland areas, or in late fall when herpetofauna have entered hibernacula (Michigan Natural Features Inventory 2012a). Be aware that some species do not follow these general patterns (e.g., salamanders are generally active in early spring). When selecting chemicals, refer to the information labeled on the product to determine how quickly it degrades. It is also important to keep in mind that degradation can vary based on weather and soil conditions.



Apply persistent chemicals earlier in the year, when possible - Early season application is preferable to late season applications because warmer temperatures increase soil microbial activity, which can increase the rate at which herbicides degrade (Helander et al. 2012). Some herbicides, such as glyphosate, can persist in the environment for at least 4 months during cool temperatures (Edwards et al. 1980), meaning that even when applied later in the season, herbicides will still be present in the spring when egg and larval abundance is highest. Other herbicides, such as triclopyr, can be detected in nearby aquatic systems up to 13 months after treatment (Battaglin et al. 2009). For chemicals with extended persistence, extreme care and consideration should be used to determine the necessity of use.

Exclude or relocate rare species during times of greatest risk - If any rare species occur within a treatment area, a wildlife barrier fence to reduce movement into treatment areas during application should be undertaken. The temporary relocation of the animals from the treatment area should be considered.

1. Using a hand-sprayer to spot-treat individual plants with herbicide is labor intensive but uses less herbicide. This reduces the cost of herbicide and the impacts on amphibians and reptiles.

Consider use of alternative, low-toxicity substances and biocontrols - Several alternative products, such as essential oils, soaps, low toxicity pesticides, surfactant-free herbicides, are available that reduce potential ecological degradation and reduce impact to herpetofauna communities. Direct contact with amphibians and reptiles should still be limited to reduce impacts to these sensitive communities; however, these substances generally do not persist for long periods of time and can be less toxic in the long-term. Use of biocontrols, or other organisms to control pests, can also be an alternative to chemicals; however, extensive research and testing is necessary to determine the full range of consequences of introducing one species to control another. Although still potent chemicals, use of surfactant-free glyphosate-based herbicides (e.g., Accord, Rodeo) may reduce mortality of tadpoles and juvenile frogs that is commonly associated with use of glyphosate-based herbicides that contain surfactants (Trumbo 2005, Howe et al. 2009, Relyea and Jones 2009). Always review if a product has been evaluated for amphibians and reptiles. Consult a professional herpetologist or certified wildlife biologist for recommendations.

2. This novel wetland system is comprised of a treatment wetland that mitigates the pH and temperature of stormwater runoff. The water is then outlet to this larger wetland area where herpetofauna and other wildlife thrive. Habitat features including projected nesting sites and basking logs were also placed to maximize site functionality.

Intercept runoff of chemicals before they reach aquatic systems - In areas where minimization of chemical application and strategic timing are not options or where particularly hazardous chemicals are applied, specifically designed bioremediation systems may be implemented. These systems work by retaining and treating contaminated runoff. Soil-based and biobed (tank enclosed) systems can degrade heavy loads of pesticides to acceptably low concentrations for discharge into groundwater and surface water systems (Rose et al. 2003) and prevent chemicals and pathogens from entering ground water. These systems generally consist of a multi-tank arrangement, including a tank enclosed pit in the ground, which contains a mixture of straw, soil and compost where the majority of treatment occurs (ADAS 2006). These systems are inexpensive and are able to degrade chemicals (Boivin and Guine 2011).


Glenn Barrett

1. When applying chemicals near sensitive habitat, measures should be taken to reduce harm to amphibians and reptiles.

2. Chemicals applied throughout the landscape along with residential and commercial debris often accumulate in nearby wetlands like the one this Bullfrog is occupying.

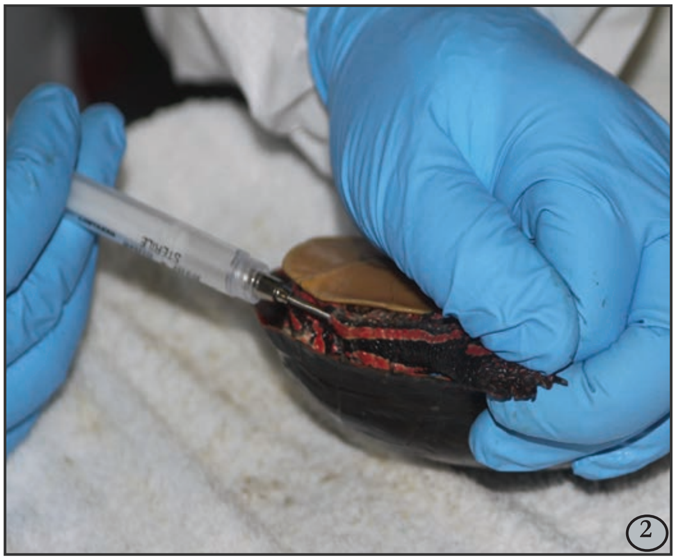
Apply chemicals sparingly - Only using the specific amount of chemicals to obtain a desired effect (pest control, plant growth) can save money and reduce ecological impacts by applying the smallest amount necessary. Application of herbicides through spot treatments - using an applicator (e.g., hand sprayer, sponge, glove, etc.) to apply herbicide to individual plants - may involve more labor compared to larger spray treatments using machinery but also uses less herbicide. Spot treatment targets a specific plant and reduces side effects to non-target organisms. Broadcast application should be avoided, as it indiscriminately affects target and non-target organisms over application and airborne drift is difficult to avoid. This method is not always possible as the type of invasive plant may require broadcast application to effectively eradicate. When chemical application is necessary, time applications to minimize impacts on species known or suspected to occur at a site. Use soil testing and plant nutrient uptake (i.e., integrated nutrient management) to determine how much fertilizer plants will be able to utilize. Avoiding over-application of fertilizers results in healthier plants, monetary savings, and fewer ecological impacts.

Identify and prevent non-point nutrient inputs - Industry, urban runoff, and residential runoff can input substantial nutrient loads. By following general principles of stormwater management (i.e., reduce volume, increase time, and increase quality before reaching surface waters), the concentration of nutrients in these sources can be significantly decreased.

Oil and Chemical Spill Response

Post-spill crude oil exposure has been related to lower egg fertility, hatching success, and hatchling abnormalities in Snapping Turtles and Painted Turtles (Bell 2005). Oil spills can cause loss or displacement of aquatic turtles at a site (Luiselli and Akani 2003) and chemical burns, sloughing of scutes, and respiratory problems can also result (Mifsud personal observation 2022). When dealing with long-lived species such as turtles, it is important to address these issues as populations can be negatively affected by the loss of relatively few individuals.

Timely Response - Rehabilitation of oil-exposed wildlife is time sensitive with the greatest results occurring from prompt action (Saba and Spotila 2003). The faster post-spill response and rehabilitation action is taken, the more individual animals may be rehabilitated and re-released into a restored or healthy habitat. Rescue of herpetofauna should be conducted in a humane and timely manner.



1. Chemical spills can result in the direct loss of animals. Exposure can compromise immune systems as well as alter thermoregulation opportunities for reptiles.

2. It is critical to document long-term behavior and survival of animals affected by a chemical spill. This can be done through tagging animals and performing mark-recapture studies.

Provide appropriate conditions for recovering herpetofauna - Decontamination and rehabilitation facilities should provide appropriate shelter, controlled temperatures, high-quality food, clean water, and levels of cleanliness standard in zoological and animal husbandry settings.

Get professional assistance - A professional herpetologist and a qualified veterinarian or veterinary technician with expertise and experience with amphibians and reptiles should be contacted for assistance in planning and conducting herpetofauna rescue efforts.

Metal and Toxic Contamination

Industrial and municipal wastewater and other brownfield/ contaminated sites can contain metals such as nickel (Ni), tin (Sn), zinc (Zn), cadmium (Cd), and selenium (Se). These metals can inhibit physiological response (Hopkins et al. 2003), lead to deformities in amphibians (Rowe et al. 1996, Rowe et al. 1998), pose toxic effects to aquatic turtles, and accumulate in turtle eggs, which may lead to reduced hatchling success and life function (Tryfonas et al. 2006). Because of the variety of contaminants and the range of contamination levels at each site, a site-specific decontamination plan is necessary in most situations. For more information, visit the EGLE or EPA websites.

Stormwater Management and Soil Erosion Control

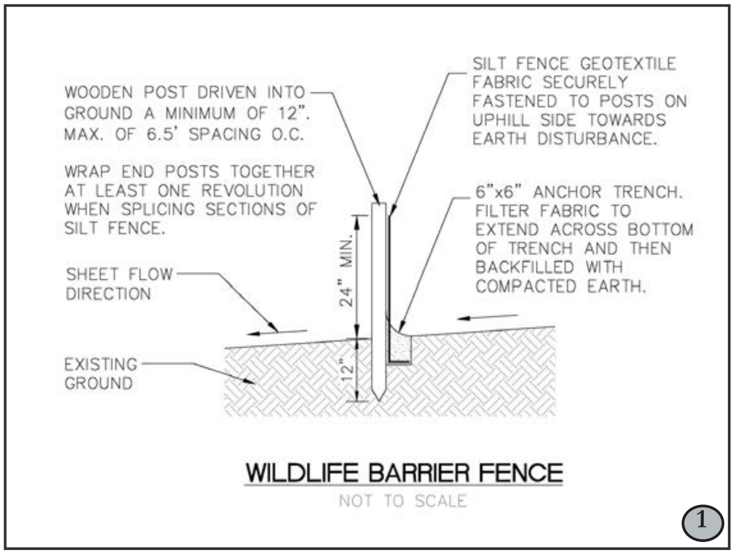
Land management and development influences what happens to precipitation that runs off a landscape as stormwater and can affect the rate of erosion. Several problems, such as downstream flooding, bank erosion,, increased sedimentation and turbidity, and associated contamination can result from improper stormwater management leading to impacts on water-dependent herpetofauna (Booth and C.R. 1997, United States Environmental Protection Agency 1999, Public Sector Consultants 2002, Murray and Hoing 2004, Massal et al. 2007). These impacts can degrade amphibian and reptile use through fragmentation, and destruction of plant communities, and change the distribution of habitat features that support specific species (See Section 3).

Stormwater management and soil erosion control (SEC) should be an essential part of any construction project and is required by EGLE for activities that disturb one or more acres of land. Visit the EGLE Soil Erosion and Construction Stormwater webpage for more information on these requirements and the MDOT Soil Erosion and Sedimentation Control Manual for detailed information on commonly used techniques. Techniques to manage stormwater and control erosion help improve the quality of stormwater that enters surface and ground water sources as well as enhance and maintain the health of herpetofauna and other wildlife communities.

Create a stormwater management and erosion control plan - Develop a comprehensive plan that complies with current EGLE regulations and takes into account the presence of local herpetofauna. The planning stage is the optimal time to assess which stormwater management and SEC measures will be used and the potential benefits and risks these measures pose to herpetofauna. Consider techniques that create wildlife habitat and provide long-term stormwater management and erosion control.

Wildlife Barrier Fencing

Wildlife barrier fencing (WBF) is an effective proactive measure for protecting herpetofauna through reducing the risk for species to be physically injured or killed by excluding animals from active impact areas. WBF typically consists of a three-foot-tall silt fence or net-less soil erosion control fencing with at least twelve inches below the soil surface with the remaining twenty-four inches exposed to be effective at excluding wildlife from a construction area. Silt fencing, commonly used for soil erosion control, and WBF can be used interchangeably to serve dual purposes in many cases. WBF should preferably be orange in coloration when installed in locations with the potential for rare species, such as the Eastern Massasauga Rattlesnake, to alert project personnel protected species may be in the area. When rare species of herpetofauna are not suspected to occur within the area, typical black WBF coloration is preferred. Each terminal end of WBF should have a "J-hook" that forms a curve facing away from the construction site. The radius of J-hook curves is most effective when it is at least three feet in diameter. This design will help deflect animals traveling along the fence away from the project area.



1. Sample detail of a standard wildlife barrier fence design.

2. Example of a J-hook curve used to deflect animals traveling along the barrier away from the project site.

WBF should be installed after brush and groundcover have been removed within the proposed delineation but before any construction activities occurs, including the removal of trees and any other remaining woody vegetation within the area. The specific locations for WBF placement are dependent upon the proposed project activities and limits of disturbance. Project personnel should inspect WBF daily to search for holes, tears, and other gaps or damage to prevent herpetofauna from potentially entering the workspace. Any deficiencies should be repaired and area investigated for wildlife before any vehicles or equipment operates within the workspace. Vehicles and equipment should

U. S. Fish and Wildlife Service

1. Large swaths of plastic SEC netting pose a major threat to herpetofauna and wildlife populations, especially when utilized near sensitive natural resources.

2. A State Threatened Eastern Fox Snake observed trapped within plastic SEC material.

3. An Osprey entangled with plastic SEC netting. Many other wildlife species are also negatively impacted by harmful SEC materials.

not travel outside WBF if within identified habitat areas. WBF should remain in place and be properly maintained until construction activities are complete. It is recommended that WBF be removed during the final cleanup of a project on the condition that herpetofauna dormant season has begun (November through March) or activities are closely monitored by qualified biologists. Silt fence and WBF can create an unintended barrier for herpetofauna (Kittredge Jr and Parker 1995, Calhoun et al. 2005, Glista et al. 2009) and can reduce connectivity when it remains on the landscape after a construction project is completed.

Wildlife-Friendly Soil Erosion Control

SEC materials are a critical component of restoration projects and are typically necessary to ensure the success of a site's establishment. A significant portion of SEC material used in projects is photodegradable and contains plastic mesh that is intended to degrade after two years. However, once these materials achieve their intended purpose and vegetation is established, UV energy becomes limited or no longer reaches the matting, preventing the complete breakdown of the material. As a result, this plastic monofilament mesh, the same material used for fishing lines, presents major risks to wildlife as it can remain on the landscape for up to a decade or more. Substantial evidence indicates this type of SEC causes direct injury or mortality to wildlife that become entangled (Walley et al. 2005, Kapfer and Paloski 2011, Minnesota Department of Natural Resources 2013, U.S. Fish and Wildlife Service 2022). While a number of animals are known to be vulnerable to SEC materials, herpetofauna, and snakes in particular, are believed to be the most affected, likely due to their limited mobility (Walley et al. 2005).

Reports of reptile entrapment in SEC netting often contain descriptions of lacerations on entrapped animals, which appear to suffer high rates of mortality after becoming entangled, often due to dehydration, overheating, stress, and/or physical trauma (Walley et al. 2005, Kapfer and Paloski 2011). The most common reason for reptiles becoming ensnared in SEC netting is likely that apertures in the netting are too small to allow many snakes and lizards to pass through safely (Kapfer and Paloski 2011). At least nine species of native snakes in Michigan have been documented ensnared in SEC netting. These include at least three State-listed species and one Federally-listed species; the Eastern Fox Snake, Black Rat Snake, Butler's Garter Snake, and Eastern Massasauga Rattlesnake. Anecdotal evidence of impacts of SEC netting to some amphibians has also been reported, including the entanglement of Eastern Red-backed Salamanders and metamorph frogs in mesh with fine apertures. Because the mesh tends to break down slowly, it can also impact turtle nesting opportunities and entrap hatchlings that may be under the surface at the time of fabric placement, resulting in increased predation or desiccation.

Not Wildlife-Friendly	Less Risk to Wildlife	Wildlife-Friendly
• Square plastic netting that is: - Degradable - Photodegradable - UV-degradable - Oxo-degradable - Oxo-biodegradable • Made from: - Polypropylene - Nylon - Polyethylene - Polyester • SEC left longer than required	• Elongated mesh netting - Mesh > 2.54 cm	• Natural fiber netting or no netting • 100% biodegradable • Loose weave, non-welded, movable jointed netting (leno or gauze) • Weed or seed-free • Secure SEC with wooden stakes or live stakes • Bury edges of blankets & mats • Remove SEC when no longer required • Spray on mulch • Seed & plant native vegetation

U. S. Fish and Wildlife Service

1. Attributes of SEC materials and their designation as non-wildlife-friendly, wildlife-friendly to a lesser degree, and wildlife-friendly. Wildlife-friendly specifications should be selected as much as possible.

Alternative options for SEC netting that use biodegradable materials are available. These wildlife-friendly products consist of natural netting materials as opposed to plastic monofilament mesh. These materials should include at least 30% natural jute, coir, or other organic fiber with inner matrix consisting of coconut, straw, aspen or similar organic fibers. Wildlife-friendly SEC material ideally incorporates leno weave (or equivalent) top and bottom netting, is approximately ¼ inch thick, possesses large apertures at least 4cm x 4cm, and contains weed-free contents. SEC blankets should also be thoroughly secured to the ground surface to eliminate spaces under the netting, and to avoid lifting as vegetation grows. The requirements of a project site and desired longevity of SEC can help determine which design and materials should be used. Natural, biodegradable products have been shown to provide SEC that is as effective and also contributes to retaining moisture for plant growth. Additionally, the cost of biodegradable products is comparable to that of commonly used plastic materials (Slesar 2009). Recognizing the importance of using such products, some government agencies have updated the standard specifications for work throughout their respective states.

U. S. Fish and Wildlife Service

2. Example of wildlife-friendly, biodegradable SEC material.

Stabilize slopes with native plants instead of turf grass to reduce long-term erosion - Often turf grass is planted as a means to stabilize a slope or to reduce long-term erosion. Turf grass is typically mowed and has greatly reduced root penetration compared with native vegetation (United States Environmental Protection Agency 2012). Root depth is directly related to the amount of water the vegetation allows the soil to absorb during a precipitation event, and thus related to the ability of the vegetation to prevent erosion. Turf grass maintained as lawn has limited value for native wildlife and provides little cover or food for herpetofauna. Unfortunately, turf grass seed

1. Detention ponds allow stormwater to be filtered while providing habitat for amphibians and reptiles. Caution should be made regarding salt inputs from roads as over time increases in salinity can degrade habitat

2. Excess nutrients in runoff from agricultural areas can contribute to algal growth and poor habitat conditions for aquatic amphibians and reptiles.

mixtures typically contain non-native varieties, and require large quantities of water to maintain a lush, green appearance. These water inputs often times are from potable water sources (Kjelgren et al. 2000) or draw from local water tables during the summer when water levels are lower. Seeding or planting native plant species can help contribute to herpetofauna habitat by stabilizing slopes with plants having longer roots and by providing a diversity of niches (Ingram 1999). Native plants often require less water and maintenance, which can reduce pressure on water supplies and maintenance costs.

Reduce impermeable surfaces - Where possible, impermeable surfaces should be removed or replaced with permeable materials (e.g., vegetation, permeable paving). These permeable materials allow stormwater to be absorbed and to replenish groundwater and surface waters via soil infiltration. The result is higher quality waters, which are healthier for humans and wildlife. A reduction in impermeable surfaces can reduce costs initially by simply reducing the area being covered. Although permeable pavement installations are similar to traditional paving materials (e.g., concrete and asphalt) in installation costs (i.e., \$3-\$15 per square foot; Foster et al 2011), it can contribute to long-term monetary savings. Permeable paving in urban areas can reduce the need for additional stormwater management infrastructure and salt application (Wise et al. 2010). This method can also reduce human health costs associated with inadequately managed stormwater (Gaffield 2003), and avoid property and infrastructure flood damage (Foster et al. 2011). Substituting areas with native vegetation for pavement can also reduce long-term maintenance costs compared to non-native varieties, as native plants that are appropriate for the site condition require little care beyond establishment.

Retain and detain stormwater using detention and retention ponds, constructed wetlands, filter strips, swales, rain gardens, and green roofs - Where possible, construct or maintain vegetated areas where stormwater runoff can be directed. Detention and retention ponds vegetated with native plants, small constructed wetlands, planted filter strips, vegetated and bio-retention swales, rain gardens, and green roofs improve water quality (Friedlich et al. 2007, Baltrenas and Kazlauskiene 2009). These features allow water from precipitation and runoff to be absorbed by plants and percolate slowly through the soil, thus reducing the amount of runoff entering surface waters, filtering the water, and gradually releasing water from melt and precipitation events into surface waters. This can reduce flooding and erosion, as well as ensure that the water entering the surface waters will be cooler, cleaner, and provide higher quality amphibian and reptile habitat.

Amphibians and reptiles as well as other wildlife can benefit from the creation of stormwater retention and detention features in sites that are connected to other areas of habitat. Place structures for nesting, basking, and hibernation within or adjacent to these features to avoid the

Rain garden or vegetated or bio-retention swale - A vegetated, shallow ditch designed to move water and sediment slowly to increase infiltration. Side slopes should be less than 1:4. Common uses are around parking lots and along roads. Rain gardens are vegetated depressions that temporarily hold standing water and allow for water to infiltrate and pollutants to be filtered by the soil and plants. The water is directed to groundwater because of the permeable soils of this feature.

Retention and detention ponds - These ponds intercept surface runoff before it reaches an adjacent water body. Retention ponds can also be used to control flooding and permanently hold water. Detention ponds temporarily hold water and slowly release water to nearby water bodies. In some cases, the establishment of native vegetation may be beneficial in preventing erosion and increasing wildlife habitat and biodiversity.

Sean Zera

Sean Zera

Green roof or living roof - A vegetated roof with a variable depth of planting media. The vegetation and soil intercept rain and reduce the stormwater runoff from a roof.

creation of an ecological "sink" where herpetofauna may be drawn to nest, but are not able to successfully reproduce or carry out their life functions. Stormwater retention and detention features that function as natural systems with connectivity to other habitat areas can improve habitat functionality and often require less maintenance than manicured landscape areas.

Isolate detention and retention features that mitigate heavily polluted runoff - Pollution from roadways, chemicals applied to the landscape, contaminant spills, and other sources of pollution on the landscape are transported by stormwater runoff to nearby water bodies. Construction of detention and retention features can help filter and contain pollutants to prevent the contamination of natural water bodies. However, herpetofauna or other wildlife that travel to these polluted water bodies will be exposed to these contaminants through eating contaminated food sources and absorption through their skin (See Section 3 for a range of impacts of pollution on amphibians and reptiles). Locate detention and retention features that collect pollution in areas without hydrologic connectivity with sensitive wetlands. Some researchers recommend that retention and detention ponds be located at least 750 feet away from vernal pools or other sensitive wetland areas (Calhoun and Klemens 2002). Also, high levels of pollution may threaten the viability of herpetofauna that immigrate to a retention or detention feature and may warrant the creation of a barrier (e.g., permanent silt fence with one-way excluder gates) around the feature to reduce use by sensitive herpetofauna. These precautions will reduce the risk that these areas will become biological traps. Additionally, use of natural wetlands as retention or detention areas for potentially polluted stormwater runoff is not recommended.

If heavy metals (e.g., lead, chromium, cadmium) or other substances that do not readily degrade (e.g., arsenic) are present in runoff entering the area of filtration, the soil will accumulate these pollutants (Davis 2007, Muthanna et al. 2007) and may need to be removed and replaced if the concentration reaches an unacceptable level or becomes toxic.

Separate storm and sanitary sewer systems - Many urban areas have combined storm and sanitary sewers, which under typical circumstances drain to a water treatment facility. During severe, or relatively minor, storm events, the overflow from these systems results in raw sewage entering rivers (United States Environmental Protection Agency 1999). The increase in thermal, chemical, and biological pollutants can degrade habitat quality for herpetofauna.

Balance withdrawals and discharge from water reservoirs - Water being withdrawn for irrigation, drinking water, industrial use, etc., should be balanced by water inputs and also consider the seasonal fluctuations in water level required by herpetofauna and other wildlife. Maintenance of the water level will avoid drawdowns and ensure the water necessary for herpetofauna at critical life stages (i.e., eggs, larvae, breeding adults).

1. Woody debris from forest management can be repurposed as cover and basking objects for amphibians and reptiles.

Forest Management

Common forestry management practices can be important in maintaining healthy forest ecosystems however they involve activities that can also degrade habitat structure and be detrimental to amphibians and reptiles (Hansen et al. 1991, DeGregorio 2008). Machinery can cause direct mortality to forest herpetofauna such as Wood Turtles and Eastern Box Turtles (Erb and Jones 2011) as well as create pools in ruts, pits, and behind soil ridges, which block drainage. These created pools may provide water for breeding but dry too quickly to support metamorphosis of amphibian larvae (Calhoun and Demaynadier 2004). Tree removal in upland areas can result in less canopy cover, reduced woody material on the forest floor, and alterations in hydroperiod of forested wetlands (Calhoun and Demaynadier 2004). Since forest dwelling amphibians respond

1. Maintaining canopy cover through various harvest techniques can help salamander populations persist. It is important to maintain woody debris as microhabitat during forestry management.

to these habitat characteristics (Feder 1983, DeMaynadier and Hunter 1995, Demaynadier and Jr. 1998, DeMaynadier and Hunter Jr 1999, DiMauro and Hunter 2002) their populations can be significantly reduced as a result of these practices. Vernal pools - seasonal forest pools - are only seasonally inundated or may hold water year-round except in times of severe drought. Vernal pools that hold water year-round are shallow and freeze solid and/or become anoxic during the winter and kill off fish. Vernal pools are particularly sensitive to disturbance and are critical to the survival of several amphibian species that do not successfully reproduce or have low species richness in the presence of fish (Figiel Jr and Semlitsch 1990, Hecnar 1997, Snodgrass et al. 2000).

Strategic planning of operations can lessen the impact forestry has on herpetofauna directly and indirectly through reduction of sediment and erosion near rivers, minimization of disturbances near vernal pools, and maintenance of amphibian and reptile habitat components (Dupuis and Steventon 1999). The MDNR manages state forest lands using an ecosystem-based approach (Michigan Department of Natural Resources 2013), and it is our intent that the following recommendations help to support this aim.

Vehicle Use

Use tracked vehicles - Tracked vehicles distribute the weight of the equipment over the surface of the entire track, which lowers the pressure applied to the ground and decreases soil compaction compared to wheeled vehicles (Bol 2007). This can minimize short and long-term impacts to the landscape and better maintain habitat quality for wildlife.

2. Construction mats help to reduce the compaction of hydric soils and prevent ruts caused by equipment from forming.

Use construction mats - Large landscape timbers connected together to form 10'x10' mats can be placed in a temporary road formation to convey construction equipment over wetlands while minimizing compaction of soil. Mat roads reduce the creation of ruts in sensitive wetland areas and maintain the quality of herpetofauna habitat throughout forested areas. Although these mats reduce long-term impacts to forest conditions, if not cleaned between uses they can be vectors for disease and introduce invasive plant species into areas that are currently not infested.

Clean equipment after use - Equipment that is not cleaned between uses at sites can introduce invasive plant seeds and roots from other sites. Although permits may not require equipment to be cleaned between uses at sites, this practice is advisable to maintain the ecological integrity of a site and to reduce impact to valuable herpetofauna habitat.

A timeline of amphibian and reptile and forest management actions. Consider which species are likely present and their life stages when planning management actions.

Reduce use of vehicles off-road - Restricting vehicle traffic (machinery and all-terrain vehicles - ATVs) to roads will reduce the damage to wildlife habitat and reduce direct herpetofauna mortality by crushing or collision in forested areas (Congdon and Keinath 2006). Tire ruts can hold water and may appear as suitable nesting areas for vernal pool breeding amphibians but may not hold water long enough for eggs to metamorphose into adults (Calhoun and Demaynadier 2004). If these ruts do not exist, adults will likely continue onward to a vernal pool with a suitable hydroperiod to support larval amphibians. Reducing habitat disturbances from vehicle traffic can also reduce the introduction of invasive plant and animal species.

Season	Soil Condition	Amphibian and Reptile Actions	Management Actions
Spring	Saturated	Migrations between uplands and wetlands. Breeding in wetlands.	Minimize harvest or machinery use. Place branches over roads in early spring.
Summer	Dry	Adult movements into uplands to forage.	Minimize harvest or machinery use. Survey areas on foot for herpetofauna.
Fall	Partially Saturated	Juveniles migrate upland and some overwinter in pools. Begin hibernation.	Begin harvest with light machinery in late fall.
Winter	Frozen	Hibernation underground and in areas with heavy litter layer.	Use equipment in least sensitive areas and restrict movements to roads as much as possible.

Conduct excavation, fill, and grading during warm weather - Amphibians and reptiles are active during warmer seasons and are less likely to be burrowed in the soil. They are better able to escape disturbance during warm weather; however, most amphibians and reptiles are relatively slow-moving and an effort to relocate individuals from sensitive or at-risk populations may be necessary to avoid significant mortalities.

1. Earthwork conducted during warm weather gives slow-moving amphibians and reptiles a chance to evacuate a disturbed area. Work outwards from a single point to better allow these animals to escape. When possible conduct a rescue and relocation to avoid mortality especially with rare and declining species.

2. Eastern Box Turtles are susceptible to crushing by heavy equipment.

3. Water gathering in the tire tracks indicates that this road was placed in too wet of an area. This artificial pool may attract breeding amphibians and trap larvae.

Use heavy equipment or off-road vehicles when the ground is frozen - Forest-dwelling amphibians and reptiles, such as Eastern Box Turtles, are particularly susceptible to crushing from motorized vehicles during timber harvest and clearing from ground thaw until ground freeze. With the onset of colder weather, these animals hibernate underground. The frozen ground is better able to support heavy machinery and vehicles without rutting the soil and crushing herpetofauna (Bol 2007). Depending on the extent of vehicle use and compaction caused by the equipment, hibernating animals may also be crushed during the winter. Using heavy machinery that uses treads instead of tires and working at the coldest times of the year when ice roads can be used can reduce soil compaction and crushing of animals burrowed in the ground, but avoidance of high-quality habitat is the best option. Restrict motorized vehicle use on wood roads, skid roads, and staging areas to times of year when the ground is frozen (i.e., December 1st to March 30th).

Place logging roads in low impact areas - The creation of any road will result in direct road mortality as well as habitat fragmentation and degradation. Logging roads should be located in areas not likely to impact forested wetlands, vernal pools, or hydrologic processes. Road placement should also take into consideration species-specific habitat requirements, such as Wood Turtles nesting areas, and avoid bisecting other valuable habitat areas.

Seasonally close roads and place structure over roads - Some forest-dwelling amphibians, such as salamanders and Wood Frogs, seasonally migrate between wetland and upland areas. These migrations typically occur during some of the first warm, rainy spring nights of the year and closing roads in key migration areas during these times can reduce mortality of amphibians (Timm et al. 2007). This management practice is utilized successfully in Shawnee National Forest in southern Illinois. Additionally, closing roads during the rainy times in spring can reduce compaction of soil, erosion, and creation of ruts which can fill with water and become an ecological trap for amphibians looking for a place to breed. These ruts will likely dry out before the eggs metamorphose and reduce the number of surviving amphibian offspring. Boughs and branches should be placed over access roads that are not actively being used. This cover can help to reduce the impact of the road as a physical barrier to herpetofauna by providing suitable habitat conditions to facilitate their movement across the landscape.

1. Branches placed across inactive seasonal roads can provide refugia and necessary microclimate to facilitate movement of herpetofauna across the landscape.

Harvest Techniques

Harvest during late fall to early winter - Harvest and general forest management should occur from late fall to early winter or when temperatures are cold and animals are inactive. Also, operating heavy machinery on frozen ground reduces crushing animals and disturbances (e.g., reduces soil compaction and rutting), which would create unsuitable conditions for herpetofauna like salamanders that burrow into the soft soil and litter layer of the forest floor.

Consider various tree harvest techniques - Using shelterwood (removing taller trees while maintaining shorter trees to protect seedlings and the forest floor), group selection (small-scale clearcut), or single-tree selection (removal of individual trees) cuts can help maintain various levels of canopy and understory cover, which are beneficial for herpetofauna while meeting forest management objectives. These techniques may reduce the relative abundance of salamanders, but since these techniques maintain more canopy cover than clearcuts or seed tree cuts, they may better facilitate the persistence of salamander populations (Brooks 1999, Harpole and Haas 1999). Timing of tree removal for winter when the ground is frozen and use of smaller equipment can minimize habitat disturbance. By only removing some of the trees, canopy cover and understory cover can be maintained which can help preserve landscape connectivity for some salamander species.

2. To avoid causing harm to the herpetofauna occupying a site, various tree harvesting techniques including selective cutting should be utilized. Timing activities to minimize harm to herpetofauna is encouraged.

Avoid clearcutting large areas - Strategic clearcuts and seed tree cuts (cutting all trees except a select few to remain to provide seeds for forest regeneration) can be used to create habitat features for some wildlife (i.e., snowshoe hare, Kirtland's warbler) and can be conducted in accord with regard for biodiversity (Conroy et al. 1979). However, clearcutting can be detrimental to Michigan amphibians, specifically salamander communities, which have been shown to have significant reductions in abundance compared to non-clearcut control sites (DeMaynadier and Hunter 1995, Semlitsch et al. 2009) and can take decades to rebound (Petranka et al. 1993). Seed tree cuts also reduce most canopy cover, which can reduce landscape connectivity and relative abundance for salamanders (Harpole and Haas 1999).

Consider the wildlife habitat value of the resulting landscape pattern - When conducting forest management, whether clearcutting or simply removing a few select trees, fragmentation and resulting landscape pattern should be considered to minimize negative effects on amphibians and reptiles that rely on forest (i.e., those that use forest surrounding vernal pools) (Hansen et al. 1991). Maintaining corridors of high-quality upland habitat among wetlands can help to maintain landscape connectivity for amphibians and reptiles. Also, tree community types contribute various

1. The Western Fox Snake inhabits pine and oak woodlands including brush-covered clear-cuts within Northern Michigan.

2. Leaving woody debris and ensuring proper understory conditions following timber harvest provides habitat for species such as the Northern Red-bellied Snake.

levels of herpetofauna habitat and landscape connectivity (Degraaf and Rudis 1990), and several species of Michigan herpetofauna rely on conditions provided by hardwood stands (e.g., oak-hickory and beach-maple) (Mitchell et al. 1997, Harding and Mifsud 2017). Removal of softwoods, such as poplars, contributes to herpetofauna habitat to a lesser degree and their removal will likely have little impact on herpetofauna.

Use coarse woody debris to create simple habitat structures - It is not uncommon for woody debris to be cleared from an area after timber harvest, thus reducing ground cover and shade necessary for forest floor amphibians and reptiles. To provide structure and conditions beneficial for salamanders, frogs, snakes, and the Eastern Box Turtle, some snags, fallen trees, and treetops should be left in clearcut areas (Hansen et al. 1991, Ash 1997, Bol 2007). For details of these structures see Section 6. In addition, fallen logs may already provide vital structure for wildlife and should not be disturbed.

Maintain the litter layer and understory vegetation to provide appropriate microclimate conditions - Understory vegetation and the litter layer of fallen leaves and decomposing materials on the forest floor helps to maintain moisture levels and cool temperatures needed to support a diversity of herpetofauna (Dupuis et al. 1995, Baldwin et al. 2006, Semlitsch et al. 2009).

Rotate cuts - Rotating cutting to allow 20-70 years between harvests, depending on flora and fauna present, will likely allow for the re-establishment of herpetofauna populations after a cut (Petranka et al. 1993; Ash 1997). The presence of an established population will also provide individuals to colonize other nearby clearcut areas that regenerate and provide suitable herpetofauna habitat. Cuts should also be rotated in a manner to maintain forested corridors between wetlands and to avoid cutting near vernal pools and other forested wetlands.

1-2. Vernal pools in forested areas are sensitive and important breeding and foraging grounds for many species of amphibians, such as the Small-mouthed Salamander (1). Turtles and snakes may also feed and breed near these pools. Protecting these small wetlands is vital to maintaining population connectivity.

Vernal Pool Protection and Conservation

Vernal pools provide specialized breeding habitat for several sensitive amphibians that take advantage of the low-disturbance and predatory fish-free conditions. These isolated, temporarily flooded, depressional wetlands provide amphibian larvae a relatively safe environment to develop, though predation still occurs from non-fish predators, including turtles and snakes (Kenney and Burne 2001, Colburn 2004). These wetlands also act as stepping stones through uplands for wetland-dependent wildlife and provide refuge for amphibians and reptiles during migration. Several salamanders and frogs use vernal pools for breeding and larval life stages; however, most species spend most of their lives in the surrounding upland areas (Semlitsch 1981, Vasconcelos and Calhoun 2004, Petranka et al. 2007, Holman 2012). Species that rely on vernal pools often experience drastic seasonal shifts in their distribution, clustering around vernal pools when breeding and dispersing throughout adjacent upland areas throughout the rest of the year (Gibbs and Reed 2007). Many of these amphibians will return to the same vernal pool where they developed to breed and lay eggs (Sinsch 1990, Semlitsch 2008). If these pools are destroyed or degraded, entire populations of amphibians can be lost. Some vernal pools are critical breeding pools (contain sufficient water to support breeding in most years) and are the primary sites where annual reproduction occurs for vernal pool dependent amphibians and other amphibians and reptiles that use them opportunistically. Vernal pools often support a concentration of biodiversity and population density, particularly for herpetofauna, within forested landscapes (Zedler 2003, Colburn 2004).

Indicator species - Most frog and salamander species utilize vernal pools for breeding, development, foraging and/or hibernation at some point in their life (DeMaynadier and Houlahan 2007, Semlitsch and Skelly 2008). However, many species are classified as vernal pool indicator species, meaning they depend on vernal pools for all or part of their life cycle (Kenney and Burne 2001, Colburn 2004). In Michigan, indicator species include the Wood Frog and most Mole Salamanders (*Ambystoma* sp.) such as the Blue-spotted Salamander, Spotted Salamander, Marbled Salamander, Unisexual Salamander, and Small-mouthed Salamander. These species are reliant on

1-5. Northern Spring Peeper (1), Spotted Salamander (2), Blue-spotted Salamander, (3) Blanding's Turtle (4), and Wood Frog (5) are some of the species that rely on vernal pools.

vernal pools for breeding, with their eggs and larvae developing in these wetlands before dispersing into upland woods as juveniles (Kenney and Burne 2001, Colburn 2004, Craft et al. preprint). Most mole salamander species are relatively long-lived, a necessity due to the wide variation in reproductive success associated with breeding in seasonal wetlands like vernal pools. The longer lifespans of mole salamanders provide a safeguard against catastrophic reproductive failures, but also underscore the importance of ensuring these salamanders and their vernal pool habitats are protected (Taylor et al. 2006).

Facultative species - Other species that use vernal pools during part of their life cycle but do not require them for survival are known as facultative species (Kenney and Burne 2001, Colburn 2004). Amphibian facultative species include the Eastern Tiger Salamander, Eastern Newt, Eastern American Toad, Fowler's Toad, Eastern Gray Treefrog, Cope's Gray Treefrog (*Hyla chrysoscelis*), Northern Spring Peeper (*Pseudacris crucifer crucifer*), Midland Chorus Frog, and Green Frog (Colburn 2004, Luymes and Chow-Fraser 2022, Craft et al. preprint). The Eastern Tiger Salamander, though a mole salamander species that often utilizes vernal pools, can sometimes coexist with predatory fish and thus is not an obligate vernal pool species. Vernal pools play an important role for Blanding's Turtles as a source of food, hydration, and shelter, particularly during their long, seasonal migrations (Markle and Chow-Fraser 2014). The Blanding's Turtle, as well as the Spotted Turtle and Eastern Snapping Turtle, will spend considerable amounts of time in vernal pools in the spring foraging for amphibian eggs, invertebrates, and other organisms (Kenney and Burne 2001, Coury 2022). Other reptile facultative species include the Northern Water Snake, Northern Ribbon Snake, and Eastern Garter Snake which all can be found in and around vernal pools as they are areas of high prey density (Kenney and Burne 2001, Colburn 2004).

Threats to vernal pool herpetofauna - Vernal pools, and the herpetofauna they support, are vulnerable to a myriad of threats. Pools themselves and their surrounding habitat are frequently lost to the conversion of habitat for agricultural or development purposes (Windmiller and Calhoun 2008, Baldwin and deMaynadier 2009). Sedimentation, soil erosion and compaction, and runoff can detrimentally alter the water quality and quantity of vernal pools for herpetofauna (Colburn 2004, DeMaynadier and Houlahan 2007). Breeding amphibians are the most negatively affected as their skin is highly permeable, exposing them to any pollutants in the water, and the hydrological changes may also increase the mortality of their offspring (Hecnar 2004). Activities that open the canopy around pools can lower humidity levels and degrade the habitat for many amphibian species (Skelly et al. 2002, DeMaynadier and Houlahan 2007). Vernal pool

1-2. Vernal pools typically hold water in the spring and fall (1), but may dry completely for part of the year (2). These habitats are obligate breeding sites for a number of amphibians and important seasonal habitat for many species of herpetofauna and other wildlife.

herpetofauna are frequently on the move, traveling between pools and the surrounding landscape. However, these landscapes are increasingly fragmented by the construction of roads and human developments. The isolation of vernal pools can restrict gene flow between populations of herpetofauna, potentially leading to genetic drift and inbreeding (Gibbs and Reed 2007, Gabrielsen et al. 2013, Homola et al. 2019). Fragmented landscapes also jeopardize migrating herpetofauna through increased road mortalities (Windmiller and Calhoun 2008, Craft et al. preprint). Climate change may cause some vernal pools to dry out earlier in the year due to increasing droughts and precipitation shifts, disrupting amphibian life-cycles (Cartwright et al. 2022). Lastly, gaps in the detection and protection of vernal pools further increase the difficulty of conserving pool associated herpetofauna (Baldwin and deMaynadier 2009).

Conditions at vernal pools can be sensitive to land use changes affecting hydrologic processes, pollution inputs, and vegetation cover. Forestry and other forest disturbances should aim to avoid vernal pools and the surrounding upland areas where amphibians and reptiles live. However, in some cases protecting the highest quality habitat at the expense of larger contiguous habitat may not be the most prudent decision as these ecosystems and their herpetofauna are dependent on the balanced proximity of aquatic and terrestrial habitats. These decisions should be based on thoughtful evaluation of the landscape and future uses and impacts. Suggestions for how to incorporate these unique habitat requirements into forestry management are detailed below.

Identify vernal pools - Accurate identification of vernal pools is the first step toward conserving them and the species they support. Vernal pools are seasonal, relatively small bodies of water found in forested depressions throughout Michigan (Colburn 2004). Size is variable, but vernal pools are generally smaller than 2.5 acres and less than 3 feet deep. In the spring they fill with snowmelt, runoff, and groundwater before reaching a maximum size and then drying through the summer and fall. Filling can also occur in the fall and winter. The periodic drying prevents the establishment of fish populations which would otherwise predate amphibian eggs and larvae. Water is confined to the pool and does not flow continuously through an inlet or outlet. When dry, the pools reveal hydric soil substrates typically covered in leaf litter. Vernal pool vegetation varies from none at all to woody species, marsh species, or aquatic species. Vernal pools may be identified with aerial photography, but the confounding potential of small pool size, forest cover, shadows, and wetland connectivity necessitate confirmation with ground surveys (Calhoun and Klemens 2002, DiBello et al. 2016).

1-2. Maintaining a wide buffer of 600-1,000 feet, or a core area of at least 100 feet, helps to maintain the functional value of vernal pools to breeding herpetofauna.

Do not impact the pool depression or core buffer area within minimum of 100 feet - These areas should be protected from any management or development actions. The depression should be defined by the size of the vernal pool at the spring high water mark. When dry, this area can be identified by the presence of leaves darkened and stained by the water/silt as well as water marks on trees and rocks. Preserving the pool basin itself is critical as construction alters water quality and quantity, damages buried eggs and larvae, and results in the removal of vegetation used by amphibians for egg-attachment (Calhoun and Klemens 2002). If this buffer area cannot be protected, at least 100 feet must be protected as the amphibian species using vernal pools are often extirpated (locally extinct) when this area is impacted (Calhoun and Klemens 2002, DeMaynadier and Houlahan 2007). The protection of this core buffer area is essential for the maintenance of water quality, availability of shade and leaf litter, and provisioning of moist, upland forest floor conditions (DeMaynadier and Houlahan 2007).

Aim to protect a wider buffer (600-1,000 feet) - The distance from vernal pools that amphibians occupy varies by species. Some salamander populations have up to 95% of individuals within 550 feet surrounding vernal pools (Semlitsch and Bodie 1998); Wood Frogs disperse as far as 1,500 feet from vernal pools (Berven and Grudzien 1990). However, protecting the terrestrial buffer 600-1,000 feet from the pool will protect core habitat and most first year pool-breeding amphibians (Semlitsch 1998, Semlitsch and Bodie 2003, Calhoun et al. 2005). The importance of this terrestrial buffer zone surrounding vernal pools is often underestimated. However, this area is essential habitat for entire juvenile and adult herpetofauna populations for feeding, growth, maturation, and maintenance (Semlitsch 1998). Simply preserving the 100 foot core buffer area without this critical life zone does not adequately protect vernal pool associated herpetofauna (Semlitsch 1998, DeMaynadier and Houlahan 2007). Management or development actions within this buffer should not impact greater than 25% of the area to reduce risk of local population declines (Calhoun and Klemens 2002). This 25% should also be selected based on relative quality and proximity to contiguous habitat. This buffer should be clearly marked in the field prior to any disturbance. Consult a professional herpetologist or certified wildlife biologist for recommendations specific to the wildlife communities present at a site.

Maintain forest canopy - Forest canopy cover helps to retain moisture on the forest floor which is necessary for amphibians and reptiles to stay cool and/or moist. Additionally, canopies provide an input of leaf litter which serve as the base of vernal pool food webs (Calhoun et al. 2014) canopy. Forest canopy cover in and near vernal pools influences the presence and abundance of salamander and frog species (Skelly et al. 1999, Skelly et al. 2002). Maintaining a similar forest canopy cover in and near a vernal pool can help to continue to provide habitat for the species

1. Properly created or restored vernal pools provide similar functional value to herpetofauna and other wildlife.

2. Rivers and streams provide habitat for species like the Wood Turtle and Northern Water Snake as well as numerous fish and aquatic macroinvertebrate species.

present. Though clearcutting is not compatible with the preservation of vernal pools, selective harvesting can coexist with effective herpetofauna habitat management (DeMaynadier and Houlahan 2007, Calhoun et al. 2014). Suitable forest habitat surrounding vernal pools must maintain a minimum of 50% canopy cover (Patrick et al. 2006, DeMaynadier and Houlahan 2007).

Maintain habitat corridors - In addition to buffers and canopy cover, corridors that allow for salamanders and frogs to colonize and recolonize pools should be preserved (Semlitsch 1998, Vasconcelos and Calhoun 2004). When possible, excluding roads from the pool's buffer, particularly roads with moderate to high projected traffic volume, can help maintain habitat corridors (Fahrig et al. 1995, Colino-Rabanal and Lizana 2012). As vernal pools are an inherently vulnerable habitat, corridors are necessary to counteract the extinction of local populations through the colonization of new sites (Gill 1978). These corridors will help ensure long-term viability for salamander and frog populations. Consult a professional herpetologist or certified wildlife biologist for recommendations specific to the wildlife communities present at a site.

Carefully restore and create vernal pools - Vernal pools can be restored and created if constructed and sited correctly. These pools should reference nearby pools with similar hydrologic conditions. Pool design criteria, including objectives addressing hydrologic processes, provision of woody materials for egg attachment, establishment of native vegetation, and presence of herpetofauna, should be established at the onset of pool planning to improve likelihood of success and to better provide for a diversity of herpetofauna (Lichko and Calhoun 2003). Seek professional assistance from a wildlife biologist, wetland ecologist, restoration ecologist or other experienced individual to ensure successful pool restoration and creation that is responsive to specified criteria. The creation of man-made vernal pools, when done correctly, can sustain similar ecological function and herpetofauna diversity as natural vernal pools (Korfel et al. 2009). Restored and created pools can provide important ecosystem services, however creation of pools through normal harvesting activities (i.e., vehicle tracks) is not recommended. Ruts from vehicles may temporarily provide water required for egg laying but do not provide adequate water throughout the season, canopy shade, or appropriate soil conditions for amphibian and reptile survival (DiMauro and Hunter 2002, Calhoun and Demaynadier 2004).

Streamside/Riparian Zone Harvest

Avoid disturbing riparian zones and adjacent terrestrial areas - Harvest of trees along riparian areas can reduce channel stability, tree canopy, and large woody debris (Murphy et al. 1986), which reduce herpetofauna habitat suitability. Streamside harvest also can reduce tadpole density and tadpole

1. This wetland acts as a potential habitat corridor among an area of agricultural fields.

2. Clearing of vegetation around wetlands particularly forested sections can significantly impact system function and breeding success.

habitat quality for stream and river dwelling frogs(Dupuis and Steventon 1999). Depending on the herpetofauna and other wildlife species present, consideration should be given to protect 600 - 1,000 feet from the edge of the water (Semlitsch 1998, Semlitsch and Bodie 2003, Calhoun et al. 2005). Maintenance of a terrestrial buffer at least 100 feet from the water with no harvest is recommended for ecological and stream stability (Steinblums et al. 1984, Lee et al. 2004). Eliminating disturbance in these areas can provide habitat for a greater diversity of species and better protect water quality. An experienced wildlife biologist or herpetologist should be consulted to determine an appropriate buffer width. Clearly mark the outer edge of the buffer using tree marking tape or staking prior to any harvest activities.

If riparian harvest is necessary, maintain understory and place temporary erosion control measures - Where trees are removed within potential buffer zones (approximately 1,000 feet or closer to a waterway) include logs and woody debris to provide structure and habitat. Understory vegetation will help hold the bank in place, prevent severe erosion, and reduce colonization by invasive plant species. Temporary erosion control measures, such as silt fence and natural fiber mesh can prevent sedimentation from entering surface waters until the bank has re-stabilized.

Prescribed Burns

Fire has historically played an important role in maintaining and restoring open prairie or savanna ecosystems in the Midwest, and can be a useful tool to manage vegetation structure of native and invasive plants. Prescribed fire can be used to restore native plant communities and can be valuable for increasing suitable habitat (e.g., maintain open areas, which can facilitate basking) for some Michigan herpetofauna (Mushinsky 1985, Semlitsch and Bodie 2003, Setser and Cavitt 2003, Harner and Geluso 2011). Fire can be useful to reduce mid-story canopy, such as that created by thickets of invasive plant species which can restrict movement of herpetofauna through the landscape (Bury 2004, Wilgers and Horne 2006). Open, sunny areas created post-burn can enhance opportunities for connectivity and migration of herpetofauna to restored habitats.

Although various amphibians and reptiles respond differently to burn regimes (Cavitt 2000, Wilgers and Horne 2006, Kaufmann et al. 2007, Melvin and Roloff 2018), most Michigan herpetofauna are not adapted to frequent and intense burns. Although fire as a management tool has been shown to directly and indirectly impact rare and common herpetofauna, the full impact of fire on herpetofauna is yet unknown (Pilliod et al. 2003). Populations of vulnerable, rare, or threatened species can be negatively impacted by burns (Cross 2009, Gibson 2009, Woodley and Kingsbury 2011, Cross et al. 2015, Hileman et al. 2018, Harris et al. 2020a). However, loss of herpetofauna diversity in small burned areas may be offset by greater diversity on a larger scale

(McCleod and Gates 1998). If a controlled burn is to be conducted as part of restoration or land management, the following points can help to reduce negative effects to herpetofauna and other wildlife.

Restrict burning frequency - By restricting the frequency of burns, unnecessary mortality of herpetofauna can be avoided. Also, some species (e.g., autumn olive; multiflora rose; and raspberry, *Rubus* spp.) respond to fire by vigorously re-sprouting (Michigan Natural Features Inventory 2012b). For these species, several burns or a fire with the heat needed to kill the stems and roots may result in death of buried or burrowed herpetofauna. Some sites should avoid use of fire as a management tool if the impacts outweigh the benefits to the target wildlife.

Tom Beauvais

1. Fires that occur before Eastern Smooth Green Snakes emerge from hibernation in the spring lessen the impacts on this and other sensitive amphibian and reptile species.

2. Burning during dry late fall or winter days when amphibians and reptiles are still inactive and many are underground reduces their exposure to fire.

Conduct pre-burn inventories - It is important to identify which herpetofauna occur (or may occur) and to conduct baseline inventories to determine the presence of rare species within areas proposed for management. This is critical for effective holistic land management and to evaluate the overall success of management strategies.

Know the natural history and life cycles of herpetofauna present - Annual and daily cycles and the response of various amphibians and reptiles to temperature, moisture, food sources, nesting, etc., can aid in planning fire to reduce negative impacts. Many herpetofauna have extremely limited mobility, and most exhibit life history characteristics that make them particularly vulnerable to even minor losses due to rapid and high-impact management techniques such as burning (See Section 3). Some species, such as Northern Ring-necked Snakes, have a higher abundance in areas with a longer fire return interval (Wilgers and Horne 2006). The vegetation structure in unburned areas likely provides increased moisture levels in soils and an abundance of earthworms (a primary food source), which makes these sites more suitable for Northern Ring-necked Snakes. Information regarding the life traits of some sensitive species can be found on the MNFI Rare Species Explorer webpage.

Account for undetected rare species - Rare herpetofauna populations can be difficult to detect and particularly sensitive to burns as they are not likely to recover quickly and generally do not have characteristics that help them withstand fire. The loss of individuals can be particularly devastating for species with a long time until sexual maturity. The loss of only a few adults within select species can dramatically affect population viability. Eastern Box Turtles are an example of one such species. At present, it is often assumed that post-fire surveys are effective means of assessing the burn-induced mortality of Eastern Box Turtles. However, the average detection probability 48 hours after a burn event is “low and highly variable among observers”, even for radio telemetry-tracked turtles (Melvin and Roloff 2018). In response to the presence of fire, Eastern Box Turtles are known to actively negotiate the flame front and bury themselves (Melvin 2017). These behaviors leave the turtles exposed to harm from the fire. Buried turtles remain

1. This Eastern Box Turtle has been severely wounded and lost about half of its scutes in a prescribed burn. Due to the extent of injuries, it is unlikely that this turtle survived.

2. Northern Ring-necked Snakes have a higher abundance in areas of long-term, unburned treatments than in areas burned with a higher frequency.

underground for up to 12 hours and quickly relocate to unburned areas after resurfacing, while still suffering burn-induced wounds oftentimes resulting in later mortality (Melvin and Roloff 2018). It may therefore be necessary to assume prescribed burn techniques are more harmful to turtle populations than surveys might indicate. Incorporating these considerations of rare species into plans can reduce losses. Prior to burning (or the use of other high-impact management methods such as mowing) in known rare or sensitive herpetofauna habitats, managers should carefully consider whether the result will benefit population viability and whether the actions can be modified or timed to reduce or eliminate mortality. Any management plan that threatens the local or large-scale destruction of vulnerable native animal populations should be reassessed.

Conduct burns during seasons when herpetofauna are at less risk - Herpetofauna within the Midwest are generally inactive in late fall through winter. During these times, they remain underground or underwater, reducing their vulnerability to predation and the elements as well as to the impacts of fire. Understanding the ecological requirements and life cycles of the herpetofauna of a site is important to avoid mortality and to enhance biodiversity. Conduct burns during the very early spring before emergence from hibernation (typically, before April 1), summer after turtle nesting and spring migrations, and very late fall after hibernation has begun (Congdon and Keinath 2006, MWPARC 2009a, Harris et al. 2020a). Conduct spring and fall burns only after an extended cool spell (<50°F) when animals are less active and have a greater likelihood of being underground in burrows or hibernacula (MWPARC 2009a). Spring soil temperatures lower than 46 F at a depth of 10 cm indicate a high probability that Eastern Massasauga Rattlesnakes are still underground (Hileman et al. 2018). Spring burns in forests may harm Eastern Box Turtles, salamanders, and Wood Frogs emerging from hibernation. As the duff layer and woody debris on the forest floor are burned, so are these amphibians and reptiles that take cover there. Late spring and early summer burns in grasslands can impact nesting sites and staging female turtles, as well as snakes using these habitats seasonally. When burning must be conducted in the active season, actions should be taken to avoid impacts whenever possible. For example, conducting a warm season burn in July rather than June can have a significant impact on nesting turtle survival and maintain population viability. In June of their second active season, neonate Eastern Box Turtles remain very close to their natal openings in open canopy habitat (Laarman et al. 2018). However, by July the neonates disperse into nearby forests and wetlands. This suggests that burns of open canopy habitat should occur after July.

Chris Woodley

Monitor herpetofauna and wildlife communities pre- and post-burn - Incorporate wildlife monitoring as a metric for measuring restoration success. This will provide a more comprehensive approach to understanding the benefits and timing of prescribed burns and minimize future impacts to amphibians, reptiles and other sensitive wildlife. Land managers should consider that traditional post-burn survey methods may not accurately reflect the mortality of herpetofauna such as the Eastern Box Turtle (Melvin and Roloff 2018).

Avoid burning near wetlands - Burning the understory in

1-2. Burning around logs should be avoided due to the high number of herpetofauna that use these structures for protection including this Eastern Garter Snake. Burn breaks are an effective way to minimize impact to these fire refugia.

wooded areas near wetlands reduces the leaf litter and woody debris layer where salamanders, Wood Frogs, and Eastern Box Turtles take cover. Burning here creates unsuitable habitat conditions for these species and exposes them to risk of direct mortality. If wetland or adjacent upland communities adapted to periodic burning and fire is deemed necessary for management, conduct burns during the hottest summer periods when many species have either migrated to shaded upland areas, are estivating underground, or can more easily escape. In areas where amphibians and reptiles are present in the spring, or remain throughout the summer, burning during or directly following warm weather can result in high herpetofauna mortality (Frese 2003, Woodley 2013).

Create refuge areas - Creating brush piles, snags, or other small areas with vegetative cover which will not be burned can provide herpetofauna with a safe place to flee to during a fire (Cross 2009). These features can often be created at no additional cost as these materials are often already on site.

Create fire breaks or protect critical herpetofauna habitat features from fire - Salamanders, some frogs, snakes, and Eastern Box Turtles hide under cover objects and duff on the forest floor. By not burning these essential habitat components, these animals are given some protection from fire. There are both natural and mechanical methods for establishing breaks though we encourage natural breaks as these do not result in greater landscape disturbance.

Avoid burning brush and leaf piles or logs - These features can provide cover during the active season and during hibernation for reptiles and amphibians. Animals will likely seek out refuge in these features during pre-burn site preparation, and burning these features will likely cause needless mortality (Cross 2009). Create fire breaks around these features, soak them with water, or create burn patterns to avoid their ignition. If brush and leaf piles are not desired features a management unit or project area, they should be thoroughly checked for amphibians and reptiles before burning or before removal to a different location.

Burn small areas infrequently - Burning various small areas at a 3-7 year frequency, as opposed to a typical 2-3 year burn frequency, can avoid reduction of amphibian diversity while maintaining a diverse native plant community (Schurbon and Fauth 2003). As various wildlife species respond differently to areas that have been burned and to the time since burning, a burn schedule should create a matrix of differently aged burned areas (Fuhlendorf and Engle 2004, Wilgers and Horne 2006).

In areas with herpetofauna that may be able to escape the site, create slow-moving fires - Although most herpetofauna are not fast moving, some species, such as frogs, have been known to flee from the sound of fire (Grafe et al. 2002) and may benefit from slow-moving burns, which

Chris Hoving

Matt Smar

1-2. Burning small areas allows for amphibians and reptiles to take refuge in nearby unburned areas.

they may be able to 'out-run'. The use of ring fires should be avoided or used in conjunction where refugia are present.

In areas with herpetofauna that cannot escape the site, create fast moving fires - Fast moving fires are more likely to leave logs, cover objects, and parts of the duff layer unharmed. These objects can protect herpetofauna that are not able to quickly flee an area. However, fire can be especially detrimental to the Eastern Box Turtle. These turtles, even if partially buried, are often exposed directly to fire during a burn, resulting in life threatening injuries if not outright mortality. Alternatives to fire should be considered in areas where the Eastern Box Turtle is present or is likely present (MWPARC 2009a).

Create a burn intensity that is appropriate for conditions reduces fire severity - Fire severity is generally described as the condition of the ground and amount of organic matter lost after a burn (Keeley 2009). Depending on the type of burn conducted and current conditions of a site, the severity of a fire can vary. Since most herpetofauna are not fast-moving, fires should be executed to burn at cooler temperatures (MWPARC 2009a, Harris et al. 2020a). Slow moving, low intensity fires may give some herpetofauna the chance to escape, however they can have a large effect on the remaining soil because they burn over a longer period of time. Fast moving, high intensity fires cause higher flames and temperatures but if conducted during times when the soil and forest floor are moist, the severity of the burn is less. When conducting a burn, evaluate which type will be most effective while minimizing direct and indirect impacts to herpetofauna.

Avoid use of fire retardant chemicals near wetlands - Use of fire retardants to create fire breaks releases sodium ferrocyanide into wetland environments. This chemical is highly toxic to amphibians even in dilute concentrations (Pilliod et al. 2003). Instead, use leaf blowers or rakes to create fire breaks (MWPARC 2009a).

Documentation of findings - It is imperative that data both on dead and living amphibians and reptiles be recorded as part of any burn management activities. Historically most groups have not documented wildlife response. Groups Like Oakland County Parks and Recreation and the City of Ann Arbor are model organizations which commonly document the presence (live and dead) of herpetofauna post burns. This data should be contributed to the Michigan Herp Atlas program.

Managing with Animals

Wildlife and livestock can be utilized in a non-invasive manner to manage the landscape and set back succession favorably for herpetofauna. Fens, wet meadows, and other high quality habitat for herpetofauna can be maintained and restored by the grazing of large herbivores (Middleton

et al. 2006, Reshetiloff 2009, Cornelissen 2017). Many large herbivores have been eradicated from the landscape, including the American Bison (*Bison bison*) which used to inhabit southern Michigan, facilitating the spread of woody vegetation into important habitats (Hornaday 1889). The reintroduction or management of this large mammal on certain landscapes can support herpetofauna populations as they are ecosystem engineers that help sustain diverse plant and arthropod populations in prairies through their grazing and wallowing habits (Collins et al. 1998, Nickell et al. 2018). Additionally, they also create wallows which compact the soil and fill with water following rain events. The bison then either expand or abandon these flooded wallows (Barkley and Smith 1933). Abandoned, inundated wallows have been used by frogs and toads for breeding habitat in Kansas (Gerlanc and Kaufman 2003).

1. Domestic goats are an effective means of removing invasive plant species when utilized in a managed environment.

Domestic goats, a much more accessible and feasible herbivore alternative to the American Bison in most situations, are woody plant specialists (Glasser et al. 2013). Goats are adept at converting shrub-infested landscapes into grassy prairies and meadows more suitable for herpetofauna. Goats will consume brush and weeds before converting them into nutrients that cycle through the ecosystem (Hart 2001). Clearing out shrubs allows forbs and grasses to emerge as they are no longer shadowed and out-competed by woody plants. Goats are resistant to several plant toxins and anti-nutritive factors, allowing them to consume a wide variety of plants that cows are unable to eat, including tree bark (Hart 2001). These features allow goats to successfully restore and maintain wetlands and other habitats for the benefit of herpetofauna (Reshetiloff 2009). The grazing of other livestock, such as cattle, can potentially benefit herpetofauna as well, particularly those occurring in open-canopy habitats (Howell et al. 2019). However, grazing intensity, particularly by cattle, must be monitored as overgrazing can lead to permanent reductions in biodiversity (Middleton et al. 2006).

2. WDD with an Eastern Box Turtle as part of a radio telemetry study.

Small mammals can also positively influence herpetofauna richness and density. Often, herpetofauna will use the burrows created by small mammals as shelter from unfavorable climatic conditions or as a refugia from predators (Gálvez Bravo et al. 2009, Buyandelger et al. 2022). Burrowing small mammals in Michigan, such as the Groundhog (*Marmota monax*), are ecosystem engineers that provide important habitat features. The protection of a steady population of burrowing mammals on a landscape is beneficial for herpetofauna.

Animals can aid herpetofauna not only in the manipulation of the landscape, but also in active conservation and management practices through the use of wildlife detector dogs (WDDs). These dogs can be used in a herpetofauna inventory capacity, but can also importantly be used to locate herpetofauna for clearance purposes (Powers 2018). Their heightened olfaction sense allows WDDs to detect herpetofauna more efficiently than humans can on their own (Heaton et al. 2008, Nussear et al. 2008, Kapfer et al. 2012). The use of WDDs is growing, particularly to locate at-risk turtle species, like the Eastern Box Turtle, for academic research purposes (Kapfer et al. 2012, Harris et al. 2020b). However, WDDs can also provide immense benefit for herpetofauna through the applied usage of surveying and clearing species, such as the Eastern Box Turtle, that are vulnerable to management techniques like mowing and prescribed burns (Harris et al. 2020a).

1. The Shiawassee National Wildlife Refuge contains several diked wetlands which are drawn down in such a way and rate that the herpetofauna are able to migrate to suitable areas. Incorporating best management practices like this not only achieve the desired goals, but also reduce unnecessary risk to wildlife.

Lakes, Ponds, and Rivers

Lakes and ponds are often managed for multiple reasons including, aesthetics, recreation, wildlife viewing, waterfowl hunting, fishing, transportation, and the protection of human health. Management often includes control of aquatic plants (weeds) for aesthetics, ease of boating, and the promotion of native plant communities geared to game fish. Although these management objectives are not generally focused on wildlife, in most cases a few simple modifications to timing and technique of maintenance activities can benefit herpetofauna.

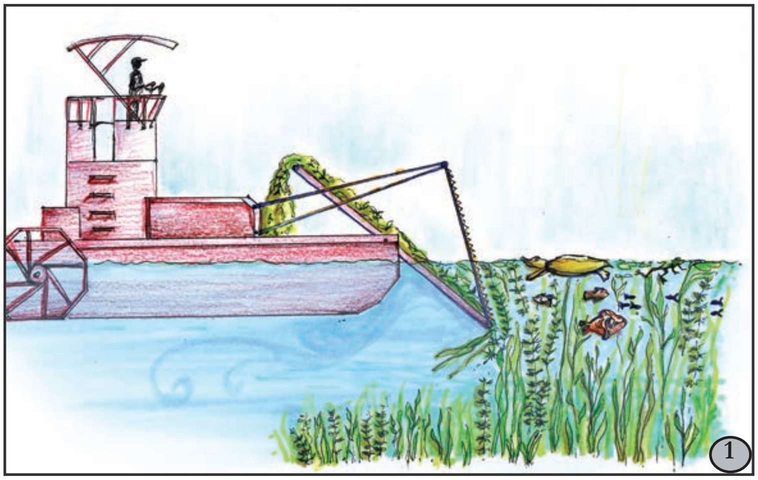
Aquatic Weed Control

Aquatic weeds can be native plants which are an important part of aquatic ecosystems and which provide habitat for amphibians and reptiles, or aquatic weeds can be non-native, invasive plants, such as Eurasian watermilfoil (*Myriophyllum spicatum*), which alter ecosystem function. Herpetofauna-friendly strategies for aquatic weed control are detailed below.

Control nutrient inputs - The most effective and sustainable aquatic weed control is through management of nutrient inputs, usually nitrogen (N) and phosphorous (P) (Smith and Schindler 2009). These nutrient inputs often come from residential or agricultural land uses near a water body where aquatic weed control is a priority. Simple, yet wide-reaching changes, such as reductions in lawn fertilization and the creation of unmowed buffers near water bodies, can help to minimize fertilizer inputs and reduce growth of aquatic weeds.

Intercept nutrients in the water - Filtration and abatement techniques for nutrient and pollution in water bodies are being developed and becoming more available on the market. One example is floating treatment wetlands, which use plants growing on floating mats to convert excess nutrients into plant matter, sequester phosphorous, and absorb pollutants through phytoremediation (Zhao et al. 2012). These mats also serve a similar function as floating bog mat structures by increasing the diversity of habitat structures within wetlands and providing protected basking sites for amphibians and reptiles.

Avoid mechanical aquatic weed harvesting - Removal of aquatic vegetation removes essential habitat for larval amphibians and hatchling turtles, and reduces available prey items for multiple species. Mechanical aquatic weed harvesting and cutting also displace, and often kill, turtles and



1. Aquatic weed harvesters remove turtles and frogs basking at the surface of the water amongst submerged vegetation.

amphibians (Booms 1999). Turtle fragments have been observed in the chopped plant material (Mifsud personal observation 2022). Weed harvesting can be largely ineffective as plants quickly regrow (Fox and Murphy 1990). Additionally, there is currently no machinery that excludes herpetofauna. Some machinery operators may try to avoid processing amphibians and reptiles with vegetation; however, this strategy is unlikely effective at avoiding small individuals which are difficult to see and individuals under the surface of the water.

Avoid chemical control - Herbicides can harm amphibians and reptiles as well as other non-target plant and animal species (Getsinger et al. 2008). Herpetofauna are especially sensitive to herbicides during egg and larval stages and chemicals should not be introduced into aquatic systems during these times. Low-concentration application of some herbicides used for aquatic weed control, such as Fluridone (brand name SONAR), while useful in controlling Eurasian watermilfoil, is required to be present in the water for over two months to effectively reduce Eurasian watermilfoil (Madsen et al. 2002). Although immediate amphibian and reptile die-offs have not been noted for this chemical, other herbicides have been linked to lowered reproduction rates and deformities from long-term exposure and/or bioaccumulation of herbicides (Johnson et al. 1999, Hayes et al. 2002, Hayes et al. 2003, Coady et al. 2004, Howe et al. 2009, Relyea and Jones 2009). Sadly, many herbicides and other chemicals used in the environment are not tested for their effects on amphibians and reptiles, and the negative impacts on amphibians and reptiles are unknown for these chemicals.

Louis M. Landry

2. Aquatic plants like *Elodea canadensis* are an important food source and serve a role in nutrient absorption, oxygen production and critical cover for many amphibians and reptiles.

If avoidance is not possible, carefully time aquatic weed control - If suitable management of nutrient inputs is not possible, carefully timed herbicide application or mechanical aquatic weed harvesting may be considered based on the amphibian and reptile species present. If this option is selected for vegetation control, pre- and post-treatment monitoring of herpetofauna should be conducted. Monitoring can help assess the negative effects on herpetofauna and guide methods to reduce or avoid future losses.

Encourage native biological controls - Turtles, like Midland Painted Turtles and Red-eared Sliders, consume large amounts of aquatic plants. Creating suitable habitat conditions for these species may help to control aquatic weed growth. Encouraging native wildlife and maintaining healthy, diverse ecosystems is an effective strategy for reducing and preventing nuisance aquatic weeds.

Prevent introduction - The easiest way to control exotic vegetation is by preventing

1. Red-eared Sliders can consume large amounts of both native and non-native vegetation, helping to provide health to aquatic ecosystems.

its introduction. One of the primary ways exotic vegetation is introduced to water bodies is by people transporting pieces of plants on equipment and boats. Following recommendations by Michigan Sea Grant (Gunderson et al. 2004) to 1) assume every water body is contaminated 2) clean and dry boats and equipment between trips, and 3) decontaminate equipment following each use which can reduce the likelihood of introduction of invasive vegetation to other water bodies.

Lake and River Level Alteration

To manage aquatic vegetation, reduce structural damage to marinas, boat docks, and launches, and increase habitat for waterfowl and other wildlife, wetland and lake levels are altered via drawdowns and inundations (Ducks Unlimited 2005). However, depending on the timing of these management techniques, herpetofauna numbers can be significantly reduced (See Section 3). Also, drawdowns can simulate drought conditions and force herpetofauna to travel in search of another water source. Many herpetofauna can only migrate short distances from wetlands and other bodies of water (approximately 200-300 meters) as they are sensitive to dry conditions and can easily desiccate (Schmid 1965, Grover and Ross 2000, Semlitsch 2000). The following management recommendations can provide information about when and how to alter water levels with minimal impacts to amphibians and reptiles.

2. Eastern Spiny Softshell Turtles are particularly susceptible to drawdowns on account of their soft, leathery skin and dependence on an aquatic environment. Timing such activities with consideration for their physiology and natural history can reduce mortality.

Avoid artificially elevating water levels or conducting drawdowns when egg and larval stages will be affected - When altering water level, the life stages of herpetofauna present should be considered. Water levels artificially elevated in late summer may drown riverine turtle eggs laid in the riparian zone (Tucker et al. 1997, Standing et al. 1999). When conducting early spring and summer drawdowns, be aware of amphibian eggs, larvae, and adults present and their level of mobility and ability to adjust to new conditions. Survival of juvenile amphibians is dependent on precipitation and inundated conditions (Berven 1990). Avoid draining areas with large numbers of amphibian eggs to prevent mortality (Kaltenecker et al. 1999). Without water these eggs will desiccate and the adult population the following year will likely be greatly reduced.

If necessary, conduct drawdowns during early fall - Drawdowns at any time of year can present risks to wetland herpetofauna; however, cooler temperatures and moist conditions in early fall can reduce stress on amphibians and reptiles. Most animals have metamorphosed by early fall, aside from a few species of frogs with tadpoles which can overwinter, and will have an opportunity to relocate to a suitable area for hibernation before a fall drawdown (Hoffman-Sailor West 2003). If drawdowns cannot be timed for early fall and suitable cover habitat and other wetland areas are available nearby, a late-summer drawdown may be considered. However drawdowns between March and July should be avoided (Paton and Crouch III 2002). In this instance, it is especially important to evaluate the ability of herpetofauna to relocate to nearby wetlands without a high mortality rate.

1. Water control structures can help manage water levels to assist in habitat restoration, and to more naturally mimic hydrologic regimes. However, if timed poorly these activities can have significant effect on native wildlife.

Do not conduct winter drawdowns - Winter drawdowns expose hibernating amphibians and reptiles to conditions and temperatures that cause them to freeze or desiccate and die (Bodie and Semlitsch 2000b, Bodie and Semlitsch 2000a). These drawdowns also kill littoral zone vegetation, which is inhabited by several species of herpetofauna, by exposure of the roots to freezing. Elect instead to conduct drawdowns in early fall.

Drain water towards small pools which will remain - When planning for a drawdown, locate 'low' areas within the area to be drained which will maintain water after the drawdown. Drain all water towards these areas. As water is slowly drained, any larvae will be able to move to these low areas and avoid being trapped in areas that will become dry. Additionally, by maintaining some inundated areas Green Frog and Bullfrog tadpoles will be able to overwinter.

Ensure suitable habitat nearby - Conducting a drawdown will reduce the habitat suitability for some amphibian and reptile species within the drawdown area. It is important to ensure that there is suitable habitat adjacent to the drawdown area and to evaluate the ability of herpetofauna to safely relocate.

2. Turtles and other herpetofauna should be trapped by certified wildlife biologists or herpetologists and relocated to off-site habitat prior to severe drawdowns.

Conduct trapping and relocation prior to late season drawdowns - Drawdowns that begin in late fall and early winter should be avoided since amphibians and reptiles hibernating at a specific water depth in a wetland will be exposed to fatal temperatures and conditions at a time when these animals are inactive. If a late season drawdown is necessary, trapping and relocation of herpetofauna to nearby wetlands should be evaluated and conducted by a certified wildlife biologist or professional herpetologist before the drawdown when herpetofauna are still active. State and/or Federal permits may be necessary to conduct amphibian and reptile recovery and translocation.

Maintain water in newly inundated areas – Herpetofauna

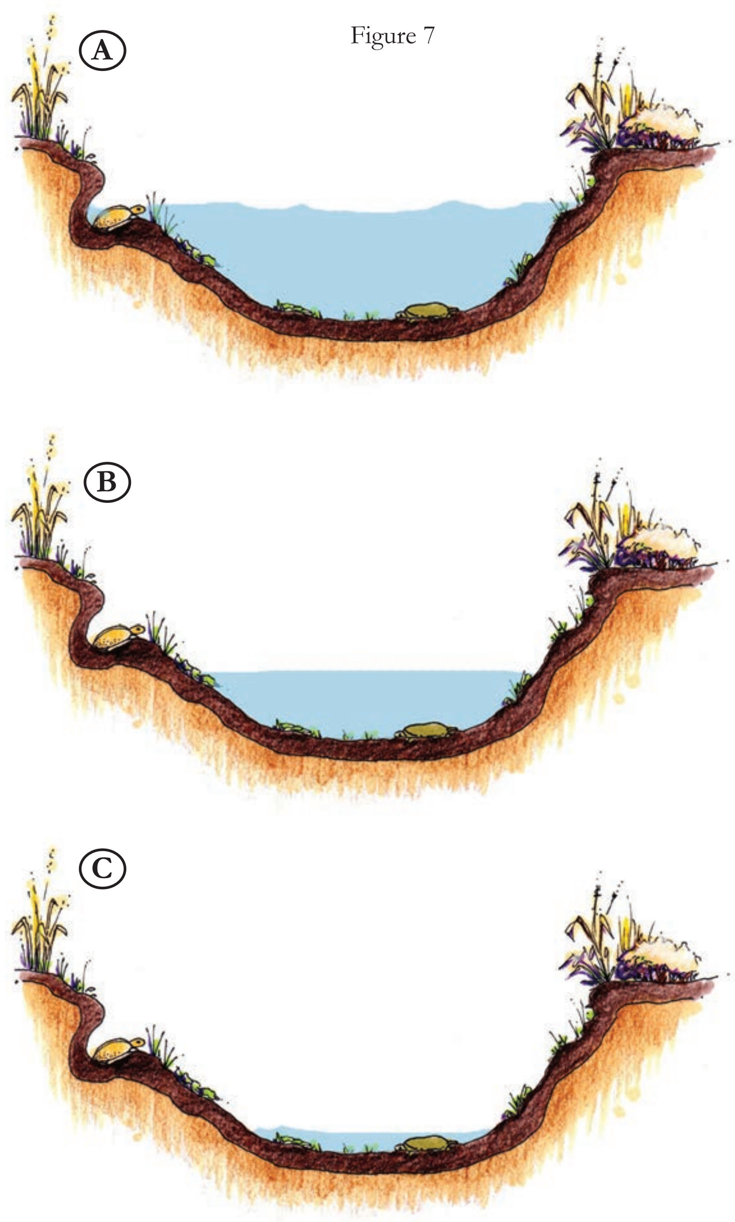


Figure 7. Late fall and winter draw downs can expose amphibians and reptiles that hibernate in the underwater banks of the wetland (A). Severe drawdowns can cause the remaining water to become anoxic as overwintering fish and turtles burrowed into sediments at the bottom continue to consume oxygen (B). An almost complete lack of water will cause what little water is left to freeze solid (C).

that may colonize this new wetland require water for the duration of egg and larval stages. Due to the variety of pond-breeding amphibians that can occur in the same wetland and their varied habitat requirements, water should be maintained for four to nine continuous months to provide for the life cycle of these amphibians (Paton and Crouch III 2002).

Fisheries Sampling and Management

Fisheries management can provide structure that contributes to habitat and a source of prey for amphibians and reptiles. High-quality headwater and riparian areas can provide amphibian habitat and ensure high-quality fish habitat (Naiman and Latterell 2005). Small, floodplain pools can provide essential habitat for fish and amphibians (Hoover and Killgore 2002). Turtles will often retreat to backwater pools or oxbows to mate in spring to avoid the strong current of rivers. Native fish, amphibian and reptile species also likely benefit from the control of aquatic invasive species, as the invasion of exotic species can degrade local ecosystems (Patel et al. 2010, Strayer 2010) and high-quality waters (Naiman and Latterell 2005). Despite the overlap in the end goal of habitat management for both groups, some commonly used fisheries sampling and management techniques (i.e., electroshocking, fyke net surveys, use of rotenone) can be harmful to aquatic amphibians and reptiles. Mudpuppies are particularly vulnerable to bycatch mortalities and have been found as bycatch in the Detroit River resulting from a variety of fishing equipment including setlines, minnow traps, fyke nets, eggmats, and cement anchors (Craig et al. 2015, Lennox et al. 2018).

Hook and Line Fishing

Snakes, Mudpuppies, and turtles are commonly impaled on hooks intended for catching fish or other game species. When these animals are not able to be removed from hooks, these hooks are sometimes left in the flesh indefinitely and can affect the survival of the individual. Herpetofauna, particularly Mudpuppies, often ingest bait hooks which can cause mortality (Lennox et al. 2018). For some species of turtles, females and larger individuals are more likely to ingest fishing hooks than males and smaller individuals (Steen et al. 2014). Fishing tackle should always be removed from the environment

1. Eastern American Toad larvae can co-occur in habitat that support fish. This amphibian is toxic to most fish species.

when finished and tackle containing lead should always be avoided.

To reduce the risk of causing additional harm to a non-target amphibians or reptiles, hooks should not be forcibly removed when it is difficult to do so. Barbless hooks are preferable to barbed hooks when fishing as they are easier to remove from hooked turtles. Circle hooks are more difficult to remove from turtles' mouths than J-hooks and simply cutting the line is more likely to result in the turtle's survival than attempting to remove the hook (Parga 2012). The greatest risk longline fishing poses to turtles occurs when fishermen pull the line on board the boat without using a net, causing the hook to embed deeper into the turtle (Parga 2012). Instead, a net should be used, or the turtle should be lifted out of the water by its shell. Pliers should then be used to gently grab and twist the hook's shank, but if not possible then the line should be cut as close to the hook as possible. Similarly, deep set hooks in Mudpuppies are dangerous to remove and the line should be cut as close to the hook as possible in hopes that they can pass or shed the hook (Lennox et al. 2018). For shallower set hooks in Mudpuppies, using pliers to gently grab the shank of a hook and twisting is the best way to try and free the individual.

Sean Zera

2. This Midland Painted Turtle has suffered permanent damage from a fishing hook.

Mudpuppies are killed when caught by anglers due to the assumption that they are predators of some game fish species, however this is not true, and the unnecessary killing of these animals should be discouraged. Use of salamanders and frogs as bait is also strongly discouraged. Commonly used species such as the Eastern Tiger Salamander, Spotted Salamander, Northern Leopard Frog, Pickerel Frog (*Rana palustris*), and Mink Frog, are experiencing population declines. Suitable artificial baits are available that provide a similar function without need of harm to herpetofauna.

Electroshocking/Electrofishing

U.S. Fish and Wildlife Service

3. When conducting electrofishing, be aware of the short term effects that nearby herpetofauna may experience.

Although electrofishing has been documented as a safe way to sample aquatic salamander communities (Williams et al. 1981), this technique does cause temporary paralysis in herpetofauna, much the same as it does in fish. One species frequently reported in bycatch during electroshocking is Mudpuppies. When catching and releasing these and other herpetofauna, surveyors should be aware that shocked and stunned herpetofauna are subject to potential predation and it is recommended that these species be carefully released as quickly as possible to an area with adequate submerged cover to reduce chances of predation.

USDA-Forest Service

1. Due to their harmful effects on amphibians, Rotenone treatments should be avoided whenever possible. If necessary, removal of sensitive and rare herpetofauna should be conducted.

2. Eastern Tiger Salamander larvae are particularly sensitive to Rotenone and other chemicals as they can take multiple years to metamorphose into adults. If treated prior to metamorphosis the entire generation of species recruited could be lost.

Chemical Fish Control and Sampling

Chemical control, mainly through use of rotenone, is used to remove diseased fish populations or non-native and native fish with unbalanced populations (Ball 1948, Turner et al. 2007). Since rotenone kills all fish (i.e., is a broad-spectrum poison), it can also be used in fish hatcheries to remove fish not caught before stocking new fry. This natural compound is lethal to fish and degrades quickly in the environment, thus it is also used as a tool to sample fish in small areas (Turner et al. 2007). Rotenone affects fish and wildlife, including amphibians, at the cellular level (Bradbury 1986). Rotenone has been related to mortality of turtles, larval and adult frogs, sirens, and other salamanders (Haag 1931, Bradbury 1986, Fontenot 1994, McCoid and Bettoli 1996, Billman et al. 2011). Larval stage and adult amphibians have a high sensitivity to rotenone, likely due to the ability of their skin and gills to readily absorb water and any compounds in the water (Turner et al. 2007). Despite the potential negative impacts of rotenone on amphibians, use of rotenone to remove fish from ponds can improve amphibian reproductive success (Walston and Mullin 2007). The following recommendations can help to reduce impacts of rotenone application on amphibians and reptiles.

Apply rotenone or other chemicals to control fish late in the year - Applying rotenone in the fall or winter after larval amphibians have lost their gills and move between the water and land will reduce the potential contact amphibians have with rotenone (Turner et al. 2007). However, Mudpuppies, Western Lesser Sirens, non-metamorphosed tadpoles, and aquatic turtles occupy aquatic areas year-round and are prone to impacts. Also, better results are produced during this time of year as rotenone is more persistent in cold water. Research should be conducted to determine effects of rotenone on overwintering turtles as this might be an issue during cold weather application.

Do not apply rotenone in areas with rare herpetofauna - There is a high likelihood that any amphibians and reptiles which come in contact with rotenone will die. Taking rare amphibians and reptiles will only further reduce their populations and their chances of survival.

Lamprey Control

TFM (3-trifluoromethyl-4-nitrophenol) is a poison used to control fish but has also traditionally been the chief control method for sea lamprey, an aquatic invasive species in the Great Lakes which significantly affects native fisheries, such as lake trout. Rotenone (as discussed in Section 3) is also utilized as a lampricide; however it is not used as frequently as TFM. Unfortunately, lampricides also impact non-target species, including amphibians and possibly reptiles (Boogaard

Dick Bartlett

U.S. Fish and Wildlife Service

1-3. To avoid direct mortality of aquatic salamanders including the Mudpuppy (1) and Western Lesser Siren (2), lampricides and similar chemicals should be applied in the winter.

et al. 2003, Dawson 2003, Hubert 2003, McDonald and Kolar 2007). More recently, alternative treatments including use of pheromones, sterilization, trapping, and use of barriers have successfully reduced local sea lamprey populations (Lavis et al. 2003, Johnson et al. 2005, Bergstedt and Twohey 2007, Johnson et al. 2012).

Avoid use of lampricides - While these treatments effectively kill most sea lamprey and are generally considered safe for most adult amphibians and reptiles when applied at normal concentrations to kill target species (Farringer 1972), they can be lethal for gill-breathing larval amphibians and adult amphibians, particularly Mudpuppies (Gilderhus and Johnson 1980, Boogaard et al. 2003, State of Vermont 2011) Also, long-term accumulation of lampricides in Mudpuppies may result in shortened lifespans and decrease reproductive ability (Parren and Hart 2012). Reports of hundreds of Mudpuppies dying after treatment are not uncommon (Michigan Herp Atlas 2022). Since lampricide applications are repetitive (i.e., reapplied every 3-5 years), this high level of mortality for this imperiled species, which is also the obligate host to the State Endangered Salamander Mussel (*Simpsonaias ambigua*), is likely highly unsustainable.

Use alternatives, such as pheromones, trapping, and sterile male release - Alternative lamprey management includes use of pheromones to attract and trap lampreys (Wagner et al. 2006), injury-released chemical alarm cues which are chemosensory repellents (Imre et al. 2010), and sterile male release (Bergstedt and Twohey 2007). These techniques can successfully control lamprey populations and have potential to reduce the lamprey population throughout the Great Lakes without damaging herpetofauna.

If lampricide use is necessary, target areas and seasons with reduced amphibian presence or inactivity - When alternatives to lampricide are not a viable option, application of lampricide chemicals should be targeted to lamprey habitat, avoid Mudpuppy habitat, and application timing should avoid the presence of amphibian larvae. This compound has been shown to have high lethality to Mudpuppies and in some cases hundreds have died in a single application along single sections of streams in Michigan. Though efforts have been made to refine such impacts consideration of the system as a whole in use of such compounds is encouraged. Incorporating use of pheromones and other techniques to concentrate sea lamprey into small areas can reduce the area to be treated with lampricides and the extent of negative effects on wildlife. This can also reduce the cost of lampricide and can potentially increase percentage of successfully culled sea lamprey. To achieve these application standards, a professional herpetologist or professional wildlife biologist with demonstrated expertise in herpetofauna should be consulted.

Kurtz Fish Hatchery

1. In general fish hatchery ponds can make good amphibian and reptile habitat with little to no impact on fish.

Fish Hatchery Rearing Ponds

Most fish hatchery and rearing ponds are earthen dikes and can help support healthy amphibian and reptile communities while also addressing the needs of the fisheries community. Turtles and frogs are some of the animals that may be beneficial in or around rearing ponds. Most of their prey is weak, diseased, or dead fish. These feeding habits help to maintain overall higher quality fish stock and prevent the spread of disease in rearing ponds.

Although amphibians and reptiles can help maintain health and ecological balance in a rearing pond, occasionally rotenone may need to be used to cull a group of diseased fish or to "clean" the water between fish harvest and the introduction of a new batch of fish. Rotenone treatments will not only kill unwanted pathogens, they will also kill developing salamander larvae. Eastern Tiger Salamander larvae in particular can be impacted by rotenone treatments as they can take multiple years to metamorphose into adults. If rotenone or other chemicals must be used, first translocate all herpetofauna to a nearby wetland with similar conditions to that of the rearing pond. Then place wildlife barrier fence (i.e., soil erosion control fence or other similar barrier) to prevent herpetofauna from entering rearing ponds and becoming subject to poisoning by rotenone.

Net Sampling

Some fish sampling is conducted by using nets submerged as much as three feet below the water surface. These nets can safely hold fish hours or days until a sampling technician checks the trap. However, turtles are also captured in these nets and die because they cannot rise to the surface to breathe (Barko et al. 2004, Dorcas et al. 2007). In some circumstances, even nets placed with "breathing room" (e.g., a milk jug float) can still result in significant turtle mortalities (Larocque et al. 2011). Hoop-nets result in the bycatch and death of several species of Michigan turtles including the Midland Painted Turtle, Eastern Snapping Turtle, Northern Map Turtle, and Eastern Musk Turtle (Larocque et al. 2011). A turtle that has taken decades to reach sexual maturity can die in a matter of minutes because it cannot reach the surface.

Dr. Don Uzarski - CMU

2. This fish sampling net has been properly placed in order to reduce harm to any amphibian or reptile that is caught. When placing traps in open water habitat, leave room within the device for animals to reach the surface to breath.

Place traps that have turtle escape routes or allow turtles to breathe - Turtles and other non-gilled amphibians and reptiles must occasionally rise to the surface of the water to breathe. Do not set traps at depths where turtles cannot reach the surface and avoid placing traps at times of year when turtles are active and likely to be caught in traps (i.e., late spring to early fall) (Larocque et al. 2011). Incorporating devices such as turtle excluders or turtle chimneys can prevent turtle mortality from drowning (Epperly 2002, Fratto et al. 2008). Turtle chimneys allow turtles to rise to the surface to breathe but prevent fish from escaping, and turtle excluders allow turtles to escape nets. The use of floats within fyke nets can reduce the frequency and intensity of anoxia in trapped turtles, though are not always entirely effective in preventing mortality (Larocque et al. 2012). These different features can be incorporated into net construction to reduce turtle mortality (Larocque et al. 2012).

Do not set traps in warm water - Set traps in water ranging 40-50°F (Ultsch et al. 1984, Herbert and Jackson 1985). Turtles are more likely to be found dead in nets/traps that are set in warmer, deeper water than cooler, shallower water (Barko et al. 2004). Higher water temperatures increase the metabolic rate of turtles and require them to breathe more often to maintain suitable oxygen levels in their blood (Herbert and Jackson 1985). Higher temperatures also decrease the dissolved oxygen in the water, making intake of oxygen increasingly difficult. Because turtles have extrapulmonary gas exchange (breathe in part through their skin), lower dissolved oxygen levels can decrease turtle survival when trapped under water (Ultsch et al. 1984, Herbert and Jackson 1985). In addition, when turtles are stuck in traps they cannot move to a cooler location to thermoregulate and maintain a body temperature required for survival.

Avoid setting traps in marsh habitats - The placement of nets in most cases occurs in the open portion of lakes and is aimed at sampling open water fish communities. Sometimes nets are set randomly or within a variety of habitats including marshes. Sampling in these habitats often yield high quantities of turtle by-catch. To minimize impacts to turtles these locations should be avoided or traps should be set shallow enough that animals can reach the surface. Whenever trapping results in an amphibian or reptile bycatch, observations should be submitted to the Michigan Herp Atlas website.

Invasive Species Management

The presence of invasive species (non-native and native species that are facilitated by anthropogenic forces) can reduce biodiversity, compromise ecological function, and reduce abundance and species richness of amphibian and reptile communities (See Section 3). The most effective way to reduce these impacts is by preventing the establishment of invasive species by maintaining healthy ecosystems and minimizing introductions of non-native organisms.

1. Decontaminate equipment between visiting sites. Use a 3-10% bleach solution for 30 minutes to reduce the spread of invasive plant and animal species and pathogens.

Decontaminate clothes and equipment - Since many invasive species are unknowingly introduced (See Section 3), decontamination of clothing, equipment, vehicles, and pets that have been in the field is essential to stop the movement of invasive species and disease. Boots and field equipment should be dried for three days or, if needed sooner, they should be cleaned with a 3-10% bleach solution for 30 minutes, and field clothing should be laundered or dried (DAPTF 1991, Coscarelli and Bankard 1999, Young et al. 2007, MWPARC 2012). Alternatively, equipment can be rinsed with hot water >110°F or frozen at 0°F for at least 24 hours (Coscarelli and Bankard 1999). Larger aquatic equipment, such as boats, should be drained of water and dried before moving to another location to minimize the transmission and establishment of invasive species (The Green Marina Education and Outreach Project

Ann Arbor Miller

1. Educational signs can be an effective tool in preventing the spread of invasive species.

2012). Terrestrial passenger and recreational vehicles as well as equipment used for construction, agriculture, forestry, land management, and road work should be inspected and cleaned to remove all invasive plant and animals (Halloran 2013). Inspections should be conducted before entering a new area, especially one that may not have invasive species established, and after exiting an area where invasive species may have been present. Any vehicle or equipment that has operated in muddy conditions should be inspected and cleaned as seeds of invasive plants are easily embedded in mud. Inspections should include the underside of the vehicle where plant material or mud may adhere. As part of cleaning, vacuum the inside of a vehicle and wash the outside in an area at least 100 feet away from a water body (Halloran 2013).

Place educational signs - Education about the impacts of invasive species and how to prevent their spread can also be effective tools in prevention and developing a greater understanding of the extent of this problem (The Green Marina Education and Outreach Project 2012).

Limit human access to sensitive or high-quality wetland areas - This will reduce the threat of introduction of invasive plant seeds, pathogens, and disturbance.

Monitor sites for long-term success - Long-term monitoring and removal programs can prevent invasive species from becoming established. Strategies to prevent invasions include holding bonds for construction jobs until native species are established and involving community or conservation groups in long-term monitoring and removal of any invasive individuals.

Unfortunately, the introduction of some invasive species is inevitable; however, preventative measures and control techniques can limit the effect these invaders have on ecosystems that include herpetofauna. Although amphibians and reptiles can be impacted by the presence and expansion of invasive species, some techniques used to control invasive species can also harm native herpetofauna. Control techniques specific to invasive plants and animals are detailed below and concur with recommendations by PARC and align with goals set forth in the 2013 Michigan's Aquatic Invasive Species State Management Plan, MNFI, and Sea Grant's Aquatic Invasive Species-Hazard Analysis and Critical Control Point (Gunderson et al. 2004, Michigan Department of Environmental Quality et al. 2013).

2. Invasive plants including *Phragmites* and flowering rush quickly colonize disturbed and degraded areas. Due to the dominance and density of such plants, these areas are seldom used by herpetofauna.

If planning to implement an aggressive invasive species control program, agencies such as EGLE, the MDNR, or USDA Wildlife Services can provide the most recent information regarding specific invasive control techniques and programs.

Plant Invaders

There are several invasive plant species that are common throughout Michigan's aquatic and terrestrial communities (e.g., aquatic invaders:

1. Even native plant species can become invasive and choke out other wetland vegetation on which amphibians and reptiles rely.

exotic *Phragmites*; narrow-leaved cattail, reed canary-grass; Eurasian watermilfoil; purple loosestrife; Terrestrial invaders: autumn olive; glossy buckthorn; honeysuckle; multiflora rose; oriental bittersweet (*Celastrus orbiculatus*)) that can negatively impact ecosystems and reduce amphibian and reptile communities. These plants were originally introduced from Europe, Asia, South America, and other locations in North America.

Removal of invasive plants and concurrent restoration of native plant communities is a time-intensive process, typically requiring years of dedication to support the native plant community while invasive plants are controlled and drop out of the local seed bank. Even after restoration is 'complete', there is constant threat of invasion as invasive seeds may remain in the seed bank much longer than native seeds (D'Antonio and Meyerson 2002). Seeds of invasive species transported from nearby populations may sprout and become established if regular maintenance (i.e., hand-pulling, herbicide application) is not continued. Management plans without a long-term outlook can allow 'restored' areas to revert back to their previously disturbed state, which does not provide vegetation structure appropriate for herpetofauna. Short-term plans may also introduce toxins (herbicide) and/or cause mortality through mowing, thus reducing the herpetofauna community without providing an appropriate plant community structure required for the herpetofauna community to rebound (i.e., the herpetofauna community experiences stress from management activities and the continued presence of invasive species) (D'Antonio and Meyerson 2002). Methods of control may need to be integrated for successful management (Dodici et al. 2004). Recommendations for control of invasive plants are detailed below.

Weigh the need for non-native plant removal - Non-native plants can also provide ecological services, such as erosion control. In this situation, the stabilization provided by non-native plants may be more important than the removal of these plants at the risk of increasing erosion.

Consider and integrate multiple treatment methods - Controlled burns, use of herbicides, alteration of water levels, mowing, and other emerging management techniques should be considered when controlling invasive species. Selecting a combination of methods that optimizes control of invasive species while reducing impacts to herpetofauna and other native wildlife will help to restore ecosystem function. The plant species being treated will also help to determine which treatment methods to select, as various plant species may differ in response to mowing, fire, submersion, and chemicals. Mowing invasive plant species, such as *Phragmites*, can stimulate root growth and actually increase the severity of the infestation. In some cases, mowing may be used as a temporary measure to establish openings in the landscape, which can allow light to reach native plants. For more information about mowing, burning, and chemical application techniques, refer to prior information presented in this section.

2. Bare soil can quickly become colonized by invasive plants.

Controlling *Phragmites*

Exotic *Phragmites* is a highly invasive plant, which has dominated several wetland and coastal ecosystems throughout Michigan. As *Phragmites* dominates wetlands, these areas become unsuitable for most herpetofauna and contribute to habitat degradation and fragmentation for these animals. Since *Phragmites* is a highly resilient invader, control of established stands of *Phragmites* requires a multi-phase approach over several years to successfully eradicate a local population. As researchers continue to study *Phragmites* and explore alternative avenues for control, the ideal control methods will likely be updated for more effective, cost-efficient, and environmentally sustainable techniques. At the current time, general *Phragmites* control that accounts for conservation of local herpetofauna follows these steps:

1. Conduct baseline surveys to better understand the amphibian and reptile community composition to best minimize negative effects. These surveys will also provide a baseline for establishing restoration metrics.

2. Chemical Treatment - Use Glyphosate and/or Imazapyr herbicides in **late summer**/early fall when herpetofauna have migrated from wetland areas (Hokanson; Michigan Department of Environmental Quality 2007).

3. Mechanical Treatment - Prescribed fire should be conducted the year following herbicide treatment, either in late summer (mid-July through August) or winter (January until prior to spring green-up). Use of fire in winter is preferable, as herpetofauna will be in hibernation at this time and at less risk (Hokanson; Michigan Department of Environmental Quality 2007). Alternatively, mowing using weed whips, small mowers, brush hogs, and flail mowers or hand-cutting of stems and seed heads can be used in late summer.

Flooding can also be used in systems with water control structures after initial chemical treatment and either prescribed fire or mowing. Areas should be flooded immediately after burning or mowing if conducted in late summer. If burning or mowing is conducted in winter, flooding should be conducted in the spring after hibernating herpetofauna has emerged. Areas should remain flooded (≥6" of water) for at least one year. Drawdowns should be conducted in late summer (late July) to maintain and promote native vegetation and to avoid reestablishment of *Phragmites* and avoid disruption of herpetofauna during hibernation.

4. Follow-Up Spot Treatment and Monitoring - Monitoring and spot control should be planned for several years following the initial herbicide and mechanical treatments. *Phragmites* can re-grow quickly and off-site areas may continue to be a source of seeds. The presence of other opportunistic invasive species, which often occurs following treatment (invasive cattail, reed canary grass, etc.), should also be monitored and spot treated.

1. The above wetland is populated with invasive plant species: flowering rush, purple loosestrife, reed canary, European frogbit and autumn olive. Though invaded by multiple non-native species, this particular wetland supported a relatively rich amphibian and reptile community in part because no one species dominated. Control of invasive species is important, but also considering location and current use by wildlife is important when deciding on how and when to restore.

Cover or treat freshly graded soil - Earthwork creates disturbed conditions, which allow invasive plants to easily become established. Cover bare soil with mulch or plant non-invasive cover crops or native plants to prevent invasive plant establishment and soil erosion.

Monitor and spot-treat for individual plant growth - Since invasive plants can quickly become established, vigilant monitoring can identify and eliminate individual plants that could otherwise spread.

Do not plant invasive plants - Do not buy or plant seed mixtures and nursery plants that are invasive species. Select plants that are native species and varieties. Information to help consumers identify which plants to avoid is available from the EGLE, the Midwest Invasive Plant Network (MIPN), in the Invasive Plant Atlas of the United States supported in part by the National Park Service.

Conduct management techniques during times when wildlife is least likely to be harmed - Regardless of which management technique is selected, timing is of the utmost importance both for a successful outcome and the minimization of potential negative impacts on herpetofauna. If possible conduct management actions during times of the year when resident animals may not be present at the treatment location (i.e., treating a wetland when animals have migrated to upland areas) or when animals may be inactive (i.e., during times when they are burrowed in the substrate, estivating, hibernating). To determine when animals are inactive, an inventory of species present will need to be conducted (See Section 5). Consult a professional herpetologist or wildlife biologist with demonstrated amphibian and reptile experience for recommendations specific to the wildlife communities present at your site.

Consider use of biological control - Use of host-specific insect herbivores can control invasive plants. Control of purple loosestrife by the introduced black-margined loosestrife beetle (*Galerucella calmariensis*) and golden loosestrife beetle (*Galerucella pusilla*) has eliminated up to 95% of purple loosestrife in some areas without the beetles shifting host to other native plants (Blossey et al. 2001). However, use of biological controls is highly cautioned as the successful implementation of a biological control program requires extensive research and testing to determine the full range of consequences of introducing one non-native species to control another.

Animal Invaders

Several invasive animal species throughout Michigan's aquatic and terrestrial communities (e.g., mute swan, emerald ash borer, rusty crayfish, zebra mussel, quagga mussel, sea lamprey, round goby, Eurasian ruffe, and spiny and fishhook waterfleas) have negative impacts on

1. Nitrile Gloves or equivalent should be worn to reduce exposure of chemicals to amphibian skin and the potential spread of disease.

2. Encouraging healthy populations of Northern Water Snakes can help reduce invasive round goby abundance.

ecosystem function and on herpetofauna (See Section 3). Although a number of Michigan's amphibians and reptiles have begun to feed on these species, which reduces their overall success, continued efforts to reduce the spread or introduction of new species are necessary. Specific recommendations for control of invasive animals are detailed below.

Wear gloves to reduce spread of disease - Gloves should be worn when handling animals to reduce the potential spread of disease between sites and animal populations (MWPARC 2012).

Do not move animals or **vegetation** - Moving animals or vegetation from the water body or upland area where they were found to a different area can spread invasive species (e.g., moving firewood between counties has increased the rate of spread of emerald ash borer).

Do not release pets - The release of pets and non-natives can introduce disease to which native species are susceptible and increase competition for resources. Some species released, which are tolerant of Michigan's weather conditions may become established, leading to changes in species composition and shifts in community dominance towards the introduced animal. At popular "release" areas, such as public parks and ponds, large communities of common pet species like goldfish can be seen at high densities, which can impact ecosystem balance. Make sure you learn about the time and resource commitment of keeping and having a pet before bringing it home. In the event you are unable to care for your pet any longer, many organizations will take unwanted pets and should be consulted.

Encourage native biological control - Certain native species have adjusted to recognize some invasive species as a food source (e.g., Mudpuppies and Northern Water Snakes eat round gobies and Northern Map Turtles will eat zebra and quagga mussels). Encouraging healthy populations of native species may help control and minimize invasive fauna species.

Restore site conditions for native species - Create conditions that are beneficial for native herpetofauna and other native wildlife species. Invasive species often become established in disturbed areas that do not provide food, shelter, and reproductive opportunities for native species. By restoring vegetation and other structural and functional components (e.g., branches, logs, snags, or mounds of loose gravel and sand) suitable for native species, habitat suitability for invasive species may decrease.

Consider trapping and culling programs - Trapping and euthanizing can be very effective at

1. Trapping can be an effective tool when dealing with invasive animal populations.

reducing invasive populations (e.g., mute swan, feral swine, raccoon). However, public education and acceptance are critical to the success of any control program.

Only use toxicants/poisons if non-target species have a low probability of impact - When toxicants and poisons are used to control invasive species (e.g., European Starling, feral swine) (Campbell and Long 2009), measures should be taken to minimize risk to non-target species. In aquatic environments this method may not be acceptable, as it is difficult to control which organisms come into contact with chemicals released into a water body.

Avoid chemical controls - Chemicals used to control sea lamprey, zebra mussels, and invasive fish can be harmful to non-target species, including larval amphibians and Mudpuppies (Gilderhus and Johnson 1980, Kane et al. 1993, Waller et al. 1993, Boogaard et al. 2003, Dawson 2003, McDonald and Kolar 2007, Billman et al. 2011). If applied, target sea lamprey populations and avoid locations and times of year when larval amphibians and Mudpuppies are present. Applications should be conducted near the beginning of the winter (i.e., December-January) to prevent residual rotenone effecting amphibians as they come out of hibernation.

2. Where invasive bird populations are an issue, fertility control including egg addling can be used. However, this technique can be time and labor intensive.

Consider fertility control - Methods of fertility control are dependent on the species in question and have variable levels of success (e.g., variable successes controlling sea lamprey and feral swine populations). However, these methods may enhance success in a multi-faceted invasive management plan. Since fertility control requires a considerable amount of research and field trials, we recommend consultation of the MDNR or USDA Wildlife Services if considering fertility control measures. Egg addling and nest destruction are labor intensive methods to control invasive bird species (e.g., mute swan). Egg addling entails removing eggs from the nest, then terminating embryo development by shaking or greasing eggs. The eggs are then placed back in the nest, thus misleading the parent into not laying additional viable eggs. Sterilization in sea lamprey and birth control in nuisance mammalian wildlife species (Cooper and Larsen 2006, Bergstedt and Twohey 2007) have been used, but at the present time these techniques are not effective solutions for large scale invasive eradication. Use of pheromones to attract sea lamprey can help to increase efficacy of other control measures (e.g., lampricide or collection for sterilization) without effect on non-target species. This method also allows for the invasive species to be trapped and removed without significantly impacting herpetofauna.

Subsidized Predator Management

1. Raccoon populations often are subsidized by available food sources and a lack of top tier predators in urban environments.

2. Turtle nests are frequently predated by raccoons, sometimes resulting in almost 100% nest mortality at some sites. This trend is unsustainable and if it continues will likely result in impacts to population viability.

Urbanization and human actions often help to subsidize mesopredator species like raccoons, opossums, and feral cats by increasing food availability (e.g., trash cans, agricultural leavings, intentional feeding) and by creating urban environments with a lack of larger, top-tier predators (e.g., large cats or wolves) (Prugh et al. 2009) Urbanization also leads to a creation of roads, sidewalks, open lawn and park areas which fragment herpetofauna habitat but are easily navigated by raccoons or other urban-adapted wildlife, which disperse widely across the landscape. These conditions have helped to facilitate dense populations of raccoons in urban and suburban landscapes (Prange et al. 2003) Unfortunately, raccoons and other mesopredators are savvy predators of turtle nests (Standing et al. 1999, Burke et al. 2005) often eliminating all turtle reproduction in an area – and also prey on adult and juvenile turtles (Seigel 1980, Seabrook 1989, Browne and Hecnar 2007, MWPARC 2009b, Herpetological Resource and Management 2011, Harding and Mifsud 2017). Although turtles have relatively good defenses (ability to hide in their shells, swiftly swim away, or deliver a 'snapping' bite), raccoons' intelligence and well-adapted hands allow them to dig up turtle nests and catch and eat turtles as well as many other reptiles and amphibians.

The general survival strategy of turtles as a group is high adult survival to offset naturally high juvenile mortality. Because many turtle species are long lived with a slow rate to maturity and low reproductive rate, mortality exceeding the normal rate of loss could lead to population declines and possible long-term population/species extirpation. However, predation from raccoons and other mesopredators frequently leads to complete nest and juvenile mortality and significantly reduces adult survival (Christiansen and Gallaway 1984). The lack of recruitment of younger age classes paired with the loss of long-lived adults can lead to turtle population declines and local extirpations of rare and especially sensitive species (Congdon 2001, Browne and Hecnar 2007). Efforts to return the natural population densities of subsidized mesopredators include direct species control, education and outreach regarding the ecological and human safety concerns, and improved regulations and enforcement. For turtles and other sensitive herpetofauna and wildlife to be sustained in Michigan, populations of raccoons and other problematic mesopredators must decrease substantially through preventative and control measures.

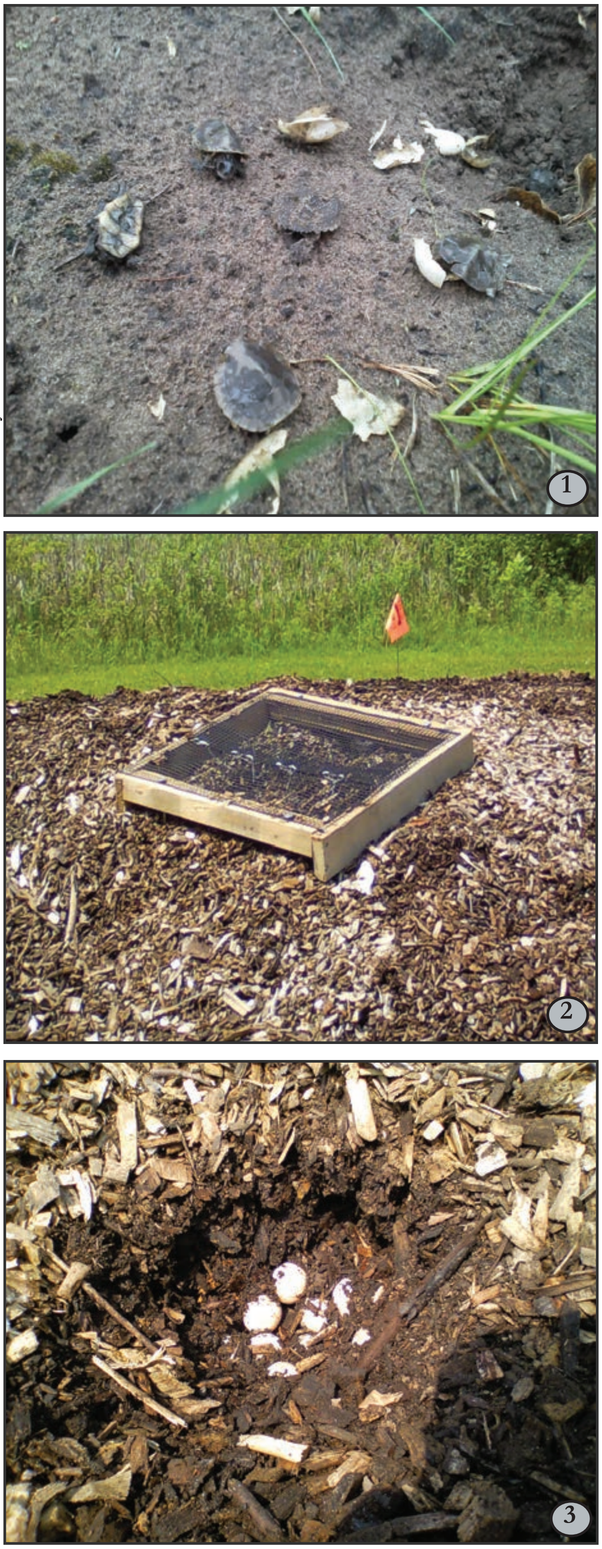
Discourage feeding of raccoons and other mesopredators - Further increases in populations of problematic mesopredators should be prevented by eliminating access to food sources, such as trash cans, and by discontinuing fostering, rehabilitation, and trap and release of these animals.

Implement control measures - In many places with established raccoon populations, lethal control methods can reduce pressure on turtles and other wildlife (Garmestani and Percival 2005, Engeman et al. 2006, Suzuki and Ikeda 2020). Michigan allows raccoon trapping year round, and developing a relationship with a local trapper may also provide a viable and inexpensive option for raccoon control (MWPARC 2009b). Raccoons can be caught in live traps with marshmallows as bait or in foothold traps baited with sardines; both trap and bait combinations reduce capture of non-target mammals including pets (Curtis and Sullivan 2001). Free-ranging cat spay/neuter and lethal control programs can be implemented to reduce the negative impact of cats on wildlife. Within small geographic areas, these control methods can be implemented by trapping cats, allowing for the avoidance of harming pet cats (Cecchetti et al. 2020). Shooting and lethal injection are considered the most human measures of the lethal control of cats. The lethal toxin Paraaminopropiophenone is relatively humane as it causes quick loss of conscious and death in as little as thirty-seven minutes (Cecchetti et al. 2020). Lethal control and spay/neuter programs are most effectively implemented on farms with livestock as they are more likely to support several free-ranging cats than other residences (Coleman and Temple 1993). Warfarin, the active ingredient in the only feral hog bait approved by the United States EPA, effectively kills feral hogs and, when used in the correct concentration, poses a reduced risk to non-target wildlife species (Poche et al. 2019). Raccoon, cat, feral swine, and other predator control methods should always be conducted humanely and comply with state regulations.

Engage the public - Public education is necessary to support and implement these measures with long-term success and benefits for turtles and other sensitive wildlife populations impacted by raccoons, feral or outdoor cats, and other mesopredators. Explaining the importance of balanced ecosystems and the necessity for selective management strategies, such as mesopredator control in urban and suburban areas, can help the public to accept management strategies. Public education can also include simple strategies, such as placing signs to inform the public about local species conservation needs. Vet clinics and pet stores can also educate pet owners on the dangers posed by cat and dog predation to wildlife (Twardek et al. 2017).

Protect turtle nests and other sensitive herpetofauna habitat - Using fencing and other covers to exclude predators from turtle nests can help to increase turtle nest and hatchling survival (Brown and Macdonald 1995, Ratnaswamy et al. 1997, Smith et al. 2012), especially in areas where lethal control is not a viable option. The

Carl May



1-3. Protecting turtle nests from predation by an artificial cover (2) will increase the chances of egg and hatchling survival.


Jim Harding & Hailey Brown

1


Jim Harding & Hailey Brown

2

1-2. Eastern Box Turtles, like many other turtle species, carefully excavate a nest underground using their back legs and subsequently cover up the hole, never laying eyes upon the eggs themselves (1). Within an incubation period of approximately 2 months, hatchlings will emerge from the nest (2). Monitoring and controlling subsidized predator populations or implementing nest protection devices are essential in ensuring turtle population stability and growth.

installation of a two-wire electric fence with wires five and ten inches aboveground is an effective method of excluding raccoons from an area (Curtis and Sullivan 2001, Quinn et al. 2015). Various designs of physical nest protective structures have proven effective in excluding raccoons including a square wire design (Bougie et al. 2020) and lightweight, conical, wooden dowel design (Buzuleciu et al. 2015) of exclusion cages. It should be noted that these techniques are labor and time intensive and do not remove predation pressure on adult turtles by mesopredators. In addition to the physical protection of turtle nests themselves, the active removal of raccoons has increased the survivorship of Blanding's Turtle nests (Urbanek et al. 2016). In areas where feral swine are an issue, hog exclusion fences can be effective tools to protect sensitive herpetofauna habitat (Brown et al. 2015).

Do not allow outdoor cats and dogs - Cats, whether beloved pets or feral, are an invasive species that alters the composition and abundance of small mammal, bird, amphibian, and reptile communities (Woods et al. 2003, Baker et al. 2005, Beckerman et al. 2007, Dauphine and Cooper 2011). It is estimated that domestic cats kill 1.4-3.7 billion birds and 6.9-20.7 billion mammals annually in the United States (Loss et al. 2013). Keeping pets indoors prevents herpetofauna and other wildlife from being harmed in addition to increasing the lifespan of pets themselves (Loyd et al. 2013). Though highly discouraged, if cats must be let outside, certain products can reduce their negative impact on herpetofauna. Birds-Be-Safe cat collar covers (Hall et al. 2015) and CatBibs (Calver et al. 2007) are both harmless to cats and may reduce herpetofauna mortality rates. Providing refuge habitat of dense vegetation on a site can also increase the safety of herpetofauna and decrease predation by cats (Edgar et al. 2010).


3

3. Domestic cats have been shown to live longer, healthier lives when kept indoors as opposed to being outside.

8. Development Techniques

This section describes approaches that should be taken during development activities within natural, urban, and rural areas. These recommendations can be utilized by land developers, consultants, landscape architects, and those interested in minimizing disturbance to herpetofauna. Several common development practices are known to have negative effects on amphibian and reptile populations, however by practicing these strategies the impacts can be mitigated. The goal is to minimize impacts to the natural resources while still addressing the development goals and objectives.

Horizontal Directional Drilling and Boring

Horizontal directional drilling (HDD) is a construction technique that foregoes open-cut trench installation of natural gas pipeline and transmission line segments and instead utilizes a tunnel drilled underneath the right-of-way (ROW). The underground tunnel travels in an arc line from the entry point, underneath the specified crossing, and to the surface of the opposite side. Advanced technology and highly trained technicians guide the drill head and resulting path electronically to maintain precise angle, depth, and exit point to adhere to environmental and engineering protocols. During the drilling process, a bentonite clay mixture (natural, non-toxic substance) is utilized to lubricate the tunnel and remove drill cuttings. Once the underground tunnel is complete, the pipeline segment can be pulled through the arched tunnel to the opposing side to be welded or connected to the rest of the system. Boring is a similar installation technique to HDD but does not require a deep arc path and is typically utilized for smaller diameter segments such as cable or optic lines.

1. HDD machinery and workspace.

Additional precautions should be taken when conducting HDD or boring to avoid an inadvertent mud release (IMR) of the bentonite clay mixture used for drilling, particularly when used under sensitive habitats, waterways, and areas of concern. The use of this non-toxic substance has little to no direct impact when contained within the drill path; however, if unintentionally released into wetlands or waterways due to fractures in sub-surface geology, wildlife including benthic invertebrates, aquatic plants, fish and their eggs, mussels, and all life stages of

1. A fen wetland possessing suitable habitat for the Eastern Massasauga Rattlesnake located along a pipeline corridor. This location will utilize HDD installation to greatly minimize impacts to this sensitive natural resource.

herpetofauna species can be smothered by the fine particles. An environmental contingency plan that includes protocols for monitoring and preventing IMR as well as an organized, timely, and "minimum impact" response in the unlikely event of a release during HDD or boring activities should be implemented to minimize the risk to sensitive ecological areas.

Despite the potential for an IMR, the HDD and boring processes have a significantly reduced impact on the landscape as they minimize impacts on the area above the drill. There are no direct or indirect impacts to herpetofauna along the path of the ROW as no existing habitat, vegetation, or hibernacula is temporarily impacted and no herpetofauna are likely to be injured or killed. HDD and boring are the preferred burial methods of pipeline or cable segments as opposed to open-cut trenching which results in the temporary removal of habitat and potential impact to herpetofauna.

Site Grading and Topography

Topography can determine how wildlife traverse a site, how water flows over or through a site, and what niches are available for flora and fauna. In areas where the original topography has been altered, historical maps, soil maps, and water table depth may give clues about the original community types that were present on the site. Such an analysis may help to determine the appropriate trajectory for restoration efforts.

Any site grading should preserve intact areas of wildlife habitat to prevent further degradation during construction. Additional recommendations are listed below.

Create gradual slopes in wetlands - Site grading should be gradual, especially along the banks and shoreline of wetland areas. Slopes in wetlands and uplands should be less than 1:10 and 1:3, respectively, with gradients as shallow as 1:15 to 1:20 preferable to support a greater variety of amphibians and reptiles and their prey items. These gentle slopes are easily traversed by amphibians and reptiles as well as equipment used to create various habitat structures. These slopes should be maintained along the banks of wetlands with deeper pockets in the center to avoid overgrowth of vegetation including reed canary grass, Phragmites, and hybrid cattail.

Create islands in constructed wetlands or lakes - Islands provide a place with reduced mammalian predator pressures on amphibians and reptiles.

Develop microtopography features - Microtopography is critical in wetland areas and some upland areas as it provides a variety of niches with unique hydroperiods, which can accommodate a rich variety of animals. Fine grading should be used to develop microtopography features (<6" deep) (Wisconsin NRCS 2010).

Create compaction on the lower edge of wetland areas - During grading, vehicle tracks will compact the soil. These paths should be minimized, in general, but can be located on the lower side of wetland areas where soils need to be less permeable to water.

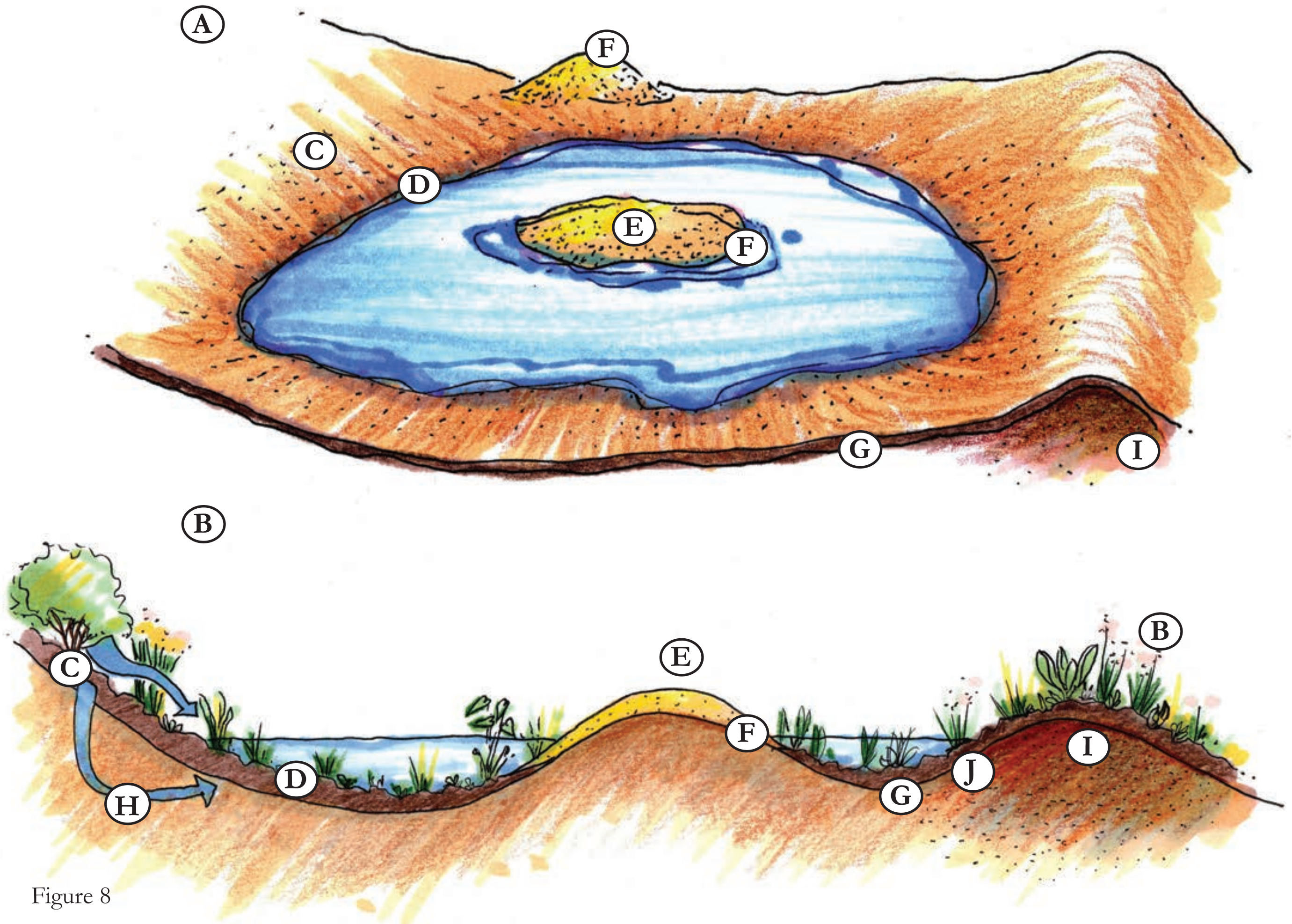


Figure 8

Figure 8. A conceptual drawing of final grading to create a wetland (A) and a section of the same wetland after vegetation has become established (B).

Create slopes that are <1:3-1:10 in upland areas (C) and slopes that are at least as shallow as 1:15-1:20 in portions of the wetland (D).

Create islands in wetlands to provide a protected area for turtle nesting and amphibian and reptile basking (E).

Sand can be used to create turtle nesting areas on islands and near the water (F). Soil high in organic matter can be distributed over a site to provide ideal growing conditions for a wide range of wetland and upland plants (G). Non-clay soils should be placed where infiltration is desired (H). Clay can be placed and compacted at the lower side of a wetland to create a berm which helps retain water (I).

Use fine grading to develop microtopographic features <6" deep (J).

Stockpile and use sand, clay, topsoil, and high organic matter soils judiciously - Various soil types vary in texture and permeability and can be used to create a variety of wetland features and structure. Sand can be used to create well-drained areas, such as turtle nesting structures; clay can be used to create berms or slopes on the lower side of wetlands; and organic soils and topsoil can be used to topdress terrestrial areas for plant establishment (Biebighauser 2011). Organic soils should be combined with mineral soils with a high capacity for holding water to prevent loss before dense vegetation can be established.

1. Western Painted Turtles and other reptiles and amphibians are at risk as they cross roads during their seasonal migrations to breeding or nesting sites.

Figure 9

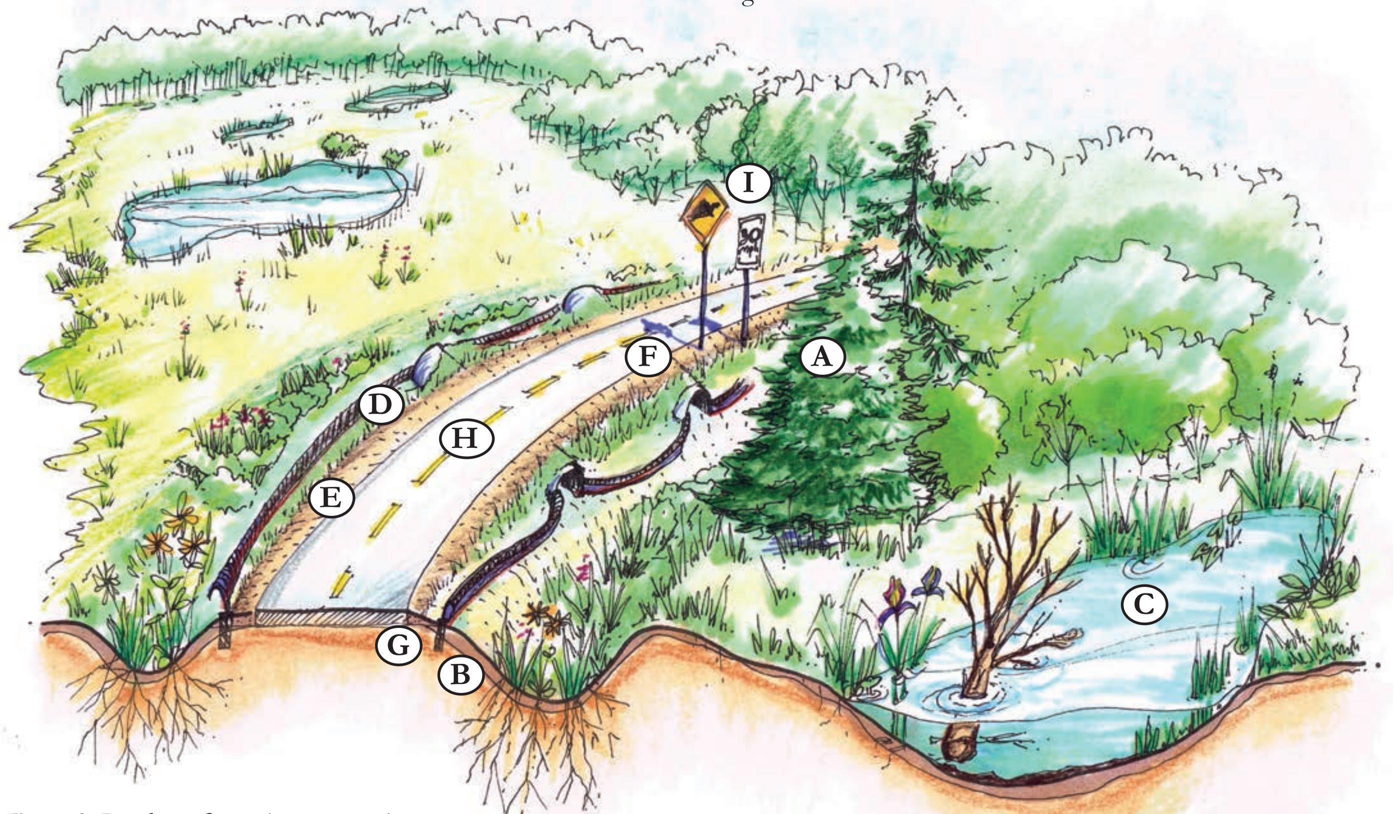


Figure 9. Road configuration, vegetation planted to block salt spray (A), and pollution-catching vegetated buffers (B) preserves high quality wetlands (C).

Do not mow along the shoulder in the spring during turtle nesting season (D).

No curb and gutter system to trap amphibians and reptiles on the road (E).

Road crossing structures maintain connectivity between amphibian and reptile habitat (F). An embedded barrier with curved top directs animals toward the crossing structures and restricts their movement into the road (G).

Reduced salt application in the winter reduces water salinity (H).

Wildlife crossing signs and lower speed limits at kill zones raise driver awareness and reduce road mortality (I).

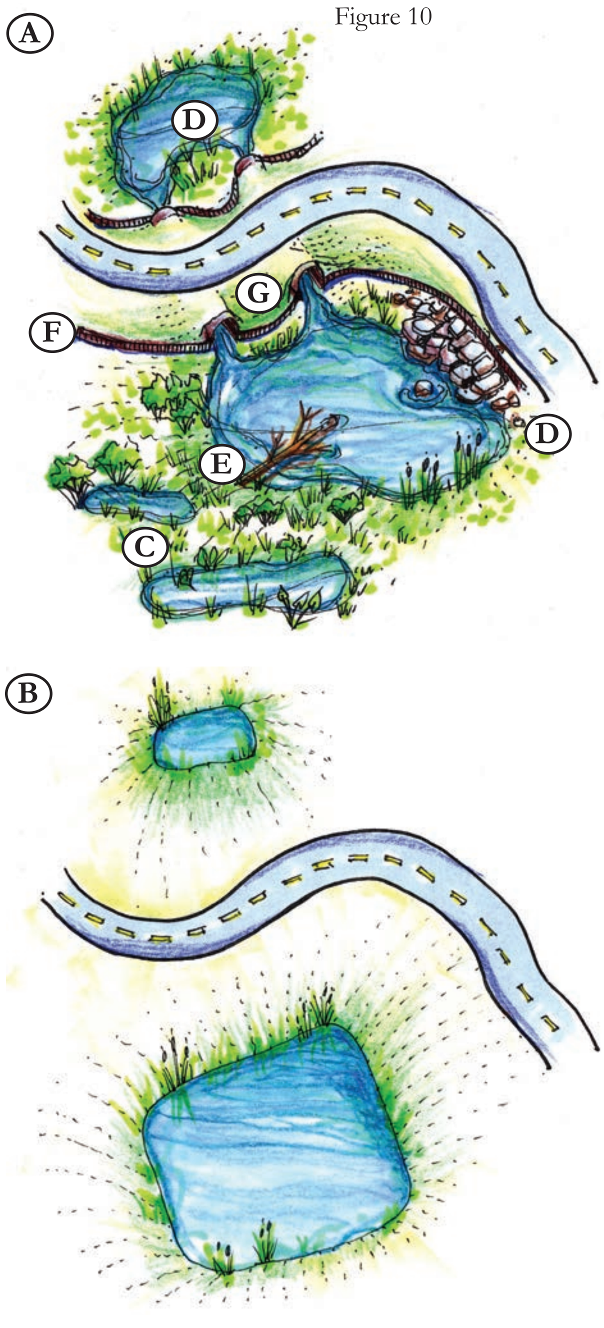


Figure 10. Landscapes which maintain hydrology, a variety of wetland types, and animal movements (A) provide habitat for a greater variety of amphibians and reptiles than do simplified landscapes with disconnected hydrology (B).

Fishless wetlands (C), rock retaining walls with crevices suitable for reptile cover (D), native vegetation and woody debris (E), herpetofauna barriers (F), and road crossing structures (G) support a variety of amphibian and reptile species.

Transportation

Roads and railroads present several types of threats to amphibians and reptiles including habitat replacement, habitat degradation through decreased water quality, barriers to movement across the landscape, road mortality, and functioning as an attractive hazard for basking and travel corridors (Trombulak and Frissell 2000, Steen and Gibbs 2004, Andrews and Gibbons 2005, Rowe et al. 2005, Bartoszek and Greenwald 2009, Patrick et al. 2011, Iosif 2012, Clauzel et al. 2013, Hartzell 2015, Dornas et al. 2019) (See Section 3). Boating traffic poses several threats to herpetofauna including direct mortality and injury, shoreline habitat degradation and erosion, and reduced water clarity (Bulté et al. 2010, Fonseca and Malhotra 2012, Lester et al. 2013, Hollender et al. 2018, Bilkovic et al. 2019, Schafft et al. 2021). Despite the many threats to herpetofauna associated with transportation, transportation placement, construction techniques, and maintenance, public education can be used to lessen the impact of roads, railways, and boats on herpetofauna.

Road Placement

Road placement relative to herpetofauna habitat can greatly affect the level of mortality along a road (Gunson et al. 2012) and create a barrier for movement of herpetofauna across the landscape (Gibbs 1998). Roads that do not conflict with seasonal migratory routes and herpetofauna habitat are less likely to have herpetofauna "kill zones". Also, road salt, petroleum, hydrocarbons and heavy metals are typical pollutants associated with roadways. Roadway design also dictates how road maintenance and vehicle use will impact water quality and the herpetofauna in those habitats. Prevention of pollutants from entering wetlands via the roadway is the best option.

Avoid herpetofauna habitat - Locating roadways away from essential herpetofauna habitats can minimize the impact on herpetofauna. Plan for roads to circumvent all habitat areas when possible; however, if this is not feasible, essential or high-quality communities should be avoided at a minimum. The Michigan Herp Atlas is a useful tool for determining known occurrences of herpetofauna and road-related mortality (if available). If placing a road near an essential habitat feature (e.g., a vernal pool), a landscape buffer should be used to mitigate impacts to that feature and the herpetofauna using it (Calhoun and Klemens 2002). Unmowed buffers (sometimes referred to as "grow zones"), rain gardens, and vegetated swales placed along roads can reduce erosion, intercept chemical and sediment adsorbed (non-point) pollution, and degrade pollutants before discharge of the water into herpetofauna habitat. Finally, if a wetland area cannot be avoided entirely, the road should be placed so that wetland is only on one side of the road to reduce mortality of amphibians and reptiles crossing between the wetlands (Langen et al. 2009).

Consider seasonal routes of movement for amphibians and reptiles - Roads should be placed to avoid or lessen impacts on local herpetofauna during their seasonal movements and migrations. Some Michigan herpetofauna use migratory routes that differ only slightly in location among years (Russell et al. 2005, Jenkins et al. 2006); however, most movements across the landscape are tied to animals' life histories and long-term ecological conditions (Russell et al. 2005, Semlitsch 2008). Annual migrations often are dependent on habitat features, such as the distribution of suitable areas for mating, egg laying, feeding, hibernation, and basking (Shine et al. 2001, Jenkins et al. 2006). Weather conditions, such as temperatures and precipitation, can trigger migrations between upland and wetland areas for mating, egg laying, post emergence dispersal, and hibernation (Sexton et al. 1990, Russell et al. 2005).

Road Crossing Structures

If a road must be placed in or near areas of frequent herpetofauna movements or suitable habitat, under-road crossings and directional barriers greatly reduce habitat fragmentation and herpetofauna mortality (Bassel 2002, Dodd et al. 2004, Pelletier et al. 2005, Rees et al. 2009, Colley et al. 2017). Turtle, snake, frog, salamander, and lizard species have all been observed crossing through under-road passages (Jackson and Tyning 1989, Yanes et al. 1995, Jackson 1996, Allaback and Laabs 2002, Schrag 2003, Taylor and Goldingay 2003, Laidig and Golden 2004, Gartshore

Figure 11. Culverts historically have been undersized (left). This can create an impoundment upstream (A) and incise the channel downstream (B). This restricts hydrology and natural stream meanders as well as wildlife crossing in the culvert. Oversized culverts and overflow culverts (right) accommodate natural hydrology and provide more light and air circulation in culverts. Wingwalls or barrier fences (C) directing animals towards culverts can further decrease road mortality. Grates (D) in the top of culverts let in natural light.

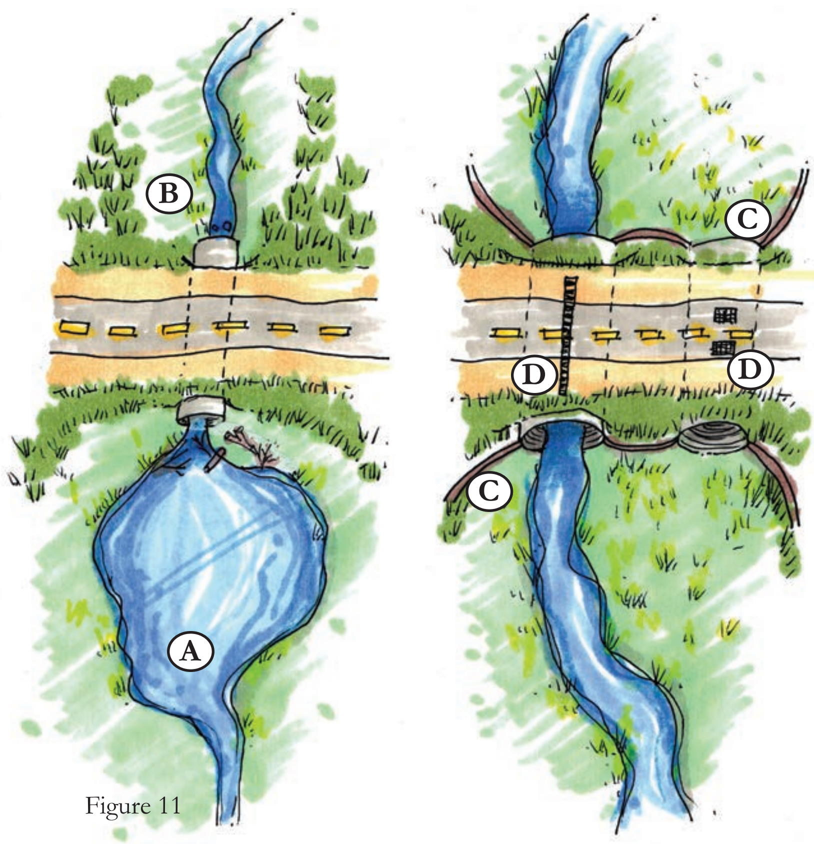


Figure 11

1. Wildlife culvert systems like this one can have a large impact on reducing road mortality.

1. Under-road culverts allow amphibians and reptiles to move over the landscape without entering dangerous roadways.

2. Incorporating barrier walls help guide wildlife into culverts and reduce road mortality.

3. Amphibians and reptiles, like this Eastern Snapping Turtle, may cross roads during migrations or bask on the warm surface

4-5. Dead-on-road amphibians and reptiles, like this Blanding's Turtle (4) and Eastern Fox Snake (5), are a common sight. This is most common during spring emergence, turtle nesting season, and fall migration.

et al. 2005, Kaye et al. 2005, Painter and Ingraldi 2007, Patrick et al. 2010, Caverhill et al. 2011, Pagnucco et al. 2012, Parren 2013, Bain 2014, Jackson et al. 2015, Sievert and Yorks 2015, Colley et al. 2017). A professional designer or engineer should be consulted on the design of these structures to ensure public safety.

Document "kill zones" - Understanding where amphibians and reptiles cross roads and have the greatest risk is necessary to effectively and efficiently reduce mortality. Data collection can begin with anecdotal accounts but there is no substitute for conducting a "road-cruising" survey throughout the active season to clearly define the extent of "kill zones". However, it has been suggested that "kill zone" analysis does not account for high-traffic roads where previous roadkill mortality has already reduced population size to the point of decreasing roadkill (Fahrig et al. 1995). To compensate for this, models of animal movement behavior and habitat distribution should be taken into account when identifying road-crossing sites (Lesbarrères and Fahrig 2012). A herpetologist or professional wildlife biologist that has demonstrated experience with herpetofauna can provide assistance conducting these surveys. It is important that observations of all amphibian and reptile data – dead or alive – be contributed to the Michigan Herpetological Atlas to help document these areas and help managers mitigate the negative impacts.

Install barriers and crossing structures at "kill zones" - Implementation of crossing structures at identified "kill zones" reduces herpetofauna mortality (Bassel 2002, Dodd et al. 2004, Pelletier et al. 2005, Rees et al. 2009, Colley et al. 2017). Fencing and/or barrier walls, when used in conjunction with wildlife culverts, can further decrease road mortality (Aresco 2005, Glista et al. 2009). Fencing and barrier walls help to keep animals off roads and guide them toward crossing structures. In situations where habitat connectivity is not an issue, fencing may be used as a standalone mitigation measure to reduce road mortalities (Jackson et al. 2015). A silt fence or drift fence can be used as a temporary, low cost solution to help move reptiles and amphibians safely

1. Wildlife barriers which are anchored into the ground prevent amphibians and reptiles from burrowing under or crawling over into roadways or other hazardous areas.

across roads (Glista et al. 2009). However, several manufacturers produce plastic, metal, and concrete wildlife barrier products that are more aesthetically pleasing and durable. Barriers should be embedded at least 6" into the ground to prevent "burrowers" (e.g. Mole Salamanders) from gaining access to the road. The top of these barriers should curve or angle away from the road to prevent "climbers" from going over. This type of barrier has reduced road mortality for herpetofauna and other wildlife (Bassel 2002, FHWA 2003, Dodd et al. 2004). Barriers should be placed to funnel herpetofauna directly into the entrances of an existing culvert or bridge, or a new crossing structure designed specifically to provide passage. Angling barriers toward crossing structures rather than positioning them parallel to the road may encourage greater tunnel use (Pagnucco et al. 2012).

Maintain barriers and road crossings to ensure animal use - Overhanging vegetation can provide a path for herpetofauna over barriers and onto the road, particularly for excellent climbers like Cope's Gray Treefrogs and Eastern Gray Treefrogs (Dodd et al. 2004). Vegetation next to barriers should be maintained to ensure that none is overhanging or leaning on barriers. Road crossing structures that also convey water may occasionally need to be cleared of vegetation to ensure animals are not blocked from crossing through the structure.

Place crossing structures no more than 150 feet apart - More crossing structures spaced close together will decrease the barrier effec created by a road. However, crossing structures placed 150 feet apart appear to be suitable for several species (Ryser and Grossenbacher 1989). Even small herpetofauna, like the Spotted Salamander, have been observed successfully traveling to and utilizing road crossing structures placed over 90 feet apart (Jackson 1996).

Shorter crossing structures are better - Amphibians have been documented traveling over 130 feet through an under-road structure, but herpetofauna typically respond better to shorter crossing structures, crossing faster and with less hesitation (Krikowski 1989). Amphibians and reptiles using crossing structures potentially have a greater susceptibility to predation while using the structure since a predator could more easily corner or trap its prey in a confined area. A shorter crossing structure reduces the time for crossing and minimizes predation risk.

2. Oversized culverts with metal grated tops and soil bottoms let more light in and create conditions that are more natural and easier for amphibians and reptiles to navigate.

Oversize culverts for wildlife - Oversized culverts are favorable as they can be easier for herpetofauna to find and negotiate. This type of structure can also reduce maintenance and repair costs that result from large flood events, which are increasing due to climate change. Culverts should have a **minimum** of 1 foot of vertical clearance inside, and 2 feet of horizontal clearance. Some research suggests that tunnels >1.6 feet will likely accommodate the passage of the greatest number of amphibian and reptile species (Woltz et al. 2008). If a wildlife crossing structure contains a stream or river, the design recommendations discussed later in this Section should be consulted.

Carefully select culvert materials - Investigate potential impacts

Kim Barrett

Kim Barrett

1-2. Wildlife crossing structures are becoming increasingly used throughout the U.S., Canada, and Europe.

Figure 12. Section of a culvert with dry ledges to accommodate amphibian and reptile passage even when water levels are high.

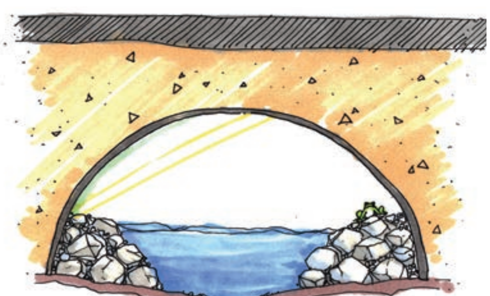


Figure 12

from the culvert material. Galvanized metals and some plastics may leach chemicals, and concrete retains moisture. Metals are excellent conductors, and air in tunnels may remain colder longer than the surrounding air. Current engineering guidelines should be consulted before a new structure is installed however, when possible select products with low-impact manufacturing processes, such as those that meet or exceed the American Green Building Council's LEED (Leadership in Energy and Environmental Design) standards. All work should also be in accordance with Federal and State engineering standards for roads, culverts, and bridges. Passage structures and materials used should be selected based on target species and their habitat needs present on each side of a roadway.

Mimic natural conditions - Crossing structures which are largely open to ambient light and more closely mimic natural conditions typically encountered by wildlife are more suitable for herpetofauna to cross (Dexel 1989, Jackson 1996, Sievert and Yorks 2015). This can be accomplished by creating larger tunnels or installing grates or slotted tops on culverts. Culverts with an open or lined bottom allow amphibians and reptiles to cross on natural substrates and may be better suited for amphibian and reptile crossings than culverts with a metal or concrete bottom (Mazanti 2003, Lesbarrères et al. 2004). Also, planting native herbaceous plant species near culverts (as opposed to the turf grass typically planted along roads) can increase microclimate suitability for herpetofauna and increase the likelihood of culvert use (Mazanti 2003). Avoid using rip-rap or other stone placement near culverts. If rocks must be used, use as little as possible. Rock should be placed with gaps planted with native herbaceous vegetation to provide better access and cover for amphibians and reptiles (Yanes et al. 1995, Mazanti 2003).

Size culverts and crossing structures to accommodate seasonal water levels - Pre-construction hydrologic processes should not be restricted by the crossing structure. Depending on the site, one or many culverts may be necessary to facilitate hydrologic processes without altering the ecosystem on both sides of the road. Spring amphibian migrations to breeding pools often coincide with snowmelt runoff and spring rains, creating treacherous flood conditions in culverts (Patrick et al. 2010). Creation of dry ledges along the inside edges of a culvert or small bridge that is seasonally inundated can provide areas of refuge for smaller species to pass safely during periods of peak flow.

Examine the potential for predation at crossing structures - Raccoons and other predators are known to use culverts (Land and Lotz 1996, LaPoint et al. 2003). In areas of high predator densities, barrier fences and crossing structures may provide "easy pickings" for predators. Incorporation of grates on culvert ends can help reduce such predation pressures though it limits passage for larger herpetofauna such as turtles.

No benefit would be gained by placing a crossing structure if predation would cause as much mortality as road-kills.

Provide habitat structures on both sides of a road - If creating a crossing structure is not feasible, creating features, such as turtle nesting sites or suitable breeding pools, away from the road surface. When possible, placement on both sides of the road may reduce or avoid the need to cross.

Figure 13

Curbs, Gutters, and Drains

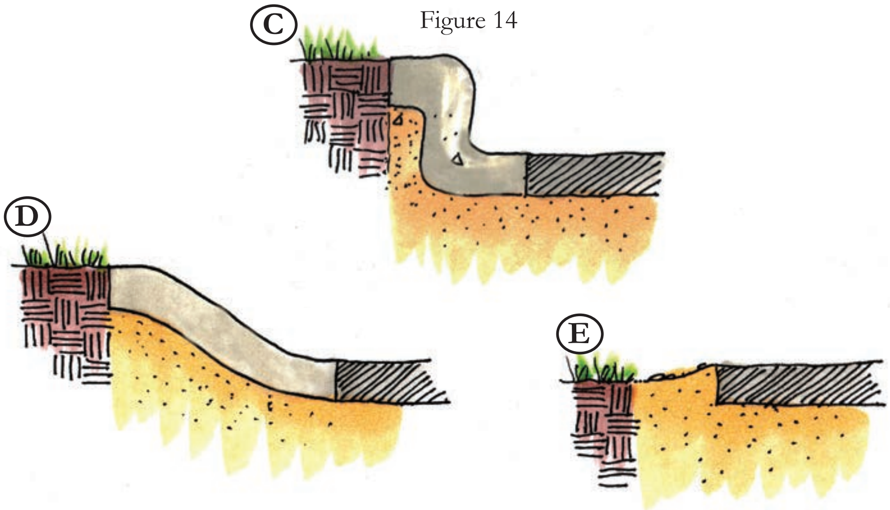
Vertical curbs trap small herpetofauna which have crawled, slithered, or hopped onto a road and try to exit on the opposite side. Once trapped by the curb, these animals are either killed by a vehicle or have to travel the length of the curb to find a traversable exit point. If an animal encounters a drain with typical-sized grate holes while traveling along a curb, they are likely to fall in and not be able to escape. This unfortunate fate is all too common for hatchling turtles or small frogs (Piepgras et al. 1998, Harding and Mifsud 2017, Mifsud personal observation 2022). Recommendations to avoid this unnecessary road mortality are described below.

Avoid placing or remove standard 6" vertical curb and gutter - A vertical 6" standard curb can trap small herpetofauna in the road. By not placing or by removing a standard 6" curb and gutter, they can more quickly cross the road thereby lessening the time in a 'danger zone'. Also, the lack of a curb and gutter allows for sheet drainage to the side of the road, and drains which can pose a threat to herpetofauna become unnecessary. Gutters often redirect runoff away from wetlands and can lead to altered wetland hydrologic processes.

Place rolled curb - In instances where a curb is still needed to direct

Figure 13. Typical drain grate (A) and wildlife friendly (a.k.a., bicycle safe) grates (B). Grates with smaller openings and grating along the curb prevent amphibians and reptiles from falling through.

Figure 14



Figures 14. Standard 6" curbs (C) can trap small amphibians and reptiles in roadways. Rolled curbs with a gentle slope (D) or no curb (E) can help small animals move to safety.

stormwater, a rolled curb with a <45° angle to the road will allow herpetofauna to climb over the curb (Piepgras, Sajwaj et al. 1998).

Fit drains with excluding grates - All drains should be fitted with grates with openings no larger than 1” x 1”. This smaller size hole can ensure that even hatchling turtles are able to cross safely. These grates are sometimes advertised as “bicycle-safe” drains with small openings that prevent bicycle tires from becoming wedged in grates.

Marvin Blaine

1. Within Kensington Metropark, the installation of turtle and snake crossing signs at appropriate locations along the road appear to have helped decrease herpetofauna road mortality. Park patrons also have become more aware of the rich herpetofauna communities within the park and the need to protect these species. It is important to report observations of amphibians and reptiles on roads (both live and dead) to help document areas of high density to the Michigan Herp Atlas. Do not put yourself in danger by using extreme caution and always adhering to traffic laws.

Maintain Amphibian and Reptile Friendly Roadways

While road and culvert construction play a large role in the reduction of herpetofauna road mortality, post-construction measures can preserve water quality of nearby wetlands, further reduce fragmentation, and prevent road mortality to help maintain populations of herpetofauna.

Minimize salt and de-icer application - Use of salt should be avoided or reduced on roads, especially near wetlands, as increased salt concentrations can decrease survival of pollution-sensitive amphibians such as Spotted Salamanders, Wood Frogs, Northern Spring Peepers, and Green Frogs (Karraker et al. 2008, Collins and Russell 2009), and are linked to increases of malformation in amphibians (Karraker and Ruthig 2009). Reductions in road salt application can also reduce the cost of purchasing and applying salt.

Buffer roads with vegetation - Where road salt is applied, the use of vegetated ditches can help infiltrate water to reduce runoff. As polluted water infiltrates the soil, plant roots and soil microbes can sequester harmful compounds or degrade them into inert compounds (Baltrenas and Kazlauskiene 2009).

Educate the public and motorists - Given the overwhelming evidence that use of salts as road de-icers increases the salinity of drinking water supplies and ecosystems (Jackson and Jobbágy 2005, Kaushal et al. 2005), the public should be informed of how salt reduction policies can increase the quality of their community. Other local public education efforts can make the community aware of the need to protect and slow down for amphibians and reptiles as they move across the landscape where humans have built roads.

Time maintenance to avoid herpetofauna - Curb and shoulder maintenance can be scheduled to avoid activities during breeding and nesting seasons (typically April-June), migrations, or peak foraging times in areas where there are important herpetofauna populations. During these times, several species of herpetofauna migrate overland to look for mates and nesting areas, and turtles use the warm, dry substrate at the edges of roads for nesting.

Install wildlife crossing signs - Wildlife crossing signs may decrease road mortality through public awareness (Gunson and Schueler 2012). Signs should be implemented in documented or potential areas of high road mortality (i.e., between two wetlands), and sign type and graphics should be consistent at a regional scale (Gunson and Schueler 2012). These efforts should focus on migratory and breeding seasons of local amphibian and reptile species when they are most susceptible to road mortality.

1. Amphibians and reptiles, such as this Eastern Snapping Turtle, often become trapped between railroad rails and either desiccate or are crushed.

Temporarily close roads - In rural areas with mass migrations of herpetofauna or other wildlife, a temporary road closure may prevent mass mortality and benefit local herpetofauna populations (Gibbs and Shriver 2005, Timm et al. 2007). These road closures have been successful in Europe, Canada, and parts of the U.S. (Seigel 1986, Jochimsen et al. 2004).

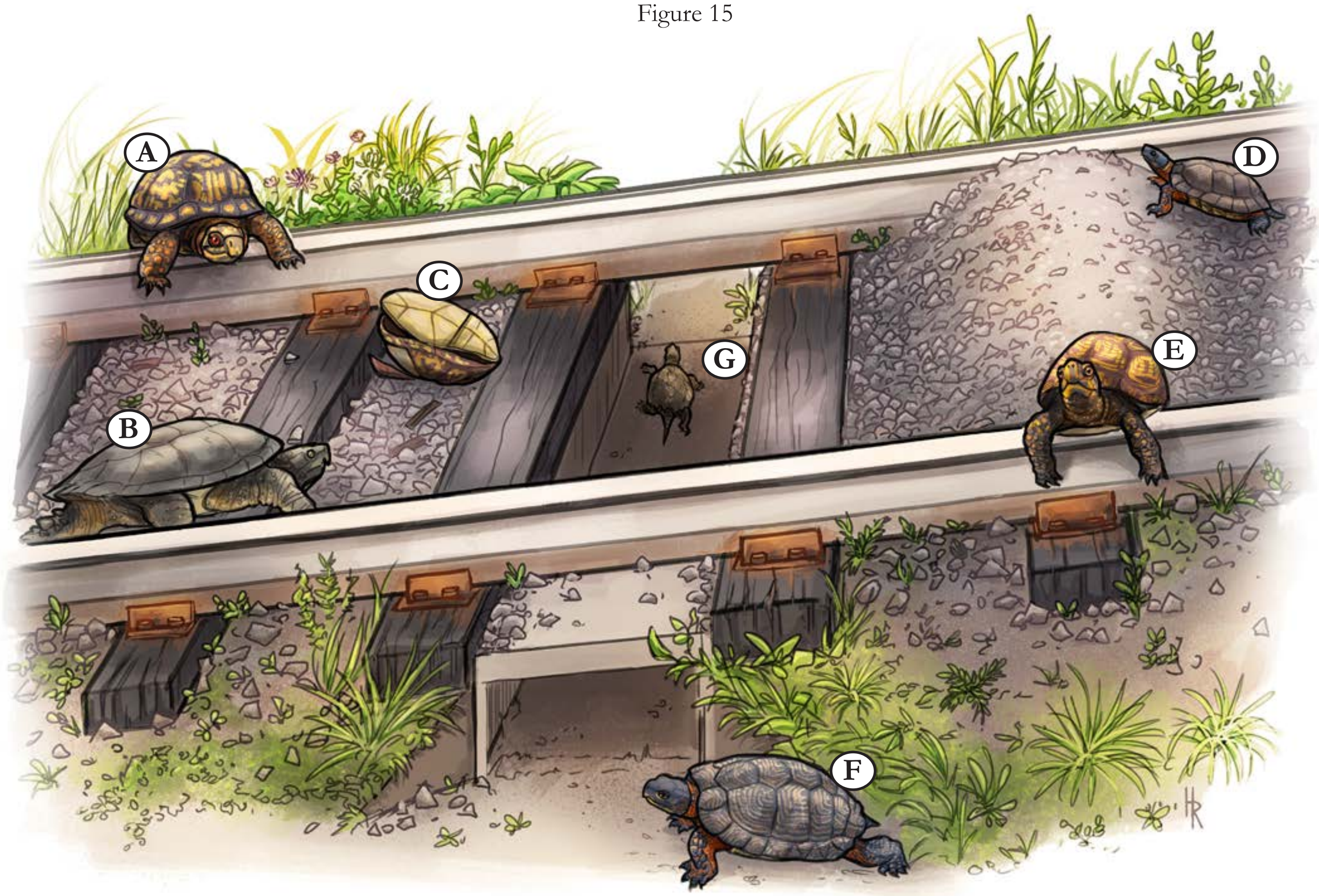
Engage the public to move animals - Movement of animals across roads during migration events can be a viable option to reduce mortality, especially if locally supported in the community (Minnesota Herpetological Society 2010). These programs are only a temporary solution as they are incredibly labor intensive (they require catching animals using drift fences) and have inherent risks to participants. These events should only be conducted if an acceptable level of safety can be maintained for participants.

Slow traffic - Reduced speed limits and speed bumps can reduce traffic speeds which also reduces road mortality. This may be an option in residential or rural areas (Walston 2010).

Railroad Mitigation Measures

The placement and crossing structure guidelines outlined for roads are generally applicable for railroads as well. However, some railroad mitigation measures are unique given the design of railroads. Due to the steep angle between the rails and the interior of the track, turtles who find their way onto the railroad often become unable to escape. While trapped, these turtles can easily overheat and desiccate (Kornilev et al. 2006). Various engineering solutions can be implemented to provide an escape route for trapped herpetofauna. Asphalt can be placed between the rails in such a way that it gradually thins and slopes downward, similar to a common crossing structure for vehicles (Malloy et al. 2014). This ramped solution could allow turtles to exit the railroad. Another option is the implementation of an interlocking plastic crossing apparatus between the rails. Designed for vehicle crossings, these structures could also allow trapped turtles to escape a railroad with the addition of ramps on either side of the plastic (Turtle Plastics 2019). Similar to road culverts, open-air crossings beneath the metal rails can be utilized to facilitate safer travel across a railroad. Spotted Turtles have been documented utilizing this type of crossing structure (Pelletier et al. 2005).

Figure 15



Hailey Brown

Figure 15. This figure depicts railroad-associated turtle mortality and methods that can be put in place to mitigate it.

Turtles, and other herpetofauna commonly disperse across large areas to seek out additional habitats, mates, and nesting areas. As a result, these animals often encounter railroads that bisect their natural habitats. These animals then climb over in an attempt to reach their destination (A).

The ground between the rails is oftentimes lower in elevation than the ground along the outside of the railroad. This results in turtles and other animals that were able to initially traverse the rail to become entrapped between the rails on the inside of the tracks. Even large turtle species, such as the Eastern Snapping Turtle, are commonly trapped (B).

Trapped turtles are oftentimes crushed by a passing train or die of exposure and desiccation (C).

Implementing mounds of crushed rock sloping to or near the top of the rails allows trapped turtles and other herpetofauna to escape (D-E).

The usage of wildlife culverts positioned underneath railroad tracks, especially when utilized at railroads that bisect high quality habitats, allows turtles and other wildlife that frequently attempt to cross safe passage to the opposite side (F-G).

1. Watercraft of all sizes can impact amphibians and reptiles. Care should be taken to reduce risk to aquatic wildlife and their habitat.

Boating Mitigation Measures

On water bodies with large populations of aquatic turtles, such as Northern Map Turtles and Eastern Spiny Softshell Turtles, use of high-powered motorized boats is discouraged because of possible injury to turtles. However, lower-powered motorized boats with electric or trolling motors do not typically harm turtles. Propellers can also cause turbulence, erosion, and destroy plants which results in loss of habitat for herpetofauna and other aquatic organisms. Speed limits can provide turtles more time to evade oncoming boats and lessen the wave action produced by the boat that may damage the shoreline (Sorensen 1973, Hazel et al. 2007, Bulté et al. 2010, Hollender et al. 2018, Bilkovic et al. 2019). Closing certain areas with high densities of turtles during their active season can protect turtles from direct collision mortalities as well as prevent the wake-induced erosion of crucial shoreline that provides nesting opportunities for turtles and habitat for many other herpetofauna (Schwimmer 2001, Bulté et al. 2010, Fonseca and Malhotra 2012, Lester et al. 2013). Other areas to consider for boat closures include prime basking sites, communal hibernation sites, and nesting areas (Bulté et al. 2010, Heinrich et al. 2012).

2. Northern Map Turtles and Eastern Spiny Softshells are often injured by high powered motorized boats. Incorporating no-wake zones and non-motorized zones can help maintain healthy turtle populations.

Improperly maintained and older engines can also introduce PAH contamination, and their use should be limited in sensitive wetlands or where sensitive or threatened species are known or likely present. Noise pollution produced by motors and motorized vessels can increase stress levels in fish and other wildlife (Morton and Symonds 2002, Wysocki et al. 2006, Slabbekoorn et al. 2010) and may also disrupt herpetofauna. Although these impacts are likely comparatively small to other threats to Michigan herpetofauna, little is known about how noise pollution impacts amphibians and reptiles, and this stressor may contribute to already declining herpetofauna populations. Use of non-motorized watercraft (e.g., row-boat, canoe, kayak) or electric watercraft can also avoid chemical and noise contamination (Heinrich et al. 2012). Boater education courses that teach boat operators the effects boats can have on wildlife and how to avoid these detrimental impacts can aid in the long-term protection of aquatic herpetofauna (Heinrich et al. 2012, Lester et al. 2013).

Maintained Landscapes and Park Open Space

1.Grass maintained at <2” in height will deter amphibians and reptiles from inhabiting lawns and subsequently reduce mortality during mowing.

Figure 15. Alternately letting grass grow to >6” will provide cover and prey for amphibians and reptiles.

Simple steps in landscape maintenance can improve habitat quality, connectivity, and save money. By reducing or finding “herpetofauna-friendly” alternatives to the chemicals and pesticides used for management, herpetofauna diversity and abundance can be maintained or increased. Encouraging the presence of frog and snake species which eat pests can decrease the need for additional treatment.

Mowing

Although mowing can also be an effective management tool for reducing woody plant growth, it can cause direct mortality (Mitchell 1988; Durbian 2006; Meshaka Jr, Huff et al. 2008; Humbert, Ghazoul et al. 2009) and severely injure amphibians and reptiles as well as discourage use of sites by amphibians and reptiles and have significant negative impacts (Saumure, Herman et al. 2007). Mowing also affects habitat structure, temperature, humidity, and exposure to predation and desiccation.

Mow infrequently and during the hottest times of the year - Less frequent mowing results in less mower-related mortalities of herpetofauna and other wildlife. Also, mowing less frequently costs less and reduces carbon emissions. The best time to mow is during the hottest time of year, which in Michigan is generally July, when animals can flee or in late fall to early winter when animals are inactive. Turtles use edges of lakes and ponds and even grasslands of sandy upland areas for nesting. These turtles are slow-moving and sometimes require several hours to dig a nest and deposit their eggs. To avoid hitting turtles with mowers, mow prior to or preferably after turtle nesting season (i.e., after early June). Mowing should be timed to avoid the turtle nesting season and the peak foraging and migration seasons of other amphibians and reptiles.

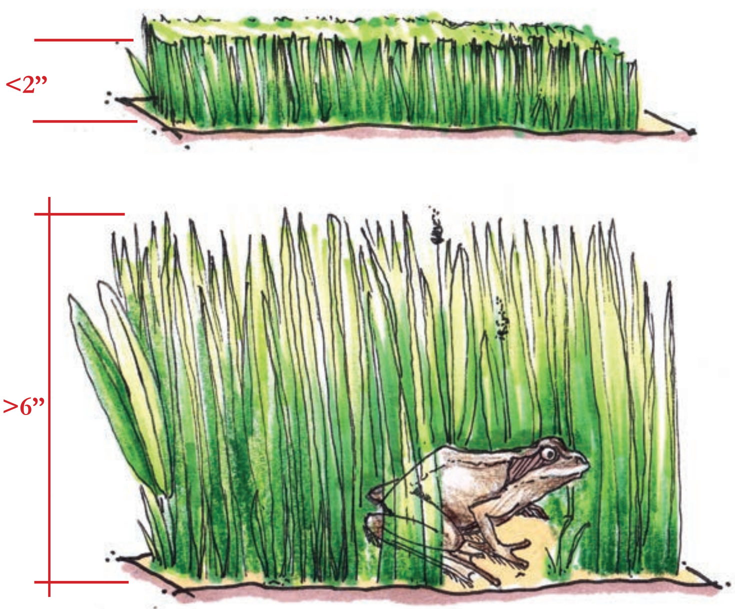
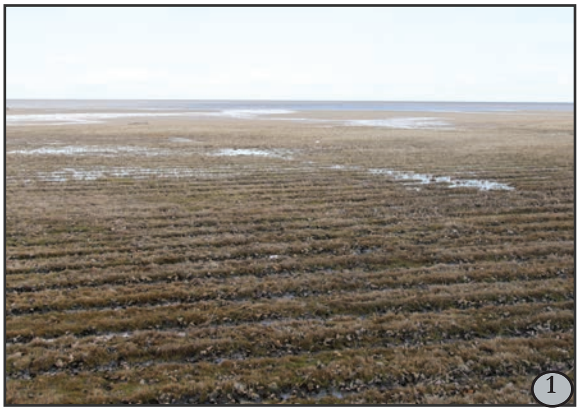


Figure 16

Set mower decks high (>6”) or low (<2”) - Setting mower blades 6” or more from the ground can help to avoid ground-dwelling wildlife. Additionally, by beginning in the center of the area to be mowed, herpetofauna may escape in all directions (Iowa NRCS 2005). Alternatively, if the presence of herpetofauna is not compatible with a landscape (e.g., discouraging Eastern Massasauga Rattlesnakes in public areas), mowing grass short (<2”) can discourage the movement of herpetofauna into mowed areas and will reduce mower-mortality. This can be particularly effective for areas of known Massasauga encounters.



1. Beach grooming that includes tilling and mowing reduces the wildlife value and is often a continuous battle to maintain an artificial sandy beach area. This tilled and mowed coastal area has become rutted and compacted, making it unsuitable for people in search of a sandy beach and herpetofauna in search of cover, food, and nesting areas.

2. Light fixtures that reduce spillage into the surrounding landscape are less likely to disrupt the natural cycles of amphibians and reptiles that are triggered by light cues.

Light Pollution

The intrusion of artificial light into wildlife habitat at night affects a diversity of wildlife species (Calhoun and Klemens 2002) and can alter the foraging, reproductive, and defensive behaviors of amphibians (Buchanan 1993; Wise and Buchanan 2006). Herpetofauna respond to artificial light in much the same way they do to natural light (Yorks and Sievert 2012). Herpetofauna use light as a cue for movement related to their need to thermoregulate (Sievert and Hutchison 1991), food availability, distribution, and movement between landscape features, as well as egg and breeding ground suitability (Halverson, Skelly et al. 2003). Additionally, disruptions to a natural photoperiod may cue seasonal changes (Buchanan 2006).

Apply 'dark-skies' principles - To avoid disruption of movement patterns and timing of life processes, low-lighting strategies should be used, especially near herpetofauna habitat (e.g., closer than 750 feet of a vernal pool; (Calhoun and Klemens 2002). Use low-spillage lights (lights that direct light downwards) and avoid use of fluorescent and mercury vapor lights (Calhoun and Klemens 2002). For further information and lighting recommendations, go to the International Dark Sky Association website.

Controlling Access

Contact with nature can provide health benefits for people and enhance their appreciation and subsequent protection of the environment (Maller et al. 2008). Unfortunately, human access to natural areas can result in degraded wildlife habitat (Leung and Marion 1999, Marion and Farrell 2002). Areas of high-quality wildlife habitat or areas which support rare species should be protected from human disturbance and maintained as uninterrupted contiguous landscapes. Human disturbances such as trails, picnic areas, campgrounds, and hunting and fishing activity can facilitate the introduction of invasive species, create conditions suitable for opportunistic predators (e.g., raccoon, skunk, crow), increase erosion, and decrease water quality (Simberloff and Cox 1987, Simberloff et al. 1992, Hess 1994). They also fragment landscapes and increase potential for negative human interaction and persecution.

Kathy Evans

1. Dredging in Muskegon Lake to remove toxins and pollution.

2. For projects that involve direct habitat alteration such as dredging, or a drawdown, animals should be collected from the area and relocated.

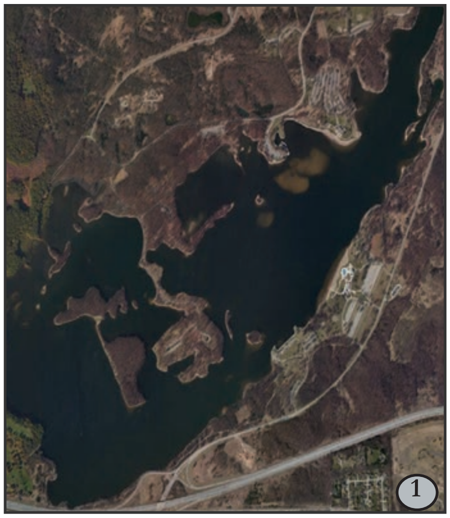
Altered Hydrologic Processes and Aquatic Construction

Many amphibian and reptile communities rely on natural hydrologic processes to maintain seasonal water levels, water velocity, water chemistry, sediment movement, streambed structure, and lake bed composition that are suitable for their habitat requirements (Kupferberg 1996). Shoreline development, dredging, impounding, and filling in aquatic systems as well as construction of impermeable surfaces and land draining in upland areas can alter the flow of water and sediment, stream stability, channel size, floodplain area, and fluctuations in water levels (Malmqvist and Rundle 2002, Graf 2006). These changes reduce the food, nesting, and cover opportunities that herpetofauna need, and thus alter the composition and reduce the diversity and breeding success of herpetofauna communities (Vandewalle and Christiansen 1996, Snodgrass et al. 2000, Bodie 2001, Paton and Crouch III 2002, Lenhart et al. 2011). Construction of dams or locks can also create barriers for and fragment populations of aquatic herpetofauna (e.g., Northern Map Turtles) (Bennett et al. 2010), whereas seawalls can create barriers to more terrestrial herpetofauna that require access to land and water for nesting, basking, and cover (Engel and Pederson Jr 1998, Witherington et al. 2011). The following information describes ways to avoid altering hydrologic processes.

Reduce disturbances to natural hydrologic processes - Altering the flow of water can create disturbances, which increase the likelihood of colonization by invasive plants and animals (Galatowitsch et al. 1999, Zedler and Kercher 2004). When seasonally dry wetlands become inundated year-round, fish may colonize the deeper water, and amphibians and reptiles without defenses against predaceous fish can suffer high predation (Bradford 1989, Figiel Jr and Semlitsch 1990, Hecnar 1997, Goodsell and Kats 1999). Increases in amphibian diversity and prolonged larval period can result from the removal of predatory fish from these ponds (Walston and Mullin 2007). Many amphibians will also avoid breeding in these sites, thus reducing recruitment and population viability (Kats and Sih 1992).

Also, sites with a shortened hydroperiod have a decreased time frame for larval development, which can result in smaller adults at time of metamorphosis and lowered survival (Rowe and Dunson 1995). Managing water levels to mimic natural cycles and water depths will provide the necessary conditions (egg laying conditions, basking, food sources, cover areas, hibernacula) for herpetofauna and improve overall ecosystem function.

Maintain historical water connections - Historical connections and spatial flow regimes between water bodies should be examined and compared with current water levels and inputs to determine the location, size, and number of pipes and/or culverts. Often culverts are insufficiently sized to meet hydrologic and biological requirements and wildlife movements at a site. Culvert



1. While creating impoundments should be avoided, those that have been around for 50+ years or more, can develop a suite of wildlife associated with that community.

sizing is typically assessed for the baseflow, or water entering a stream via groundwater flow, and does not account for heavy precipitation or seasonal flooding. Undersized culverts can result in insufficient hydrologic equalization and impoundment of water upstream of a culvert causing streambed scour and channel incision downstream of a culvert. Culverts should be sized appropriately to not disrupt the natural flow of water in all seasons. Placement of additional overflow culverts is beneficial to alleviate flooding in case of a severe storm (e.g., 500 year storm) and to enhance landscape connectivity for wildlife. An engineer or hydrologist with experience in culvert sizing and placement in natural systems should be consulted on high-risk or large projects.

Decrease impermeable surface area - Urbanization and increased impermeable surfaces within a watershed can alter hydrologic processes, degrade water bodies, and reduce wildlife diversity (Booth and C.R. 1997, Roy et al. 2003). Maintaining a high proportion of permeable surfaces and instituting water conservation construction techniques, such as rain gardens, bioswales, and non-combined sewer systems (e.g., in (United States Environmental Protection Agency 1999)), can help maintain more natural hydrologic processes.

Avoid impounding aquatic systems - Impeding the flow of water can change a wetland to a lake with reduced value for herpetofauna on the high side of the impediment, and virtually eliminate the wetland on the low side of the impediment, which also reduces herpetofauna habitat. If creation of impoundments is necessary, relocate animals prior to construction and associated drawdowns, and time construction and drawdowns for when herpetofauna are most mobile and able to respond to the change.

Design bridges to follow "natural channel" design principles - A useful alternative to road crossings are bridges that allow herpetofauna to cross streams safely. Temporary bridges can provide the benefits of a permanent crossing without the immediate and long-term effects that can result from building structures such as culverts. Bridges should be installed to span as much of the floodplain as possible to allow for the channel and floodplain to remain intact and reduce impacts to stream stability and habitat.

Do not fill or drain wetlands - Wetlands of all sizes (regulated and unregulated) are biologically important as they have a rich assemblage of amphibian species and provide valuable breeding and recruitment areas for several amphibians and reptiles (Semlitsch and Bodie 1998). Filling or draining even a small, seasonal wetland will displace or impact the population of amphibians and reptiles that rely on it to support their life cycle.

Avoid dredging in the littoral zone - The littoral zone is essential habitat for several species of herpetofauna that rely on this shallow, vegetated zone to carry out their life functions. Dredging in this area may displace herpetofauna to search for another suitable location. Often drawdowns are conducted prior to dredging operations, which will displace resident animals and could result in mortality if the drawdown is not conducted over a period of time that allows for movement out of the area or if conducted outside of the appropriate window.

1. Vertical sea-walls with no land-water access and absent native vegetation provide extremely limited habitat for herpetofauna and other wildlife

2. Dock Ramps allow turtles and other wildlife to access terrestrial habitat to bask.

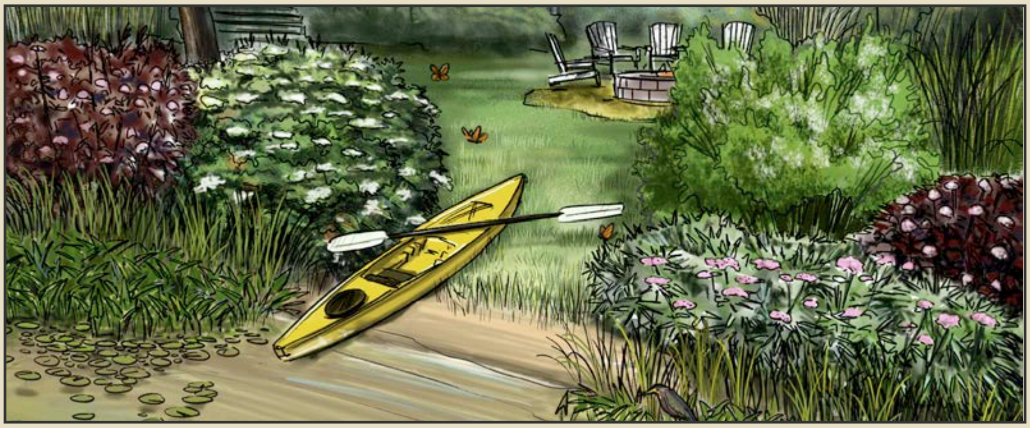
Improve low-quality wetlands through dredging and restoration practices - Wetlands dominated by invasive vegetation (e.g., non-native cattails - *Typha angustifolia* and *Typha x. glauca* - or *Phragmites*) can provide little habitat for amphibians, reptiles, or other wildlife, and leaf litter from invasive vegetation may fill in areas of open water in the littoral zone. Although dredging is typically discouraged in littoral zones, in low-quality wetlands dredging (only in circumstances where this method is shown to be warranted and necessary) can provide a variety of water depths to support a rich diversity of amphibian and reptile species. If paired with responsible restoration practices, such as revegetation with native plants, well designed and carefully implemented dredging can improve wildlife habitat quality and meet other project objectives.

Repurpose materials slated for demolition to become habitat structures on site - The less material needed to be removed from a construction site, the less cost is incurred. Concrete, rocks, trees, logs, and other structures slated for demolition can be repurposed and installed on site as basking structures, hibernacula, egg laying areas, and cover for amphibians and reptiles. See Section 6 for details.

Install or maintain vegetated buffers and natural rock as an alternative to seawalls and hardened channels - Structures intended to reduce shoreline erosion are often subject to undercutting and washouts and prevent amphibians and reptiles from accessing upland habitat for basking, nesting, and foraging (Engel and Pederson Jr 1998, Mosier and Witherington 2002, Witherington et al. 2011). This habitat fragmentation leads to reduced breeding success and greater competition for available resources. Planting or maintaining native vegetation in the 100-1,000 foot buffer along lake and river edges can stabilize the banks and shoreline while providing structure for amphibians and reptiles (Semlitsch 1998, Bodie 2001, Semlitsch and Bodie 2003, Calhoun et al. 2005). Natural rock provides crevices and irregular surfaces which diffuse water velocity and give herpetofauna a place to hide.

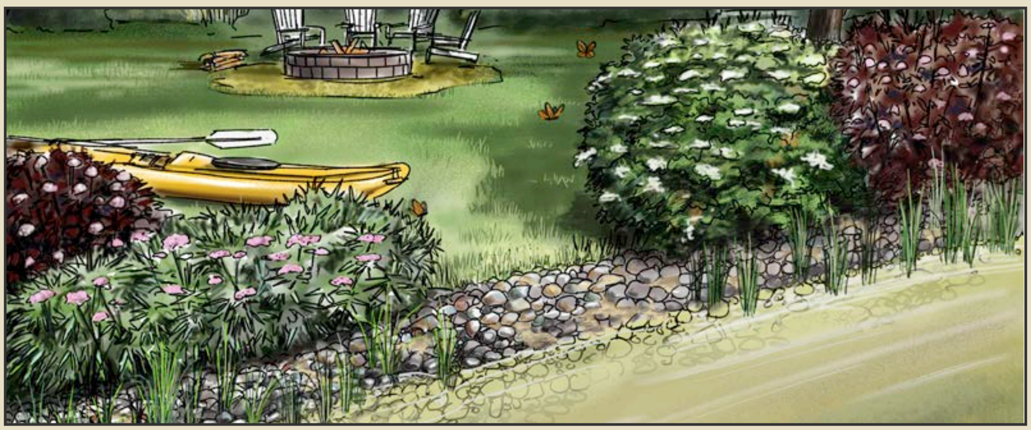
When seawalls, break waters, or jetties are necessary, include modifications to provide structure for herpetofauna - With a few minor modifications, break water, jetty, and seawall construction can provide herpetofauna cover, hibernacula, and basking structures. For example, using repurposed concrete and variable-sized stones to create crevices and tunnels into the structure provide places for snakes to take shelter and hibernate. A rough surface with several horizontal surfaces can provide places where a turtle or snake can climb out of the water to bask.

Herpetofauna-Friendly Shoreline Development Designs



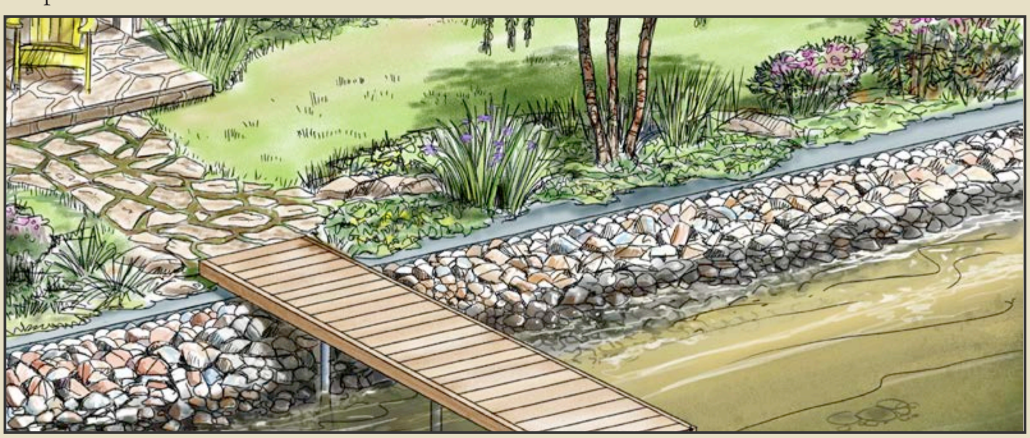
Bruce Kerr & EGLE

Low-Energy Design - Natural shoreline vegetation and substrate provides low to moderate wave energy absorbtion while maximizing nesting opportunities and habitat for herpetofauna, macroinvertebrates, fish, and wildlife.



Bruce Kerr & EGLE

High-Energy Design - Natural shoreline vegetation and rip-rap provides moderate to high wave energy absorbtion while still providing both terrestrial and aquatic habitat for herpetofauna and other wildlife.



Bruce Kerr & EGLE

Seawall Design - Sloped, fortified rip-rap seawall provides maximum wave energy absorbtion while still offering herpetofauna and other wildlife land-water access and habitat.

Create Oxbows during Dam Removal

Although not a true oxbow, a backwater portion of the Manistee River was preserved during a restoration of the fast-moving natural channel that had been impounded. This ponded area provides protection and food for sensitive hatchling turtles and other amphibians and reptiles that benefit from calm waters.

Michigan has over 2,500 dams (Michigan Department of Natural Resources and Michigan Department of Environmental Quality 2004). As these structures age, they need to be repaired or removed to ensure public safety. Repair is costly, making removal of dams which are no longer used or pose an environmental threat an economical option. Dams create barriers for amphibians and reptiles and can also greatly alter hydrologic processes and thermal conditions which effect breeding, nesting, basking, and hibernation (Lind, Welsh Jr et al. 1996; Bettaso 2013). The removal of these structures that impede the natural flow of water along watercourses can help restore the diversity of wildlife and may greatly increase population connectivity and enhance population viability in river systems. However, impoundments provide ponded areas which may support species not associated with the restored watercourse. Wetlands and exposed slopes within an impoundment often serve as important nesting areas for turtles. Dam removal and dewatering of riparian wetlands displaces animals, alters chemical, physical, and biological processes which affect herpetofauna habitat (Hart 2002). It is important to prepare for, and address, these potential problems to minimize impacts to the larger ecosystem. Wherever practical, consider creating an oxbow (a U-shaped lake formed when a meander is cut off from a river bend) areas or preserving some ponded portions along the watercourse to allow for species which have colonized wetlands and backwaters associated with the impoundment. The water current is much slower and water temperatures are warmer in these shallow wetlands than the main connecting watercourse and can be an ideal place for turtle mating, and basking, amphibian breeding and larvae development, and snake foraging grounds. Oxbows also provide excellent opportunities for placement of turtle nesting areas or other herpetofauna habitat structures. Review of historic aerial photography and soils maps will help guide locations of areas where wetlands were historically dominant prior to impounding. Consider the placement of turtle nesting structures along south slopes to provide secure replacement turtle nesting opportunities. When dewatering be prepared for migrating animals leaving the site and provide barriers to prevent reptiles and amphibians from entering adjacent roads. If possible, these animals can be relocated to nearby appropriate habitat or held and introduced to newly established backwater habitats onsite. When planning dam removal, it is extremely important to address short-term downstream sedimentation and possible contaminated soils. Increased sediment loads can very quickly impact macroinvertebrate communities thus causing serious disruptions to both aquatic and terrestrial food webs.

Dam removals are typically complicated, multifaceted projects that require coordination among many interested parties. Aquatic and upland areas are involved, and flowing water, removal of contaminated sediments, reconstruction of channel structure, restoration of aquatic and upland vegetation, protection of fish and wildlife communities, as well as typical construction concerns such as soil erosion control must be coordinated. Since these projects are complicated and each has a unique set of site conditions, a professional restoration biologist or other qualified professional should be contacted to proceed with any dam removal project. After a dam is removed, the exposed substrate in the previously impounded area is left bare and susceptible to colonization by invasive plants (Orr and Koenig 2006; Collins, Lucey et al. 2007). Invasive plants can be especially problematic if the substrate is high in micronutrients or is contaminated with toxic chemicals to which many native plants are not tolerant. Guidelines presented in this manual dealing with soil erosion control, wetland mitigation and restoration, stream and river restoration are applicable to dam removal.

Renewable Energy

Renewable energy can provide benefits for wildlife including the mitigation of damage caused by climate change. However, the construction, infrastructure, and operations that are byproducts of renewable energy can alter the landscape detrimentally for herpetofauna. Some steps can be taken to reduce the negative effects of renewable energy on herpetofauna while maintaining the positive impacts.

Wind Energy

Wind energy is the largest source of renewable energy in Michigan, accounting for over 60% of the state's renewable electricity (U.S. Energy Information Administration 2022). Though the bulk of scientific literature has focused on assessing the direct mortality impacts of wind turbines on bats and birds, wind energy can also directly and indirectly affect herpetofauna. Additionally, wind energy is the most likely source of renewable energy to inflict widespread impacts to herpetofauna given its prevalence in the state. There is evidence of wind farms reducing the density, richness, and anti-predator behavior of herpetofauna (Santos et al. 2010, Keehn and Feldman 2018, Trowbridge 2020). The negative impacts of wind farms can primarily be attributed to the habitat destruction and fragmentation involved with the construction and operation of wind farms (Kuvlesky Jr et al. 2007, Perrow 2017). Additional detrimental effects include mortality and stress from roads, noise effects, vibrations and shadow flicker, electromagnetic pollution and heat effects, microclimate/macroclimate impacts, predator attraction, and increased fire risk (Perrow 2017).

1. Wind energy is the most abundant source of renewable energy in the state and can both directly and indirectly impact populations of herpetofauna and other wildlife.

2. The shadow flicker, also known as the flicker effect, caused by the shadows of rotating turbine blades can simulate a predator, such as a bird of prey, and over time can decrease anti-predator avoidance and responses to actual threats leaving particular amphibian and reptile species more vulnerable to predation.

Wind farms involve the highest land-use intensity per unit output of energy than every other type of renewable energy besides biomass production (McDonald et al. 2009). However, wind energy also allows for the retention of habitat throughout these farms between installed turbines, roads, and other infrastructure. The installation and operation of wind turbines can alter this remaining habitat including changes in soil densities and composition, water infiltration, erosion, microclimate, and vegetation composition (Lovich and Bainbridge 1999, Lovich and Ennen 2011). Fragmentation caused by degraded habitat and the roads associated with windfarms can potentially disrupt gene flow corridors (Fischer and Lindenmayer 2007) and result in road mortalities (Andrews et al. 2008). Noise from the machinery and blades of wind turbines, as well as their associated roads, may interfere with herpetofauna hearing, phenology, and acoustic communication, particularly in frogs (Brattstrom and Bondello 1983, Lengagne 2008, Vargas-Salinas and Amézquita 2013).

Wind farms produce vibrations that can be broadcast long distances (Styles et al. 2011), which can interfere with the behavior and communication of herpetofauna. All groups of herpetofauna occurring in Michigan (salamanders, frogs, lizards, snakes, and turtles) are known to perceive vibrations and could potentially be affected by the turbines (Perrow 2017). Turbines also produce light flicker caused by the reflection of sunlight off the blades as well as shadow flicker caused by the spinning blades interrupting sunlight. The alternating shadows can simulate the shadows produced by birds of prey, common predators of herpetofauna. As such, shadow flicker can increase the predator response of herpetofauna (Cooper 2009). The microclimate of the habitat within windfarms can be affected by vegetation removal, construction, and soil disturbance (Liechty et al. 1992, Chen et al. 1999). Wind turbines themselves can also directly influence the microclimate through the vertical mixing of air from blade movements and the macroclimate through altered wind, precipitation, evaporation, and soil moisture patterns (Abbasi and Abbasi 2000). Lastly, wind farms increase the risk and frequency of fire which can be damaging to herpetofauna populations (Starr 2010).

Once wind turbines are in place, it is difficult to reduce the negative impacts to wildlife. However, measures can be taken during the placement and construction phases of wind farm development that can mitigate the damages to herpetofauna populations. When selecting the location for wind farms, avoid areas that are within approximately 2,000 feet of wetland complexes greater than 2.5 acres (Ewert et al. 2011). Herpetofauna often disperse long distances between water and this buffer will prevent the loss of essential habitat and maintain connectivity of breeding and nonbreeding habitat (Ewert et al. 2011). Additionally, the use of HDD or boring during the installation of any cable segments underground can prevent the fragmentation of habitat. Lastly, crossing structures and reduced speed limits can prevent road mortalities within wind farms (Woltz et al. 2008, Walston 2010).

1. If following the Woody Biomass Harvesting Guidelines and the Best Management Practices provided within this manual, biomass can be a herpetofauna-friendly source of renewable energy.

Other Renewable Energy Sources (Biomass, Hydropower, Solar)

Biomass and hydropower provide the vast majority of the remaining renewable energy in Michigan, while solar energy produces a relatively small amount of electricity in the state (U.S. Energy Information Administration 2022). The impacts these energy sources inflict on herpetofauna populations vary significantly. Biomass harvesting often occurs in natural communities where the trees provide little ecological value, and the overall habitat does not support high diversity of herpetofauna (i.e., pine plantations). As a result, biomass harvesting typically creates a neutral, or even positive, impact for herpetofauna

1. Leaving behind woody debris and tree tops can provide shelter for herpetofauna and other wildlife following a clearcut harvest.

(Verschuyl et al. 2011, Homyack et al. 2013, Homyack and Verschuyl 2019).

Adhering to Woody Biomass Harvesting Guidelines can help ensure that biomass harvesting does not negatively affect herpetofauna or other wildlife (Michigan Department of Natural Resources and Environment 2010). Following these types of guidelines increases the retention of downed woody debris, which can provide important shelter for herpetofauna following harvesting (Fritts et al. 2014). Downed, dead woody debris and standing dead trees (snags), as well as the tops of some trees, can be retained to provide important herpetofauna habitat (Michigan Department of Natural Resources and Environment 2010). Avoiding the clearcut harvest of ecologically significant trees and communities can help protect herpetofauna from the negative impacts of biomass harvesting.

Unlike biomass production, hydropower is incredibly detrimental to herpetofauna populations, particularly for turtles and amphibians, and mitigating this damage is incredibly difficult. Changes in river flow can result in reductions of feeding habitat (Tucker et al. 2012) and turtle nesting habitat (Bodie 2001, Norris et al. 2018, Tornabene et al. 2018). Dams also create a physical barrier to movement and can isolate populations of turtles and amphibians, reducing their genetic connectivity (Bennett et al. 2010, Gallego-García et al. 2019, Peek et al. 2020) (Dare et al. 2020) and overall density (Dare et al. 2020). Alterations of reservoir water quality caused by dams include oxygen reductions (Clark et al. 2009) and increases in contaminants such as pesticides (Douros et al. 2015) and mercury (Ferriz et al. 2021).

2-3. Dams alter the flow of water and sediment, water temperature, and habitat suitability for amphibians and reptiles.

The mitigation of hydropower impacts on herpetofauna can prove difficult to achieve. One mitigation method involves the conservation, restoration, or creation of habitat within the reservoir (Tornabene et al. 2019, Pitt et al. 2021). The restoration of native vegetation reduces erosion, improves water quality, and encourages the reestablishment of herpetofauna (Santoro et al. 2020). Passes in dams are often used to

Cypress Creek Renewables

1. Positioning solar farms within areas such as former agricultural fields and preserving nearby natural resources is essential for maintaining local amphibian and reptile populations.

maintain connectivity of fish populations, though turtles have primarily been observed using these passes for feeding rather than movement (Agostinho et al. 2012). The development of passes appropriate for turtles and other herpetofauna could preserve the genetic connectivity of these riverine ecosystems (Takahashi et al. 2016). Increasing the safety of terrestrial passages around dams through the use of barrier installations and road crossing structures (Bassel 2002, Pelletier et al. 2005, Rees et al. 2009, Heaven et al. 2019) can reduce road mortalities and ensure the connectivity of herpetofauna populations. Lastly, monitoring populations of herpetofauna upstream and downstream of dams can inform whether translocation efforts are required to maintain population connectivity.

Given the relative scarcity of solar farms in Michigan, negative impacts on herpetofauna are currently unlikely to be widespread. However, these facilities are growing in size and number within the state (Solar Energy Industries Association 2022) and are known to negatively impact herpetofauna in regions where solar farms are more common (Lovich and Ennen 2011). The construction of solar plants results in the loss of habitat stemming from the removal of vegetation and surface grading spanning large areas (Harrison et al. 2017, Taylor et al. 2019). Solar farms may also degrade habitat by reducing the availability and quality of water (Bennun et al. 2021). The loss and degradation of habitat can result in barrier effects where herpetofauna populations are fragmented and connectivity is reduced or eliminated (Knutson et al. 1999, Dodd et al. 2003, Bennun et al. 2021). Similar to wind energy, the roads associated with solar facilities can lead to herpetofauna mortalities (Lovich and Ennen 2011). Solar facilities can create microclimate effects by increasing albedo effects and outputting heated air (Lovich and Ennen 2011). The resulting increases in temperature and evapotranspiration can alter vegetation communities, reduce prey availability, and directly impact herpetofauna sensitive to these altered climatic conditions, particularly reptiles (Hulin et al. 2009, Sinervo et al. 2010, Shoo et al. 2011, Barrows et al. 2016). Lastly, pollution, including dust, light, noise, vibration, and solid/liquid waste generated by solar plants may detrimentally impact herpetofauna (Lovich and Ennen 2011, Bennun et al. 2021, Chock et al. 2021).

The importance of mitigating the negative impacts of solar farms on herpetofauna in Michigan will only increase as this industry continues to grow. The best method to mitigate damages for herpetofauna is to avoid placing solar facilities in ecologically important and sensitive habitats (Cameron et al. 2012, Hernandez et al. 2015, Arnett and May 2016, Agha et al. 2020). Translocating herpetofauna is often used as a solution to mitigate the effects of solar energy development, however the success rate of this method is variable and species-dependent (Germano and Bishop 2009, Sullivan et al. 2015, Dickson et al. 2019, Agha et al. 2020). The creation of meadow and prairie habitats within solar farms can help to provide ecological value and habitat for herpetofauna that would otherwise be non-existent (Bennun et al. 2021).

9. Conclusions and Next Steps

Cooperative Conservation

The protection and conservation of herpetofauna communities can be implemented into any maintenance, management, development, or ecological restoration work. Despite the many threats to the continued survival of herpetofauna species and communities in Michigan, people working in land management or development as well as concerned citizens can significantly improve habitat conditions and protect amphibians and reptiles. While all of the recommendations in this manual may not be feasible or practical at all sites, the potential to incorporate these BMPs can be considered whenever planning a project. The likelihood of sustained amphibian and reptile populations in Michigan can be greatly improved through planning, education, and thoughtfully prepared and implemented restoration and habitat enhancement techniques focused on the natural history and conservation of herpetofauna communities. A lack of information about herpetofauna communities and threats to their viability is one obstacle to better conservation. Collecting information on species' status and distribution and threats to herpetofauna can help to clarify baseline conditions and present the 'big picture' of the condition of our herpetofauna communities. This information is vital in measuring success of conservation efforts, in prioritizing areas and species for conservation, and in helping to increase the efficiency and usefulness of species regulations. Only through a cooperative effort involving people in all fields with an impact on our natural resources can we protect not only herpetofauna, but all of Michigan's natural resources.

1-3. Implementing the practices introduced in this manual can contribute to improving the ecological integrity of a site. Utilizing herp-friendly activities will promote species richness and ensure long-term viability of Michigan herpetofaunal populations.

1-3. Long-term monitoring efforts like those conducted by Jim Harding on Wood Turtles in Michigan for over 45 years are critical to glean the extent of impacts and trends in threats. Few have been as dedicated as Mr. Harding to his work in amphibian and reptile conservation. Jim serves as a model for others in understanding the commitment necessary to conserve long-lived species. Our work today is built on the foundation of people like Jim and those that came before him. His work is also a reminder that the decisions we make today for amphibian and reptile conservation are not measured by the response next season but by the next generation.

Measuring Success

The original Michigan Amphibian and Reptile BMP manual published in 2014 was the first step towards an all-encompassing guide for amphibian and reptile conservation in Michigan. The manual was intended to be a living document with planned future revisions to continue to provide the most up-to-date, herpetofauna-friendly solutions to the complex issues Michigan's ecosystems face. The Second Edition of the Michigan Amphibian and Reptile BMP manual is the continuation of original's mission and another step towards the protection and conservation of amphibians and reptiles in Michigan, but alone does not ensure success. A monitoring program to determine the success of recommendations described within the manual needs to be implemented potentially integrating Herp HAT as a tool. An adaptive approach could work to improve the efficacy of use of the BMP by setting realistic goals with measurable targets and realistic timeframes, monitoring those targets, and using collected data to reassess and revise the BMP. As the strategies and methods recommended in this manual are vetted in a wide variety of situations and conditions, in the short and long-term, and at local and landscape-wide scales, the solutions will continue to be refined to be more economically and ecologically sound. We intend for this to continue to be a living document and subsequent revisions will produce updated versions available in an on-line format through HRM and project partners.

Appendix A: Community Matrix

		Michigan's Habitat Communities																									
	Species	Federal Status	State Status	Lakes and Ponds	Streams, Rivers, and Floodplain	Emergent Marsh	Emergent Marsh Reed Canary Grass	Emergent Marsh Phragmites	Emergent Marsh Cattail	Great Lakes Coastal Marsh	Submergent Marsh	Bog/Muskeg	Fen	Wet Meadow	Wet Prairie	Floodplain Forest	Shrub Swamp	Deciduous Swamp	Coniferous Swamp	Vernal Pools	Deciduous/Mixed Coniferous Forest	Prairie /Grassland	Shrub/Scrub	Sandy Uplands /Dunes	Old Field	Agriculture Areas	Urban/Suburban
Snakes	Kirtland's Snake *(Clonophis kirtlandii)*		E											X	X	X	X	X			X	X					
	Blue Racer *(Coluber constrictor foxii)*		SN									X	X	X	X						X	X		X	X	X	X
	Northern Ring-necked Snake *(Diadophis punctatus edwardsii)*		SN													X				X	X	X					X
	Eastern Hog-nosed Snake *(Heterodon platirhinos)*		SN										X	X	X						X	X	X	X	X	X	X
	Eastern Milk Snake *(Lampropeltis triangulum triangulum)*												X	X	X						X	X	X	X	X	X	X
	Copper-bellied Water Snake *(Nerodia erythrogaster neglecta)*	T	E	X		X	X						X	X	X	X	X	X		X	X	X	X		X	X	X
	Northern Water Snake *(Nerodia sipedon sipedon)*			X	X	X	X		X	X	X		X	X		X				X							
	Eastern Smooth Green Snake *(Opheodrys vernalis vernalis)*		SC										X	X	X							X	X	X	X		
	Eastern Fox Snake *(Pantherophis gloydi)*		T	X		X	X	X	X	X				X	X						X	X	X		X	X	X
	Black Rat Snake *(Pantherophis spiloides)*		SC													X	X	X			X	X	X		X	X	X
	Western Fox Snake *(Pantherophis vulpinus)*		SN		X																X			X	X	X	X
	Queen Snake *(Regina septemvittata)*		SC	X	X	X																					
	Eastern Massasauga Rattlesnake *(Sistrurus catenatus)*	T	T		X	X	X		X	X		X	X	X	X	X	X					X			X		X
	Northern Brown Snake *(Storeria dekayi dekayi)*					X	X			X			X	X	X		X				X	X			X	X	X
	Northern Red-bellied Snake *(Storeria occipitomaculata occipitomaculata)*					X	X			X			X	X	X		X				X	X			X	X	X

SN, Species of Greatest Conservation Need; SC, Special Concern; T, Threatened; E, Endangered

	Species	Federal Status	State Status	Lakes and Ponds	Streams, Rivers, and Floodplain	Emergent Marsh	Emergent Marsh Reed Canary Grass	Emergent Marsh Phragmites	Emergent Marsh Cattail	Great Lakes Coastal Marsh	Submergent Marsh	Bog/Muskeg	Fen	Wet Meadow	Wet Prairie	Floodplain Forest	Shrub Swamp	Deciduous Swamp	Coniferous Swamp	Vernal Pools	Deciduous/Mixed Coniferous Forest	Prairie /Grassland	Shrub/Scrub	Sandy Uplands /Dunes	Old Field	Agriculture Areas	Urban/Suburban
		Michigan's Habitat Communities																									
Snakes (Cont.)	Butler's Garter Snake *(Thamnophis butleri)*		SC		X	X	X			X						X	X			X	X	X			X		X
Snakes (Cont.)	Northern Ribbon Snake *(Thamnophis sauritus septen-trionalis)*			X	X	X	X		X	X			X	X	X		X			X		X					
Snakes (Cont.)	Eastern Garter Snake *(Thamnophis sirtalis sirtalis)*			X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Lizards	Five-lined Skink *(Plestiodon fasciatus)*																				X	X		X	X	X	X
Lizards	Six-lined Racerunner *(Aspidoscelis s. sexlineata)*		T																		X	X		X	X	X	X
Turtles	Eastern Spiny Softshell *(Apalone spinifera spinifera)*			X	X					X	X																
Turtles	Eastern Snapping Turtle *(Chelydra serpentina serpen-tina)*			X	X	X	X		X	X	X	X	X							X							X
Turtles	Western Painted Turtle *(Chrysemys picta bellii)*			X	X	X	X		X	X	X	X	X							X							X
Turtles	Midland Painted Turtle *(Chrysemys picta marginata)*			X	X	X	X		X	X	X	X	X							X							X
Turtles	Spotted Turtle *(Clemmys guttata)*		T	X		X						X	X	X	X			X		X							
Turtles	Blanding's Turtle *(Emydoidea blandingii)*		SC	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X		X	X		X
Turtles	Wood Turtle *(Glyptemys insculpta)*		T		X																X	X		X	X		
Turtles	Northern Map Turtle *(Graptemys geographica)*			X	X					X	X																
Turtles	Eastern Musk Turtle *(Sternotherus odoratus)*			X	X	X				X	X																X

SN, Species of Greatest Conservation Need; SC, Special Concern; T, Threatened; E, Endangered

	Species	Federal Status	State Status	Lakes and Ponds	Streams, Rivers, and Floodplain	Emergent Marsh	Emergent Marsh Reed Canary Grass	Emergent Marsh Phragmites	Emergent Marsh Cattail	Great Lakes Coastal Marsh	Submergent Marsh	Bog/Muskeg	Fen	Wet Meadow	Wet Prairie	Floodplain Forest	Shrub Swamp	Deciduous Swamp	Coniferous Swamp	Vernal Pools	Deciduous/Mixed Coniferous Forest	Prairie /Grassland	Shrub/Scrub	Sandy Uplands /Dunes	Old Field	Agriculture Areas	Urban/Suburban
		Michigan's Habitat Communities																									
Turtles (Cont)	Eastern Box Turtle *(Terrapene carolina carolina)*		T			X							X	X	X	X	X				X	X		X	X	X	X
	Red-eared Slider *(Trachemys scripta elegans)*			X	X	X	X				X																X
Salamanders, Newts, and Mudpuppies	Blue-spotted Salamander *(Ambystoma laterale)*		SN			X											X	X	X	X	X						X
	Spotted Salamander *(Ambystoma maculatum)*		SN			X											X	X		X	X						X
	Marbled Salamander *(Ambystoma opacum)*		E														X	X		X	X						
	Unisexual Salamander *(Ambystoma sp.)*															X	X	X	X	X	X					X	X
	Small-mouthed Salamander *(Ambystoma texanum)*		E														X	X		X	X						
	Eastern Tiger Salamander *(Ambystoma tigrinum)*		SN	X		X								X	X		X	X		X	X	X			X	X	X
	Southern Two-lined Salamander *(Eurycea cirrigera)*		SC		X																X						
	Northern Dusky Salamander *(Desmognathus fuscus)*		SC		X																X						
	Four-toed Salamander *(Hemidactylium scutatum)*		SN									X					X	X	X	X	X						
	Mudpuppy *(Necturus maculosus)*		SC	X	X																						
	Central Newt *(Notophthalmus viridescens louisianensis)*			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X						X
	Red-spotted Newt *(Notophthalmus viridescens viridescens)*			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X						X

SN, Species of Greatest Conservation Need; SC, Special Concern; T, Threatened; E, Endangered

	Species	Federal Status	State Status	Lakes and Ponds	Streams, Rivers, and Floodplain	Emergent Marsh	Emergent Marsh Reed Canary Grass	Emergent Marsh Phragmites	Emergent Marsh Cattail	Great Lakes Coastal Marsh	Submergent Marsh	Bog/Muskeg	Fen	Wet Meadow	Wet Prairie	Floodplain Forest	Shrub Swamp	Deciduous Swamp	Coniferous Swamp	Vernal Pools	Deciduous/Mixed Coniferous Forest	Prairie /Grassland	Shrub/Scrub	Sandy Uplands /Dunes	Old Field	Agriculture Areas	Urban/Suburban
		Michigan's Habitat Communities																									
Salamanders, etc. (Cont.)	Eastern Red-backed Salamander *(Plethodon cinereus)*															X					X						X
	Western Lesser Siren *(Siren intermedia nettingi)*		E	X	X	X																					
Frogs and Toads	Blanchard's Cricket Frog *(Acris crepitans blanchardi)*		T	X	X	X				X			X	X	X							X					
	American Toad *(Bufo americanus)*			X		X	X		X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Fowler's Toad *(Bufo fowleri)*		SC	X		X			X	X			X	X	X						X	X		X	X		X
	Cope's Gray Treefrog *(Hyla chrysoscelis)*			X	X	X	X		X	X			X			X	X	X		X	X	X	X		X		X
	Eastern Gray Treefrog *(Hyla versicolor)*			X	X	X	X		X	X			X			X	X	X		X	X	X	X		X		X
	Northern Spring Peeper *(Pseudacris crucifer crucifer)*			X	X	X			X	X			X	X	X	X	X	X	X	X	X	X	X		X	X	X
	Boreal Chorus Frog *(Pseudacris maculata)*		SC	X		X				X		X								X							
	Midland Chorus Frog *(Pseudacris triseriata)*		SN	X	X	X	X		X	X			X	X	X	X	X	X	X	X	X	X	X		X	X	X
	Bullfrog *(Rana catesbeiana)*			X	X	X	X		X																	X	X
	Green Frog *(Rana clamitans melanota)*			X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X						X	X
	Pickerel Frog *(Rana palustris)*		SC	X	X	X						X	X	X	X							X			X		
	Northern Leopard Frog *(Rana pipiens)*		SN	X	X	X	X		X	X		X	X	X	X		X					X			X	X	X
	Mink Frog *(Rana septentrionalis)*		SC	X		X	X		X			X	X														
	Wood Frog *(Rana sylvatica)*			X	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X						X

SN, Species of Greatest Conservation need; SC, Special Concern; T, Threatened; E, Endangered

Rana (=Lithobates); Bufo (=Anaxyrus)

Appendix B: Project Action Timeline

Project Action	January	February	March	April	May	June	July	August	September	October	November	December
Road maintenance	■	■	■				■	■			■	■
Herbicide, insecticide, and pesticide application	■	■	■				■			■	■	■
Dredging contaminents						■	■	■				
Aquatic weed harvest	■	■				■	■				■	■
Drawdowns						■	■	■	■			
Inundations					■	■	■	■				
Electrofishing					■	■	■	■	■			
Lampricide application	■	■	■								■	■
Mowing							■			■	■	■
Off-road vehicle and heavy machinery use							■	■				
Clearcutting and vegetation harvest						■	■	■	■			
Fire	■	■	■									
Construction						■	■	■				
Site grading						■	■	■				
Stream mitigation and dam removal						■	■	■	■			
Create habitat structures		■	■	■								
Relocation and translocation				■	■	■	■	■	■			

This timeline represents generalized recommendations, exact dates for activites are not provided due to variability in weather and site conditions. Decisions should be guided by species present and management objectives. It is recommended that a professional herpetologist or wildlife biologist with demonstrated experience with reptiles and amphibians be contacted before beginning any of the listed activities.

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