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HEE Hardwood Ecosystem Experiment

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FORESTRY AND NATURAL RESOURCES

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The Hardwood Ecosystem Experiment: Indiana Forestry and Wildlife

Many of Indiana's forests, especially in the southern part of the state, have been dominated by oak and hickory trees for thousands of years. In recent decades, however, forest researchers and managers in the East-Central United States have recognized that these tree species are not replacing themselves with new seedlings. Instead, another group of trees, most notably sugar maple, red maple, and American beech, now make up the majority of the forest understory (Figure 1). As a result, Indiana's forests are poised to change dramatically in the future as a new group of species comes to dominate the forest. This change will impact the entire ecosystem by altering the habitat available to wildlife that depends on our forests.

Many wildlife communities have adapted over the centuries to count on oaks and hickories for their survival. Some species of small mammals rely on oak acorns and hickory nuts for food. Other wildlife, like owls, feed on the mice and chipmunks that eat oak acorns. Some birds, like the cerulean warbler, appear to prefer nesting in oak trees instead of maples. Many woodland bats can be found roosting in the exfoliating bark of shagbark hickories and hunting for insects at night in the relatively open area beneath the main canopy in oak-hickory forests.

Human communities are dependent on these trees, too. Thousands of families eat dinner every night on oak tables or store their dishes in hickory cabinets. Many other families in Indiana are supported by jobs producing those oak tables and hickory cabinets. Others enjoy recreation in forests with tall trees and open views that are characteristic of our oak-hickory forests. But without young oak and hickory trees in Indiana's forests to replace the ones we have now, the forest of the future, and the wildlife that lives there, may be very different.

Recognizing this issue, many stakeholders concerned with the status of Indiana's forests convened in the late 1990s to determine the best approach to understanding this transition and to develop strategies for maintaining our oak-hickory ecosystems. As a result of the meetings of this working group, the Hardwood

Figure 1. An image typical of Indiana's oak and hickory forests. A large oak tree stands in the middle of this picture with its crown in the main forest canopy. Surrounding the tree is a dense layer of much smaller American beech trees; these trees block most of the sunlight from reaching the forest floor and will prohibit future oak seedlings from germinating and growing. When the oak tree dies, the established American beech trees will take its place in the canopy.

Ecosystem Experiment (HEE) was initiated in 2006 (see Box 1 for a timeline of the HEE project).

The HEE has four main objectives:

- to develop forest management strategies that can be used to maintain and restore oak and hickory forests,
- to understand the impacts of these forest management strategies on ecological communities, particularly plants, birds, mammals, reptiles, amphibians, and insects,
- to assess the impacts of alternate forest management approaches on local human communities, and
- to provide novel educational and outreach opportunities for the public to become more knowledgeable about forest ecology and more engaged in forest management issues.

A Quick History of the HEE

Pre-2006: Numerous meetings of the Partnership for Sustainable Working Forests result in the conceptual framework for the HEE.

2006: First year of pretreatment data collection. Breeding bird, oak mast, beetle, and bat mist-netting surveys initiated.

2007–2008: Additional pretreatment field surveys initiated, including bat acoustics, salamanders, cerulean warblers, timber rattlesnakes, eastern box turtles, moths, and overstory and understory vegetation.

2008–2009: Initial timber harvests are implemented across the HEE sites from late fall to early spring.

2009: First year of post-treatment data collection for all previous surveys; owl surveys conducted mainly by volunteers are also initiated in early winter.

2010: Numerous additional, smaller-scale surveys are initiated, including deer exclosure vegetation, nightjars, ruffed grouse, American woodcock, and year-round resident birds.

2011–2014: Post-treatment surveys continue for most projects, resulting in 6 years of data monitoring responses.

Box 1. A quick history of the Hardwood Ecosystem Experiment.

The HEE is intended to last for 100 years, because many of the changes that occur in these forests happen over decades. In fact, many of the strongest effects of the transition from oak and hickory forests may not even be observable until we near the end of the project.

Forest Disturbance, Forest Management and the HEE

The types of trees that grow in a forest depend strongly on the amount of sunlight available to seedlings on a forest floor. The types of seedlings that are able to grow on the forest floor, in turn, determine which species will eventually dominate the forest canopy. Some trees grow very well in the shade (known as shade-tolerant species, Figure 2), while others need full sunlight to survive and grow (known as shade-intolerant species). Many species that are classified as having intermediate tolerance of shade (known as shade mid-tolerant) fall in between. They do not grow as fast as shade-intolerant species in full sunlight, but they are unable to survive for a long time in dense shade.

Many of Indiana's oaks and hickories are considered either shade-intolerant or mid-tolerant. The amount of sunlight that they need to grow only reaches the forest floor where

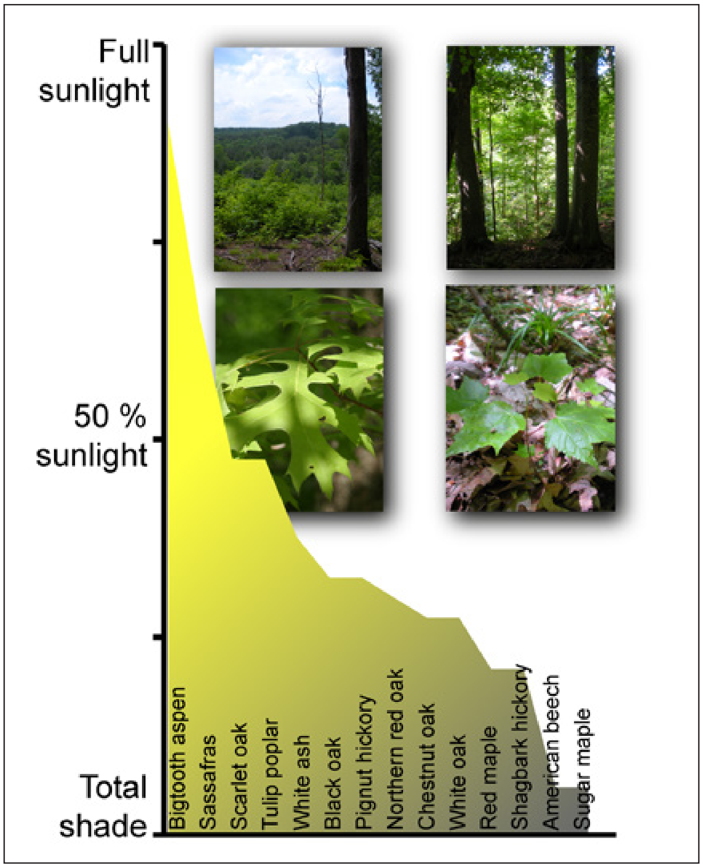


Figure 2. Shade tolerance classifications for some of the most common trees species on the HEE sites and in Indiana. The level of shade tolerance is equivalent to the amount of sunlight a tree needs to survive. This is shown in the figure as the colored area directly above each individual species. The upper row of images shows the characteristics of a forest opening with close to 100% full sunlight (upper left) and one with close to 0% sunlight, or total shade (upper right). The second row of images gives examples of tree species with contrasting levels of shade tolerance. Scarlet oak (lower left) is classified as shade-intolerant and can only survive in areas with relatively high sunlight, while red maple (lower right), which is classified as shade-tolerant, can survive for decades with 25% or less of full sunlight at the forest floor.

Figure 3a. Natural mortality of a single oak tree on one of the HEE sites. The cause of mortality is unknown, though insects, disease, or environmental conditions most likely played a role. Note the amount of sunlight coming through the canopy; only a small amount of additional sunlight is available to the forest floor from the death of this tree, meaning that shade-intolerant or mid-tolerant tree species will be unable to grow.

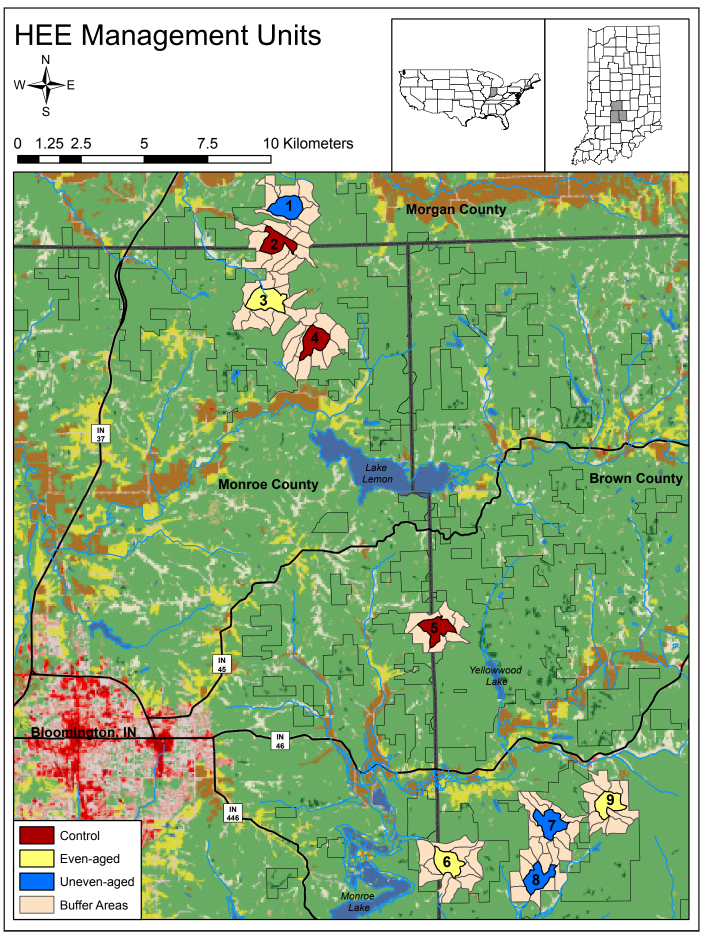
disturbances create gaps in the forest's main canopy by removing leaves, branches, or whole trees. These disturbances can be natural, such as when a single tree dies from an insect defoliation or a fungus (Figure 3a) or when hundreds of acres are destroyed by tornado (Figure 3b). These can also be human disturbances, such as timber harvesting. Because natural disturbance is such an important factor influencing tree species composition, foresters are trained to understand how different tree species respond to different natural disturbance events and to mimic the resulting conditions in forest management operations.

Since the maintenance of historically dominant oak and hickory forests was the primary underlying issue that led to the initiation of the HEE, the forest management practices being implemented are intended to provide a range of light conditions on the forest floor. Researchers will observe the conditions and determine which disturbances are best for establishing and growing new oak and hickory trees.

Figure 3b. Extensive natural tree mortality caused by the tornado in Clark State Forest, Indiana, in March of 2012. Nearly all the forest canopy was removed over an area covering hundreds of acres. These natural disturbance events allow close to full sunlight at the forest floor, which, in turn, allows tree species intolerant of shade to become established and grow. This picture was taken in early summer, 2014. The rapid regrowth of vegetation in only two years has created important habitat for wildlife species that depend on regenerating forest for food and cover.

To compensate for differences in forest soils and environment, nine separate areas, known as management units, were designated across Morgan-Monroe and Yellowwood State Forests in southern Indiana (Map 1). Each management unit includes a central research core surrounded by a buffer area. All experimental harvesting treatments and a majority of surveys have taken place within the research core area. The research cores average about 200 acres in size, allowing the researchers on the HEE to study not only individual harvests, but also the impact of a small area of harvesting in a much larger forested area. In this publication, research studies described in the Research Projects section below that are focused around the harvest areas are classified as harvest-level studies, while those which cover the entire area of the HEE units are considered landscape-level studies.

More details of the design of the project can be found on the HEE website (http://HEEForestStudy.org) and in the publication *The Hardwood Ecosystem Experiment: a Framework for Studying Responses to Forest Management* (Swihart et al. 2013) (http://www.nrs.fs.fed.us/pubs/42882). More information about the HEE treatments, including detailed maps, are available there.



Map 1. Hardwood Ecosystem Experiment Management Units in southern Indiana. The total linear distance between the northernmost unit and the southernmost unit is more than 20 miles. The numbered, colored areas represent the central research core of each unit, where experimental treatments and surveys are conducted. Management in the buffer areas adjacent to the research cores will be limited to uneven-aged management techniques to provide a consistent border area to all treatments. Management units 1–4 are in Morgan-Monroe State Forest, while units 5–9 are in Yellowwood State Forest. *Figure reprinted from figure 1 in Kalb and Mycroft 2013.*

The HEE was designed to track the effects of three contrasting forest management approaches, uneven-aged (generally creating a forest with trees of many different ages and sizes), even-aged forest management (generally creating a forest with patches of trees of similar sizes and ages), and a no management control. These three approaches, which are described in more detail in Box 2, were distributed randomly among the nine research cores.

Within each managed research core, two distinct treatments were used and will continue to be used through the end of the project. Single-tree selection and patch cutting were used in uneven-aged management cores, while shelterwoods and clearcutting were used in even-aged management cores. These specific treatments are shown and described in the series of panoramic photos in Figure 4a-e, showing forest development over time at specific points on the HEE. These photos represent a gradient from the least intensive disturbance (control, Figure 4a) to the most intensive (clearcut, Figure 4e). Pictures are taken every year in spring and photography will continue for 100 years.

Even-aged Units

Key Characteristics

- Large forest openings (about 10 acres)
- Half of the openings will be created in multiple stages (shelterwoods)
- Trees in regenerating forest openings will be all of the same age
- Necessary to satisfy the growth requirements of shade intolerant tree species
- Future treatments over 100 years will create a mosaic of twenty 10 acre patches
- Patch ages will be either 100 years, 80 years, 60 years, 40 years, or 20 years old

Clearcut | Shelterwood | Future Treatments

Uneven-aged Units

Key Characteristics

- Dispersed small openings created over most of the area by removing single trees (single-tree selection)
- Twenty percent of area harvested in larger openings in 2008 (patch cuts)
- Single-tree selection areas will be harvested every 20 years for the next 100 years
- Treatments favor shade-tolerant tree species
- After 100 years entire area will consist of trees of multiple ages and sizes

Single-tree selection | Patch cut

No Management Units

Key Characteristics

- No active forest management will occur
- Natural mortality will create small openings in the canopy when single trees or small groups of trees die
- No management will favor shade tolerant species and the area will consist of trees of multiple ages and sizes after 100 years
- Processes similar to uneven-aged forest management, though changes occur more slowly
- Will provide a control area where researchers can compare dynamics in managed forests to unmanaged forest areas

Box 2. General description of the forest management approaches utilized on the HEE research units.

No Management (Control)

Figure 4a. Panorama of forest development over time in a HEE control unit from 2008 through 2014. The creation of small gaps through natural tree mortality will provide some increase in sunlight at the forest floor over time, but mainly shade-tolerant species will survive in the control units.

Uneven-Aged Management (Single-Tree Selection)

Figure 4b. Panorama of forest development over time following single-tree selection in a HEE uneven-aged unit from 2008 through 2014. Single-tree selection is a treatment used in uneven-aged forest management in which individual trees are harvested over a large area. For example, approximately 90% of the area within the HHE research cores assigned to uneven-aged management received some level of single-tree selection treatment. These areas will continue to be managed using single-tree selection, with 20 years between harvesting entries, for the remainder of the project.

Uneven-Aged Management (3-acre patch cut)

Figure 4c. Panorama of forest development over time following the creation of a 3-acre patch cut in a HEE uneven-aged unit from 2008 through 2014. The removal of groups of trees is also a treatment that is often employed in uneven-aged forest management. The size of the resulting openings can range widely depending on the ecology of the tree species that are present. In Indiana, openings are typically not much more than a few acres in size, though they must be large enough to prevent trees bordering the openings from casting shade inside the opening. The most shade-intolerant tree species (bigtooth aspen, tulip poplar) will often grow at the center of these openings, while mid-tolerant species are often found in partial shade along the edges of the opening. Approximately 10% of the area in uneven-aged HEE research cores were treated with patch cuts. These cuts ranged in size from 1 to 5 acres.

Even-Aged Management (Shelterwood)

Figure 4d. Panorama of forest development over time following the first stage of a shelterwood in a HEE even-aged unit from 2008 through 2014. The intent of this forest management treatment is to provide an intermediate amount of sunlight for a period of time that will allow mid-tolerant tree species to become established and grow. To do this, foresters implement a series of treatments, generally two or three, to slowly remove the canopy over a period of years. The shelterwoods on the HEE will have three stages. In the first stage, all trees except oak and hickory below the main forest canopy are removed to increase the sunlight on the forest floor by about 5% or 10%. Five to ten years later, a second treatment is initiated, and trees from the main canopy are removed to increase sunlight levels to between 20% and 60% of full sunlight. The final stage is implemented once seedlings of the desired tree species, which, in the case of the HEE, are mainly oaks and hickories, have grown to about head height and are tall enough to create their own shade on the forest floor. At this point, the remaining portion of the original forest canopy is removed. Since many of the oaks and hickories in Indiana can be considered to be intermediate in shade tolerance (see Figure 2), it is thought that the appropriate application of this treatment in Indiana forests may provide the best environment for oak and hickory regeneration. However, results in the state have thus far been mixed, and continued research is necessary to modify the treatment for forest conditions unique to Indiana. In the HEE even-aged research cores, the first shelterwood stage has been completed in areas that cover approximately 10% of the research cores. The second and third stages will be implemented in the next decade. Every 20 years, another 10% of the research core will be treated with a shelterwood harvest.

Even-Aged Management (10-acre clearcut)

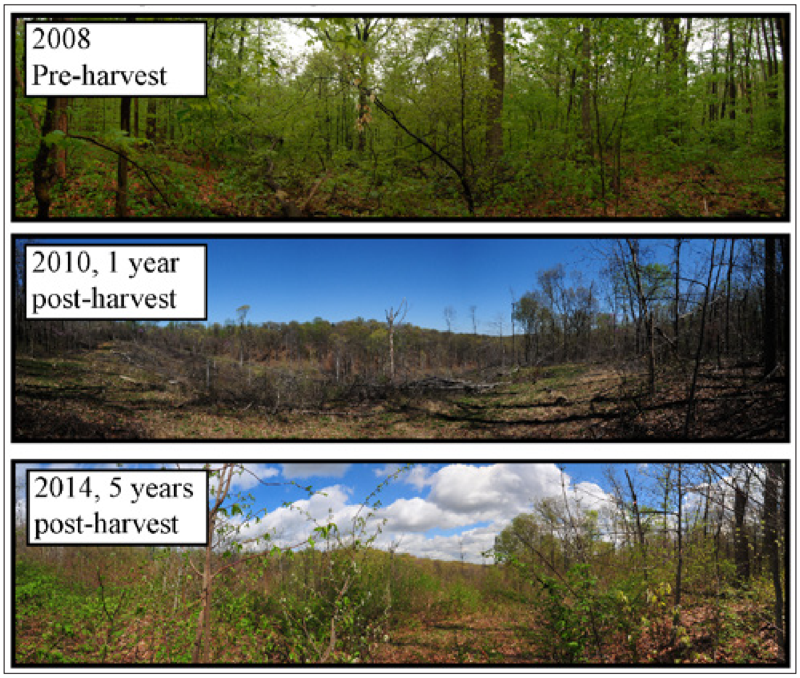


Figure 4e. Partial panorama of forest development over time following a clearcutting treatment in a HEE even-aged core from 2008 through 2014. A partial panorama is shown to emphasize the large size of the treatment. The HEE clearcuts are the most intensive treatment being used on the HEE and will provide researchers with a large area to determine ecosystem responses to large-scale disturbance. In a clearcut, all trees are removed at one time. Any residual trees left after the harvest are deadened and all harvesting debris (e.g., limbs and tops) are left on the site to provide important wildlife habitat and to decompose back into the forest floor. Though all of the canopy trees are removed, the forest responds very quickly. Within only a couple of years of harvesting, vegetation within the clearcuts is already more than 10 feet tall. These areas provide very unique habitat for wildlife that is characterized by dense thickets of bushes and a large number of berry-producing shrubs that are absent in the adjacent forest. Like the HEE shelterwoods, the clearcuts have been implemented on 10% of the area of the HEE even-aged cores. Every 20 years until the end of the project, another 10% of the area of each of the even-aged research cores will be clearcut. By the end of the project, the even-aged research cores will consist of a mosaic of 10-acre areas that range in age from 0 to 100 years old.

Wildlife and Forest Management

Not only does forest management influence the tree species that grow in a forest, it also impacts wildlife, including forest insects, reptiles, amphibians, birds, and mammals. It is, therefore, also very important to understand the positive and negative consequences of forest disturbance on wildlife communities. This is the second main objective of the HEE.

Since all forests regularly experience some level of disturbance, the wildlife that is present in those forests reflects the distribution of habitat created by that disturbance. Some wildlife species prefer areas that have not been disturbed for decades. These species will generally avoid areas with recent disturbances.

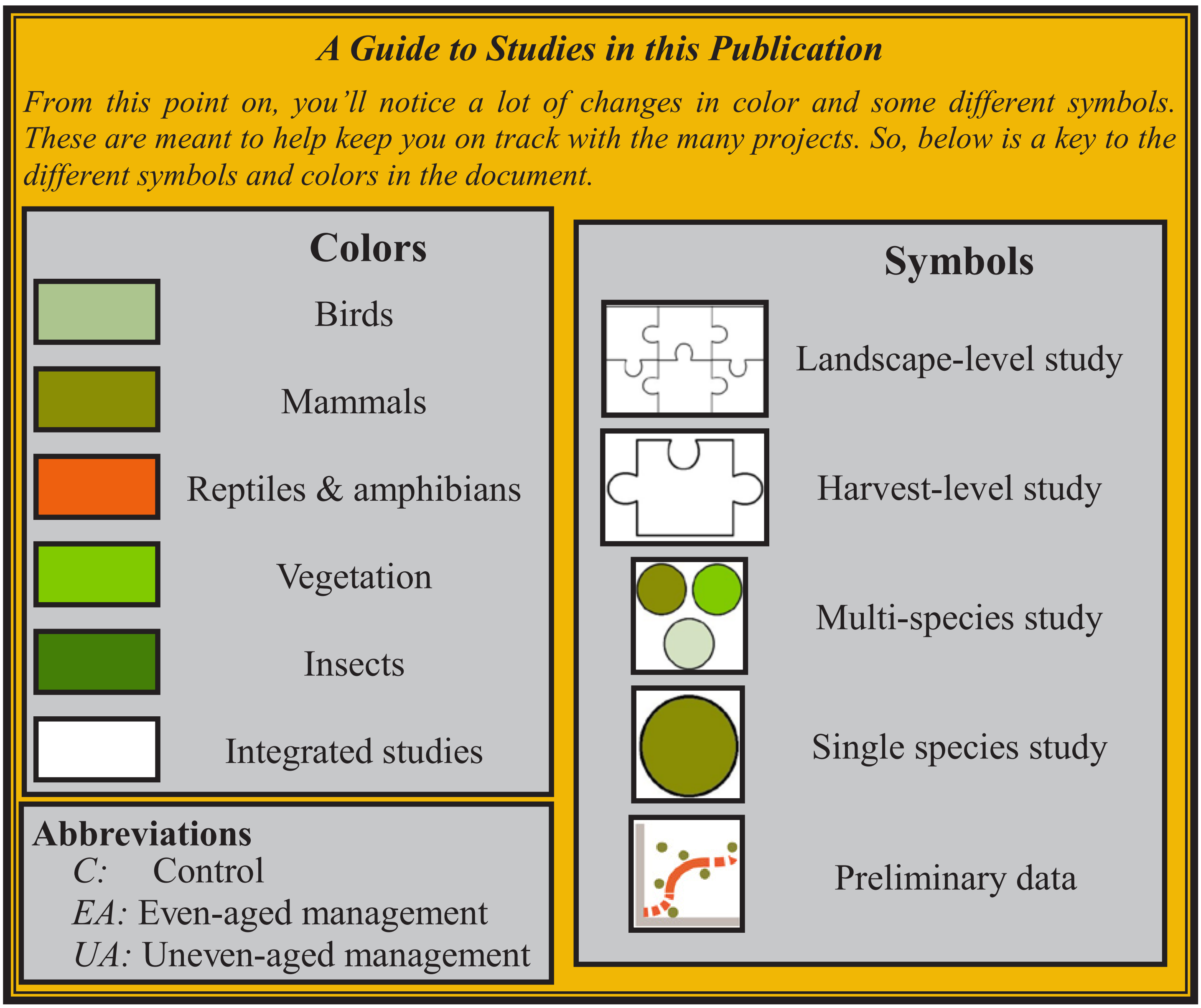
Other wildlife species prefer forests that have had some intermediate level of disturbance, similar to that which occurs in uneven-aged forest management treatments (Box 2). This type of disturbance is thought to be especially beneficial for wildlife that utilizes small openings for hunting for food.

Still other wildlife species can only be found in large patches of heavily disturbed forest. These areas of habitat are often only available for a few years following events like a large windstorm (Figure 3b) or even-aged forest management treatments (Box 2). They disappear quickly as rapidly growing young trees create a new forest canopy. Once the new forest canopy has filled in, disturbance-dependent species disappear from the area to seek out other areas of recently disturbed forest.

Many species benefit the most from having a diverse set of forest conditions available. These animals might use one area for foraging, another for shelter, and yet another for raising young. A major challenge for the ecologist, the forester, and the conservationist alike is to determine which wildlife species to consider when setting habitat goals and determining forest management strategies that can bring about the development of habitat that is closest to meeting those goals.

Since the HEE was designed to test three levels of experimental forest disturbance in the form of forest management, it also provides a valuable opportunity understand how forest management in southern Indiana impacts wildlife communities through habitat manipulation. At the same time, data from the HEE can be used to develop more comprehensive strategies for creating optimal habitat for wildlife species of interest through the use of planned disturbances in the form of forest management.

The remainder of this publication provides a brief summary of each of the main research projects being conducted to determine responses of different plant and animal communities to timber harvests on the HEE. Table 1 provides a list of the main projects and the years for which surveys have been completed. The information in Box 3 will help guide you through the different projects and allow you to see connections between them. Each project summary provides information about the researchers leading the projects. More information about the researchers and their projects can be found on the HEE website at http://HEEForestStudy.org. A list of all of the publications from the different projects is provided in the HEE Publications section at the end of this document. Links to these publications are available on the HEE website. These additional resources should also help you keep up-to-date with new findings from the HEE. Analysis of responses to forest management has not been completed, yet, for some of the projects. These projects are shown with a symbol for preliminary data (see Box 3), meaning that results will be submitted in the future to scientific journals.



Box 3. A guide to symbols and colors in this publication.

Table 1. An overview of HEE research projects and years in which the surveys were completed. A check mark below each year indicates that a component of an individual survey was completed in that year. A detailed summary of findings from each of the main surveys is provided int eh following pages.

Project	Year								
	Pre-treatment			*Post-treatment*					
	2006	2007	2008	2009	2010	2011	2012	2013	2014
Birds									
Breeding birds	✓	✓	✓	✓	✓	✓	✓		✓
Year-round birds[1]					✓	✓	✓	✓	✓
Cerulean warblers		✓	✓	✓	✓	✓	✓	✓	✓
Owls				✓	✓	✓	✓	✓	✓
Ruffed grouse					✓	✓	✓	✓	✓
American woodcocks[1]							✓		
Nightjars[1]					✓	✓	✓		
Golden eagles[2]								✓	
Mammals									
Small mammals		✓	✓	✓	✓	✓	✓		✓
Bats (mist-netting)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bats (radio-tracking)		✓	✓	✓	✓	✓	✓	✓	✓
Bats (acoutsic sampling)							✓	✓	✓
Fawn dispersal[2]								✓	✓
Reptiles & amphibians									
Woodland salamanders		✓	✓	✓	✓	✓	✓	✓	✓
Timber rattlesnakes		✓	✓	✓	✓	✓			
Eastern box turtles		✓	✓	✓	✓				
Vegetation									
Overstory vegetation			✓	✓				✓	✓
Understory vegetation					✓			✓	
Insects									
Beetles	✓	✓	✓	✓	✓	✓		✓	✓
Moths		✓		✓	✓	✓	✓	✓	✓
Integrated studies									
Oak mast	✓	✓	✓	✓	✓	✓	✓	✓	✓
Deer exclosure vegetation					✓	✓		✓	

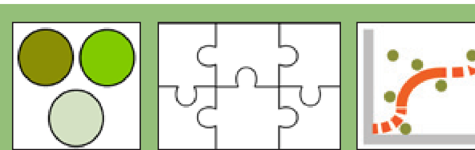
[1] Indicates an unfunded pilot project or side project that is being completed as time allows

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

HEE Major Research Projects

Breeding Birds

J.B. Dunning, Purdue University
Graduate Student: M. Malloy



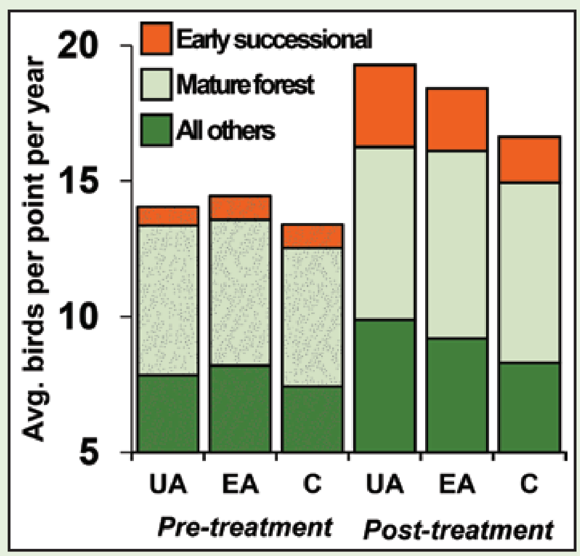
Summer Tanager

Project Goals & Methods

Responses of breeding birds to the different timber harvesting treatments on the HEE have been monitored since 2006. Breeding bird survey points are distributed on a grid across each research core. Analyses focus on a subset of bird species that are usually found in mature forests and another subset that are associated with disturbed areas (early successional birds). These points are visited during the breeding season (May and June) of most years. Data analyses have been completed through the 2011 season.

Results

The average number of birds counted per survey point for all species increased for all treatment types, including the no-harvest areas, through 2011 (see graph). In harvested research cores (EA and UA) there was a large increase in the number of early successional (or disturbance-dependent) birds. The responses of mature forest species varied, but there were no major decreases in any of these species, Brown-headed cowbirds, which lay their eggs in other birds' nests and are often considered a problem when creating forest openings, did not increase. Overall species diversity was higher in harvested research cores.



Data from Malloy 2012, Master of Science thesis, Purdue University.

Summary

Timber harvesting generally had a neutral or positive impact on bird populations. Mature-forest bird responses varied by species, so management for particular mature-forest bird species may need to be tailored to individual species of concern.

Cerulean Warblers

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

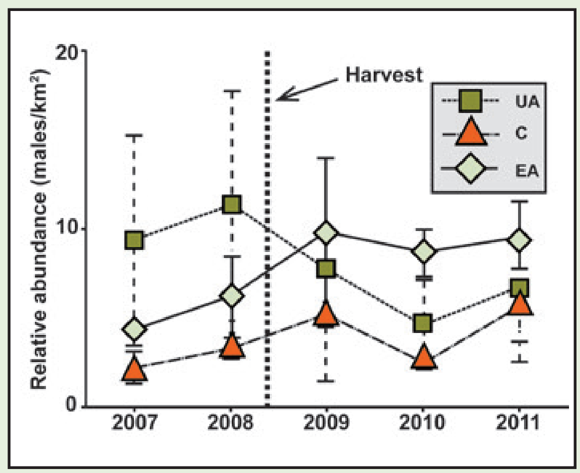
Cerulean Warbler

Project Goals & Methods

The cerulean warbler is a state endangered species in Indiana that nests high in forest canopies. Its populations have declined substantially over the last few decades. Cerulean warblers are thought to benefit from gaps in a mature forest canopy, but studies have shown variable responses of birds to forest management in the eastern United States. The HEE studies were established to monitor long-term impacts of forest management on cerulean warbler populations, breeding success, and behavior.

Results

The total number of singing male cerulean warblers increased from the preharvest period to the postharvest period in both the even-aged and control research cores (see diagram). The number decreased in the uneven-aged cores, though there was substantial variation between years. The increase was highest in even-aged research. Breeding success has been highest in control cores and lowest in uneven-aged cores, but statistical tests showed that the differences were minor. However, only a small number of nests have been located in control areas, so there is not enough information yet to make definitive conclusions. Breeding males appear to be clustering adjacent to even-aged harvests and on northeast facing slopes.



Adapted from Figure 2 in Islam et al., 2012, and reprinted courtesy of *Ornitologia Neotropical.*

Summary

Populations showed substantial variation between years, and this variation means that more years of data are needed to make definitive conclusions. Birds appear to be using habitat that includes recent harvests; however, it is still unclear how successful the birds are at reproducing in this habitat.

Barred Owls and Eastern Screech-Qwls

J. B. Dunning, R.K Swihart, Purdue University
Undergraduate Students: O. Leonard, J. Moore

Barred Owl

Project Goals & Methods

Different owls live in different habitats. Some, like the barred owl, are associated with large tracts of mature forest, while others, like the eastern screech-owl, often inhabit disturbed areas where prey is abundant. In addition, barred owls attack eastern screech-owls in their territory. This study is intended to determine whether forests with active timber harvesting have different owl populations than those that don't. Much of the data collection for this study is being done by citizen-scientists from the community.

Results

The average number of owls at survey points varied from year to year. Barred owls were present more often from 2009–12 at survey points in the northern part of the Hoosier National Forest (including the Deam Wilderness Area) than in the state forests (which are currently more actively managed for timber), though numbers were the same in 2012–13. Very few barred owls were heard in Brown County State Park. Eastern screech-owls were generally less common across all properties, but were most common on the state park. In most cases, differences were not strong enough to be considered statistically valid differences.

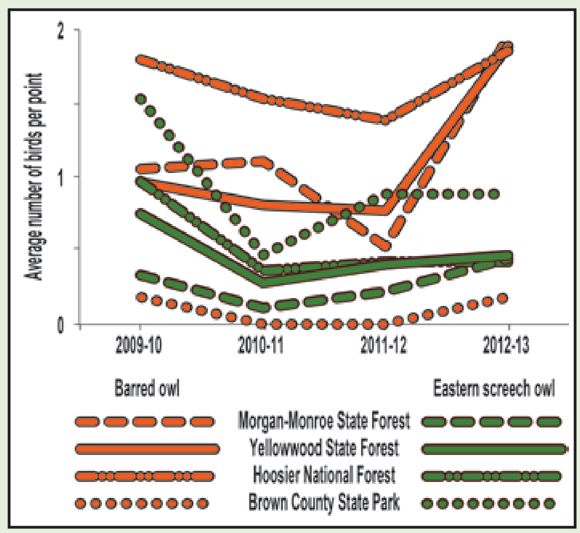


Figure created from raw data related to data in Figure 3, Leonard et al., 2015.

Summary

The data from this study has shown no significant impacts of forest management on either barred owls or eastern screech-owls. More detailed information is needed related to habitat differences between the properties and the availability of food.

Small Mammals

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

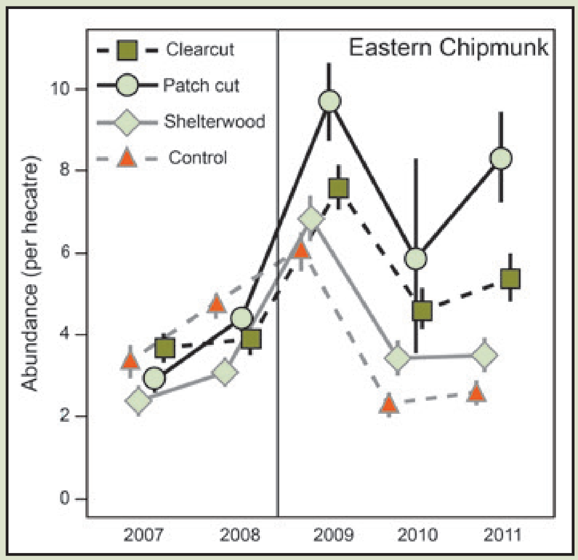
White-footed mouse

Project Goals & Methods

Small mammals are important consumers of insects and plant material, especially oak acorns and hickory nuts, and they, in turn, are important prey for other animals. Different small mammal species have different habitat needs, and some are more dependent on oak acorns than others. The objective of this study is to understand the impacts of different management treatments on small mammals and how changes in oak and hickory seed production influence mammal populations.

Results

Small mammals were trapped, fitted with ear tags, and released over multiple summers in different harvest types. Eastern chipmunks (see diagram), were found most often in the largest openings, while white-footed mice and short-tailed shrews were most often encountered in small openings and areas that were not harvested in 2008–09. Pine vole numbers decreased across all treatment types. Acorn production was low 2008 and 2009 (see mast section below) so captures of species most dependent on acorns, like chipmunks and white-footed mice, were substantially lower in 2010.



Adapted from Figure 3 in Kellner et al., 2013, and reprinted courtesy of the *Journal of Wildlife Management.*

Summary

Timber harvesting can have negative impacts on some species, but it can have positive impacts on others. Species that are dependent on oak acorns declined substantially following a failure of the acorn crop, so a loss of oak and hickory trees from these forests may have long-term impacts.

Bats

J.M. O'Keefe, J.O. Whitaker, Jr., Indiana State Univ., T.C. Carter, Ball State Univ.; J.E. Duchamp, Indiana Univ. of Pennsylvania. *Graduate Students*: J. Sheets, M. Caylor, S. Bergeson, H. Badin, K. Caldwell, T. Divoll, J. Karsk

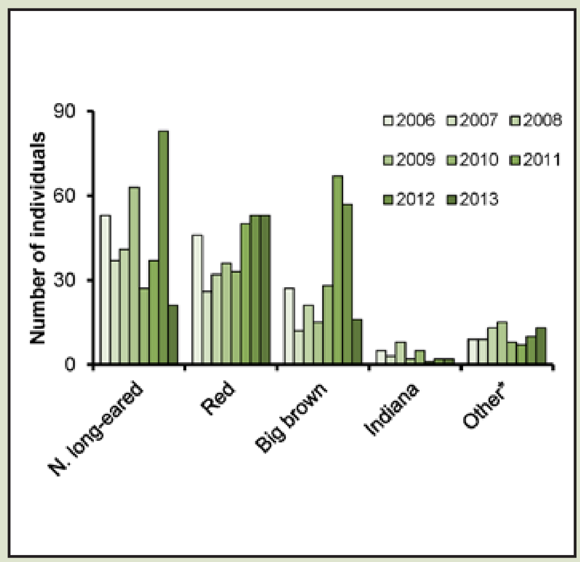
Big Brown Bat

Project Goals & Methods

Woodland bats are an important component of forested ecosystems and play a key role in consuming forest insects. They are often forgotten, because they are most active at night. But, a disease called white-nose syndrome has been reducing populations throughout the eastern United States. Bats use different habitats for finding food and for roosting. Forest management can influence the quality of both habitats. Bats are studied on the HEE by capturing them in nets and using radio-tracking. Nightly bat calls are also recorded and analyzed.

Results

Northern long-eared bat and red bat were the most common species captured on the HEE. The endangered Indiana bat was also present in small numbers (see diagram). Analysis of bat calls has shown that bat feeding activity was higher in areas with recent harvests. Almost all species were most active in shelterwood harvests in which only the midcanopy was removed; bat species responded differently to the other management types. Big brown bats were most active in clearcuts, while northern long-eared bats foraged more in intermediate-sized openings and adjacent intact forest. Roosting bats were found in both intact and recently harvested forest.



* "Other" species group includes tricolored, little brown, silver-haired and hoary bats. Unpublished data from T. Carter and J. Whitaker, Jr.

Summary

Most bats feed more actively, at least initially, in open conditions following timber harvesting. If forestry operations retain patches of mature forest and sufficient suitable trees for roosting, forestry can probably co-exist with bats. The spread of white-nose syndrome in Indiana's bats poses a more immediate threat.

Woodland Salamanders

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

Northern Zigzag Salamander

Project Goals & Methods

Salamanders are considered by some to be a measure of long-term ecosystem health, because they are sensitive to changes in the environment. They also provide an important food source for higher-level predators. Woodland salamanders are being tracked on the HEE primarily using wooden cover boards that provide shelter for salamanders and a way to systematically sample them. Other surveys have assessed populations in naturally occurring habitat, such as under leaves and decaying logs.

Results

Only a handful of salamander species are regularly found on the forest floor in Indiana. As a result, almost 95% of the salamanders observed on the HEE sites before and after harvesting were from two species: eastern red-backed and northern zigzag. Salamander numbers have decreased in larger HEE openings (5- and 10-acre patch cuts and clearcuts) when compared to areas that were not harvested in 2008. Red-backed salamanders declined in all areas, including controls, but declines were more pronounced in 2008 harvest areas. Zigzag salamanders did not, however, decline in harvested areas, though numbers were higher adjacent to clearcuts.

	Amphibians	
	Species	**Response**
No harvest	Eastern red-backed salamander	Relative abundance declined
Uneven-aged	Northern slimy salamander and eastern red-backed salamander	Relative abundance declined
Even-aged	Northern zigzag salamander	Relative abundance increased on sites adjacent to clearcuts

Adapted from Table 3 in Macneil et al., 2013, and reprinted courtesy of Purdue University Extension and the authors.

Summary

Creating large openings has at least a temporary negative impact on salamander numbers, especially for red-backed salamanders. Future HEE monitoring and research efforts will provide a better understanding of how long it takes for salamander abundance to recover within large openings.

Timber Rattlesnakes

B.J. MacGowan, Purdue University
Graduate Student: A. Currylow

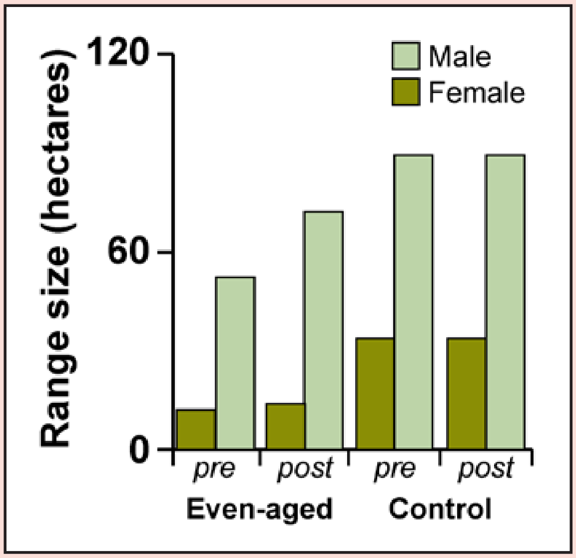
Timber Rattlesnake

Project Goals & Methods

Timber rattlesnakes are state-endangered in Indiana. They inhabit forests in the southern part of the state, and forest management may have an impact on their use of habitat. Historically, little was known about the impacts of forestry on rattlesnake habitat use. On the HEE, radio transmitters were surgically implanted into snakes to enable tracking of snake movements over time. This study tracked 47 snakes to determine whether forest management activities influenced their behavior or habitat use.

Results

The use of habitats by snakes was determined by calculating the average size of snake home ranges (see diagram) and the daily movement of individuals. The occurrence of large, harvested openings in even-aged units did not affect the size of the overall area used. Some snakes spent a considerable amount of time in harvested areas, though the openings made up, on average, less than 4% of the area used by snakes. Between 72% and 98% of snakes survived per year,—a high rate of survival. Snakes may be most vulnerable to the impacts of harvesting activities near den sites. However, because no den areas were in HEE harvest areas, it is still unclear what impacts harvesting near den sites may have.



Unpublished data from B. MacGowan.

Summary

Timber rattlesnakes were not negatively impacted by timber harvesting—and habitat quality may even be increased with some level of timber harvesting. General persecution of rattlesnakes by humans remains a substantial threat to snake populations.

Eastern Box Turtles

R.N. Williams, B.J. MacGowan, Purdue University
Graduate Students: A. Currylow, S. Kimble

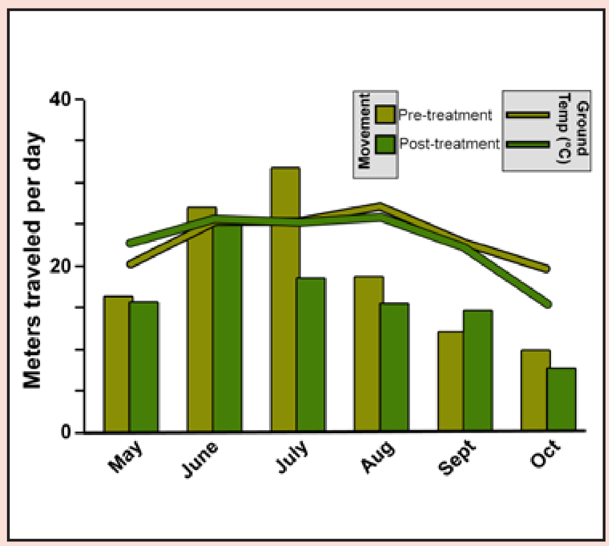
Eastern Box Turtle

Project Goals & Methods

Eastern box turtles are another reptile species of conservation concern in Indiana's forests. Box turtles are long-lived and move slowly, so they can be susceptible to disturbances in the environment. The HEE box turtle study used radio transmitters and temperature sensors attached to their shells to track turtle movements in relation to timber harvests. Temperature sensors were also used to determine impacts of harvests on body temperature regulation during summer and winter.

Results

Turtles generally moved shorter distances per day in patch cuts and clearcuts than in the intact forest. Average daily movements were reduced following harvesting (see diagram); however, individuals used the edges of openings more than the interior. Turtles using harvested openings had higher body temperatures due to increased solar exposure in the openings. There was no difference in the size of area used between harvested and control cores. The average amount of area used by an individual turtle was about 17 acres. From year to year, approximately 95% of turtles survived. Soil temperatures during hibernation were lower in harvested openings.



Adapted from Figure 3 in Currylow et al., 2012b and reprinted courtesy of the authors and the journal *PLoS ONE*.

Summary

Box turtle movements were reduced in years immediately following timber harvests, likely due to changes in solar exposure and temperature following canopy removal. While survival remained high during the period of study, it is unclear what long-term effects harvesting has on box turtles and their populations.

Overstory and Understory Vegetation

M.R. Saunders, M.A. Jenkins, Purdue University
Graduate Students: J. Aresnault, A. Meier

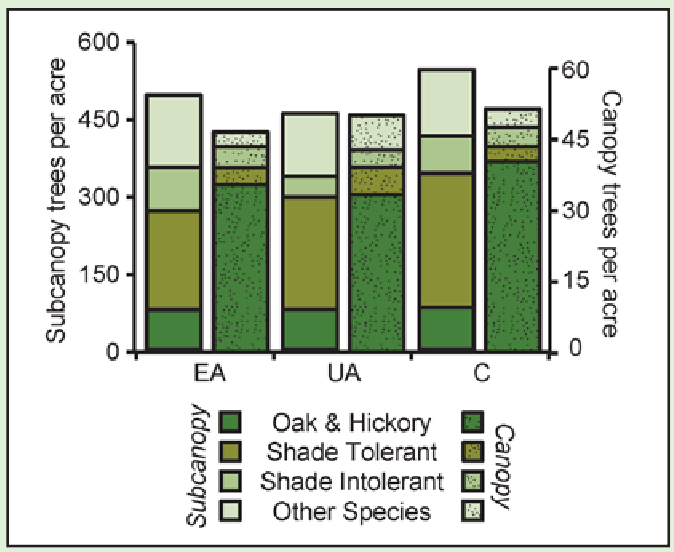
Oak Regeneration in a HEE Patch Cut

Project Goals & Methods

All of the wildlife and insects on the HEE depend in one way or another on the many plants that grow on the study sites. Long-term trends in wildlife populations are strongly related to long-term trends in vegetation, so canopy trees will be tracked in 700 plots, each approximately ¼-acre in size over the next 100 years. This will provide a description of the impacts that management decisions have on forest dynamics and how changes in forest vegetation may influence wildlife populations over a long period of time.

Results

In preharvest inventories, more than 60 different tree species were observed on the HEE research sites. The most dominant trees in the forest canopy were oaks and hickories, though shade-tolerant species dominated counts of smaller, subcanopy trees (see diagram). Within each research core, there was substantial variation in the distribution of trees and tree species. But, when averages for each core were compared, all cores were similar. The first postharvest inventory was completed in 2014, and data has not yet been analyzed to quantify the impacts of harvesting on vegetation.



Created from data in Saunders and Arsenault, 2013.

Summary

Pre-harvest forest conditions were similar for all research cores, so changes following harvesting can most likely be associated with the impacts of harvests. Tree diversity is very high on the HEE sites, and inventory data indicates that oaks and hickories will gradually disappear from the sites unless there is intervention.

Beetles

J.D. Holland, Purdue University

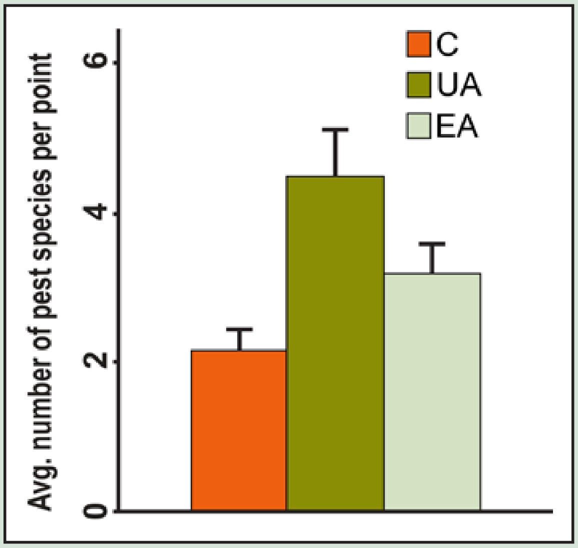
Gaurotes cyanipennis

Project Goals & Methods

Insects are important components of forested ecosystems. Beetles, particularly longhorned beetles, play an important role in the decomposition of dead wood. However, a small subset of longhorned beetles are pests that attack and kill living trees. Various traps are placed on the HEE sites every summer to capture beetles. These beetles are the brought back to the lab for identification and analysis of change in the prevalence of different beetle species in response to the timber harvesting treatments.

Results

To date, over 120 species of longhorned beetles have been found on the HEE. Beetle diversity increased rapidly immediately following the harvests as beetles that specialize in consuming dying or recently dead wood appeared, but fewer new species are found with each year that passes since the harvest. Areas with harvesting had higher diversity and numbers of pest species than areas not harvested in 2008 (see diagram). Variation in species diversity was also lower in traps that were placed at a greater distance from harvested areas.



Unpublished data from J. Holland.

Summary

Timber harvesting creates an immediate influx of new longhorned beetle species that feed on woody debris from harvested trees, thereby increasing diversity. However, many of these species also attack living trees, and large harvest areas may temporarily increase the prevalence of these pest species.

Lepidoptera (Moths)

K.S. Summerville, Drake University

Luna Moth

Project Goals & Methods

Because there are so many different species of moths on the HEE, the HEE moth study has focused on understanding how timber harvesting impacts species diversity (also called species richness) and how moth communities rearrange themselves following disturbance. This study uses black-light moth traps that are placed in three of the research cores at Morgan-Monroe State Forest every summer to determine how moth communities change following harvest.

Results

There was a significant decrease in the number of species and total number of moths captured between years regardless of treatment, though the decreases between surveys preharvest (2007) and immediately postharvest (2009) were higher in harvested research cores (see diagram). Uneven-aged cores had the lowest diversity following harvesting. Further analyses (see Summerville 2013) indicate that three years following harvest, species richness had only recovered to preharvest levels in first stage shelterwood treatment areas; species richness was still lower in patch-cuts and clearcuts.

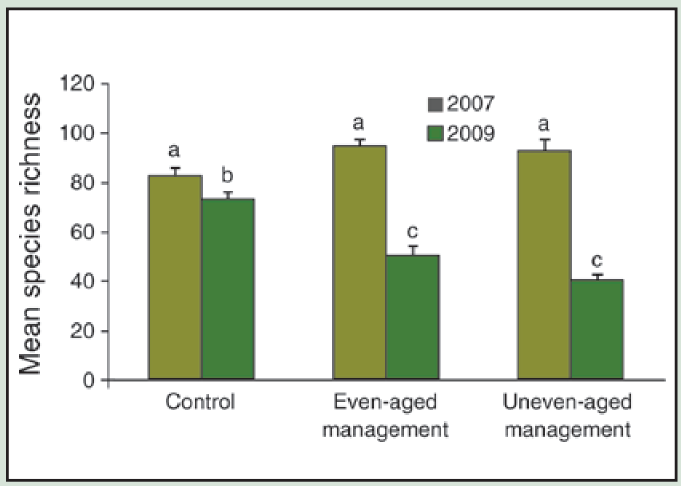


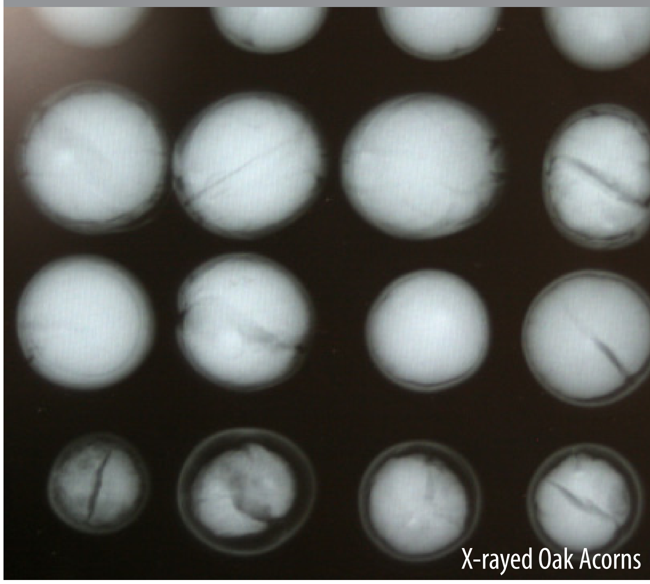
Figure from Summerville, 2011, Fig. 3, reprinted courtesy of the author and with permission from the journal *Ecological Applications.*

Summary

Declines in moth species richness occurred across all sampling areas in the years following harvest, including unharvested areas, though the declines were greatest where large canopy openings were created. Longer-term data is needed to identify how long communities take to recover to preharvest conditions.

Oak Acorn Production and Predation

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



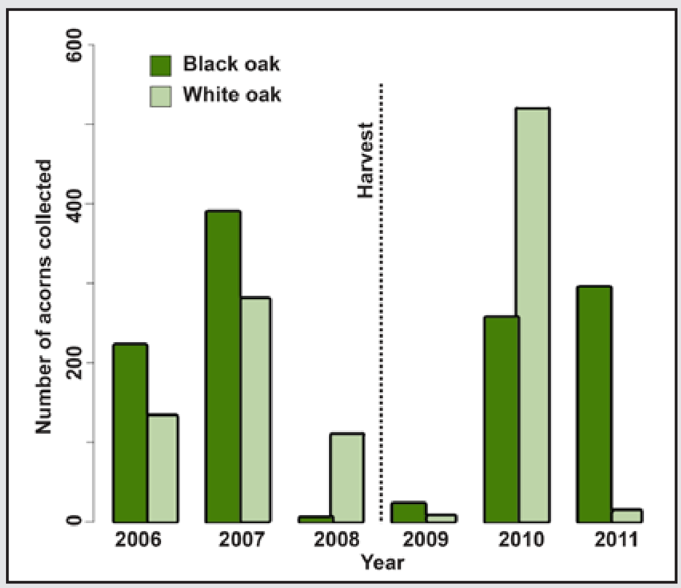
X-rayed Oak Acorns

Project Goals & Methods

Oak acorns are a primary food source for many different animals (and insects), but some oak acorns need to germinate and develop into trees to maintain oak forests. Acorn production is being tracked on more than 100 black and white oak trees on the HEE. Some acorns from each of those trees are then put into cages that exclude some animals—but not others—to determine which animals consume the largest number of acorns. Other acorns are brought back to the lab to be x-rayed, looking for infestation by beetle larva.

Results

Acorn production was not affected by harvest, but some years had high levels of acorn production while others had very low levels (see diagram). Forest wildlife moved or consumed nearly half of the acorns that were placed in different sized cages. Removal of acorns by wildlife can sometimes be beneficial, since squirrels and some birds bury acorns to consume later. Some of these acorns are able to germinate. In years with high acorn production, fewer acorns were eaten. In very low acorn years, almost all acorns were infested with insect larvae and were, therefore, less valuable for food and less likely to germinate.



Unpublished data from Kellner and Swihart. Some of this data is included in Kellner et al., 2013.

Summary

Just as oak trees have an important influence on wildlife populations, wildlife can affect the likelihood that oak acorns will germinate and become seedlings. Successful oak regeneration events are most likely to occur in years with high acorn crops.

Conclusions

Six years following the initiation of harvesting treatments on the HEE, it is apparent that different species of plants and animals respond differently to forest management, and, in some cases, the responses vary depending on the specific treatment type. Some species have responded positively, others negatively. Still others have shown no response at all. For many groups studied, variation between years is much stronger than variation between harvesting types. This could indicate that harvesting has little effect on these groups. Or, it could indicate that normal, annual fluctuations in wildlife populations are being observed and, in order to adequately determine the long-term impacts of harvesting on these populations, it is imperative that we continue to collect data.

The one message that appears to be surfacing is that forests with higher levels of habitat diversity are likely to have higher levels of animal, plant, and insect biodiversity. While retention of mature forest habitats critical for threatened or endangered species, such as the Indiana bat or the cerulean warbler, remains a paramount goal, it is important to use management approaches that improve the habitat for other species, too. It is also necessary to understand that disturbance in a forest is a natural part of ecosystem function; the wildlife in these forests, including our endangered or threatened species, are adapted to deal with and even to benefit from disturbance.

But, we're less than a decade in. This is just the first chapter in a long novel. Maybe 20 years from now things will look completely different. So, keep on checking back with the HEE to see how things change over a century in Indiana's forests.

Acknowledgements

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Photo credits: All photos were taken by the author with the following exceptions:

- 2008 and 2010 panoramic photos—**J. Maxwell**, Indiana DNR;
- 2014 panoramic photos—**F. Oliver**, Indiana DNR;
- summer tanager, male cerulean warbler—**K. Barnes**;
- barred owl—**J. Moore**;
- Indiana bat and big brown bat—**T. Carter**;
- timber rattlesnake—**B. MacGowan**;
- *Gaurotes cyanipennis*, **Pennsylvania Department of Conservation and Natural Resources – Forestry Archive, Bugwood.org**;
- luna moth—**C. Mycroft**.

HEE Publications

HEE background and study design

Kalb, A. and C.J. Mycroft. 2013. The Hardwood Ecosystem Experiment: goals, design, and implementation. Gen. Tech. Rep. NRS-P-108. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station. [CD ROM] pp. 36-59.

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