

DOES TIMBER HARVESTING AFFECT CERULEAN WARBLER FORAGING  
ECOLOGY?

BY

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**DOES TIMBER HARVESTING AFFECT CERULEAN WARBLER FORAGING  
ECOLOGY?**

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## INTRODUCTION

Research on *Dendroica* species has shown that males and females differ in foraging behavior; males tend to forage higher in trees, close to their singing perches, and females forage lower in trees near their nest site (Morse 1968). This divergence in foraging height could reflect an increase in foraging efficiency. Both sexes can catch the amount of food they require but only spend time foraging in part of the territory, thereby decreasing their energy expenditure (Morse 1968, Williamson 1971). Differences in foraging behavior could also be due to forest structure as vegetation varies with height or tree species.

The Cerulean Warbler (*Dendroica cerulea*) is a small, neotropical migratory songbird whose breeding range encompasses the Mid-Atlantic and midwestern United States and southern Ontario, Canada (Hamel 2000). Its wintering range consists of forests in the South American Andes. Cerulean Warblers prefer large, continuous, mature tracts of deciduous forest for nesting; thus, loss of available habitat in the breeding range has a profound effect on the future of this species (Hamel 2000). Once a common summer migrant, the Cerulean Warbler has experienced a population decrease at the rate of 4.1% per year from 1966-2007 (Sauer *et al.* 2008). The species is known to be monogamous through nesting attempts and sometimes the whole breeding season (Hamel 2000).

Knowledge of Cerulean Warbler foraging ecology is limited to anecdotal observations. The species is insectivorous and the primary method of catching prey is gleaning (Hamel 2000). There is little information on Cerulean Warbler foraging characteristics and any behavioral differences between the sexes. Additionally, most

studies examining Cerulean Warbler response to silvicultural treatments have been limited to measuring relative abundance, not behavioral changes. A study in West Virginia found a higher abundance of Cerulean Warblers in mature forests compared to 15- 18-year-old clearcuts, but the results were not significant (Wood *et al.* 2005). In southern Indiana, Register and Islam (2008) found no difference in Cerulean Warbler abundance among control sites, even-aged sites, and uneven-aged harvest sites. No research focusing on foraging behavior changes relative to habitat alterations has been conducted on this warbler.

A recent emphasis within avian foraging ecology studies is to determine tree preferences. Barg *et al.* (2006a) determined that bitternut hickories (*Carya cordiformis*) were very important song-perch trees in Ontario, Canada. Male Cerulean Warblers chose bitternut hickories for singing 45% of the time; yet this tree species represented only 9% of the forest composition. They found that bitternut hickories had significantly more insects in their canopy than other tree species, which may explain why this tree species was preferred. Cerulean Warblers preferred shellbark hickory (*Carya laciniosa*) and avoided red maple (*Acer rubrum*) as foraging trees in southern Illinois (Gabbe *et al.* 2002). Preferred foraging tree species could vary with forest composition in different parts of the Cerulean Warbler breeding range; determining key tree species could be an integral component of major conservation efforts.

The objectives of this study were to determine a) foraging characteristics between the sexes, b) differences in foraging behaviors between pre- and post-treatment years, and c) if Cerulean Warblers have a foraging preference for specific tree species in our study

populations. We hypothesized there would be a difference in foraging behavior in units affected by harvest but not in control units.

## METHODS

### STUDY AREA AND SILVICULTURAL MANIPULATIONS

The Hardwood Ecosystem Experiment (HEE) is a long-term study established to determine effects of forest management practices on native plants and animals in Indiana, including the Cerulean Warbler ([www.fnr.purdue.edu/HEE/index.htm](http://www.fnr.purdue.edu/HEE/index.htm)). Nine management units ranging from 364-405 ha in size were established in Yellowwood and Morgan-Monroe state forests in southern Indiana (Fig. 1). Within each unit a single 200 ha core area was established where harvesting occurred.

Of the nine management units, three were controls with no treatment. Three uneven-aged units received single tree selection in which individual trees were removed. In addition, several group selection openings were cut throughout the units, which included four 0.4 ha areas, two 2 ha areas, and two 1.2 ha areas. Group selection openings create slightly larger canopy openings than single selection as a group of trees is removed. The goal of single and group selection is to balance the distribution of trees across age classes. The remaining three units were even-aged with trees of similar age and size. These units received a combination of shelterwood and clearcut treatments. Two 4 ha shelterwood areas and two 4 ha clearcut areas were established in each unit (Fig. 2). Shelterwood treatment consisted of removing most trees and leaving some trees as a source of regeneration. After regeneration occurs, the remaining mature trees are removed. Clearcut consisted of removing all trees in a given area. Timber harvest began in July 2008 and ended in January 2009. Vegetative sampling of random sites and

territories in harvested areas was conducted prior to silvicultural manipulation. Pre-treatment data were collected from 1 May – 8 August 2007 and 2008. Post-treatment data were collected 1 May – 8 August 2009.

#### POINT COUNTS AND TERRITORY MAPPING

Within each unit a 259 ha survey area, consisting of a 7 x 7 point grid with points 200 m apart, was established over the 200 ha core area (Fig. 3). The edge of each survey area was surrounded by a 50 m buffer. We conducted point counts using a 100 m radius at each survey point to locate male warblers. Surveys occurred between 05:30 and 10:30 EST on days without high wind or rain. Observers listened for vocalizations for two minutes after arriving at the point, used playback of Cerulean Warbler calls and songs for one minute, and then listened for two more minutes. Compass direction and an estimate of the singer's distance were recorded for every vocalization in order to distinguish between multiple individuals. Point counts were conducted between 1 May – 8 June 2007-2009.

To demarcate territories, points were revisited from 1 May – 30 June 2007-2009 where birds were detected for a given year. Trees where male birds were observed singing were flagged with tape and location was recorded as Universal Transverse Mercator (UTMs) in a Global Positioning System (GPS) unit (Garmin GPSMAP 76). A territory perimeter had at least five marked trees, but trees that did not increase the area of a bird's territory were not marked. Depending on the individual bird, territory marking took several hours to several days.



## FORAGING ECOLOGY

Male and female Cerulean Warblers were observed foraging from 1 May – 15 July 2007-2009. Individuals had to be in sight for at least 30 seconds for data to be recorded and observations stopped at 5 minutes from first observation of an individual. The following data were recorded for each observation modeled after Sodhi and Paszowski (1995):

1) foraging method (glean: pick prey off of substrate while perched; sally: capture flying prey while in flight; pounce: fly toward prey and capture after landing; hover: capture prey on substrate while in flight), 2) substrate of prey (leaf, twig < 0.1 cm diameter, branch > 0.1 cm diameter, trunk, air), 3) direction moved relative to trunk (up, down, in, out), 4) distance from the main stem, 5) foraging height, 6) tree species, 7) tree height, 8) dbh of tree, 9) flight distance to new substrate, 10) forest structure, 11) vertical height, and 12) time and date of observation. Foraging height and tree height were determined using a Nikon 440 Rangefinder. Flight distance was measured at the first landing of a bird in a new tree and calculated using the rangefinder with the help of several observers. Distance from the main stem is represented by the same categories with Category 1 the closest 0-20% of vegetation to the trunk and Category 5 the farthest 81-100% of vegetation to the trunk. Vertical height was based on the overall height of the surrounding forest and not just the foraging tree. Category 1 is the bottom 0-20% of vegetation, 2 is 21-40%, 3 is 41-60%, 4 is 61-80%, and 5 is the top 81-100% of vegetation.

## VEGETATION SAMPLING

Vegetative sampling within each territory was conducted from 1 July – 21 August 2007-2009 following modified methods from James and Shugart (1970) for mature trees only.

GPS units were used to travel to the approximate center of a territory. At the center of each defined territory a circular plot with an area of 0.04 ha was marked. Every tree species was recorded and dbh >10 cm was measured. Tree species with a dbh <10 cm were tallied if they fell within 5 m of the plot center. Height for the tallest tree in each quadrant was recorded. Random sites were determined using a random number generator and the possible UTM ranges in each unit. Random sites were sampled using the same methods as above. The number of random sites in each unit equaled the number of territories for that unit.

#### STATISTICAL ANALYSES

A 2-sample two-tailed *t*-test was used to test for differences in foraging height, tree height, and dbh between the sexes and between treatments. A Mann-Whitney *U* test was used for data that were not normal, e.g. average flight distance between males and females as well as for tree dbh in the control units before and after harvesting. A chi-square test of association was used to test for differences in substrate, method, vertical stratification, vertical height, and direction to trunk between the sexes. A Fisher's exact test was used to check the chi-square test in cases of small cell counts. A chi-square goodness-of-fit test was used to determine if the most common observations for both sexes occurred significantly more often than other possible outcomes for each variable (Coladarci *et al.* 2008). To determine if Cerulean Warblers select specific species of trees for foraging, a chi-square goodness-of-fit test was used. This test compared the percentage of total basal area or stem density of a tree species in all territories to the percentage of total foraging observations recorded for that tree species. We used both basal area and stem density of tree species because they can show different results in

forest composition estimations. Basal area and stem density are correlated only when tree species are very small or young (Montgomery and Chazdon 2001). All tests were calculated using Minitab 15 except for Fisher's exact test where SAS 9.2 was used. The alpha level of significance was 0.05 for all tests. Values presented are means  $\pm$  SD. Sample sizes are number of observations, not individuals. While recording continuous observations means multiple observations on an individual are not independent of each other, Morrison (1984) determined the effect pseudoreplication had on statistical analyses. When comparing single point observations (i.e. only the first recorded foraging behavior) of an individual with sequential observations, the overall results were not dramatically different. Additionally, recording sequential observations actually increased the number of rare behaviors not recorded with point observations. Morrison (1984) does caution that using sequential observations is most accurate with a minimum of 30 individuals or 150 observations.

## RESULTS

### FORAGING CHARACTERISTICS FOR ALL YEARS

For all years combined there were 1022 observations of 139 individual males and 89 observations of 22 individual females. There was no significant difference in foraging method ( $X^2_3 = 2.1, P = 0.53, n = 1117$ ) or substrate ( $X^2_3 = 0.58, P = 0.97, n = 1113$ ) between the sexes. However, gleaning as a foraging method ( $X^2_2 = 2454.88, P > 0.001, n = 1117$ ) and leaves and twigs as a substrate ( $X^2_3 = 784.1, P > 0.001, n = 1113$ ), were observed statistically more often than expected for both sexes. There was a significant difference in foraging height between males ( $19.2 \pm 5.1$  m, Fig. 4) and females [ $16.9 \pm$

6.2 m ( $t_{98} = 3.4$ ,  $P = 0.001$ ,  $n = 1117$ , Fig. 5)]. Mean height of trees used for foraging by males ( $25.48 \pm 5.03$  m) was significantly greater than for females [ $23.33 \pm 6.70$  m ( $t_{96} = 3.0$ ,  $P = 0.004$ ,  $n = 1112$ )]. There was a significant difference between males ( $41.3 \pm 15.3$  m) and females ( $36.0 \pm 17.3$  m) for dbh of foraging trees ( $t_{809} = 2.71$ ,  $P = 0.007$ ,  $n = 811$ ).

Average flight distance for females was  $2.2 \pm 2.8$  m ( $n = 10$ ) and males was  $5.0 \pm 7.2$  m ( $n = 125$ ) but was not significantly different. There was no significant difference between the sexes for direction moved relative to trunk ( $X^2_3 = 4.1$ ,  $P = 0.25$ ,  $n = 1078$ ), but “out” was observed significantly more often than other directions ( $X^2_1 = 495.6$ ,  $P < 0.001$ ,  $n = 1078$ ). There was a significant difference between the sexes for vertical stratification of vegetation, with males observed in the canopy 77% of the time and females only 59% ( $X^2_3 = 28.1$ ,  $P < 0.001$ ,  $n = 1109$ ). Females were observed in the mid-story 35% of the time with males only 14%. For vertical height, females were observed in Categories 1-3 39% of the time with males 26% of the time. Males were observed in Categories 4-5 74% of the time with females only 61% of the time ( $X^2_4 = 14.0$ ,  $P = 0.007$ ,  $n = 1087$ ). For distance from main stem, males were observed in Categories 1-2 18% of the time compared to only 6% of the time for females (Fisher’s test:  $P = 0.037$ ,  $n = 1090$ ).

Foraging was observed in 24 tree species (Table 1). The three tree species with the most observations for males were bitternut hickory, white oak (*Quercus alba*), and tulip tree (*Liriodendron tulipifera*), whereas females selected bitternut hickory, sugar maple (*Acer saccharum*), and shagbark hickory (*Carya ovata*).

## FORAGING DIFFERENCES BETWEEN TREATMENTS

There were 86 individuals with 541 observations recorded foraging in the uneven-aged units, 56 individuals with 414 observations in the even-aged units, and 19 individuals with 156 observations in the control during our study. Data were collected on 123 individuals with 1032 observations before harvesting and 38 individuals with 79 observations after harvesting. Foraging method and substrate selected did not differ between pre- and post-treatment years for either sex. For the uneven-aged units, there was a significant difference between dbh of foraging trees ( $t_{387} = 2.7$ ,  $P = 0.007$ ,  $n = 389$ ) and between tree height ( $t_{491} = 2.4$ ,  $P = 0.02$ ,  $n = 493$ ) but there was no significant difference in foraging height ( $t_{494} = 1.3$ ,  $P = 0.21$ ,  $n = 496$ , Table 2). For the even-aged units, there was a significant difference in dbh ( $t_{263} = 2.9$ ,  $P = 0.004$ ,  $n = 265$ ), tree height ( $t_{33} = 3.4$ ,  $P = 0.002$ ,  $n = 371$ ), and foraging height ( $t_{370} = 3.6$ ,  $P < 0.001$ ,  $n = 372$ , Table 2). For the control units, there was a significant difference in dbh ( $U = 3117.0$ ,  $P = 0.04$ ,  $n = 73$ ), tree height ( $t_{151} = -2.3$ ,  $P = 0.02$ ,  $n = 153$ ) and foraging height ( $t_{152} = -3.2$ ,  $P = 0.002$ ,  $n = 154$ , Table 2).

Cerulean Warblers were not observed foraging in all tree species recorded in the territories. Seven tree species plus trees recorded as snags in vegetation plots had no foraging observations recorded. Based on basal area, a measurement of space trees occupy based on their diameter, 14 out of 29 tree species recorded in the territories had foraging observations that were significantly different than expected ( $X^2_{26} = 1345.2$ ,  $P < 0.001$ ,  $n = 1076$ , Fig. 6). The tree species that occupied the largest proportion of the territories in terms of basal area were white oak, tulip tree, and chestnut oak (*Quercus prinus*) (Table 3). The three tree species with the largest difference between observed

and expected values based on basal area were bitternut hickory, big-toothed aspen, and black walnut, which were all used more than expected. For stem density, 25 species were significantly different than expected ( $X^2_{26} = 1777.3$ ,  $P < 0.001$ ,  $n = 1076$ , Fig. 7). The three tree species with the largest difference between observed and expected values were bitternut hickory, big-toothed aspen, and shagbark hickory, which were all used more than expected. The tree species that occurred most often in the territories were sugar maple, snags, and pignut hickory (*Carya glabra*) based on stem density (Table 3).

More tree species were present in random sites than in Cerulean Warbler territories. There were 35 recorded tree species present in the random sites. The tree species that had the largest basal area with all random sites combined were white oak, chestnut oak, and red oak. Compared to the basal area of the territories, there was more red maple in the random sites but less pignut hickory, snags, bitternut hickory, and sassafras (Table 4). The tree species that had the largest stem density with all random sites combined were red maple, white oak, and snags. Compared to the stem density of the territories, there was more white oak and chestnut oak in the random sites, but less tulip tree, bitternut hickory, and pignut hickory (Table 4).

## DISCUSSION

### FORAGING COMPARISON BETWEEN THE SEXES

The most common method of foraging by Cerulean Warblers in this study was gleaning on tree leaves and twigs, comparable to the description by Hamel (2000). Both sexes showed similar foraging behaviors which might be attributed to several factors. In studies on other *Dendroica* species, foraging behavior was determined by vegetative structure and prey type (Robinson and Holmes 1982, Whelan 2001). Since male and

female Cerulean Warblers show considerable overlap in tree species and foraging height, vegetative structure and the types of prey available should overlap as well. The sexes use several substrates equally between them, which could be due to the location of insects. However, prey abundance was not determined in this study.

Foraging method can also be explained by examining vegetative structure. Whelan (2001) found that two species of *Dendroica* warblers changed their foraging method based on the location of prey and leaf structure to reduce energy costs. Hovering and sallying are aerial maneuvers with a higher energetic cost compared to gleaning (Holmes *et al.* 1979). Cerulean Warblers move along branches while foraging and most often capture prey nearby without aerial maneuvers (pers. observ.). The birds were also observed moving towards or away from the trunk more often than up and down, which would require aerial movement. Whelan (2001) demonstrated that foraging method in two *Dendroica* species can differ based on the foraging tree species, as the angle of leaves and distance away from prey will change. Therefore, the high frequency of gleaning and trend towards lateral movement in Cerulean Warblers could be tied to how easily leaves can be searched in their preferred trees and the low energetic cost of gleaning for this particular warbler.

The most commonly used foraging tree species for both sexes was bitternut hickory (*Carya cordiformis*), just as Gabbe *et al.* (2002) found *Carya* spp. to be the top two foraging trees for Cerulean Warblers. For males, this preference is not surprising based on several studies of song perch tree selection. Our study sites were the same used in the study of song perch trees by Jones and Islam (2006), who found bitternut hickories to be one of the two most common song perch species. Barg *et al.* (2006a) also found

bitternut hickories to be the most common song perch tree in their study in Ontario, Canada. They attributed this preference to an open vegetative structure, delayed leafing, and higher abundance of insects in bitternut hickories. The open canopy and short branches of this tree species reduces acoustic interference for male territorial songs.

While males and females show similarities in their foraging behavior, foraging height was explicitly different. Males and females show a divergence in foraging height in some other *Dendroica* species (Morse 1968, Holmes 1986). There are a number of explanations for this difference, including an increase in foraging efficiency, as well as saving time and energy since the sexes are already separated by their nesting and territory defense duties (Morse 1968, Williamson 1971). In a study of four avian families that included three *Dendroica* species, foraging heights were directly related to song perch heights in males, and foraging heights of females were directly related to nest sites (Holmes 1986). However, females may be affected by more factors other than the location of the nest such as foraging rate and predation.

Several studies examining avian foraging behavior have documented differences in the capture rate and number of movements between the sexes. Female Red-eyed Vireos (*Vireo olivaceus*) had a larger number of movements and prey captures than males throughout the breeding season (Williamson 1971). Females of four *Dendroica* species, foraged at a faster rate than males (Morse 1968). Female warblers, including Cerulean Warblers, also spent a considerably longer time incubating with fewer trips away from the nest than most other *Dendroica* species (Morse 1968, Barg *et al.* 2006b). The divergence in flight distance observed between males and females in our study can be explained by foraging rates. Females made short trips to forage quickly, while males



were not constrained by time spent away from a nest. Barg *et al.* (2006b) suggested that the rapid foraging rate of females, shorter and more infrequent foraging trips, and longer incubation periods are attempts to decrease nest predation. Rogers (2006) found that as nest predators and parasites of Cerulean Warblers in Michigan, crows, jays, and cowbirds were responsible for a significant amount of nest failures and low nest success.

In our study area, the American Crow (*Corvus brachyrhynchos*), Blue Jay (*Cyanocitta cristata*) and Brown-headed Cowbird (*Molothrus ater*) have all been in the top twenty most common species for the past four years (R. Kalb, pers. comm.). Given the presence of these predators in the Cerulean Warbler habitat, perhaps the divergence in foraging height and difficulty in observing females reflects an antipredator response. Martin *et al.* (2000) determined that parental activity in the nest vicinity can increase nest predation. In our study area Islam *et al.* (2006) found an average nest height of 18.1 m ( $n = 9$ ) which is higher than the average for foraging females. Perhaps females increase their foraging rate away from the nest in order to return quickly. The divergence in foraging height seems to be the result of a variety of environmental factors for each sex: territory defense and song perches for males, nest site and predation for females, and the most efficient foraging locations for each.

Consistent with the foraging height difference, males were observed foraging in taller trees than females and in the uppermost vegetation more often than females. The larger, taller trees coincide with the characteristics of song perch trees selected by males (Jones and Islam 2006). Tree height may not have as much importance for females since they were generally observed more often in the midstory and less often in the canopy compared to males. Females were also observed farther away from the trunk than males,

which could be tied to their preference for vegetative characteristics rather than tree size. Prey density and abundance, and therefore tree species, may have a much larger role in female preference than tree height or dbh.

#### TIMBER HARVEST EFFECTS

When examining the effects of timber harvesting, there are several apparent impacts on foraging behavior. Foraging height decreased in both types of treatments, but increased in the control. Trees used for foraging decreased in height and dbh for each treatment as well, but increased in control. We also saw an increase in foraging height and tree size in our control units, but are not sure of the cause.

Our foraging results are comparable to a study on the Yellow-rumped Warbler (*Dendroica coronata*) in Arizona, where tree height and foraging height decreased in logged areas as well due to a reduction in tree density and removal of large trees (Franzreb 1983). A similar timber harvest study on the Hooded Warbler (*Wilsonia citrina*) using 0.02-0.5 ha areas of group selection found that arthropod abundance was greatest >100 m away from the gaps. Arthropod abundance was low in vegetation adjacent to gaps, but this did not affect the Hooded Warblers proximity (Kilgo 2005). Food abundance decreased with fragment size for the Eastern Yellow Robin (*Eopsaltria australis*) in Australia and resulted in more foraging bouts away from the nest (Zanette *et al.* 2001). While we did not examine insect populations, abundance, prey distribution, and density are known to vary between tree species (Holmes and Robinson 1981). Since foraging behavior is affected by tree and prey characteristics, differences in foraging height and foraging trees in the treatments could be a synergistic effect of alterations in the forest composition and prey populations (Whelan 2001).

Perhaps the most interesting result regarding foraging tree species was that the commonly used trees [hickories (*Carya* spp.), oaks, (*Quercus* spp.), and tulip tree] did not mirror the forest composition in our study area. The Cerulean Warbler Atlas indicates that the top three species at sites in Indiana where warblers are present are maples, sycamore, and oaks. The dominant tree species in the site with the largest number of Cerulean Warblers, Big Oaks National Wildlife Refuge, are tulip tree and white oak (Rosenberg *et al.* 2000). In our study, bitternut hickory accounted for only 6% of the trees and 7% of the basal area, yet it had the largest percentage of foraging observations with 24%. The interaction between tree use and availability has yet to be determined since forest composition varies so widely with location.

Not only are the Cerulean Warblers selectively foraging within their territories, but the territories are explicitly different from random sites. Our study area was dominated by large *Quercus* spp. with smaller trees consisting mostly of sugar maple along with oaks and tulip trees. While there is a clear preference for hickories as a foraging tree, it is difficult to rule out the possibility that warblers used their other top foraging trees (white oak and tulip tree) simply because they were widely available. The Cerulean Warbler's scarce use of maples and snags despite their prevalence makes it clear these trees do not meet foraging criteria.

Our study shows the foraging needs and tree species preference of a wood warbler in decline. The importance of preferred tree species cannot be overlooked in habitat restoration and management, especially for uncommon bird species and selective foragers (Gabbe *et al.* 2002). Unfortunately, important foraging trees are currently in decline in the breeding range of the Cerulean Warbler. Oaks and hickories currently have very little

recruitment due to an understory that has become increasingly dominated by sugar maple (Pierce *et al.* 2006). While oaks and hickories are tolerant of fire and disturbances, the recent suppression of fire in the last century has altered the landscape by promoting shade tolerant species. Important mast producers such as oaks and hickories are currently in decline and will decrease to a few large individuals (Shotola *et al.* 1992, Pierce *et al.* 2006). Conservation of important habitat and tree species will be necessary in stopping the population decline of this warbler.

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TABLE 1. Tree species used for foraging by Cerulean Warblers in southern Indiana from 2007-2009 indicated by an X.

Tree Species	Males Observed	Females Observed
	Foraging	Foraging
Red maple ( <i>Acer rubrum</i> )	X	
Sugar maple ( <i>Acer saccharum</i> )	X	X
Bitternut hickory ( <i>Carya cordiformis</i> )	X	X
Pignut hickory ( <i>Carya glabra</i> )	X	X
Shagbark hickory ( <i>Carya ovata</i> )	X	X
Flowering dogwood ( <i>Cornus florida</i> )	X	
American beech ( <i>Fagus grandifolia</i> )	X	
White ash ( <i>Fraxinus americana</i> )	X	
Black walnut ( <i>Juglans nigra</i> )	X	
Tulip tree ( <i>Liriodendron tulipifera</i> )	X	X
Black gum ( <i>Nyssa sylvatica</i> )	X	
Hophornbeam ( <i>Ostrya virginiana</i> )		X
Eastern white pine ( <i>Pinus strobus</i> )	X	
American sycamore ( <i>Platanus occidentalis</i> )	X	
Big-toothed aspen ( <i>Populus grandidentata</i> )	X	
Black cherry ( <i>Prunus serotina</i> )	X	
White oak ( <i>Quercus alba</i> )	X	X
Chinkapin oak ( <i>Quercus muehlenbergii</i> )	X	

Chestnut oak ( <i>Quercus prinus</i> )	X	X
Red oak ( <i>Quercus rubra</i> )	X	
Black oak ( <i>Quercus velutina</i> )	X	
Black locust ( <i>Robinia pseudoacacia</i> )	X	
Sassafras ( <i>Sassafras albidum</i> )	X	X
Basswood ( <i>Tilia americana</i> )	X	

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TABLE 2. Means of foraging characteristics  $\pm$  SD of Cerulean Warblers in southern Indiana between pre-treatment data (2007-2008) and post-treatment data (2009). An asterisk indicates means that were not significantly different. The medians used in calculating the difference in dbh for the control units were 39.3 cm for pre-harvest and 65.5 cm for post-harvest. They were significant at  $P = 0.04$ .

Treatment	Single/Group Selection			Shelterwood			Control		
	PRE	POST	<i>P</i> -value	PRE	POST	<i>P</i> -value	PRE	POST	<i>P</i> -value
Foraging	18.47* $\pm$	17.42* $\pm$	0.20	20.14 $\pm$	16.70 $\pm$	<0.001	20.08 $\pm$	26.58 $\pm$	0.002
Height (m)	4.94	4.62		5.16	5.83		4.94	5.25	
Tree Height (m)	24.94 $\pm$	22.99 $\pm$	0.02	26.48 $\pm$	21.88 $\pm$	0.002	25.96 $\pm$	30.08 $\pm$	0.02
	4.81	4.95		4.98	7.53		4.34	4.67	
DBH (cm)	41.10 $\pm$	33.70 $\pm$	0.007	42.80 $\pm$	34.80 $\pm$	0.004	43.17 $\pm$	55.92 $\pm$	----
	16.10	12.10		14.80	13.70		13.65	15.29	

TABLE 3. Three tree species with the largest proportions of forest composition in Cerulean Warbler territories in Morgan-Monroe and Yellowwood state forests between 2007-2009. The proportions are based on stem density and basal area with the percentage of foraging observations that occurred in each. White oak had the second highest number of foraging observations. Tulip tree and pignut hickory had the third and fourth highest number of foraging observations, respectively. Bitternut hickory had the highest percent of foraging observations but was not in the top tree species with regard to basal area or stem density.

Tree Species	Total Stem Density (%)	Total Basal Area (%)	Total Foraging Observations (%)
Sugar maple ( <i>Acer saccharum</i> )	18	-	6
Snags	11	-	0
Pignut hickory ( <i>Carya glabra</i> )	9	-	12
White oak ( <i>Quercus alba</i> )	-	15	14
Tulip tree ( <i>Liriodendron tulipifera</i> )	-	13	13
Chestnut oak ( <i>Quercus prinus</i> )	-	10	4

TABLE 4. The five largest differences in stem density and basal area of tree species between random sites and Cerulean Warbler territories in southern Indiana from 2007-2009 with the percentage of foraging observations that occurred in each. The four most commonly observed foraging trees are included.

Tree Species	Stem Density		Basal Area		Difference	Total Foraging Observations
	Random	Territory	Random	Territory		
Red maple ( <i>Acer rubrum</i> )	7	2	-	-	5	<1
Pignut hickory ( <i>Carya glabra</i> )	4	9	-	-	-5	12
Snags	8	11	-	-	-3	0
Bitternut hickory ( <i>Carya cordiformis</i> )	3	6	-	-	-3	24
Sassafras ( <i>Sassafras albidum</i> )	6	9	-	-	-3	1
Tulip tree ( <i>Liriodendron tulipifera</i> )	-	-	6	13	-7	13
White oak ( <i>Quercus alba</i> )	-	-	19	15	4	14
Bitternut hickory ( <i>Carya cordiformis</i> )	-	-	3	7	-4	24
Pignut hickory ( <i>Carya glabra</i> )	-	-	4	8	-4	12
Chestnut Oak ( <i>Quercus prinus</i> )	-	-	13	10	3	4

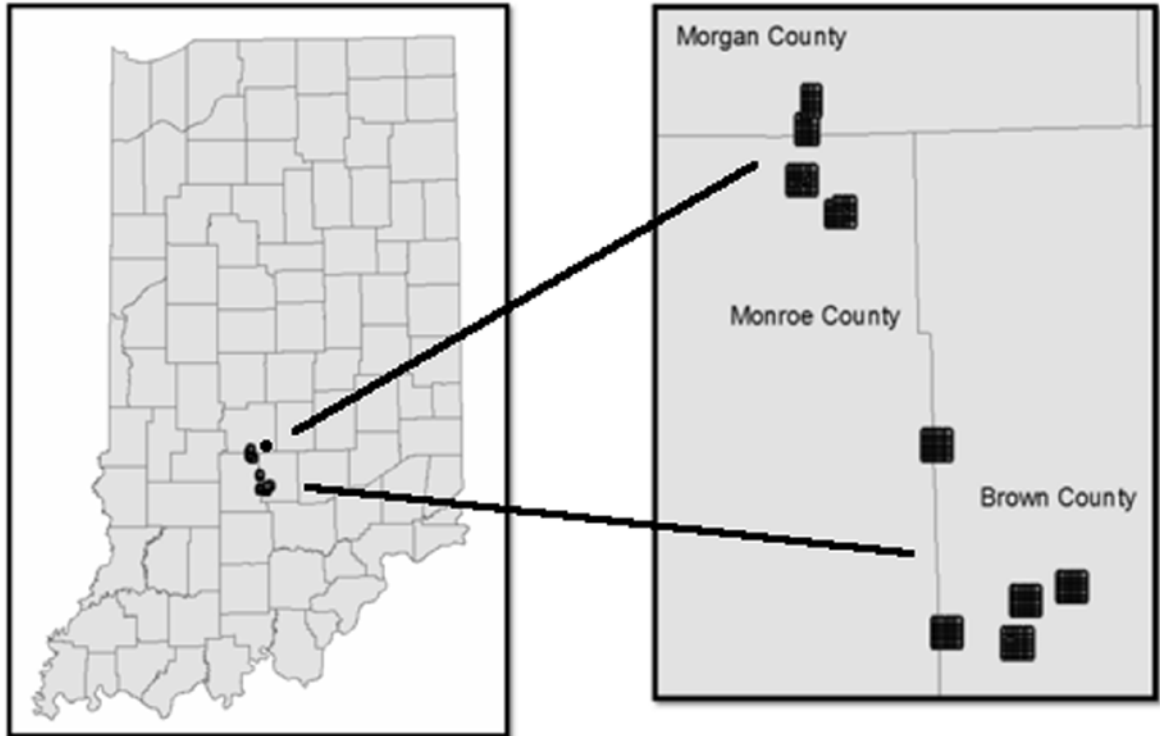


FIGURE 1. Location of nine management units in Morgan, Monroe, and Brown counties in Southern Indiana.

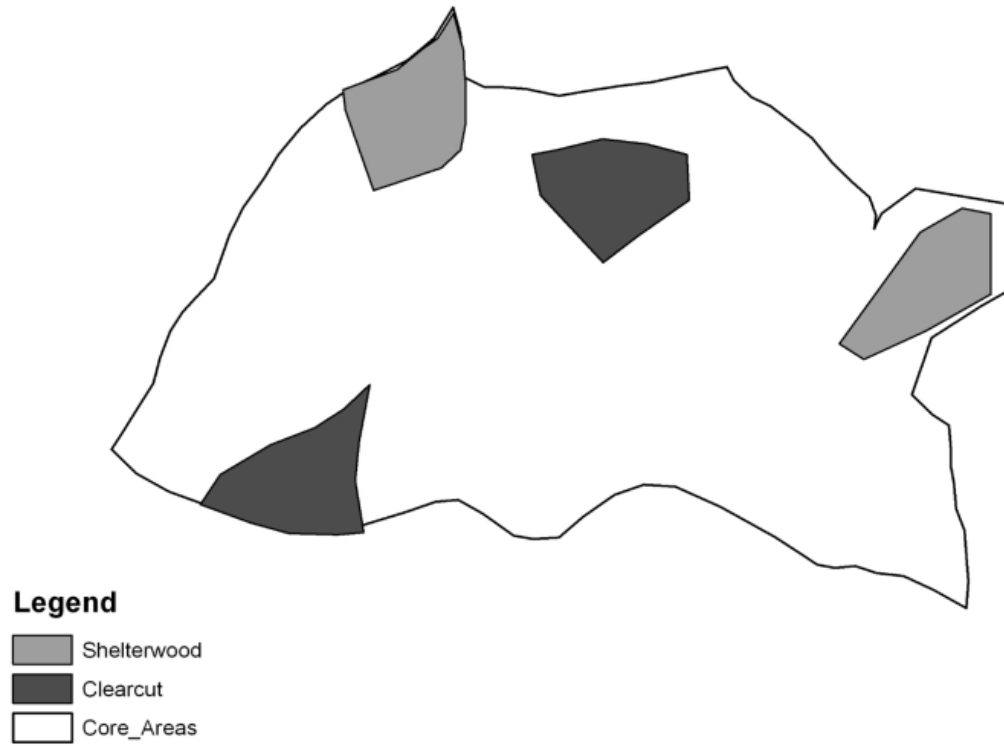


FIGURE 2. An example of an even-aged unit in Morgan-Monroe State Forest, southern Indiana. The core area is 200 ha.





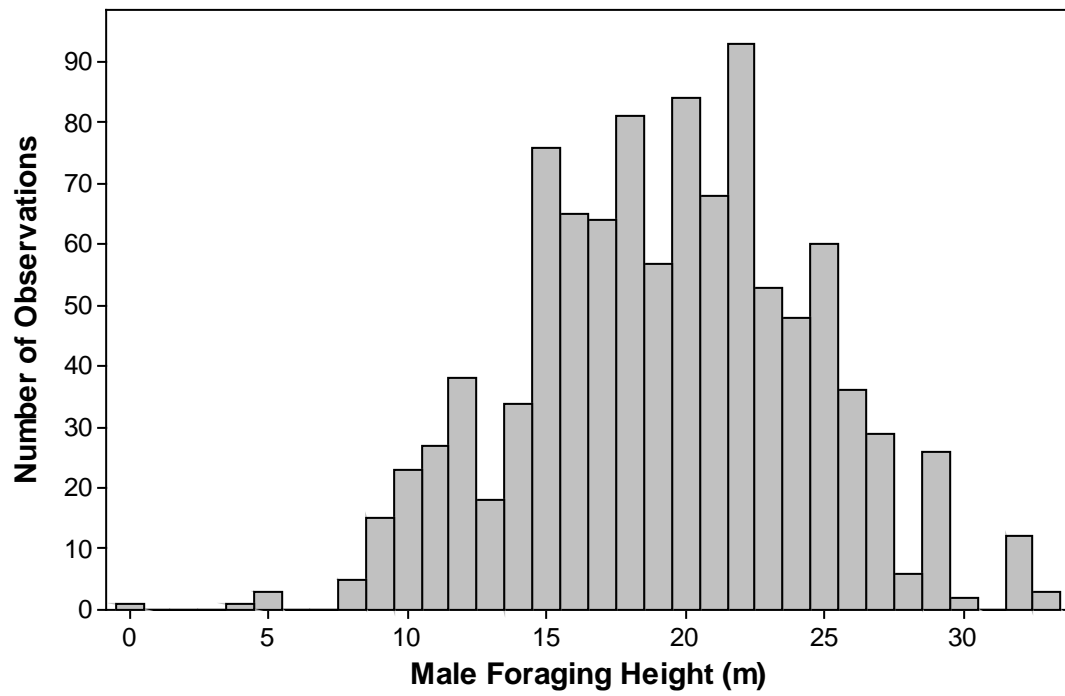


FIGURE 4. Foraging heights of 1028 observations on 139 male Cerulean Warblers in southern Indiana from 2007-2009.

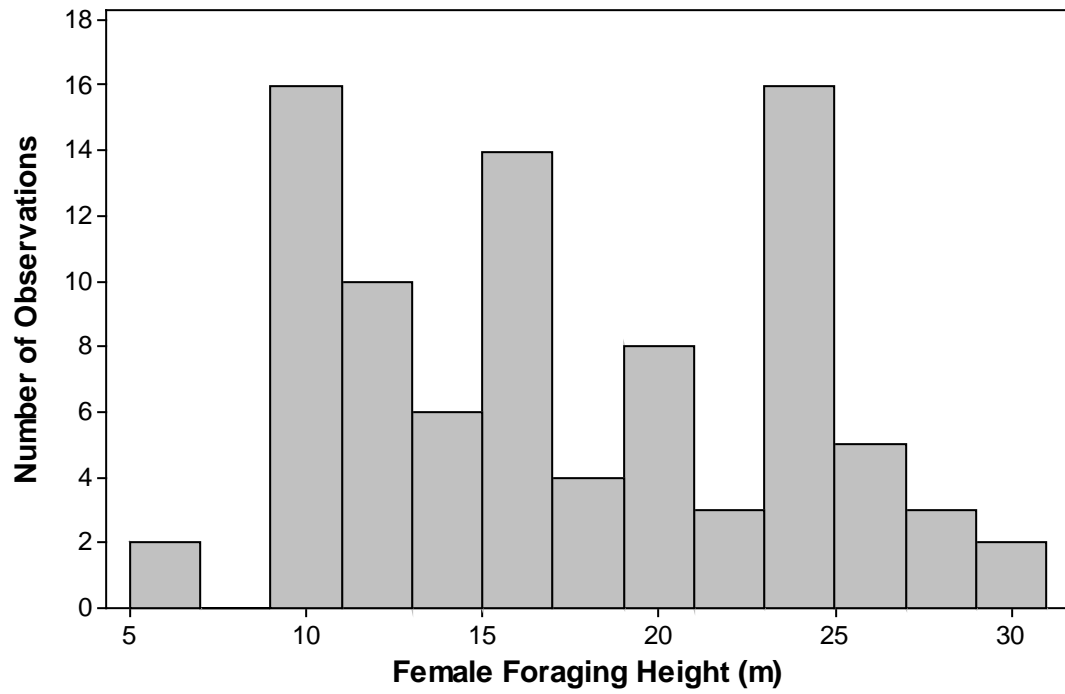


FIGURE 5. Foraging heights of 89 foraging observations on 22 female Cerulean Warblers in southern Indiana from 2007-2009.

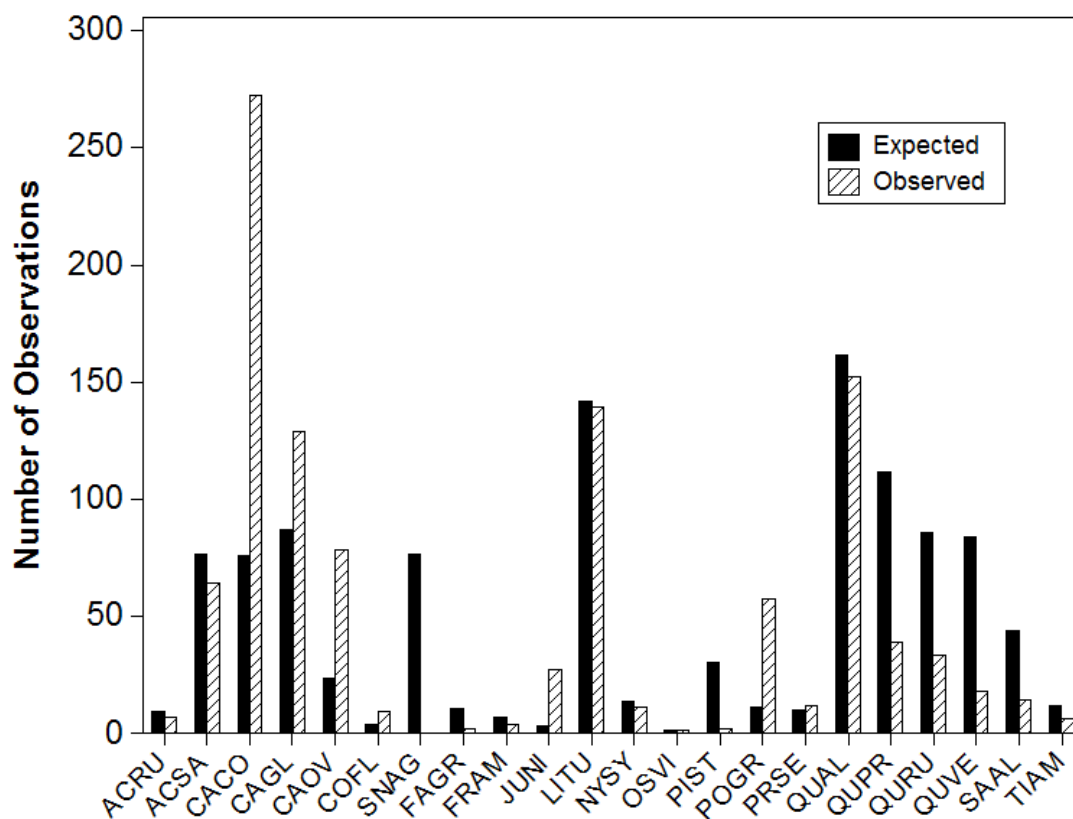


FIGURE 6: Comparison of expected to observed number of foraging observations in Cerulean Warbler territories based on basal area of each tree species in southern Indiana from 2007-2009. Abbreviations are the first two letters of the genus and first two letters of the specific epithet as listed in Table 1. Only tree species used for foraging and recorded in territory vegetation plots are shown, except for snags.

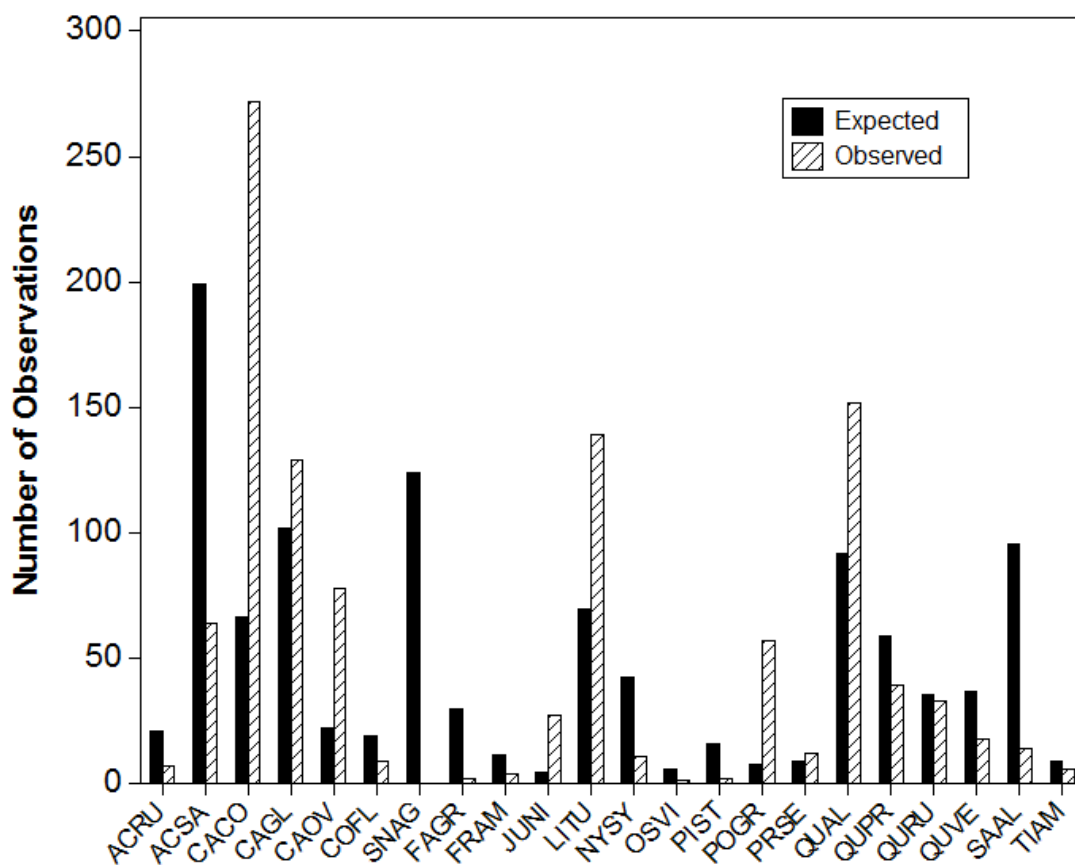


FIGURE 7: Comparison of expected to observed number of foraging observations in Cerulean Warbler territories based on the stem density of each tree species in southern Indiana from 2007-2009. Abbreviations are the first two letters of the genus and first two letters of the specific epithet as listed in Table 1 except for snags. Only tree species used for foraging and recorded in territory vegetation plots are shown, except for snags.

### Appendix I

Number of foraging observations in each tree species for male and female Cerulean Warblers in Morgan-Monroe and Yellowwood state forests in southern Indiana from 2007-2009. Presented in descending order according to observations on males.

<b>Tree Species</b>	<b>Males</b>	<b>Females</b>
Bitternut hickory ( <i>Carya cordiformis</i> )	243	27
White oak ( <i>Quercus alba</i> )	139	13
Tulip tree ( <i>Liriodendron tulipifera</i> )	129	9
Pignut Hickory ( <i>Carya glabra</i> )	126	1
Shagbark hickory ( <i>Carya ovata</i> )	63	15
Big-toothed aspen ( <i>Populus grandidentata</i> )	57	0
Sugar maple ( <i>Acer saccharum</i> )	49	15
Chestnut oak ( <i>Quercus prinus</i> )	36	3
Red oak ( <i>Quercus rubra</i> )	33	0
Black walnut ( <i>Juglans nigra</i> )	27	0
American sycamore ( <i>Platanus occidentalis</i> )	19	0
Black oak ( <i>Quercus velutina</i> )	18	0
Black locust ( <i>Robinia psuedoacacia</i> )	13	0
Black cherry ( <i>Prunus serotina</i> )	12	0
Black gum ( <i>Nyssa sylvatica</i> )	11	0
Flowering dogwood ( <i>Cornus florida</i> )	9	0
Sassafras ( <i>Sassafras albidum</i> )	9	5
Red maple ( <i>Acer rubrum</i> )	7	0
Basswood ( <i>Tilia americana</i> )	6	0
White ash ( <i>Fraxinus americana</i> )	4	0
American beech ( <i>Fagus grandifolia</i> )	2	0
Eastern white pine ( <i>Pinus strobus</i> )	2	0
Chinkapin oak ( <i>Quercus muehlenbergii</i> )	1	0
Hophornbeam ( <i>Ostrya virginiana</i> )	0	1

## Appendix II

The total basal area of each tree species recorded in Cerulean Warbler territories in Morgan-Monroe and Yellowwood state forests in southern Indiana from 2007-2009. Basal area is in square meters.

<b>Tree Species</b>	<b>Basal Area</b>
White oak ( <i>Quercus alba</i> )	10.6930
Tulip tree ( <i>Liriodendron tulipifera</i> )	9.3813
Chestnut oak ( <i>Quercus prinus</i> )	7.3799
Pignut Hickory ( <i>Carya glabra</i> )	5.7698
Red oak ( <i>Quercus rubra</i> )	5.6817
Black oak ( <i>Quercus velutina</i> )	5.5771
Sugar maple ( <i>Acer saccharum</i> )	5.0683
Snags	5.0525
Bitternut hickory ( <i>Carya cordiformis</i> )	5.0128
Sassafras ( <i>Sassafras albidum</i> )	2.8994
Eastern white pine ( <i>Pinus strobus</i> )	1.9870
Shagbark hickory ( <i>Carya ovata</i> )	1.5425
Black gum ( <i>Nyssa sylvatica</i> )	0.9184
Basswood ( <i>Tilia americana</i> )	0.7859
Big-toothed aspen ( <i>Populus grandidentata</i> )	0.7325
American beech ( <i>Fagus grandifolia</i> )	0.6832
Black cherry ( <i>Prunus serotina</i> )	0.6447
Red maple ( <i>Acer rubrum</i> )	0.6119
Shortleaf pine ( <i>Pinus echinata</i> )	0.5836
American elm ( <i>Ulmus americana</i> )	0.5389
White ash ( <i>Fraxinus americana</i> )	0.4523
Flowering dogwood ( <i>Cornus florida</i> )	0.2323
Black walnut ( <i>Juglans nigra</i> )	0.2227
Virginia pine ( <i>Pinus virginiana</i> )	0.1452
Slippery elm ( <i>Ulmus rubra</i> )	0.1094
Hophornbeam ( <i>Ostrya virginiana</i> )	0.0915
American hornbeam ( <i>Carpinus caroliniana</i> )	0.0650
Chinkapin oak ( <i>Quercus muehlenbergii</i> )	0.0380
Yellow birch ( <i>Betula alleghaniensis</i> )	0.0087

### Appendix III

The total tree count for each tree species in Cerulean Warbler territory plots in Morgan-Monroe and Yellowwood state forests in southern Indiana from 2007-2009.

<b>Tree Species</b>	<b>Tree Count</b>
Sugar maple ( <i>Acer saccharum</i> )	180
Snags	112
Pignut Hickory ( <i>Carya glabra</i> )	92
Sassafras ( <i>Sassafras albidum</i> )	86
White oak ( <i>Quercus alba</i> )	83
Tulip tree ( <i>Liriodendron tulipifera</i> )	63
Bitternut hickory ( <i>Carya cordiformis</i> )	60
Chestnut oak ( <i>Quercus prinus</i> )	53
Black gum ( <i>Nyssa sylvatica</i> )	38
Black oak ( <i>Quercus velutina</i> )	33
Red oak ( <i>Quercus rubra</i> )	32
American beech ( <i>Fagus grandifolia</i> )	27
Shagbark hickory ( <i>Carya ovata</i> )	20
Red maple ( <i>Acer rubrum</i> )	19
Flowering dogwood ( <i>Cornus florida</i> )	17
Eastern white pine ( <i>Pinus strobus</i> )	14
White ash ( <i>Fraxinus americana</i> )	10
Shortleaf pine ( <i>Pinus echinata</i> )	8
Black cherry ( <i>Prunus serotina</i> )	8
Basswood ( <i>Tilia americana</i> )	8
Big-toothed aspen ( <i>Populus grandidentata</i> )	7
American hornbeam ( <i>Carpinus caroliniana</i> )	5
Hophornbeam ( <i>Ostrya virginiana</i> )	5
Black walnut ( <i>Juglans nigra</i> )	4
American elm ( <i>Ulmus americana</i> )	4
Slippery elm ( <i>Ulmus rubra</i> )	4
Chinkapin oak ( <i>Quercus muehlenbergii</i> )	2
Yellow birch ( <i>Betula alleghaniensis</i> )	1
Virginia pine ( <i>Pinus virginiana</i> )	1