PURDUE EXTENSION

Forestry and Natural Resources
ag.purdue.edu/fnr
FNR-570-W

The Hardwood Ecosystem Experiment: 2006 – 2016

Compiled by
Charlotte Owings
Purdue University
Hardwood Ecosystem
Experiment Project
Coordinator

Introduction

Many of Indiana's forests have been dominated by oak and hickory trees for thousands of years. The historical conditions that created today's mature canopy trees have changed and these tree species are not replacing themselves with new seedlings. This lack of oak and hickory regeneration in southern Indiana has led land managers to consider what can be done to maintain these ecologically and economically important oak-hickory forests for future generations.

A History of Disturbance

The types of trees that grow in a forest depend strongly on the amount of sunlight available to seedlings on the forest floor. Some trees grow very well in the shade (shade-tolerant species), while others need full sunlight to survive and grow (shade-intolerant). Many species fall somewhere in the middle (intermediate shade-tolerance). Many of Indiana's oaks and hickories are considered shade-intolerant or mid-tolerant. The amount of sunlight that the trees need to grow only reaches the forest floor where disturbances create gaps in the forest's main canopy. These disturbances can be natural or the result of human disturbances, such as timber harvesting.

Today's state forests are a legacy of the intense land management and repeated disturbances by man over the past several centuries. Native Americans cleared the land through the use of burning and timber harvesting. This same land was later occupied by early European settlers who cleared it to create open pastures for livestock and agriculture. Many of these early homesteads were abandoned and later purchased by the state of Indiana with the onset of the Great Depression, and this land subsequently became part of the Indiana State Park and State Forest system.

Changing Land Management

Over the past 50 years or so, forest management favored infrequent removals of scattered overstory trees, creating few large canopy openings in the forest. Natural disturbances alone have not created enough large canopy openings to increase light levels on the forest floor for regeneration of oak and hickory; instead, the prominence of tree species that can tolerate these shady conditions, such as sugar maple (*Acer saccharuum*) and American beech (*Fagus grandiflolia*), has increased (Figure 1). This trend is seen in stands with and without a history of management. These factors are dramatically altering the disturbance ecology and species composition of Indiana's forests, creating a need for significant changes in forest management.

The Oak-Hickory Bottleneck

In southern Indiana, the abundance of mature oak and hickory in the overstory and lack of younger oak and hickory in the understory and sapling layers has been called an "oak-hickory bottleneck." As mature oak and hickory trees die naturally, there are not sufficient numbers of younger oak and hickory trees to replace them. Instead, forest composition is shifting as oak and hickory in the overstory are replaced by shade-tolerant species present in higher quantities in the forest sapling and midstory layers, predominantly sugar maple and American beech (Figure 2).

Figure 1. American beech regeneration beneath an oak-hickory dominated overstory.

Figure 2. American beech-dominated sapling layer in one of the Hardwood Ecosystem Experiment research areas.

Figure 3. Prescribed burning on one of the Hardwood Ecosystem Experiment research sites to promote oak and hickory regeneration.

What Has Land Managers Concerned

Maintaining oak and hickory forests in the Central Hardwood Forest Region is important both ecologically and economically.

Oak and hickory play a vital role in the forest ecosystem throughout their life cycle. Acorns and hickory nuts are sustenance for a wide variety of wildlife ranging from mammals, such as mice and deer, to birds, such as red-headed woodpeckers and blue jays. In addition, the leaves of oak trees serve as a food source for wildlife and are consumed by various insects and herbivores.

Oak and hickory trees also play an important role in providing wildlife shelter. Oak and hickory snags (dead trees) serve as potential roosting habitat for several species of forest-dwelling bats, while tree hollows provide a protected home for several species of birds and small mammals. White oak trees are a preferred tree species for the nests of the endangered Cerulean Warbler (see pages 11-12).

Oak and hickory are not only a keystone species in many forest ecosystems, but also have tremendous economic value. Some estimate that the oak-hickory resource in the eastern United States exceeds half a trillion dollars in value. Oak and hickory timber are heavily utilized in the wood-products industry to make everyday items such as tables, chairs, barrels, rockers, stools, ladders, and cabinets.

How Should Forests be Managed?

Due to the limited successful regeneration of oak and hickory in mesic regions of Central Hardwood Forests, land managers have changed tactics to maintain these species for future generations. One tactic is the reintroduction of past disturbances that were once prevalent on the landscape. Oak and hickory can benefit from prescribed burns, timber harvesting, and the high light conditions created by natural and man-made forest openings (Figure 3). In recent years, these disturbances have been used more frequently as a management tool.

The Beginning of the HEE

The Hardwood Ecosystem Experiment (HEE) was developed in 2006 to study the effectiveness of different methods of forest management in promoting successful oak and hickory regeneration. The HEE also studies the effects of various management practices on plant and animal species.

Study Objectives

When the HEE was established, 4 main objectives were defined for the project:

1. Develop even-aged and uneven-aged silvicultural systems that maintain oak-dominated forest communities and landscapes.
2. Determine the positive and negative impacts of these systems on populations of herbaceous, avian, and terrestrial amphibian species groups.
3. Determine the social and economic ramifications of these systems on local and regional communities.
4. Provide demonstration sites and develop novel educational materials and techniques to engage the public concerning forest management.

Figure 4. A 10-acre HEE clearcut treatment 1 year after harvesting.

The HEE Partners

The HEE is a collaborative project between the Indiana Department of Natural Resources Division of Forestry, Ruffed Grouse Society, and researchers from Purdue University, Indiana State University, Ball State University, the University of Indianapolis, and Drake University. Past project partners have included the Indiana University of Pennsylvania, the Indiana Department of Natural Resources Division of Fish and Wildlife, and the National Geographic Society.

While certain HEE projects are consistent year-to-year, other projects join the list of HEE studies as new research questions arise. Researchers working on new projects continually join the HEE to investigate how forest management affects different species and aspects of the forest ecosystem.

Ecosystem Effects

By studying a number of different taxa (bats, beetles, birds, trees, etc.) researchers involved in the Hardwood Ecosystem Experiment are working to better understand how timber harvesting affects the many components of the forest ecosystem. Researchers are interested in how a certain species or species group responds to timber management, and how species interact with one another in the ecosystem. For example, a decline in the number of acorns produced by oak trees in 1 year may affect small mammal populations that depend on acorns the following year. A lack of tree snags in an area may affect how many bats utilize that area of the forest for roosting. By looking at a number of species and species groups, researchers can examine how complex parts of the forest ecosystem interact and respond to forest management.

HEE Timeline of Events

Pre-2006: The development of the conceptual framework for the HEE

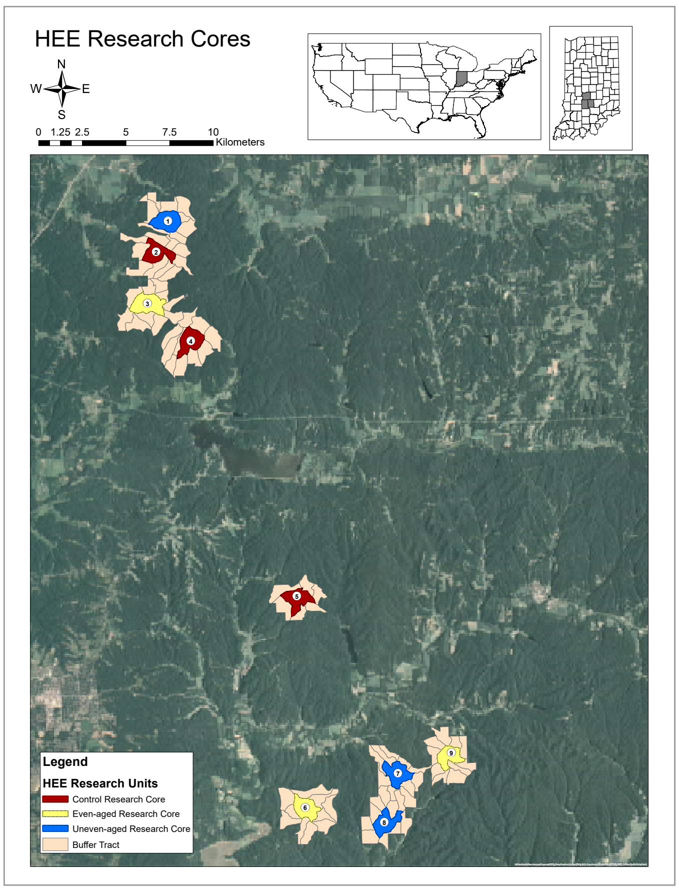
2006: Pre-treatment data collection for bat, beetle, breeding bird, and mast surveys

2007-2008: Continuation of pre-treatment field surveys with the addition of cerulean warbler, small mammal, salamander, moth, overstory, understory, eastern box turtle, and timber rattlesnake surveys

2008-2009: Timber harvests initiated on the HEE

2009: Post-treatment data collection

2015: Prescribed burning treatments initiated at the HEE and second stage of shelterwood harvests



Map 1. HEE study site locations and treatments across Morgan-Monroe and Yellowwood State Forests in Indiana.

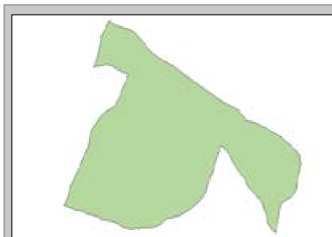
Project Length and Scale

The Hardwood Ecosystem Experiment is designed as a long-term study with the goal of lasting for at least 100 years. Pre-treatment measurements and surveys began on the HEE in 2006. After 2 years of data were collected, timber harvest treatments were implemented in the fall and winter of 2008. Data collection has continued each year since 2006 for many of the projects.

The HEE is uniquely expansive in terms of its proposed longevity and in its spatial extent. Rather than taking place in a single forest stand, the HEE study sites span over 1,800 acres in Morgan-Monroe and Yellowwood State Forests. This allows researchers to answer questions that may be overlooked when investigating a single stand; for example, the habitat use of bats, birds and even rattlesnakes extend beyond the boundaries of most forest stands.

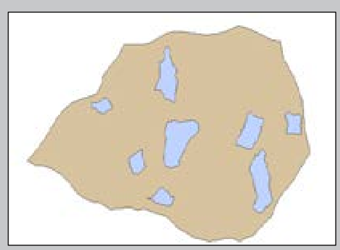
Project Treatments

Researchers that work on the HEE are studying the effects of even-aged management (shelterwood and clearcut harvesting), uneven-aged management (single-tree and patch cutting), and the absence of timber harvesting on plant and animal species. These treatments were randomly distributed across 9 research units in Morgan-Monroe and Yellowwood State Forests (Box 1).



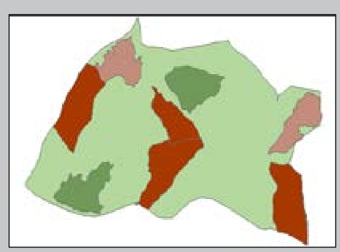
Control Units

- No active timber harvesting or prescribed burning in these units for the duration of the study



Uneven-aged Units

- Harvested in 2008
- Small "patch cut" openings (1,3, and 5 acre) surrounded by single-tree selection
- Single-tree selection harvests will continue every 20 years for the duration of the study



Even-aged Units

- Harvested in 2008
- Two 10-acre shelterwood and two 10-acre clearcut harvests
- Additional 10-acre shelterwood and clearcut harvests planned in unharvested areas every 20 years
- Prior to harvesting, areas are receiving prescribed burning

Box 1. Schematic of the 3 treatment types (control, uneven-aged, and even-aged) in the research units at the HEE. The light green indicates no harvesting, light blue indicates patch cutting, tan indicates single-tree selection, dark green indicates clearcut harvests, light red indicates shelterwood harvests, and dark red indicates future harvest areas that will receive prescribed burning treatments.

Even-aged management

In 2008, research units assigned to even-aged management received clearcut and shelterwood harvests. The clearcut and shelterwood harvests are each approximately 10 acres in size. The shelterwood harvests implemented in 2008 were done in 3 stages. The first cut in 2008 removed small shade-tolerant trees in the midstory. The second cut, which occurred in Fall 2015, removed poorly-formed canopy and subcanopy trees leaving a fairly dispersed overstory to provide seed and shade for developing oak and hickory seedlings. The third cut, still to take place, will remove the remaining overstory trees to allow seedlings and saplings that have regenerated to become the new canopy.

In the even-aged units, prescribed burning was introduced as a treatment to the Hardwood Ecosystem Experiment in 2015 with the intent of promoting advanced oak and hickory regeneration prior to future harvesting. Four 10-acre areas were designated to be burned in each of the even-aged units. These areas will be the future sites of the clearcut and shelterwood harvests in 2028.

Uneven-aged management

The uneven-aged units consist of 1-, 3-, and 5-acre patch cuts interspersed with single-tree selection across the remainder of the unit. These harvests took place in 2008.

Control

The last of the 3 management unit assignments are those assigned to no active timber harvesting or prescribed burning. These units serve as the study controls, and within these units, no active timber management takes place.

Buffer Areas

Around each of the 9 HEE research units is a buffer. The management of the buffer areas around the research cores is highly restricted with no harvesting allowed within 100 meters of the research core. Beyond 100 meters from the outer boundary of the research core, limited single-tree selection and small group openings can be made and must adhere to size and removal restrictions. More details about the initiation of the HEE and treatments can be found in the 2013 General Technical Report by Swihart et al. 2013.

Long-term Documentation

Each year, panoramic photos were taken in one of each type of HEE research treatments by an Indiana Department of Natural Resources photographer. Through these photographs, we can qualitatively see the changes in forest structure and composition that are occurring in HEE units over time. Figure 5 provides examples of panoramic photos taken of some treatment areas.

Figure 5a. Panoramas of one of the 10-acre clearcut treatments in the even-aged units taken spring immediately following harvesting and 2 and 7 years post-harvest.

Figure 5b. A control treatment area in 2009, 2011, and 2016. No timber harvesting or prescribed burning has taken place in the control units.

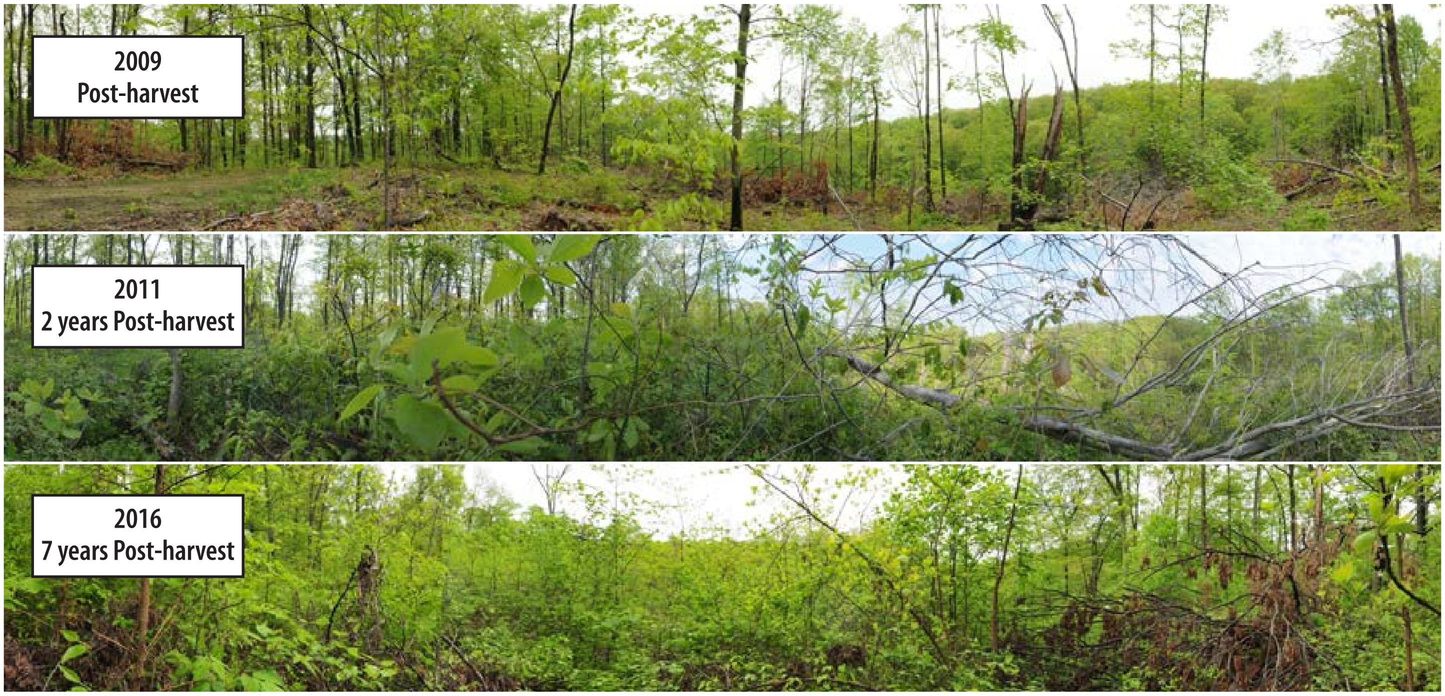


Figure 5c. Panoramas of one of the 5-acre patch cut treatments in the uneven-aged units taken in spring immediately following harvesting and 2 and 7 years post-harvest.

Plant and Animal Responses over the First Ten Years

Researchers have studied a variety of plant and animal groups over the first 10 years of the HEE project (Table 1). While HEE Researchers will continue to discover new findings as the HEE progresses, this publication provides brief summaries of the findings from a selection of the main HEE surveys. These project summaries include information about the researchers who have worked on that project, the methods used, and early findings. Project summaries are sorted by overall project group in the publication (Table 1). Publications that resulted from HEE data collected thus far are listed at the end of this publication. More information about the HEE and its projects can be found at **https://heeforeststudy.org**.

Table 1. An overview of HEE research projects and years in which project surveys were completed (indicated with "x"). Each survey is highlighted with a color corresponding to the overall project group.

Project Group		Survey Year										
		Pre-treatment			Post-treatment							
		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Birds												
	Breeding Birds	X	X	X	X	X	X	X		X	X	X
	MAPS[2]										X	X
	Year-round birds[1]					X	X	X	X	X		
	Cerulean Warblers		X	X	X	X	X	X	X	X	X	X
	Owls		X	X	X	X	X	X	X	X	X	X
	Ruffed grouse					X	X	X	X	X	X	X
	American woodcocks[1]							X				
	Nightjars[1]					X	X	X				
	Golden eagles[2]							X	X			
Mammals												
	Bats (mist-netting)	X	X	X	X	X	X	X	X	X	X	X
	Bats (radio-tracking)		X	X	X	X	X	X	X	X	X	X
	Bats (acoustic sampling)							X	X	X	X	X
	Fawn dispersal[2]							X	X			
	Small mammals		X	X	X	X	X	X		X	X	X
Reptiles and amphibians												
	Timber rattlesnakes		X	X	X	X	X					
	Eastern box turtles		X	X	X	X						
	Woodland salamanders		X	X	X	X	X	X	X	X	X	X
Vegetation												
	Overstory vegetation			X	X				X			
	Understory vegetation					X				X		
Insects												
	Beetles	X	X	X	X	X	X		X	X	X	X
	Moths		X		X	X	X	X	X	X		X
	Spiders[2]										X	X
Integrated studies												
	Oak mast	X	X	X	X	X	X	X	X	X	X	X
	Deer exclosure vegetation					X	X		X			
	Prescribed burning										X	X

[1] Indicates an unfunded pilot or side project

[2] These projects are being conducted in part on the HEE but with non-HEE funding

Breeding Birds

J.B. Dunning, Jr., Purdue University
Graduate Students: P. Ruhl, M. Malloy

Worm-eating Warbler

Project Goals and Methods

Many species of songbirds in the eastern United States are declining. This is especially true of Neotropical migrant songbirds. Forest management activities, especially on wintering grounds, may be a partial cause for this decline, but forest management activities on their breeding grounds may be a partial solution. Since the beginning of the HEE project in 2006, surveys of breeding birds have been conducted to establish the distribution and abundance of bird species across the sites and to monitor how bird communities respond to various types of forest management.

Breeding birds were surveyed between May 20 and June 20 with 10-minute, unlimited radius point counts, during which field technicians recorded all birds seen and/or heard at a number of permanently marked locations. Additionally, for 3 summers (2015-2017) we captured birds in the 2008 clearcut harvest areas, aged and measured the captured birds and released them with bands so that we could identify them again upon recapture. The purpose of the 2015-2017 study was to determine what species were breeding in the areas that were clearcut in 2008, what they were feeding on, and whether they stayed the whole summer in the openings and returned in subsequent years. We detected what kinds of food the birds used (fruits, herbivorous insects, or predator invertebrates such as spiders) by analyzing samples of feathers, blood, plasma and feces collected during the banding process, using a technique called stable isotope analysis.

Results

Red-eyed Vireo (*Vireo olivaceus*) was the most common species detected on breeding bird surveys across the first 10 years of surveys and across all treatments. Among the more common species detected each year of the surveys were Acadian Flycatcher (*Empidonax virescens)*, Worm-eating Warbler (*Helmitheros vermivorum*), Eastern Wood-Pewee (*Contopus virens*), and Ovenbird (*Seiurus aurocapilla*). Across the first 10 years of the project, 95 species were detected (Table 2).

Table 2. Total number of bird species detected during the first 10 years of breeding bird surveys (2006-2015) including pre-treatment surveys. Pre-treatment and post-treatment years are separated by the thick line between 2008 and 2009.

Year	2006	2007	2008	2009	2010	2011	2012*	2013**	2014*	2015
# Species	58	60	64	60	75	73	61		63	76

* Limited-effort surveys (156 vs 265 points) were conducted in 2012 and 2014.

** No breeding bird surveys were conducted in 2013.

Overall, data from the first 10 years of the project showed species richness of breeding birds to be greater in even- and uneven-aged research units in comparison to the control (unharvested) units post-harvest (Kellner et al. 2016). Species that increased in number after harvesting tended to be those associated with early successional habitat, such as the Indigo Bunting (*Passerina cyanea*). Early successional and shrubland specialist bird species responded quickly to the harvests, rapidly increasing in abundance in post-harvest surveys. The species that declined after harvesting tended to be associated with mature forest habitat, such as Ovenbirds. Overall, a greater number of species responded positively or negatively to uneven-aged management than to even-aged management (Kellner et al. 2016).

At first glance, this increase in the number of species detected after the harvests seems easy to explain: the harvest areas provided habitat for birds that use early successional habitat and young forest. Since such habitats were rare in the landscapes before our experiments began, those species increased enough to be detected in our surveys. But our more focused study of birds in the large harvest openings showed that there was a stronger impact of the harvests than just providing habitat for shrubland birds in a forested landscape.

The most obvious finding of the banding project (2015-2017) that took place in the 2008 clearcut harvests was that the openings were used by many species of birds, not just early successional and shrubland species. In fact, the most common species captured during all 3 years was the Worm-eating Warbler, which is usually assumed to be a mature-forest specialist. Red-eyed Vireos, Scarlet Tanagers (*Piranga olivaceus)* and Ovenbirds were also "forest" birds that were commonly caught in the shrubby young stands of the openings. Many of these birds were adults; the Worm-eating Warblers we captured in the first year included both males and females in breeding condition, well before we captured any young produced that year. This prompted us to follow radio-marked females in the second year of the study to see if we could document that this "mature-forest specialist" was actually breeding in the large openings. We documented that female Worm-eating Warblers routinely spent the nights (roosting) in the openings and at least one pair was probably breeding (Ruhl et al. 2018).

The foraging analysis concentrated on Worm-eating Warblers, Ovenbirds and Scarlet Tanagers. We found that these species primarily were found in openings within areas of dense vegetation, but that they also were foraging on insects and fruits; in other words, the openings provided multiple resources from which these birds were benefiting (Ruhl 2018).

Summary

Even-and uneven-aged forest management methods can allow for the enhancement of bird species diversity, while also allowing land managers to meet other forest management goals. Different species of breeding birds are impacted by forest management in different ways; however, when considered over larger spatial areas, a larger number of species are supported in areas that have a diversity of habitats, including forest patches of different age classes. Over a 10-year timeframe, we found that while some forest-associated bird species may decline immediately after harvest, many species seem to benefit from the increased variety of habitats and resources found in the more diverse landscape.

Cerulean Warblers

K. Islam, Ball State University
Graduate Students: L.Young, M. MacNeil, K. Kaminski, R. Dibala, J. Wagner, S. Auer, K. Barnes, D. Pirtle, C. Nemes, C. Delancey, G. MacDonald

Cerulean Warbler

Project Goals and Methods

The Cerulean Warbler has declined by 75% in the mid-western and eastern parts of its distribution in North America during the past 50 years and is listed as state endangered in Indiana. Studies elsewhere in its distribution suggest that Cerulean Warblers are associated with canopy openings and that some types of forest management can directly benefit this species.

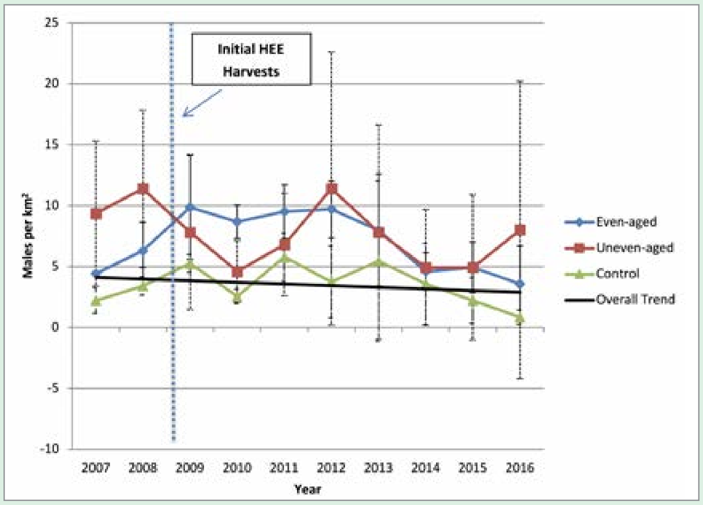
Cerulean Warblers were monitored each year at the HEE sites to determine how they responded to different forest treatments and to learn important components associated with their breeding habitat and reproduction. Each May, birds were counted as they arrived to breed. Once males established territories, the boundaries of these areas were determined from the trees that the males used to sing songs to attract females and defend these areas from other males. From May through early July, nests were located high up in the canopy of trees and monitored to determine how many nests successfully fledged young. In addition, several species of trees were surveyed to determine which trees produced the greatest number of caterpillars, which are the main source of food fed to young. In July, vegetation was measured in the territories and around the nest trees and compared with other forested areas that were not occupied by Cerulean Warblers to determine if they were selecting specific characteristics of the forest.

Results

Relative abundance estimates of Cerulean Warblers changed between pre-treatment and post-treatment years. Initially, Cerulean Warblers were attracted to forest sites with even-aged treatments based on an increase in detection rates during 4 years post-harvest but have since started to decline in these units. They appeared to respond negatively to uneven-aged treatment sites based on decreases in detection rates 2 years after harvest; however, there is much fluctuation in numbers of Cerulean Warblers across years. There was little change in detections at control sites from 2007-2016. Preliminary data suggests that there is an overall decline in Cerulean Warblers at our study sites (black line in graph 1). This decline in population is likely a reflection of the overall decline of the species across its range-wide distribution.

More than 50% of male Cerulean Warbler territories had canopy gaps that were created by a natural disturbance such as a single tree fall, or from old logging roads that were used to extract timber. Thus, uneven-age forest management should benefit Cerulean Warblers. However, this type of forest treatment is not a long-term management approach to habitat conservation because oaks and hickories require sunlight to germinate and to out-compete more shade-tolerant species such as maples and beech. Based on Cerulean Warbler reproduction, oaks (in particular white oak), and hickories were the most important tree species. Nests were found in all forest management types. More nests were found in even-aged units than in uneven-aged or control units, and nearly half of these nests were located in species of the white oak group.

The preference for white oaks by Cerulean Warblers is likely due to an association with high food availability in the canopy. At our sites, oak and hickory trees were found to contain a greater abundance of Lepidoptera larvae (moths and butterflies). Based on follow-up studies of prey items delivered to nestlings and fledglings through intensive filming of prey delivery, lepidopteran larvae were the main food source for Cerulean Warbler nestlings. Also, more than 80% of all Cerulean Warbler territories were characterized by wild grapevines. The bark and fibers of grapevines are the main nesting materials used by female Cerulean Warblers to construct their nests.



Graph 1. Relative abundance estimates (Cerulean Warbler males per kilometer squared) across the 9 HEE research units in Morgan-Monroe and Yellowwood State Forests, Indiana, 2007-2016.

Summary

There was substantial year-to-year variation in populations of Cerulean Warblers detected at our study sites, and preliminary data suggests that the population over all study areas is in decline. Maintenance of an oak-hickory dominated forested landscape characterized by wild grapevines is critical to the survival of this species, as this type of forest provides nesting locations and abundant food for the rearing of young.

Ruffed Grouse

S. Haulton, Indiana Division of Forestry, Department of Natural Resources
Project Staff: J. Riegel

Ruffed Grouse

Project Goals and Methods

Over the last few decades, ruffed grouse populations have been monitored throughout southern Indiana and declines have been dramatic. Populations throughout Indiana have been in decline since the 1980's and in many portions of their former Indiana range they are believed to now be extirpated or critically imperiled (Backs and Castrale 2010). Such declines are not unique to Indiana; throughout much of the species' southern and eastern distribution, ruffed grouse declines have been noted and largely attributed to factors related to diminishing habitat suitability (Dessecker and McAuley 2001). The decline in populations in Indiana and elsewhere parallels similar declines in the availability of young forest habitat, a necessary requirement (Thompson and Dessecker 1997). Researchers have concluded this loss of habitat is at least partly responsible for the noted declines in populations (Dessecker and McAuley 2001).

Ruffed grouse populations have been monitored at both Morgan-Monroe and Yellowwood State Forests for decades. While timber management has been an important forest management tool employed at both properties throughout the period of decline, the development of patches of young forest has remained limited. The experimental HEE harvests, particularly the clearcuts and patch cuts, provide an opportunity to evaluate the response of residual ruffed grouse populations to the creation of young forest patches.

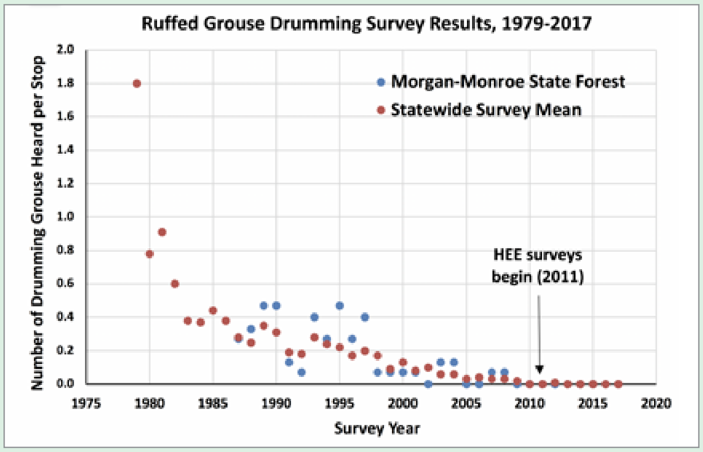
To monitor use of clearcuts and patch cuts by ruffed grouse, annual drumming surveys have been conducted at the HEE since 2011. In the spring, male ruffed grouse "drum" in young forest patches with high stem density to attract mates, providing an opportunity for surveyors to determine if regeneration openings serve as occupied habitat. Listening stations were strategically placed at each of 30 regeneration openings across the HEE's even-age and uneven-age harvest treatments. Surveyors visited each listening station 3-4 times during the late March through mid-April survey period. Surveys began 30 minutes prior to sunrise and ended approximately 3 hours later. At each station surveyors listened for drumming grouse for a period of 6 minutes before moving on to the next listening station.

Results

Despite reports of occasional ruffed grouse observations, ruffed grouse were not detected at listening stations during the entirety of annual spring surveys. Roadside ruffed grouse drumming surveys conducted by biologists with Indiana's Division of Fish and Wildlife at Morgan-Monroe State Forest also resulted in no detections during the survey period from 2011-2016.

Although ruffed grouse were not detected during the drumming surveys, several observations have been reported at or near HEE harvest areas since 2011. In 2011, a drumming male was heard in an even-age unit at Yellowwood State Forest just days before the start of the survey period. In the summer of 2015, a ruffed grouse hen and brood of chicks were observed crossing an access road bordering an uneven-age harvest unit at Morgan-Monroe State Forest. In 2016, at least one individual was observed repeatedly in an even-age treatment unit, also at Morgan-Monroe. To date, no observations have been reported of ruffed grouse within the HEE unharvested control units.

Given the infrequent nature of ruffed grouse observations, the lack of detections in the HEE regeneration openings is not surprising. One reason ruffed grouse have not been observed during the drumming surveys may be the surveys themselves. It is possible that at low abundances, the likelihood of a surveyor detecting a drumming male during the survey period is very low. The anecdotal observations in recent years suggest ruffed grouse may be using habitat in or near HEE harvest areas. While grouse may be using the HEE regeneration openings where the surveys occur, they may not be detectable using the current survey protocol. Other survey methods will likely be explored in the coming years to better detect ruffed grouse.



Graph 2. Ruffed grouse drumming survey results from one route within Morgan-Monroe State Forest (blue) and from routes located throughout southern Indiana (red, 4 routes from 1979-1986 and 8 routes from 1987-2017). Surveys conducted by Indiana Department of Natural Resources Division of Fish and Wildlife. Annual survey report and data available at https://www.in.gov/dnr/fishwild/3352.htm.

Summary

Ruffed grouse have been observed at HEE harvest areas on several occasions since 2011; however, drumming males have not been detected in HEE regeneration openings during our surveys. Given the apparent rarity of ruffed grouse across the study area, it is possible that the lack of detections is due to survey design, rather than the unavailability of suitable habitat.

Small Mammals

R.K. Swihart, Purdue University
Graduate Students: N. Urban, K. Kellner, D. Nelson

Eastern chipmunk

Project Goals and Methods

Small mammals play vital roles in forest ecosystems by serving as a main food source for many vertebrate predators, functioning as mini-predators of prodigious numbers of acorns, and aiding in germination of acorns and other nuts that they bury in shallow caches but fail to recover. Small mammal species differ in their habitat needs and so might differ in their responses to forest management. Small mammals also differ in their ecological roles, and alterations in their communities can have important implications for ecosystem processes. Our objectives have been to understand how forest management treatments affect small mammal populations and communities, and the implications of these changes for oak regeneration.

Small mammal sampling grids made up of 36 Sherman traps were placed in harvested and non-harvested areas. Within small mammal grids, each trap was 20 meters from the next nearest trap. Each grid was sampled for 5 consecutive days and traps were checked twice a day. Sex, weight, species, and reproductive status of trapped individuals were recorded. Rodents and shrews were marked to enable identification of individuals. Herbaceous and woody vegetation data surrounding each trap was recorded to understand how the microsite variables may affect use by small mammals.

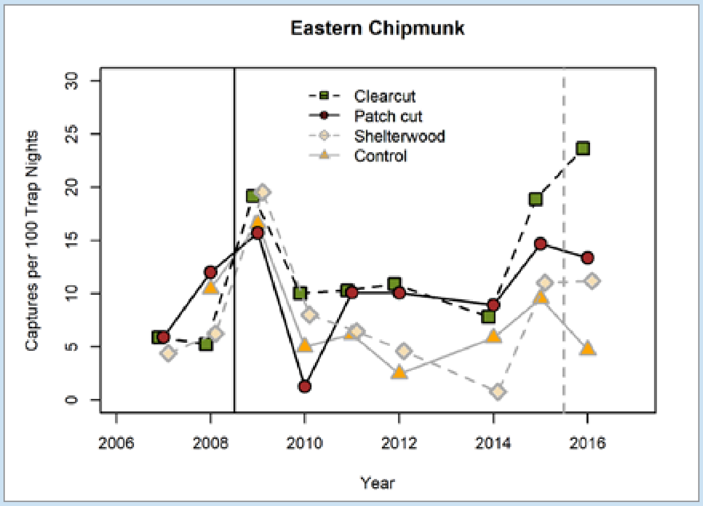
Results

Eight species of small mammals were trapped and released over multiple summers from 2007-2016 in different harvest types at 32 locations. Over 90% of the more than 12,000 captures were eastern chipmunks and white-footed mice (photos). Chipmunks increased in abundance over time on harvested sites relative to controls, with clearcuts showing the largest increases. Density of chipmunks and white-footed mice was especially high along harvest boundaries. White-footed mice tended to decline in abundance in interiors of larger harvest openings.

In addition to responses to harvest, rodent numbers generally increased in years following an abundant acorn crop (see section on Oak Acorn Production and Removal). Short-tailed shrews ranked third in relative abundance. Their populations dropped immediately following harvest, then tended to increase over time relative to unharvested control sites but still remained below control levels.

Changes in small mammal populations were related to small-scale changes in habitat. Mouse and chipmunk captures were associated with woody cover and debris like fallen logs. In contrast, short-tailed shrew captures were associated with woody debris and a thick leaf litter layer.

Figure 10. White-footed mouse



Graph 3. Unpublished trends related to data in Kellner et al. (2013) and Nelson (2017) of the captures of eastern chipmunks by 100 traps in one night; harvesting is denoted by vertical lines. The solid vertical line represents the initial harvesting for all treatments completed in the winter of 2008-early 2009. The dashed vertical line represents the second stage of the shelterwood harvests that took place in the winter of 2015.

Summary

Timber harvesting increased overall populations of small rodents, especially chipmunks, which are important prey for forest predators. Populations of shrews declined following harvest, with gradual recovery as young forest openings developed overhead cover, leaf litter, and other desirable characteristics for small mammals.

Bats

J.M. O'Keefe, B.L. Walters, and J.O. Whitaker, Jr. (Indiana State Univ.);
T.C. Carter (Ball State Univ.)
Graduate Students: M. Caylor, A. Nolder, S. Bergeson, H. Badin,
K. Caldwell, T. Divoll, J. Karsk, K. Titus, E. Beilke, J. Sheets

Project Goals and Methods

Forest-dwelling bats are key predators of insects at night and may have significant impacts on forest health. At the HEE, our goal has been to study the bat community and its interaction with forest ecosystems, including harvested and unharvested areas. We use mist nets to capture bats, radio telemetry to follow bats and find their roosts and foraging areas, and acoustic detectors to compare activity rates in different parts of the forest. We also use DNA analysis to identify prey items in bat guano. From 2012–2017, we focused on the federally-endangered Indiana bat (*Myotis sodalis*) and the federally-threatened northern long-eared bat (*Myotis septentrionalis*). Both species roost in dead or damaged trees, but their roosting habits differ in subtle ways. Further, the two bats have differing foraging habitat requirements. We aim to better describe the niche occupied by each of these bats on the HEE and surrounding Indiana State Forest lands.

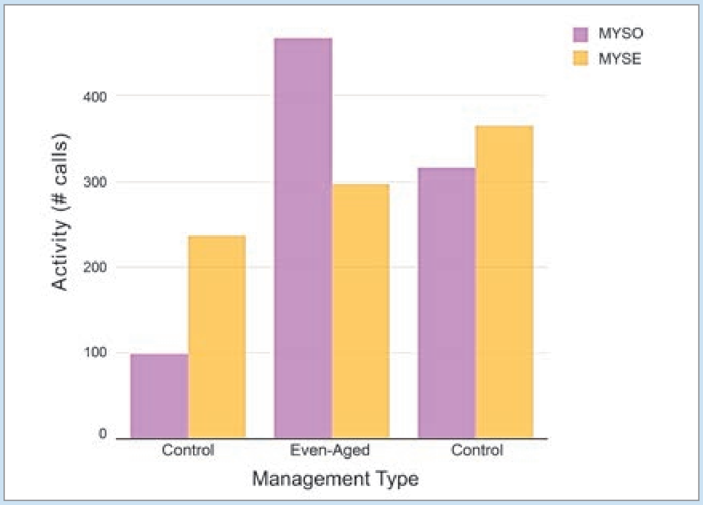
Results

Both focal bat species used harvested areas while foraging at night. Indiana bats foraged across a large area (848 ± 173 acres over 3–4 nights), selecting for patch cuts, regeneration openings, and historically thinned forest. Northern long-eared bats used a smaller area (435 ± 62 acres), selecting forest ponds, historically thinned forest, and patch cuts. We detected 3–4 times more acoustic activity for Indiana bats in the parts of the forest managed with even- and uneven-aged harvest treatments versus no harvest/control units. Northern long-eared bat activity was only slightly higher in the even- and uneven-aged harvest treatments when compared to unharvested control units.

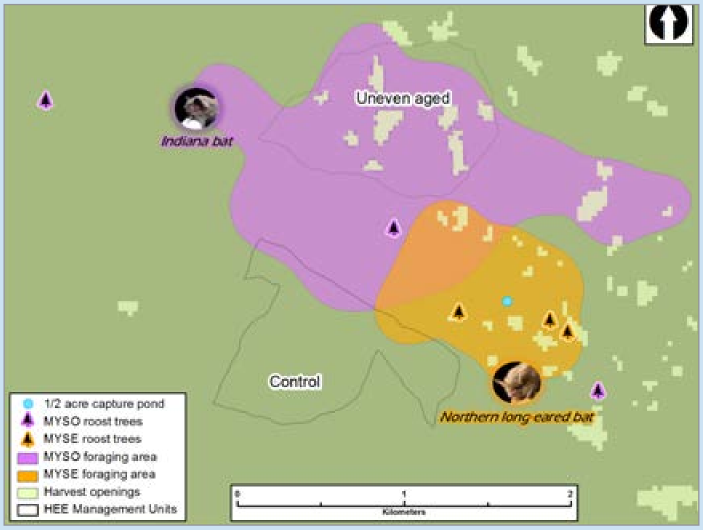
Diets of Indiana bats and northern long-eared bats were comparable (85% similar); DNA analysis showed the 2 bat species ate ≥ 488 prey types from 14 different scientific orders, mostly small moths, mosquitos, midges, crane flies, small beetles, and spiders.

Over the last 5 years, we detected a change in the relative abundance of various bat species captured, which partly reflects our switch to new sampling sites, but mainly the effects of white-nose syndrome on Indiana's cave-hibernating bats. While northern long-eared bats, eastern red bats, and big brown bats were similarly abundant in 2006–2011, eastern red bats are now primarily captured. The capture rates of northern long-eared bats, little brown bats, and tri-colored bats have declined dramatically between 2012 and 2017 (likely due to white-nose syndrome). Indiana bat captures remained steady in rate.

Indiana bats occupied 3 distinct maternity areas in Morgan-Monroe and Yellowwood State Forests, with a peak count of 184 bats exiting 1 colony. They roosted in large, dead hardwood trees (e.g., maples, oaks, and hickories); bat boxes; and a utility pole. Northern long-eared bats roosted in small groups (usually <10 but sometimes >40 bats) in hardwoods (e.g., sassafras, oaks, and maples); they were divided almost evenly between live-damaged and dead trees.



Graph 4. Acoustic activity for Indiana bats (MYSO) and northern long-eared bats (MYSE) across HEE units surveyed in 2013–2016. For both species, there was more activity in harvest (even- or uneven-aged) units versus unharvested control units, but this difference was more pronounced for Indiana bats.



Map 2. Foraging and roosting areas for an Indiana bat (MYSO) and northern long-eared bat (MYSE); both reproductive females were captured at the same forest pond in June 2014 and tracked for 3 consecutive days and nights. Both foraged near harvest openings and in the surrounding historically thinned forest, but the Indiana bat foraged and roosted farther from the capture site.

Summary

A diverse bat community uses the HEE study units and surrounding state forest, but some species are declining, likely due to white-nose syndrome. Two imperiled bat species parse the roosting and foraging niche in slightly different ways, but neither avoided harvest areas.

Woodland Salamanders

R.N. Williams, J. Riegel, Purdue University; R.N. Chapman
Graduate Student: J. MacNeil

Eastern redbacked salamander

Project Goals and Methods

Terrestrial plethodontid salamanders are an ideal group of species to monitor forest ecosystem integrity and biodiversity across the eastern United States. They play a significant role in nutrient recycling by consuming vast quantities of invertebrates and in turn serve as prey for other forest species. They are sensitive to environmental stressors and are often the most abundant vertebrates in deciduous forests. The plethodontids are lungless salamanders respiring through their skin and requiring moist habitat conditions. With their environmental sensitivity, forest management can directly impact habitat suitability for forest-dwelling salamanders.

The terrestrial salamander portion of the Hardwood Ecosystem Project is designed to evaluate the effects of timber harvesting on the diversity, abundance, and demographics of woodland salamanders. Beginning in May 2007, a total of 66 coverboard grids (30 boards per grid) were placed within the 9 study areas. The coverboard grids were checked every other week from September through November. In the spring of 2008, the sampling period was extended to include spring sampling in addition to the fall sampling.

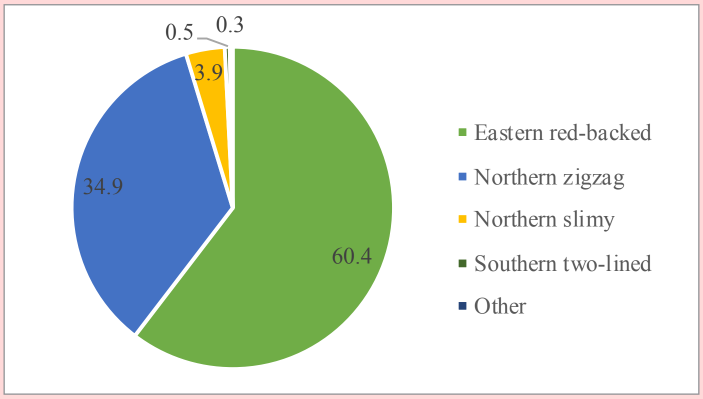
Results

Since salamander sampling began in the fall of 2007, the wood artificial cover objects have yielded 47,134 salamander encounters representing 10 species. The vast majority of captures are comprised of 4 species; these are eastern red-backed (*Plethodon cinereus,* 60.4%); northern zigzag (*P. dorsalis,* 34.9%); northern slimy (*P. glutinosus,* 3.9%*)*; and southern two-lined salamanders (*Eurycea cirrigera,* 0.5%). There are 6 additional species that have been detected, but not in large numbers (0.3%), including long-tailed salamanders (*E. longicauda*), spotted salamanders (*Ambystoma maculatum*), Jefferson salamanders (*A. jeffersonianum*), marbled salamanders (*A. opacum*), eastern newts (*Notophthalmus viridescens*), and smallmouth salamanders (*A. texanum*).

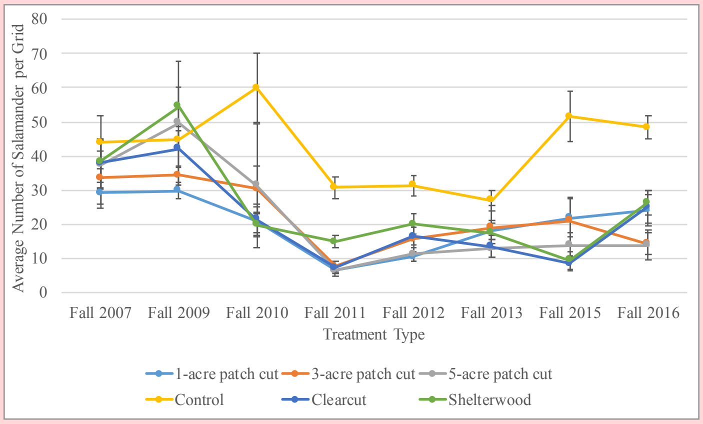
Preliminary results from 2007-2016 suggest that the regeneration openings (patch cut, shelterwood, and clearcut harvests) had a negative effect on salamander abundance locally. Data from fall 2008 was not depicted below as salamander surveys during 2008 were suspended while the first round of regeneration openings were being implemented in the HEE research areas.

Researchers are continuing to investigate salamander abundances in these areas to determine if numbers will rebound over time to their pre-harvest levels.

MacNeil and Williams (2014) looked at pre- and post- salamander abundances in fall 2007 to spring 2011 in areas where regeneration openings were created as well as in the surrounding forest at the HEE. Salamander abundance in patch cuts and clearcuts dropped after harvesting, but stayed the same in shelterwood cuts. The effects of forest management on salamander abundance resulted in declines, but only up to approximately 20 m into the surrounding forest indicating a negative effect locally initially after harvesting.



Graph 5. Preliminary data of the proportion of salamanders recorded of each species during coverboard surveys.



Graph 6. The average number of salamanders encountered per salamander grid each fall from 2007-2016 by treatment.

Summary

The salamander species encountered most frequently during salamander surveys has been the eastern red-backed salamander. Since the creation of the regeneration openings, salamander numbers have yet to recover to pre-harvest levels, but these areas will continue to be studied in years to come. An early HEE salamander study suggests that management methods that leave the canopy of the forest intact may best promote salamander populations in forested areas.

Beetles

J.D. Holland, Purdue University
Graduate students: K. Raje, H.A. Moniem, A. Kissick, T. Mager, L. Hanna

Painted hickory borer

Project Goals and Methods

Long-horned beetles are a diverse family of insects in forested habitats. They are important in the decomposition of dead and rotting wood, and pollination of flowering plants. About 20% of species in Indiana are pests of living trees. A few species can kill trees stressed by factors such as drought. The HEE beetle project is monitoring changes to the long-horned beetle community under different forestry practices. We are studying how different logging regimes alter this community and how this then affects other types of wildlife such as birds that prey upon the beetles. We are interested in how changes to the long-horned beetle community influence forest health and how resilient the community is to disturbance.

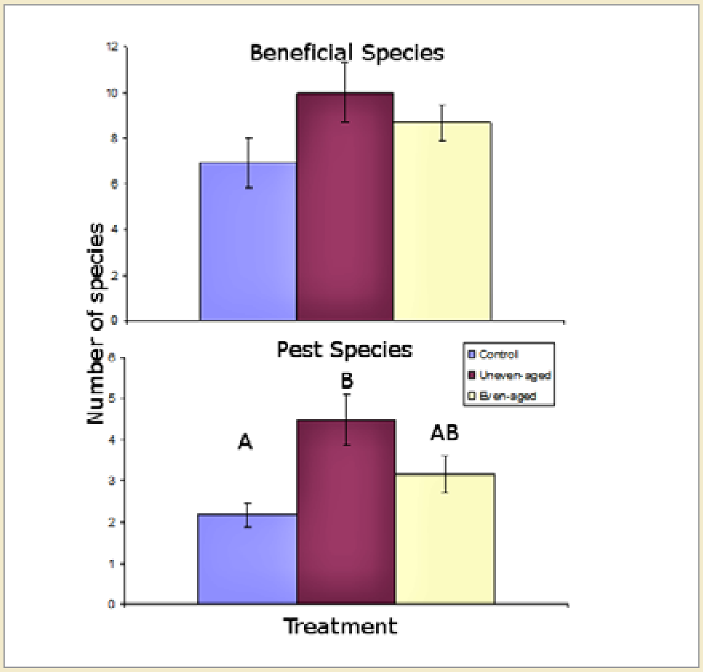
Long-horned beetles (*Coleoptera: Cerambycidae*) and metallic wood-boring beetles (*Coleoptera: Buprestidae*) were sampled using arrays of 4 different beetle traps around each trapping point throughout the summer. Each array consisted of 1 twelve-funnel Lindgren funnel trap, 1 intersecting-pane widow trap, 1 Intercept-panel trap for bark beetles, and 1 purple-sticky trap. Each trap was randomly assigned to one of the cardinal directions and hung from a branch. Insect samples were placed in a small glass jar with ethanol and returned to the lab for sorting and identification.

Results

While the long-horned beetle and metallic wood-boring beetle families are the targets of these surveys, we continue to obtain good representation of several families of beetles that are predators upon the wood-borers. We have found approximately 140 species of long-horned beetle in the HEE. Before any harvesting took place we found that the beetles that use rotting wood and tend to be pollinators showed a different spatial pattern than pest species. This suggests that we should be able to manage forested landscapes to limit pest species and encourage beneficial species at the same time.

Landscapes that received harvests showed an increase in the number of species of long-horned beetles regardless of the type of harvest. This increase was caused by more species of pests but also more species of benign and beneficial long-horned beetles. However, the species that contribute to the change from pre-harvest communities are different in areas that receive different types of harvest. The communities also change year-to-year due to differing conditions such as weather. The control landscapes are thus invaluable in allowing us to separate effects due to harvesting and effects due to other changing conditions.

Over the period 2-6 years after harvest the long-horned beetle communities have shown resilience in that they are returning to pre-harvest communities. The species that are found and the numbers of individuals of these species are becoming more similar to what was found during the 2006-2008 pre-treatment surveys.



Graph 7. Beetle richness (number of species) immediately following harvests at the HEE in the various treatments.

Summary

Long-horned beetles are a very diverse but under-appreciated group in Indiana forests, with many species that are beneficial and some pests of living trees. The species that are found change under forest management with disturbance increasing the diversity found. The communities appear to be resilient to harvests so far.

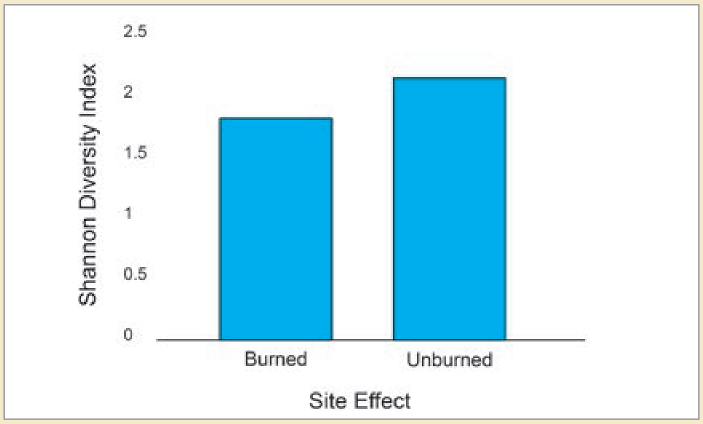
Spiders

M. Milne, University of Indianpolis
Undergraduate students: B. Deno, J. Acosta, L. Frandsen, A. Sobczak

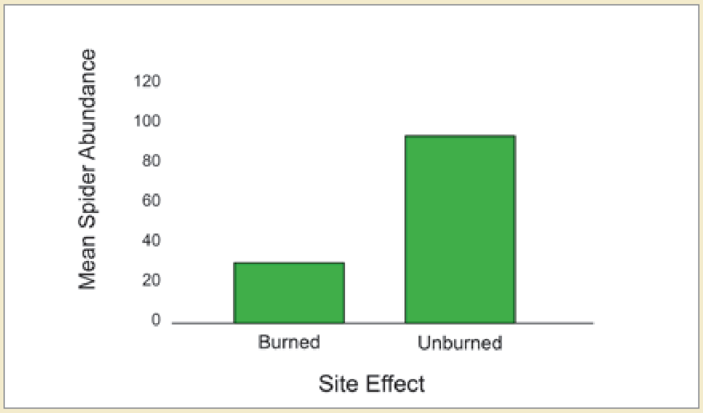
Project Goals and Methods

The goal for this study is to determine the effect of fire on spider diversity and abundance in non-logged forest habitat. Spiders are understudied in Indiana; there is not even a complete list of species that exist in the state. By studying spiders in central Indiana forests, we hope to correct this. By introducing an environmental disturbance such as fire resulting from prescribed burning treatments, we can learn the resiliency of particular spider communities.

Most months since 2015, we have collected spiders from Yellowwood State Forest and Morgan-Monroe State Forest using pitfall traps, sweep nets, hand collection, and Berlese funnels. We bring spiders back to our lab at the University of Indianapolis, separate them from the leaves and debris, and identify them to species using microscopes and a variety of books and manuscripts that possess taxonomic keys. Gathering these data from sites both before and after they were burned gives us a snapshot of spider diversity and abundance in these sites in response to fire.



Graph 8. The initial effect of burning on spider diversity, calculated using a diversity measure that takes into account diversity of the community and spider abundance in central Indiana forests.



Graph 9. The initial effect of burning on the average number of spiders in central Indiana.

Results

Since our study began in 2015, about 80% of our sites have been burned. The last sites will be burned in 2018 and then all of our collecting will be considered "post-burn."

Even though our study is ongoing, we have some interesting preliminary results. So far, we have uncovered 142 species of spiders from Morgan-Monroe State Forest and Yellowwood State Forest, 33 of which were new distribution records for the state of Indiana, and 4 or 5 of which are suspected of being undescribed species. It has been estimated that there are almost 200 spider species in these forests, and we may reach close to that number by the end of the study.

Because our study is still ongoing, we only have preliminary results when comparing burned and unburned sites. Even at this early stage of the study, it is clear that burning significantly changes the taxonomic makeup of the spider communities that live there. Early on, burned sites have a significantly lower abundance of spiders than unburned sites. Additionally, the diversity of spiders within burned sites drops by a significantly large margin when burned.

Summary

Several new spider distribution records for the state and multiple possibly-undescribed spider species revealed by this survey indicate that our knowledge of Indiana spiders is far from complete. Preliminary results suggest that initially, fire significantly decreases spider abundance and diversity and significantly alters species composition. More surveys should be conducted to determine how long this trend lasts.

Lepidoptera (Moths)

K.S. Summerville, Drake University
Undergraduate students: P. Bradley, J. Lane, D. Sinn, A. Johnson, M. DuPont, R. Schulte, T.Wausson, A.Wick, E. Hill, B. Lang, C.Parrish, R. Krehbiel, G. Baumgartner


Giant Leopard Moth

Project Goals and Methods

This project is designed to test hypotheses regarding how forest moth communities are influenced by varying levels of timber harvest, seasonal weather variation, and initial forest stand composition. The overarching goal of this project is to make specific recommendations for levels of timber harvest that are consistent with maintaining moth diversity in Indiana's forests.

Three forest management units within Morgan-Monroe State Forest were used to sample forest Lepidoptera. Each year from 2007-2015, moths were collected from forest stands using blacklight traps. Traps were placed in the approximate center of each managed stand to reduce edge effects from the forested matrix. On nights of operation, a single trap was placed at each site on a platform 2 meters above the ground and remained lit from 8:00 pm to 7:00 am CDT. Lepidoptera were sampled approximately every 14 days from May 30 – August 30. Trapping was restricted only to nights that had a minimum temperature ≥ 16˚C (60.8˚F), no precipitation and low levels of ambient moonlight. Species were classified into trait groups using the *Moths of North America* Monograph series (Wedge Entomological Research Foundation).

Results

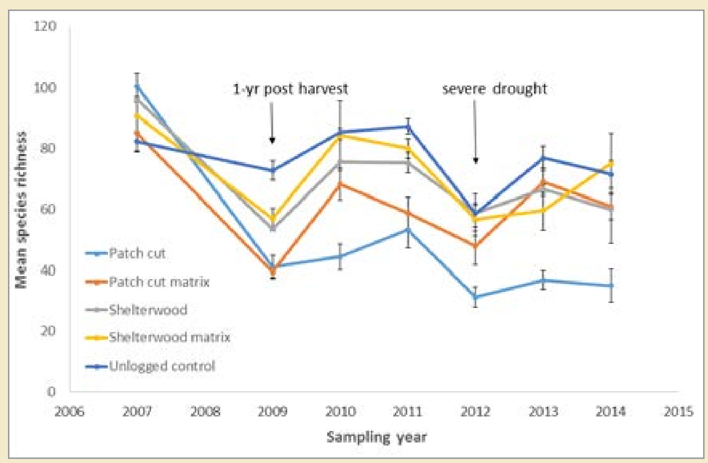
A total of 373 species were sampled from the Hardwood Ecosystem Experiment from 2007-2015. The 5 most abundant species were, in rank order: (1) *Halysidota tesselaris* (Banded tussock moth), (2) *Malacosoma americanum* (Eastern tent caterpillar), (3) *Nadata gibbosa* (White-dotted Prominent moth), (4) *Hypoprepia fucosa* (Painted lichen moth), and (5) *Lambdina fervidaria* (Curve-lined looper). These species are generalist feeders of tree foliage, except for *H. fucosa*, which feeds on lichen and mosses on trees.

Relatively few specialist species were sampled overall, even prior to timber harvest. Prior to harvest, most of the species sampled from forest stands were consumers of leaves (either in the form of living plant tissue or leaf litter). Post-harvest, stands managed with patch cut harvests or clearcutting were colonized by a number of generalist herbaceous feeders.

Total moth species richness (the number of species) was influenced by management unit and year. All forest stands contained lower moth species richness in 2009 compared to 2007. Moth species richness ranged from 83-104 among all stands sampled the year prior to timber harvest. Post-harvest moth communities were more lacking in numbers of species, with moth communities in harvested stands or in matrix stands (forested areas between the harvests) experiencing 40-50% drops in species richness. By 2011, moth communities in control stands, shelterwood stands, and matrix stands associated with shelterwood harvests had a similar species richness to that found in 2007. Neither the patch cut harvests nor the matrix stands that they were paired with recovered to a pre-harvest level of moth species richness.

Although not analyzed, clearcut stands appeared to track the same changes in species richness as observed in the patch cut stands. During the significant drought year (2012), moth species richness was diminished across all treatments, with the most significant loss of species occurring in the patch cut harvests. While species assemblages in all other treatments returned to richness levels on par with the post-harvest state by 2015, moth communities in patch cut stands appeared to remain at an impoverished equilibrium after the drought.

Moth community composition was significantly affected by harvest treatment and time since logging disturbance. Forest stands were the least changed in moth composition from 2007-2015 if they were control stands the matrix surrounding shelterwood harvests, or the shelterwood cuts themselves. These stands possessed the greatest level of compositional resilience (moth communities recovered from the disturbance quickly). By 2014, the shelterwood cut stands, the control stands, and the matrix stands in the shelterwood unit were statistically indistinguishable from the 2007 site grouping. In contrast, the 4 patch cuts, the 2 clearcut stands (not depicted above) and the 4 matrix stands associated with patch cuts have not yet recovered from timber harvest.



Graph 10. Variation in species richness of adult moths that have larvae known to consume oak foliage for the HEE taken from Summerville et al. 2016, Forest Ecology and Management https://doi.org/10.1016/j.foreco.2016.08.050

Summary

Moth species richness was lower in all forest stands the year immediately following timber harvest. Reduction of species richness, and the amount of change in species composition was related to the intensity of the harvest disturbance. Communities in unlogged controls and stands managed with an understory shelterwood harvest were resilient to changes in moth diversity.

Oak Acorn Production and Predation

R.K. Swihart, J. Riegel, Purdue University
Graduate Student: K. Kellner

Project Goals and Methods

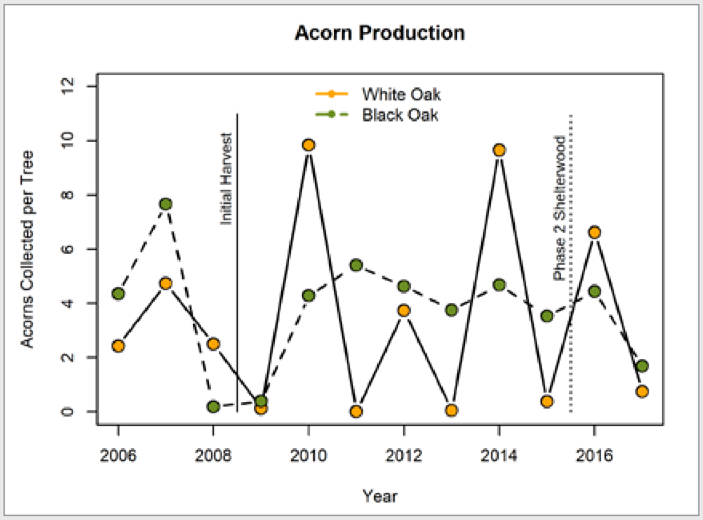
Acorns produced by oaks are an important food source for many animals. To grow into an adult tree, acorns must avoid being eaten; germinate in a favorable site for growth; survive browsing by deer, rabbits, and insects as a young plant; and outcompete neighboring plants for light and growing space. Production and removal of acorns on the HEE has been tracked annually for more than 100 black and white oak trees. Acorns are captured in special buckets, counted, then placed in cages that allow access only to certain sizes of vertebrates. Acorns are also x-rayed to determine if they were fed upon internally by acorn weevils.Additional studies have used tagged acorns to learn where rodents disperse and bury seeds, and how often they fail to recover buried acorns that then might develop into young oak seedlings.

Results

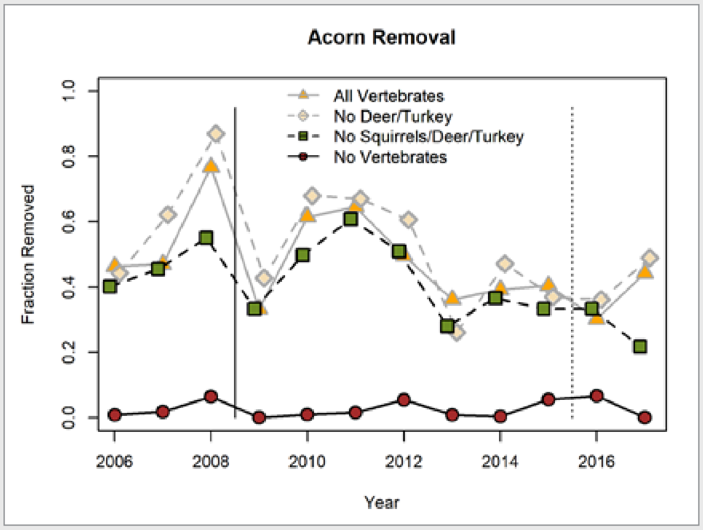
Acorn production by trees along edges of openings does not appear to be affected by harvest but is highly variable from year to year. White oak was especially unpredictable, with no or very small acorn crops in 5 of 11 years. Higher fractions of acorns were damaged by weevils in years with low acorn production; indeed, the 5 worst years for weevil damage were also the years of least total acorn production.

Vertebrates removed 20-90% of acorns from cages (Graph 11), with little impact of harvest treatments on removal. Excluding consumers, such as deer and turkey, resulted in elevated removal of acorns by remaining consumers, such as squirrels and mice. The total fraction of acorns removed was fairly constant across exclosure types (except for the cages that prevented vertebrate access).

Data from rodent dispersal of tagged acorns showed that unlike deer and turkey, rodents buried and failed to recover some seeds. Together with data on oak growth and survival in areas protected or subjected to mammal browsing, an oak population model was developed for the HEE. Of 11 factors considered crucial in determining recruitment of acorns into the next generation, the model identified the probability that dispersed acorns were buried by rodents as the most important factor. Burial of acorns greatly improves germination success and chances of survival, which is an under-appreciated service provided by rodents in oak forests.



Graph 11. Trends in acorn production by tree species, with harvesting denoted by vertical lines. Based in part on Kellner et al. (2014).



Graph 12. Trends in removal of acorns from cages designed to exclude vertebrates of varying sizes. Based in part on Kellner et al. (2014). Vertical lines indicate harvest periods.

Summary

Acorn production was highly variable from year to year, especially for white oak. Years of poor acorn crops were characterized by high rates of weevil infestation and an adverse effect on rodent abundance the following year. Vertebrates removed 20-90% of acorns, some of which were buried by rodents. Overall, increasing the rate of acorn burial was the most important factor affecting increased recruitment of acorns into the next generation of oaks.

Conclusions

Ten years since the initiation of the Hardwood Ecosystem Experiment, it is evident that there is no consistent response to forest management that holds true for all of the species studied as part of the project. Even within taxa, there are different responses to forest management. For example, some birds respond positively to timber harvesting, some negatively, and some have a neutral response thus far. One message that does stand out when looking at the effects of forest management across a landscape is that a variety of habitat availability is important to many of the species that utilize Indiana forests. For each management method, there are winners and losers. Thus, at this point in time, the way to promote a healthy forest that can be utilized by a diversity of species is to have a forest of various ages and tree sizes, a mosaic landscape.

Acknowledgements

This is a contribution of the Hardwood Ecosystem Experiment, a partnership of the Indiana Department of Natural Resources, Ruffed Grouse Society, Purdue University, Ball State University, Indiana State University, Drake University, and the University of Indianapolis. The majority of funding for the project was provided by the Indiana Division of Forestry.

Numerous technicians and volunteers that are not mentioned in the previous pages contributed to the collection of this data; without their help, many of the field surveys would not have been possible.

Thank you to the HEE researchers for drafting their sections and helping with edits. In addition, thank you to Robert Swihart, Scott Haulton, and Donna Rogler for reviewing this publication.

Photo credits

Cover page HEE landscape photo - **Travis Stoelting**

Oak tree and American beech - **Andrew Meier**

Prescribed burn on HEE site - **Jeff Riegel**

American beech in the midstory - **Andrew Meier**

Unit 9 clearcut - **Cortney Mycroft**

Figure 5 panoramas - **John Maxwell, Indiana DNR**

Worm-eating Warbler - **Patrick Ruhl**

Cerulean Warber- **Kamal Islam**

Ruffed grouse - **Patrick Ruhl**

Eastern chipmunk - **Getty Images**

White-footed mouse - **Getty Images**

Indiana Bat - **Caroline Byrne**

Eastern Redbacked salamander - **Andrew Meier**

Painted Hickory Borer- **Matt Ginzel**

Spider - **Marc Milne**

Giant Leopard Moth - **Dave Ralston**

Black oak acorns - **Dana Nelson**

Literature Cited (not included in HEE Publication List below)

Backs, S.E., and J.S. Castrale. 2010. The distribution and conservation status of ruffed grouse in Indiana: 25 years of decline. Proceedings of the Indiana Academy of Science 119(1):101-104.

Backs, S.E. 2017. Spring breeding indices of ruffed grouse – 2017. Indiana Division of Fish and Wildlife, Wildlife Management and Research Notes number 2038.

Dessecker, D.R., and D.G. McAuley. 2001. The importance of early successional habitat to ruffed grouse and American woodcock. *Wildlife Society Bulletin* 29(2):456-465.

Swihart, Robert K.; Saunders, Michael R.; Kalb, Rebecca A.; Haulton, G. Scott; Michler, Charles H., eds. 2013. The Hardwood Ecosystem Experiment: a framework for studying responses to forest management. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] 350 p.

Thompson, F.R., III, and D.R. Dessecker. 1997. Management of early-successional communities in central hardwood forests: with special emphasis on the ecology and management of oaks, ruffed grouse, and forest songbirds. U.S. Department of Agriculture, Forest Service, North Central Forest Experimental Station, General Technical Report NC-195.

HEE Publications

HEE Background

Carman, S.F. 2013. Indiana forest management history. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 12-23.

Haulton, G.S. 2013. Past is prologue: a synthesis of state forest management activities and Hardwood Ecosystem Experiment pre-treatment results. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 339-349.

Jenkins, M.A. 2013. The history of disturbance in forest ecosystems of southern Indiana. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 2-11.

Kalb, R.A. and C.J. Mycroft. 2013. The Hardwood Ecosystem Experiment: Goals, Design and Implementation. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 36-59.

MacGowan, B.J., L.D. Farlee and R.N. Chapman. 2013. The Hardwood Ecosystem Experiment: extension and outreach. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 333-338.

Saunders, M.R. and R.K. Swihart. 2013. Science in the Hardwood Ecosystem Experiment: accomplishments and the road ahead. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 315-332.

Swihart, R.K., M.R. Saunders, R.A. Kalb, G.S. Haulton and C.H. Michler. 2013. The Hardwood Ecosystem Experiment: a framework for studying responses to forest management. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] 350 p.

Bats

Sheets, J.J., J.O. Whitaker, Jr., V. Brack, Jr. and D.W. Sparks. 2013. Bats of the Hardwood Ecosystem Experiment before timber harvest: assessment and prognosis. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 191-202.

Sheets, J.J., J.E. Duchamp, M.C. Caylor, L. D'Acunto, J.O. Whitaker, Jr., V. Brack, Jr., and D.W. Sparks. 2013. Habitat use by bats in two Indiana Forest prior to silvicultural treatments for oak regeneration. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 203-217.

Pauli, B.P., Badin, H.A., Haulton, G.S., Zollner, P.A., and T.C. Carter. 2015. Landscape features associated with the roosting habitat of Indiana bats and northern long-eared bats. *Landscape Ecology,* 30:2015-2029

Divoll, T.J., V.A. Brown, J. Kinne, G.F. McCracken and J.M. O'Keefe. 2018. Disparities in second-generation DNA metabarcoding results exposed with accessible and repeatable workflows. *Molecular Ecology Resources,* 18(3):590-601.

Bergeson, S.M., O'Keefe, J.M., and Haulton, G.S. 2018. Managed forests provide roosting opportunities for Indiana bats in south-central Indiana. *Forest Ecology and Management*, 427:305-316.

Breeding Birds

Leonard, O.D., J.W. Moore, J.K. Riegel, A.R. Meier, J.B. Dunning, Jr., K.F. Kellner, and R.K. Swihart. 2015. Effect of variation in forest harvest intensity on winter occupancy of Barred Owls and Eastern Screech-Owls in deciduous forests of the east-central United States. *Journal of Field Ornithology,* 86:115-129.

Malloy, M.C. and J.B. Dunning. 2013. Breeding bird communities of the Hardwood Ecosystem Experiment. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 126-141.

Ruhl, P.J. and J.B. Dunning. 2015. Morphometrics of Worm-eating Warblers in south-central Indiana: hatching year and after hatching year comparison. *North American Bird Bander,* 43:81-84.

Ruhl, P.J., J.K. Riegel and J.B. Dunning. 2015. Confirmation of successful chestnut-sided warbler breeding in south-central Indiana. *Proceedings of the Indiana Academy of Science,* 124: 70-79.

Kellner, K.F., P.J. Ruhl, J.B. Dunning, J.K. Riegel and R.K. Swihart. 2016. Multi-scale responses of breeding birds to experimental forest management in Indiana. *Forest Ecology and Management,* 382:64-75.

Ruhl, P.J., J.M. Pierce and J.B. Dunning. 2016. An efficient and inexpensive apparatus for collecting fecal samples during banding studies: revisiting an underutilized technique. *North American Bird Bander,* 41:145-150.

Ruhl, P.J., K.F. Kellner, J.M. Pierce, J.K. Rigel, R.K. Swihart and M.R. Saunders, and J.B. Dunning. 2018. Characterization of Worm-eating Warbler (*Helmitheros vermivorum*) breeding habitat at the landscape level and nest scale. *Avian Conservation Ecology*, 13(1):11

Kellner, K.F., Ruhl, P.J., Dunning, J.B., Barnes, K.W., Saunders, M.R., and R.K. Swihart. 2018. Local-scale habitat components driving bird abundance in eastern deciduous forests. *The American Midland Naturalist*, 180 (1):52-65.

Cerulean Warblers

Islam, K., J. Wagner, R. Dibala, M.M. MacNeil, K.J. Kaminski and L.P. Young. 2012. Cerulean Warbler (*Setophaga cerulea*) response to changes in forest structure in Indiana. *Ornitologia Neotropical,* 23: 335-341

Auer, S.A., K. Islam, K.W. Barnes and J.A. Brown. 2013. Documentation of Red-bellied Woodpecker predation of a Cerulean Warbler nestling. *The Wilson Journal of Ornithology,* 125(3)642-646.

Islam, K., K.J. Kaminski, M.M. MacNeil and L.P. Young. 2013. The cerulean warbler in Morgan-Monroe and Yellowwood State Forests, Indiana: pre-treatment data on abundance and spatial characteristics of territories. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 61-77.

Kaminski, K.J. and K. Islam. 2013. Effects of forest treatments on abundance and spatial characteristics of cerulean warbler territories. *American Midland Naturalist,* 170:111- 20.

Wagner, J.R. and K. Islam. 2014. Nest-site selection and breeding ecology of the Cerulean Warbler in southern Indiana. *Northeastern Naturalist,* 21: 515-528.

Nemes, C.E., K. Islam and D.M. Pirtle. 2015. First documentation of a "double-decker" Cerulean Warbler (*Setophaga cerulea*) nest. *The Wilson Journal of Ornithology,* 127(3):534-538.

Wagner, J.R., K. Islam, and K. Summerville. 2015. Cerulean Warbler territory size is influenced by prey-rich tree abundance. *Proceedings of the Indiana Academy of Science*, 124:70-79.

Auer, S.A., K. Islam, J. Wagner, K. Summerville, and K.W. Barnes. 2016. The diet of Cerulean Warbler (*Setophaga cerulea*) nestlings and adult nest provisioning behaviors in Southern Indiana. *The Wilson Journal of Ornithology,* 128(3):573-583.

Barnes, K.W., K. Islam and S.A. Auer. 2016. Integrating LIDAR-derived canopy structure into cerulean warbler habitat models. *Journal of Wildlife Management,* 80(1):101-116.

Nemes, C.E. and K. Islam. 2017. Breeding Season Microhabitat use by Cerulean Warbler (*Setophaga cerulea*) in an experimentally-managed forest. *Forest Ecology and Management* http://dx.doi.org/10.1016/j.foreco.2016.11.008.

Delancey, C., G. MacDonald,and K. Islam. 2018. American Redstarts (*Setophaga ruticilla*) usurp Cerulean Warbler (*Setophaga cerulea*) nest in Southern Indiana. *The Wilson Journal of Ornithology, 130*(2), 554-558.

Eastern Box Turtles

Currylow, A.F., P.A. Zollner, B.J. MacGowan and R.N. Williams. 2011. A survival estimate of Midwestern adult Eastern box turtles using radio telemetry. *The American Midland Naturalist*, 165(1): 143-149.

Kimble, S.J.A. and R.N. Williams. 2012. Temporal variance in hematologic and plasma biochemical reference intervals for free-ranging eastern box turtles (*Terrapene carolina carolina*). *Journal of Wildlife Diseases*, 48(3):799-802.

Currylow, A.F., B.J. MacGowan and R.N. Williams. 2012. Hibernal thermal ecology of eastern box turtles within a managed forest landscape. *Journal of Wildlife Management,* 77(2): 326-335.

Currylow, A.F., B.J. MacGowan and R.N. Williams. 2012. Short-term forest management effects on a long-lived ecotherm. *PLoS ONE*, 7(7):e40473.

Currylow, A.F., M.S. Tift, J.L. Meyer, D.E. Crocker and R.N. Williams. 2013. Seasonal variations in plasma vitellogenin and sex steroids in male and female eastern box turtles (*Terrapene c. carolina*). *General and Comparative Endocrinology*, 180:48-55.

Currylow, A.F., A.J. Johnson and R.N. Williams. 2014. Evidence of ranavirus infections among sympatric larval amphibians and box turtles. *Journal of Herpetology*, 48(1): 117-121.

Kimble, S.J.A., O.E. Rhodes, Jr. and R.N. Williams. 2014. Relatedness and other finescale genetic processes in the box turtle. *Conservation Genetics,* 15(4): 967-979.

Kimble, S.J.A., O.E. Rhodes, Jr. and R.N. Williams. 2014. Unexpectedly low rangewide population genetic structure of the imperiled eastern box turtles. *PLoS ONE* 9:e92274

Functional Diversity

Murray, B.D., J.D. Holand, K.S. Summerville, J.B. Dunning, M.R. Saunders, and M.A. Jenkins. 2017. Functional Diversity response to hardwood forest management varies across taxa and spatial scales. *Ecological Applications* 1002/eap.1532

Mast

Kellner, K.F., J.K. Riegel, N.I. Lichti and R.K. Swihart. 2013. Oak mast production and animal impacts on acorn survival in the Central Hardwoods. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 176-190.

Kellner, K.F., J.R. Riegel and R.K. Swihart. 2014. Effects of silvicultural disturbance on acorn infestation and removal in the central hardwood forest region. *New Forests,* 45(2): 265-281.

Moths

Summerville, K.S., M.M. Dupont, A.V. Johnson and R.L. Krehbiel. 2008. Spatial structure of forest Lepidopteran communities in oak hickory forests of Indiana. *Environmental Entomology,* 37(5): 1224-1230.

Summerville, K.S., D. Courard-Hauri and M.M. Dupont. 2009. The legacy of timber harvest: Do patterns of species dominance suggest recovery of Lepidopteran communities in managed hardwood stands? *Forest Ecology and Management,* 259(1): 8-13.

Summerville, K.S. 2011. Managing the forest for more than the trees: effects of experimental timber harvest on forest Lepidoptera. *Ecological Applications,* 21(3): 806-816.

Summerville, K.S., M.R. Saunders and J.L. Lane. 2013. The Lepidoptera as predictable communities of herbivores: a test of niche assembly using the moth communities of Morgan-Monroe State Forest. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S.

Summerville, K.S. 2013. Forest lepidopteran communities are more resilient to shelterwood harvest compared to more intensive logging regimes. *Ecological Applications,* 23(5): 1101-1112.

Summerville, K.S., J.L. Lane and D. Courard-Hauri. 2013. Stability in forest lepidopteran communities: how sensitive are pest species to experimental forest management. *Insect Conservation and Diversity,* 6:(3)265-275.

Summerville, K.S. 2014. Do seasonal temperatures, species traits and nearby timber harvest predict variation in moth species richness and abundance in unlogged deciduous forests? *Agricultural and Forest Entomology,* 16: 80-86.

Summerville, K.S. 2015. Species traits fail to consistently predict moth persistence in managed forest stands. *Great Lakes Entomologist,* 48:114-124.

Summerville, K.S. and R.J. Marquis. 2017. Comparing the responses of larval and adult lepidopteran communities to timber harvest using long-term, landscape-scale studies in oak-hickory forests. *Forest Ecology and Management* http://dx.doi.org/10.1016/j.foreco.2016.08.050

Owls

Leonard, O.D., J.W. Moore, J.K. Riegel, A.R. Meier, J.B. Dunning and K.F. Kellner, R.K.Swihart. 2015. Effect of variation in forest harvest intensity on winter occupancy of barred owls and eastern screech-owls in deciduous forests of the east-central United States. *Journal of Field Ornithology,* 86(2): 115-129.

Salamanders

MacNeil, J.E. and R.N. Williams. 2013. Relative abundance and species richness of terrestrial salamanders on Hardwood Ecosystem Experiment sites before harvesting. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 142-150.

MacNeil, J.E. and R.N. Williams. 2013. Effectiveness of two artificial cover objects in sampling terrestrial salamanders. *Herpetological Conservation and Biology,* 8(3): 552-560.

MacNeil, J.E. and R.N. Williams. 2014. Effects of timber harvests and silvicultural edges on terrestrial salamanders. *PLoS ONE,* 9(12):e114683.

Small Mammals

Urban, N.A. and R.K. Swihart. 2011. Small mammal responses to forest management for oak regeneration in southern Indiana. *Forest Ecology and Management,* 261:353-361.

Urban, N.A., R.K. Swihart, M.C. Malloy and J.B. Dunning. 2012. Improving selection of indicator species when detection is imperfect. *Ecological Indicators*, 15: 188-197.

Kellner, K.F., N.A. Urban and R.K. Swihart. 2013. Short-term responses of small mammals to timber harvest in the Central Hardwoods. *Journal of Wildlife Management,* 77(8): 1650-1663.

Urban, N.A. and R.K. Swihart. 2013. A pre-treatment assessment of small mammals in the Hardwood Ecosystem Experiment. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 151-175.

Kellner, K.F. and R.K. Swihart. 2014. Changes in small mammal microhabitat use following silvicultural disturbance. *American Midland Naturalist,* 172: 349-359.

Kellner, K.F., N.I. Lichti, and R.K. Swihart. 2016. Midstory removal reduces effectiveness of oak (*Quercus*) acorn dispersal by small mammals in the Central Hardwood Forest region. *Forest Ecology and Management,* 375:182-190.

Spiders

Milne, M.A., B. Foster, J.J. Lewis, L. Bishop, A. Hoffman, T. Ploss, and B. Deno. 2016. Spiders in Indiana: seventy-one new and updated distribution records. *Proceedings of the Indiana Academy of Science* 125(1): 75-85.

Timber Rattlesnakes

Owen, D.A.S., E.T. Carter, M.L. Holding, K. Islam, and I.T. Moore. 2014. Roads are associated with a blunted stress response in a North American pit viper. *General and Comparative Endocrinology*, 202: 87-92.

Olson, Z.H., B.J. MacGowan, M.T. Hamilton, A.F.T. Currylow, and R.N. Williams. 2015. Survival of timber rattlesnakes: Investigating individual, environmental, and ecological effects. *Herpetologica,* 71:274-279.

Olson, M.G. and M.R. Saunders. 2017. Long-term research on managed hardwood forests in eastern North America. *Forest Ecology and Management,* 387: 1-2.

MacGowan, B.J., A.F.T. Currylow and J.E. MacNeil. 2017. Short-term responses of Timber Rattlesnakes (*Crotalus horridus*) to even-aged timber harvests in Indiana. *Forest Ecology and Management*, 376: 30-36.

Hale, V., B. MacGowan, L. Corriveau, D. Huse, A.F. Currylow, and S. Thompson. 2017. Radio transmitter implantation and movement in the wild Timber Rattlesnake (*Crotalus horridus*). *Journal of Wildlife Diseases*, doi: 10.7589/2016-08-186

Vegetation

Kellner, K.F., N.I. Lichti, and R.K. Swihart. 2016. Midstory removal reduces effectiveness of oak (*Quercus*) acorn dispersal by small mammals in the Central hardwood Forest region. *Forest Ecology and Management,* 375:182-190.

Kellner, K.F., and R.K. Swihart. 2016. Timber harvest and drought interact to impact oak seedling growth and survival in the Central Hardwood Forest. *Ecosphere* 7(10):e01473.

Murray, B.D., C.R. Webster, M.A. Jenkins, M.R. Saunders, and G.S. Haulton. 2016. Ungulate impacts on herbaceous-layer plant communities in even-aged and uneven-aged forests. *Ecosphere*, 7(6): e01378.

Kellner, K.F. and R.K. Swihart. 2017. Herbivory on planted oak seedlings across a habitat edge created by timber harvest. *Plant Ecology,* 218:213-223.

Kellner, K.F. and R.K. Swihart. 2017. Simulation of oak early life history and interactions with disturbance via an individual-based model, SOEL. *PLoS ONE* 12(6):e0179643.

Saunders, M.R. and J.E. Arsenault. 2013. Pre-treatment analysis of woody vegetation composition and structure on the Hardwood Ecosystem Experiment research units. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 96-125.

Wood-boring Beetles

Holland, J.D., J.T. Shukle, H.E.M. Abdel Moniem, T.W. Mager, K.R. Raje, K. Schnepp, andS. Yang. 2013. Pre-treatment assemblages of wood-boring beetles (*Coleoptera: Buprestidae, Cerambycidae*) of the Hardwood Ecosystem Experiment. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 218-236.

Holland, J.D. 2010. Isolating spatial effects on beta diversity to inform forest landscape planning. *Landscape Ecology,* 25 (9): 1349-1362.

Powell, G., R.M. Brattain and J.D. Holland. 2015. New distributional records for the genus Pytho. *The Coleopterists' Bulletin,* 66:761-765.

Abdel Moniem, H.A.M., B. Schemerhorn, A. DeWoody and J.D. Holland. 2016. Landscape genetics of a pollinator longhorned [(*Typocerus v. velutinus* (Olivier)] on a continuous habitat surface. *Molecular Ecology,* 25:5015-5028.

Raje, K.R., V.R. Ferris and J.D. Holland. 2016. Phylogenetic signal and potential for invasiveness. *Agricultural and Forest Entomology,* 18: 260-269.