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Forest Management for Reptiles and Amphibians:

A Technical Guide for the Midwest

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ABOUT THE AUTHORS

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THE PURPOSE OF THIS GUIDE

Management plans must be made with consideration for the unique physical and biological characteristics of each property, as well as the particular goals of the landowner or manager. Amphibians and reptiles are vital components of healthy forest ecosystems but have biological and ecological needs that differ from other wildlife. To this end, we hope to present a useful summary of what is known about the response of amphibians and reptiles to a variety of forest management practices in the Midwest, and to suggest general strategies to minimize negative effects of harvests on these species.

The management recommendations we present largely are based on the Hardwood Ecosystem Experiment (HEE), a large-scale study located in south-central Indiana. The HEE used experimentally manipulated treatments within a forested landscape to examine the response of several species to multiple timber harvest techniques. This study is unique in its scale and duration, and provides much-needed insights into the ecological impacts of harvests typical of the Midwest. For readers' convenience, we preface this information with a brief primer on ecosystem-based management, the ecological roles of amphibians and reptiles, and an abbreviated description of forest dynamics. We hope this guide will aid land managers in designing management plans that maintain populations of these species across the landscape.

INTRODUCTION

Forests and ecosystem-based management

We value forests for many reasons. Forests provide economic and social value in the form of wood products, jobs and revenue (Figure 1). Moreover, they provide aesthetic value in addition to opportunities for hunting, fishing and other recreational activities. Trees and forest soils play an important role in removing and storing carbon from the atmosphere (Heath and Smith 2004) and in purifying air and water (Perry 1998). In addition to these direct human benefits, forests are important in maintaining a diversity of species across the landscape. The extent to which forest management encompasses some or all of these values depends on the goals of the landowner and an understanding of how management practices impact the forest ecosystem.

For much of human history, forest management has traditionally sought to maximize the output of goods and services (i.e., wood products and revenue). Consideration was given to biological processes only in the context of optimizing and sustaining timber production (Perry 1998). Within the field of forestry, it was widely believed that good timber management incidentally resulted in good wildlife management, since timber harvests were thought to mimic natural disturbances such as those caused by wind, wildfires and outbreaks of pests and disease (Thomas 1979; Franklin et al. 2007). Indeed, many wildlife species benefit from silvicultural practices, especially game species that thrive on the diversity of food and cover resources available where forests and harvest openings meet (Leopold 1930). However, research over the past several decades has demonstrated that changes in forest habitat structure caused by timber harvesting negatively affect some species while benefiting others.

Figure 1. Forests provide a multitude of environmental (e.g., carbon sequestration, enhance water quality, wildlife habitat), economic (e.g., timber, wood products manufacturing, tourism) and social (e.g., recreation, aesthetics) benefits to society.

Most logging practices differ from natural disturbances in size or frequency and leave behind different amounts and types of biological and physical legacies (e.g., trees, snags, logs; Franklin et al. 2007). In light of these realizations, views on forestry have shifted in recent decades toward ecosystem-based management, an approach that recognizes the importance of soil processes, nutrient and water cycles, and the conservation of non-game wildlife while continuing to value the production of timber (Franklin 1989; Perry 1998). Such management requires a basic understanding of the roles of wildlife in forests, the natural dynamics of forest systems and the potential impacts of silvicultural techniques on wildlife.

The role of amphibians and reptiles in forest ecosystems

Amphibians and reptiles serve critical roles in forest ecosystems (Table 1) and can be sensitive to habitat disturbances such as those caused by forest management techniques. Collectively known as herpetofauna or "herps," amphibians and reptiles often are grouped together but represent two distinct animal groups. All amphibians and reptiles are ectothermic; that is, their internal temperature is controlled by the environment rather than maintained metabolically (Conant and Collins 1998). The physiology of herpetofauna (i.e., ectothermy) allows for more efficient rates of energy conversion and much smaller adult body sizes (many weigh less than 5 g) than those of birds and mammals (Pough 1983), allowing amphibians and reptiles to exploit prey too small to be available to larger species. Herpetofauna, in turn, provide high-quality food items to larger predators as

Table 1. The ecological roles of forest herpetofauna in the Midwest.

Salamanders		
Stream	Southern two-lined salamander, dusky salamander	Predators of aquatic insects, other invertebrates
Pond-breeding	Spotted salamander, tiger salamander	Exploit high productivity of wetlands, create energy pathway across wetland-terrestrial gradient; predators of tadpoles, aquatic insects; nutrient cycling; regulate invertebrates and decomposer organisms; influence litter decomposition; prey for snakes, birds, small mammals
Terrestrial	Eastern red-backed salamander, northern slimy salamander	Exploit prey unavailable to other predators; regulate invertebrates and decomposer organisms; influence litter decomposition; prey for snakes, birds, small mammals
Anurans	American toad, spring peeper, gray treefrog	Exploit high productivity of wetlands, create energy pathway across wetland-terrestrial gradient; regulate invertebrate populations; prey for birds, turtles, salamanders, snakes, mammals
Turtles	Painted turtle, snapping turtle, eastern box turtle	Predators of aquatic and terrestrial invertebrates, frog and salamander adults and larvae; consumers of algae, aquatic plants, mushrooms and berries; prey (eggs and young) to snakes, mammals, birds of prey; seed dispersers
Lizards	Eastern fence lizard, five-lined skink	Predators of invertebrates; prey for birds, mammals, snakes
Snakes		
Small	Eastern garter snake, midland brown snake, northern ring-necked snake	Predators of invertebrates, salamanders; prey for birds, mammals, larger snakes
Large	Gray rat snake, blue racer, timber rattlesnake	Predators of small birds, small mammals, other snakes, fish, lizards, bird eggs, insects, snails; young are prey for birds and mammals

they are relatively easy to capture, lack a covering of indigestible hair and feathers, and contain a relatively high caloric value (Pough 1983; Hairston 1987; deMaynadier and Hunter 1995).

The impact of herpetofauna as both predators and prey is enhanced by the relatively high abundance and densities reached by many species in forest habitats (Congdon et al. 1986; deMaynadier and Hunter 1995; Campbell and Campbell 2000, 2001). In addition to their roles in predator/prey dynamics, herpetofauna have indirect impacts on forest ecosystem processes. For instance, salamanders can influence rates of litter decomposition through predation of soil invertebrates (Hairston 1987; Wyman 1998) while turtles serve as seed dispersers for the plants they consume (Braun and Brooks 1987; Kimmons and Moll 2010).

The unique biological traits of herpetofauna allow these species to occupy niches that cannot be filled by other taxa (Pough 1983), but also make many species vulnerable to habitat loss and degradation (Gibbons et al. 2000). The activity of most species is tightly linked with temperature and moisture, factors which often are altered by human disturbance (Renken et al. 2004, Currylow et al. 2012b).

Unlike many bird and mammal species, most amphibians and reptiles have a limited capability to move rapidly, over long distances, or across barriers such as roads, rivers and agricultural or developed landscapes (deMaynadier and Hunter 1995; Gibbons et al. 2000). In addition, many species are behaviorally tied to specific breeding sites or overwintering sites, to which they return year after year. For these reasons, herpetofauna may be sensitive to timber harvests and merit particular attention in the development of ecosystem-based management for forest landscapes.

Forest structure and dynamics

Forests are most simply defined as areas covered primarily by trees. Although a forest ecosystem includes all biological and physical elements and their interactions (Thomas 1979), trees provide the primary structure of the forest and shape the microenvironment that favors or excludes different animal and plant life (Packham et al. 1992).

The most obvious influence of trees is the vertical structure they provide. In a mature forest, this structure often consists of multiple layers commonly referred to as the overstory, understory, shrub layer, herbaceous layer and litter layer (Kricher and Morrison 1998). The overstory, or canopy, is the uppermost layer consisting of the crowns of the tallest trees. Below this is the understory, consisting of branches and crowns of intermediate height. The shrub layer consists of tree saplings and shrubs. The herbaceous layer includes ferns, perennials, graminoids and woody seedlings, and the litter layer includes decomposing leaves, fungi, moss and wood on the forest floor. The vertical structure of the forest also extends to the subterranean level, including the soil and underground root structures.

Forests also exhibit horizontal structure created by patches of forest stands in different stages of stand development. There are four commonly recognized stages of stand development (Oliver and Larson 1990). The first is stand initiation, in which following a disturbance, surviving and colonizing plants expand into the new opening, or growing space, where primarily fast-growing species thrive in the direct sunlight (Figure 2). New plants continue to appear as long as growing space is available. This stage may last for several years and is characterized by generally high species diversity.

Figure 2. A wide range of herbaceous and woody plants grow together during the stand initiation stage of forest development. The environment changes rapidly as plants grow and new individuals occupy available growing space.

Figure 3. As trees grow taller, they occupy all growing space and either inhibit or exclude the establishment of other plants. The stem exclusion stage is characterized by a high density of young trees with a lower abundance of understory and ground vegetation.

The second stage is stem exclusion, in which the established plants compete for light, water and soil nutrients (Figure 3). In this stage, some trees become dominant to the exclusion of others, which remain stunted or die. During this stage, the forest floor is heavily shaded and has a lower abundance of understory plants than other stages. As the successful trees continue to grow, the stand enters the third stage, understory reinitiation, in which the surviving trees grow older and do not fully utilize the new growing space made available by the dying trees in their cohort (Figure 4). This allows new cohorts of slower-growing, shade-tolerant vegetation to establish in the understory.

The fourth stage is old growth, which is achieved when much of the initial cohort is lost and replaced by a secondary cohort, resulting in a multi-age stand with a complex vertical structure (Figure 5). A "true" old-growth stand is composed entirely of trees developed in this fashion; that is, no live trees established from the original disturbance event remain. The old-growth stage is structurally characterized by the presence of large live trees, large standing dead trees and large

Figure 4. As trees grow older, the speed at which they occupy newly available growing space diminishes. Tree seedlings, shrubs and herbaceous plants capable of surviving or thriving in lower light conditions are able to occupy this new growing space.

Figure 5. Old growth stands are generally characterized by the presence of large live trees, large standing dead trees and large downed woody debris resulting from the mortality of mature trees.

downed woody debris resulting from the mortality of mature trees (Oliver and Larson 1990; Frelich 2002).

Forest structure and species composition are heavily influenced by the type, frequency, size and severity of disturbances (Frelich 2002). Sources of natural disturbances include wind, tornadoes, fire, herbivory, insect outbreaks, pathogens and the natural death of mature trees (Oliver and Larson 1990; Frelich 2002). The scale of natural disturbances runs from the level of individual trees, to groups of trees (leaving small gaps), to partial canopy disturbance (leaving similar amounts of open and intact canopy), to stand-replacement disturbance (removal of all dominant trees in the stand).

Each disturbance type results in some level of tree mortality and potentially the loss of additional vegetation, but in most cases residual organic material persists on site in the form of biological legacies (Franklin et al. 2007). For example, biological legacies left by wind-created gaps include numerous boles (tree trunks), large live trees, newly released seedlings and saplings (advanced regeneration), seed banks and root wads and pits from uprooted trees (Figure 6). Fire, depending on its intensity, may leave a high density of snags, some downed boles, some large live trees and mineral-rich soil seedbeds.

In the Central Hardwood Forest Region, most fires are low-intensity surface fires that typically reduce the density of small understory stems and litter depth, but have minimal impacts to overstory trees. Legacies resulting from insects and pathogens include snags, as well as intact understories, herbaceous layers, seed banks and a relatively undisturbed forest floor (Franklin et al. 2007). Such residual legacies influence stand development following disturbance and provide critical habitat for some wildlife.

Disturbance to forest stands often is human-induced. However, just like natural disturbances, human-induced disturbances vary in terms of their type, size and severity. For example, conversion of forests to agricultural production or development results in long-term or permanent tree removal and forest fragmentation, but silviculture results in temporary changes to forest structure, setting back or advancing succession with the intent of maintaining or regenerating the forest (Oliver and Larson 1990;

Figure 6. Root wads from fallen and uprooted trees can provide micro-environments favorable to some amphibians and reptiles.

Packham et al. 1992). Even so, the biological legacies left behind by some silvicultural practices can differ from those left behind by natural disturbance regimes (Franklin et al. 2007).

Even-aged forest management, which employs stand-replacing techniques such as seed tree, clearcut and shelterwood harvests, does not traditionally retain large numbers of mature, live trees. Typically, live trees retained in seed tree cuts and the initial stages of shelterwood harvests are eventually removed (Smith et al. 1996). The structural legacies (e.g., large trees, snags, boles) left by natural disturbances are reduced in such harvests. Furthermore, even-aged harvests often differ in size, shape and edge contrast from openings created by natural stand-replacing disturbances (Franklin et al. 2007).

Uneven-aged forest management, including single-tree and group selection, may in theory mimic individual tree or small-gap natural disturbances, but the resulting changes to the forest structure may differ somewhat. Traditional single-tree or group selection harvests do not leave behind snags or downed woody debris in amounts comparable to those created by natural disturbances (Franklin et al. 2007). Thus, although disturbance is a natural process in forest ecosystems, wildlife communities may or may not respond to silvicultural practices in the same manner as natural disturbances.

FOREST MANAGEMENT FOR HERPETOFAUNA

Considerations for amphibians and reptiles

Managing forests in a way that is compatible with amphibian and reptile conservation requires that certain considerations be made for the unique biology and ecology of herpetofauna. To preface the discussion of specific research into the effects of timber harvests on target species, the following is a list of such considerations and a brief description of how each aspect of forest management planning relates to amphibians and reptiles.

Timing: Many herpetofaunal species undergo annual periods of mass movement or increased activity, such as annual migrations to wetlands (Figure 7) or spring dispersal from hibernacula (overwintering dens). The timing of harvest activities may be adjusted to avoid such periods. Furthermore, movement within a season often is related to weather patterns; for instance, amphibian and turtle activity often is heightened following moderate to heavy rainfall. Extra vigilance paid by harvest personnel during such conditions could avoid incidental mortality from logging activities.

Figure 7. Many herpetofaunal species undergo annual periods of mass movement or increased activity, such as annual migrations to wetlands. Small vernal pools like the one pictured provide critical breeding habitat for many species of amphibians.

- *Location:* Harvest location might be adjusted to avoid known den sites, breeding ponds and streams, thereby minimizing disturbance to these important habitat features (Figure 8). Semlitsch and Brodie (2003) recommended the use of buffers around wetlands and streams based on biological criteria for a broad suite of reptiles and amphibians. Sites also may be selected based on characteristics, such as slope orientation, that potentially mitigate changes to temperature and other aspects of the physical environment. Temperature fluctuations following harvest may be minimized on north- and east-facing slopes, which in the northern hemisphere receive less solar radiation than south- and west-facing slopes (Xu et al. 1997; Chen et al. 1999).

- *Canopy removal:* Reductions in canopy cover cause changes in temperature, humidity and wind exposure (Todd and Andrews 2008), increasing the chance of desiccation in amphibians (Patrick et al. 2006; Rittenhouse et al. 2009; Rittenhouse and Semlitsch 2009). Canopy removal also results in the temporary reduction or elimination of leaf litter inputs (Greenberg 2001; Patrick et al. 2006; Todd and Andrews 2008), which may negatively affect species associated with litter depth (Moorman et al. 2011). For reptiles, gaps in the canopy may provide thermoregulatory advantages in the form of basking sites and woody debris for cover (Greenberg 2001; Renken et al. 2004; Currylow et al. 2012a). Canopy openings also could influence the temperature of overwintering sites, affecting burrowing depth (Currylow et al. 2012b). Though all harvest techniques result in the loss of at least some canopy cover, the amount removed and the distribution of that removal (size and shape of gap; gap vs. partial cut) are factors that can be adjusted to minimize negative effects to herpetofauna.

Figure 8. Harvest location might be adjusted to avoid or minimize disturbance to streams and other important habitat features.

- *Harvest activity and roads:* Another aspect of harvests to consider is the act of harvesting itself. Direct mortality has been attributed to loggers (Reinert et al. 2011) or vehicles on logging roads (deMaynadier and Hunter 2000). Moreover, roads themselves may dissect and isolate populations (deMaynadier and Hunter 1995; Perry 1998), making them more susceptible to environmental and genetic stochasticity (Shaffer 1981; Soule 1987). Roads also contribute to sediment loading in streams (Moorman et al. 2011), potentially reducing habitat quality for stream-breeding amphibians. Although roadside ditches and tire ruts can serve as artificial breeding pools for amphibians (Figure 9), these may have limited reproductive success given elevated drying rates and frequent disturbance (deMaynadier and Hunter 1995).

- *Biological legacies:* A final important consideration for any harvest technique is the amount and type of biological legacies left behind (Figure 10; Franklin et al. 2007). Woody debris on the forest floor is valuable as cover from predators and for thermoregulation in both amphibians and reptiles (Patrick et al. 2006; Rittenhouse et al. 2009; Semlitsch et al. 2008; Todd and Andrews 2008). Downed logs provide ambush sites for large snakes. Newly felled wood attracts invertebrates, which provide prey for many herpetofaunal species. Standing dead trees (snags) and single or patches of live trees provide shade and litter inputs, reduce wind exposure and soil erosion,

Figure 9. Pools of water in tire ruts are used by box turtles (thermoregulation) and some amphibians (breeding). However, their value is limited due to elevated drying rates and disturbance.

and may serve as refuges for displaced animals and sources for recolonization (Pough et al. 1987; deMaynadier and Hunter 1995; Ford et al. 2002; Greenberg 2001; Homyack and Haas 2009).

The response of herpetofauna to timber harvests

Although we can identify these broad aspects of forest management as having important implications for herpetofauna, understanding their precise impacts and translating that information into useful mitigation strategies is a challenging and ongoing endeavor in the field of wildlife research. Most of the existing research on the effects of timber harvests on amphibians and reptiles is limited in scale, duration and species or harvest techniques examined, and few studies focus on the Midwest or Central Hardwood Forest Region.

The Hardwood Ecosystem Experiment (HEE; Table 2) is a large-scale study investigating the ecological effects of forest management in the Midwest. The HEE takes place in south-central Indiana in a relatively contiguous hardwood forest landscape. Nine management units (ranging 303-482 ha) were randomly assigned one of three management treatments. These treatments included even-aged management with 4.0-ha clearcuts (Figure 11) and shelterwoods (three-stage system), uneven-aged management with 0.4- to 2.0-ha patch cuts and single-tree selection, and no timber harvest (control). Detailed information on the HEE study design is described by Kalb and Mycroft (2013). The study was initiated in 2006, with the first experimental harvests implemented between July 2008 and February 2009. The herpetofaunal component of the HEE focuses on specific target species, including terrestrial salamanders (*Plethodon* spp.), the eastern box turtle (*Terrapene c. carolina*), and the timber rattlesnake (*Crotalus horridus*).

In the following section, we summarize relevant biological information, study design and methodology, and the key findings for each target species studied. It should be noted that the behavioral responses of these target species reflect the scale of timber harvesting techniques within a largely forested matrix. It is unclear how these species would respond to larger and/or more numerous harvests.

Figure 10. Woody debris remaining after timber harvesting can provide amphibians sanctuary from predators or desiccation.

Figure 11. A 4-ha clearcut on a HEE management unit after one growing season. Trees left standing in the cut were removed during post-harvest timber stand improvement (TSI). Note the amount of downed trees and treetops. Picture was taken on Nov. 7, 2009.

Hardwood Ecosystem Experiment results

Terrestrial salamanders (*Plethodon* spp.) are small, lungless amphibians that reside in the soil and leaf litter of the forest floor. They are important components of forest food webs and are sensitive to changes in temperature and moisture of the soil and litter layer. The relative abundance of terrestrial salamanders was monitored at HEE sites with artificial cover objects (wood boards placed on the forest floor and checked periodically for salamander use; Figure 12) for two seasons before harvest and for five seasons after harvest (each spring and fall from fall 2007 to spring 2011). Prior to harvests, treatments did not differ in the relative abundance of any species.

The response of salamanders to harvests was species-specific. The relative abundance of eastern red-backed salamanders (*Plethodon cinereus*) and northern slimy salamanders (*Plethodon glutinosus*) declined from pre- to post-harvest in patch cuts and clearcuts. Red-backed salamanders also declined in control sites, suggesting factors other than the harvests contributed to salamander declines over the study period. However, red-backed salamander declines observed in control sites were not as severe as those seen within patch cuts and clearcuts, indicating harvests were at least partially responsible for observed declines. The relative abundance of northern zigzag salamanders (*Plethodon dorsalis*) did not decline from pre- to post-harvest in any harvest type, and increased on sites adjacent to clearcuts. Due to this increase, during the post-harvest period the relative abundance of zigzag salamanders was lower in shelterwoods than in sites adjacent to clearcuts.

Figure 12. The use of artificial cover boards is a standardized method to assess the relative abundance of woodland amphibians. Grids of 30 coverboards were established throughout the HEE study sites. More than 21,000 salamanders were counted under cover boards during the study.

Yearly and seasonal variation in terrestrial salamander relative abundance was significant for all species throughout the study, with salamander counts under cover objects strongly correlated with temperature. Overall, techniques that removed the forest canopy (i.e., clearcuts and patch cuts) had negative effects on woodland salamanders in the harvest opening during the years immediately following harvest. Techniques that left the canopy largely intact (i.e., first stage shelterwoods and forested sites adjacent to harvests) did not negatively affect salamanders. Our findings suggest canopy removal (1-4 ha gaps) has short-term local impacts on terrestrial salamanders, but negative effects do not necessarily extend to the adjacent forest matrix. Indeed, sites adjacent to clearcuts experienced an increase in counts of zigzag salamanders, but this could reflect the evacuation of individuals from the clearcut into the intact forest. The ultimate fate of displaced individuals remains unknown.

The eastern box turtle is a long-lived, largely terrestrial species that is geographically widespread in eastern forests and sensitive to environmental disturbances (Dodd 2001; MacGowan et al. 2004; Currylow et al. 2011). To investigate the effects of forest management on box turtles on HEE sites, radio telemetry was used to track 50 turtles for two years before harvest (2007-2008) and two years after harvest (2009-2010) during the active season (May-October) and during one hibernal season (2009-2010). There was no effect of timber harvests on home-range size, but the average daily distance traveled by turtles decreased by 30 percent following harvest, and turtles maintained 9 percent higher body temperatures (Currylow et al. 2012a). Temperatures in harvest openings were 29 percent warmer in the summer and 31 percent colder in the winter than forested sites. Despite this change, turtles continued to use harvest openings during the active season (Figure 13), but

Figure 13. The percentage of box turtle locations designated harvest boundaries or home-range size did not change after timber harvesting. Box turtles frequently moved along boundaries post-harvest on the HEE. A telemetered box turtle is visible at the bottom of the picture.

Figure 14. Temperature data loggers (red button on the shell) were used to study the thermal ecology of box turtles on the HEE (top). Box turtles overwinter in shallowly (10 cm) dug depressions. The amount of leaf litter and debris seems important. Depressions in old stump holes and old root tunnels are commonly used (bottom).

tended to make shorter, more frequent movements in and out of harvests. Turtles likely used harvest edges for cover, thermoregulation and, possibly, foraging opportunities (Currylow et al. 2012a).

Hibernation depth of box turtles was estimated by comparing the body temperature of hibernating box turtles to soil temperatures at known depths (Figure 14). Box turtles hibernated at an average depth of 10 cm with a temperature of 3.28°C (Currylow et al. 2012b). All but one turtle hibernated within the forest matrix (i.e., not within harvest openings). Clearcuts were colder than forests and hibernation sites during hibernation but were the warmest areas during emergence. Within clearcuts, turtles must burrow to a depth of 20 cm to attain the average hibernation body temperature of 3.28°C (Currylow et al. 2012b).

Hibernation depth varied by slope aspect, with shallower depths on southwest-facing slopes. Thus, harvested areas offered potential hibernation sites based on soil profile temperatures, slope aspect and depth of hibernation. Some evidence suggests that site fidelity may be more important than changes in temperature profile brought on by overstory removal, as most turtles selected hibernation sites within 61 m from the previous year's location (Currylow et al. 2012b). Both active and hibernal data suggest small-scale harvesting in a relatively contiguous forest landscape has modest effects on box turtle behavior, at least in the short term.

Endangered throughout much of its range, the timber rattlesnake (Figure 15) is a large-bodied, long-lived reptile that is slow to reach sexual maturity (7-11 years for females) and reproduces infrequently (every 3-7 years; Brown 1991; Martin 1993). Individuals exhibit high site fidelity to hibernacula and birthing

Figure 15. Locations of timber rattlesnakes were determined three times weekly using radio telemetry. Downed woody debris is an important structural component for feeding, reproduction and ecdysis.

rookeries (Brown et al. 1982; Walker 2000), making them potentially susceptible to timber harvesting at or near such sites.

Timber rattlesnakes were monitored at control and even-aged HEE study sites for two years before harvest (2007-2008) and three years after harvest (2009-2011). Radio telemetry was used to track the locations of 47 individual snakes several times per week during the active season (April-October). Timber harvests had no effect on mean home-range size of male or female timber rattlesnakes. There was no evidence that snakes changed movement behaviors to avoid clearcuts. Indeed, several snakes were observed within clearcuts for several weeks and across multiple years (Figure 16). Females on even-aged management sites had greater home range shift after harvest than females in control sites, but sample sizes were too small to test statistically.

Figure 16. Clearcuts did not alter home-range size or movements of timber rattlesnakes. They frequently were observed within cut areas.

Behavioral responses of timber rattlesnakes in and around harvests may have positive and negative consequences. Timber harvesting that maintains or increases downed woody debris may improve habitat for timber rattlesnakes. For example, gravid females on the HEE almost exclusively used hollow logs, including cull logs from harvesting activities, for cover and birthing sites. However, mortality from the logging operation itself may have a greater impact on timber rattlesnakes than habitat changes caused by the harvest. Accidental or intentional killing of snakes by loggers occurred in at least one instance at HEE sites.

Management implications and best management practices

Based on our current level of knowledge, it is impossible to predict all consequences, positive or negative, of timber harvesting. For the focal species studied on the HEE, most exhibited moderate or no response in 1-3 years following timber harvests. In a similar study in Missouri, the Missouri Ozark Forest Ecosystem Project (MOFEP) (Table 2; Sheriff 2000), researchers found no immediate landscape-scale effects of even-aged or uneven-aged treatments on the abundance of most of 13 focal species, and only a few species experienced significant effects of clearcuts at the local scale (Renken et al. 2004).

The abundance of most amphibian species declined following harvest, but this decline was evident in control sites as well as treated sites. The authors suspected that declines in abundance for all species were due more to a mild regional drought than to the harvests themselves. However, species-specific differences also should be expected. On the HEE, timber harvests were at least partially responsible for observed declines in red-backed salamanders, but had minimal to no effect on the behavior of box turtles or timber rattlesnakes.

The Land-use Effects on Amphibian Populations (LEAP; Table 2) study investigated the effects of clearcuts (with downed woody debris retained and removed), partial cuts (thinning) and no-harvest management (control) on pond-breeding amphibians in the Missouri Ozarks, Maine and South Carolina (Semlitsch et al. 2009). The overall net effect of treatments during the first few years following harvest was negative, with partial harvests having the least negative effect and the clearcut treatments having the greatest negative effect (Semlitsch et al. 2009). Most of the negative effects found in clearcuts were related to amphibian movement, survival and water loss. Though reptiles were not studied at all sites, the relative abundance of small-bodied snakes in South Carolina was greater in partial cuts than in control sites or clearcuts, suggesting thinned or open canopy stands are beneficial to snakes as long as they retain access to intact leaf litter (Todd and Andrews 2008). The retention of downed woody debris in clearcuts was related to reduced water loss and increased juvenile survival of anurans (Rittenhouse et al. 2009) and reduced evacuation by salamanders (Semlitsch et al. 2008) relative to clearcuts with downed woody debris removed.

All of these studies demonstrate that the response of amphibians and reptiles to timber harvesting is variable. This variability likely is a reflection of the numerous habitat requirements and behavioral adaptions of species within these taxa, but also reflects the ecological complexity of hardwood forests in the Midwest. What management approach should be taken given this level of variability and complexity? Avoiding negative impacts to all reptiles and amphibians because of timber harvesting is neither possible nor desirable since disturbance-dependent wildlife species (Thompson and Dessecker 1997, Greenberg et al. 2011) and many mature forest species, (Chandler et al. 2012) require early successional forests. In the absence of natural disturbance, silviculture is the primary means for creating these habitats.

Forest managers who consider amphibian and reptile habitat when selecting types of silvicultural techniques and practices either should maximize habitat heterogeneity among forest successional stages or prioritize practices based on benefits to species of conservation concern. An inventory of habitat types, important features (e.g., wetlands and vernal pools) and forest developmental stages would be required for both approaches. The latter also would require baseline knowledge of the habitat requirements of each species and their abundance and distribution within the forest and surrounding landscape.

Table 2. Studies investigating the response of herpetofauna to multiple timber harvest techniques in the Midwestern United States.

Study/location	Focal species	Harvest techniques	Scale and duration	Citations
Hardwood Ecosystem Experiment (HEE) (Indiana)	3 salamanders[1] 1 snake 1 turtle	Even-aged management Clearcut (4 ha); Shelterwood (4 ha) Uneven-aged management Patch cut (0.4-2 ha); Single-tree selection No harvest management (control) Harvesting conducted every 20 yrs Cutting rotation of 100 yrs	Nine sites (303-483 ha) Total area: 3,603 ha 100 yr study (2006-2106) Pre-treatment: 1-2 yrs Post-treatment: 3 yrs (ongoing)	Currylow et al. (2013); Kalb and Mycroft (2013); MacGowan and Walker (2013); MacNeil and Williams (2013)
Missouri Ozark Forest Ecosystem Project (MOFEP) (Missouri)	4 salamanders[2] 3 frogs 4 lizards 2 snakes	Even-aged management Clearcut (3-13 ha); Thinning Uneven-aged management Group cut (21-43 m diameter) Single-tree selection No harvest management (control) Harvesting conducted every 15 yrs Cutting rotation of 100 yrs	Nine sites (314-516 ha) Total area: 3,803 ha 300+ yr study (1991-2291) Pre-treatment: 4 yrs Post-treatment: 4 yrs (ongoing)	Brookshire and Shifley (1997); Renken (1997); Renken et al. (2004)
Land-use Effects on Amphibian Populations (LEAP) (Maine, Missouri, South Carolina)	3 salamanders[3] 5 frogs	Four treatments (each 2-4 ha) per site, centered on a wetland: Clearcut (woody debris retained); Clearcut (woody debris removed); Partial cut (25% basal area removed; 50-60% canopy reduction); No harvest management (control)	Three regions (ME, MO, SC) Four sites (8-16 ha) in each region Total area: ~131 ha 1-5 yr study (2003-2008) Pre-treatment: 0-1 yr Post-treatment: 2-6 yrs	Semlitsch et al. (2009)

[1] Eastern red-backed salamander (*Plethodon cinereus*), northern slimy salamander (*P. glutinosus*), northern zigzag salamander (*P. dorsalis*), timber rattlesnake (*Crotalus horridus*), eastern box turtle (*Terrapene c. carolina*)

[2] Eastern newt (*Notophthalmus viridescens*), southern red-backed salamander (*P. serratus*), spotted salamander (*Ambystoma maculatum*), western slimy salamander (*P. albagula*), American toad (*Anaxyrus americanus*), green frog (*Lithobates clamitans*), northern spring peeper (*Pseudacris crucifer*), broad-headed skink (*Plestiodon laticeps*), five-lined skink (*P. fasciatus*), little brown skink (*Scincella lateralis*), northern fence lizard (*Sceloporus undulatus*), northern red-bellied snake (*Storeria occipitomaculata*), smooth earthsnake (*Virginia valeriea*)

[3] Marbled salamander (*Ambystoma opacum*), mole salamander (*A. talpoideum*), spotted salamander, American toad, gray treefrog (*Hyla versicolor*), northern leopard frog (*Lithobates pipiens*), wood frog (*L. sylvaticus*), southern toad (*Anaxyrus terrestris*)

Table 3. Reponses of selected amphibian and reptile species to silvicultural treatments on the Hardwood Ecosystem Experiment (2007-2011).

	Amphibians		Reptiles	
	Target species	**Species response**	**Target species**	**Species response**
No harvest	Eastern red-backed salamander	Relative abundance declined	Box turtle Timber rattlesnake	No effect on home-range size
Uneven-age (single tree and 0.4-2.02-ha patch cuts)	Northern slimy salamander and eastern red-backed salamander	Relative abundance declined	Box turtle	No effect on home-range size; Made shorter, more frequent movements in/out of cuts
Even-age (4.04-ha clear cut and shelterwood[4])	Northern zigzag salamander	Relative abundance increased on sites adjacent to clearcuts	Box Turtle	No effect on home-range size; Made shorter, more frequent movements in/out of edges of cuts
			Timber rattlesnake	No effect on home-range size or adult annual survival

Furthermore, it is likely that species and community responses noted in the studies above in the years immediately after harvest may not remain constant in future years, as the stand structure develops from stand initiation to stem exclusion (see Oliver and Larson 1990) within harvest openings, at least at the local scale. However, certain trends are clear and will help guide management decisions for amphibians and reptiles in hardwood forests. In addition to the specific silvicultural practices listed in Table 3, several considerations may improve or maintain habitat for amphibians and reptiles in managed forests, including:

- *Retention of woody debris:* Many species of amphibians and reptiles in forests utilize coarse and fine woody debris. Woodland salamanders use coarse woody debris for hiding cover; timber rattlesnakes use woody debris for birthing (Figure 17), ambushing prey, and sometimes ecdysis (shedding skin); and box turtles make forms (Figure 18) under tree tops and woody debris. Where clearcuts are conducted, the retention of downed woody debris can mitigate negative effects on amphibians (deMaynadier and Hunter 1995; Semlitsch et al. 2009).
- *Canopy retention:* For partial canopy removal techniques, 50 percent retention of overstory trees is recommended to provide adequate shade, litter inputs and debris for amphibians (Ross et al. 2000; Semlitsch et al. 2009) (Figure 19). On the other hand, snake abundance decreases with increasing basal area (Ross et al. 2000), so the optimal amount of canopy retention for herpetofauna will depend on the species of interest. For stand-replacing techniques such as clearcuts, the few canopy trees and snags left standing in clearcuts likely are more beneficial to amphibians if arranged as patches rather than widely spaced individuals. Patches are more wind-firm and provide more shade, litter and debris to serve as refugia for remnant populations (deMaynadier and Hunter 1995; Greenberg 2001). These likely will have no effect on reptiles within these cuts.

Figure 17. Downed woody debris (logs, tree tops, slash) should be retained in harvested sites. A neonate rattlesnake at birthing site is pictured above.

Figure 18. Box turtles dig shallow depressions under the leaf litter, called forms, to rest or cool off during periods of hot temperatures. Forms were commonly dug under downed tree tops and other woody debris.

Figure 19. Single-tree (pictured) and group selection harvesting results in small canopy gaps.

- *Forestry Best Management Practices (BMPs):* Implementation of forestry BMPs can reduce or eliminate impacts to herpetofauna from logging during wet periods (i.e., times of increased movements) and sedimentation in streams and waterways. Proper road design will, among other things, minimize stream crossings, establish proper grading to reduce runoff and maintain buffers between roads and waterways (Figure 20). Standard BMPs also will result in the reduction or elimination of logging activities during wet periods to prevent soil erosion and compaction.
- *Roads/skid trail traffic and use:* Road mortality for timber rattlesnakes and box turtles was observed within and around HEE management units. While the impacts of roads were not studied in the HEE, previous research suggests that forest roads can be partial barriers to movement for some salamander species (deMaynadier and Hunter 2000; Marsh et al. 2005). Thus, simply minimizing the number or density of roads within the forest matrix to the greatest extent possible likely would reduce these impacts. On forest roads that have controlled access, reducing vehicular traffic during the active season (April-May) potentially could reduce mortality to timber rattlesnakes and box turtles. Furthermore, moving cull logs and other downed woody debris away from roadsides may reduce the use of roads by timber rattlesnakes.
- *Open water:* Maintaining small ponds, emphemeral wetlands and other sources of open water can benefit some species. Box turtles will move toward and use temporary ponds during periods of high temperatures and low precipitation (Donaldson and Echternacht 2005). Box turtles on the HEE sites used the margins of small ponds and lakes during the summer (Figure 21). In 2007, one female turtle spent a period from 15 July to 6 September along the margin of Lake Monroe 1.3 km from its home range.
- *Log landings and cull logs:* Timber rattlesnakes, other snake species and lizards may use cull logs (Figure 22). The practice of leaving cull logs may be beneficial to these species by providing cover, areas for basking and/or habitat for potential prey. Placing these away from areas of high human use (e.g., hiking trails, public roadways) also may be beneficial by reducing the likelihood of people encountering wildlife, thereby reducing the risk of collection or persecution.

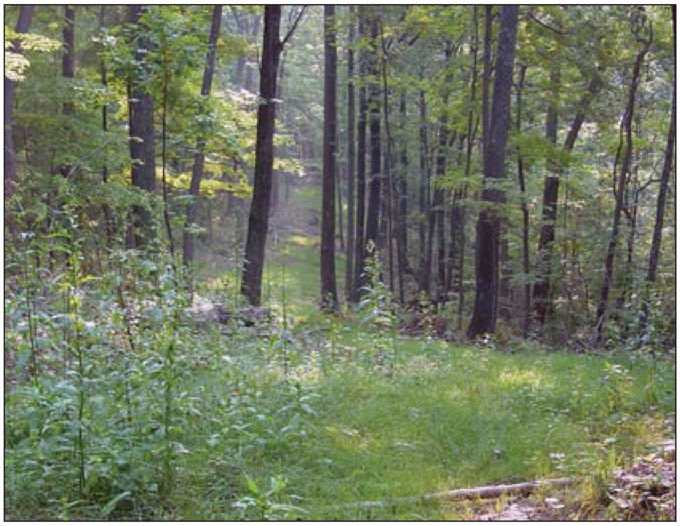

Figure 20. Skid trails and other forest roads can be constructed and maintained to reduce impacts to herpetofauna. Forestry Best Management Practices (BMPs) are a set of preventative measures that help control soil erosion resulting from timber harvesting.

Sarah McManus

Figure 21. While primarily terrestrial, box turtles regularly seek out and use open water during periods of hot weather and drought.

Figure 22. Logs with little to no market value for timber can provide cover and basking sites for reptiles.

- *Human persecution and collection:* Survival rates of timber rattlesnakes (unpublished data, B. MacGowan) and box turtles (Currylow et al. 2011) were relatively high on HEE sites. However, at least two rattlesnakes were intentionally killed by people and two were suspected to be collected or killed by people. Many states have restricted the collection of box turtles because of suspected population declines. Since persecution and/or illegal collection of reptiles and amphibians can exist in many forested areas, educational materials and policies to limit intentional killing (Reinert et al. 2011; MacGowan and Williams 2013) may help to alleviate this threat.

SUMMARY

Forest managers traditionally have placed little emphasis on reptile and amphibian conservation and management. We certainly do not expect the needs of these species to drive every management decision. In fact, we recognize that a more holistic approach is more reasonable and desirable. However, given that reptiles and amphibians have needs different from other wildlife species and are a vital component of forest ecosystems, understanding how timber harvesting impacts them is critical to healthy, productive forests. Maintaining biodiversity, in general, may result in forests that are more stable, productive and resilient to change (Thompson et al. 2009).

Lessons learned from the HEE and other studies suggest that managing forests using a variety of silvicultural methods on a rotational basis generally is compatible with forest-dwelling amphibians and reptiles. Small-scale declines and impacts on reptiles, amphibians and other wildlife groups will occur with all types of management regimes, including no harvest. With the exception of critically endangered species, these small-scale effects are acceptable as long as species and ecosystem function are sustained across the landscape. Strategies to enhance reptiles and amphibians in managed forests often include relatively minor changes to typical practices such as retention of woody debris in cut areas, while minimizing its availability in, and adjacent to, roads and areas of high human use. Many of these practices also are compatible with the conservation of other forest-dwelling wildlife.

Amphibian and reptile species studied on the Hardwood Ecosystem Experiment were a subset of the entire forest community. While we did not study responses of every species, some inferences may be made based on responses of focal species. For example, many species of snakes (*Heterodon platirhinos, Lampropeltis triangulum, Opheodrys aestivus, Pantherophis spiloides*) and lizards (*Plestiodon fasciatus, P. laticeps, Sceloporus undulatus*) observed on the HEE study sites likely will respond positively to management techniques (Ross et al. 2000; Greenberg 2001) that result in canopy openings/edges and increased amount of down woody debris.

When interpreting results from the HEE and other research studies, it is important to consider the study design as well as the spatial and temporal context of the study. The HEE is set within a predominately forested matrix. It is unclear how the focal species studied would respond to similar silvicultural treatments in a different landscape. Moreover, annual variation in abundance and/or behavior of amphibian and reptile species occurs regardless of management regime. Yearly and seasonal variation in terrestrial salamander relative abundance, for example, was observed for all species throughout the study, with salamander counts under cover objects strongly correlated with temperature. In fact, changes in temperature or precipitation may have more impact on amphibian and reptile abundance than forest management (Renken et al. 2004).

Given the complexity of forests in the Central Hardwoods Region, it is impractical for forest managers to determine *a priori* amphibian and reptiles responses for every single management decision. However, this guide will help forest managers understand the habitat needs of these species and expected results from common silvicultural practices. The information presented here is only part of the picture on how to balance the biological and social values that forests provide us all.

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NOTES

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