CERULEAN WARBLER (*SETOPHAGA CERULEA*) NEST PROVISIONING BEHAVIORS AND THE EFFECTS OF FOREST MANAGEMENT PRACTICES ON NEST SUCCESS IN SOUTHERN INDIANA

BY

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ABSTRACT

The Cerulean Warbler (*Setophaga cerulea*), a small insectivorous passerine breeding in eastern North American deciduous forests, is one of the fastest declining Neotropical wood warblers. It is listed as vulnerable by BirdLife International and is state-endangered in Indiana. Despite a substantial increase in research during the past decade, Cerulean Warbler offspring diet has not been studied. Land use practices and climate factors strongly influence arthropod assemblage and any changes to these two factors at Cerulean Warbler breeding grounds will likely influence the diet of this species' young. My primary objectives were to determine which prey types Cerulean Warblers preferred to feed their nestlings, and to describe the diet composition of nestlings. Other objectives were to determine if the proportion of Lepidoptera larvae (caterpillars) in the diet changed during the breeding season. Lepidoptera larvae have a lower chitin and higher fat content than many other arthropods and they are an important food source for numerous birds. We determined the prey types (insects and arachnids) that Cerulean Warbler parents fed their young during the 2011-2013 breeding seasons and compared the proportions of different prey types to prey availability in 2013. Proportion of Lepidoptera larvae in the nestling diet was 65% (n = 23) in 2011, 40% in 2012 (n = 18) and 53% in 2013 (n = 366). In 2013, Lepidoptera larvae comprised 83% of the diet during the peak nestling period which occurred during the end of May into early June. The proportion of Lepidoptera larvae in the nestling diet decreased during the season in 2013. Non- Lepidoptera larvae prey items included Orthoptera, Diptera, Neuroptera, Arachnida, Coleoptera, Hemiptera, and Phasmida.

INTRODUCTION

The relationship between birds and their food resources is central to the study of passerine breeding biology. Spring abundance of food resources is the primary incentive for passerine species that migrate north each spring (Lack 1950), and food availability influences avian fecundity and life-history strategies (Martin 1987). Many insectivorous songbirds take advantage of the large quantity of larval lepidopterans (caterpillars) that emerge during spring by feeding their young a high proportion of this resource (Holmes 1998, Knapton 1984, Biermann and Sealy 1982, Goodbred and Holmes 1996). Lepidoptera larvae are an excellent food source due to their high fat and low chitin (indigestible) content compared to many other arthropods (Karasov 1990, Redford and Dorea 1984). For some passerines, such as the Great Tit (*Parus major*), Lepidoptera larvae are the primary prey type for their young and factors affecting Lepidoptera larvae abundance and distribution can have important repercussions for these birds (Seki and Tekano 1998, Both et al. 2006).

The reproductive success of passerines that are dependent on Lepidoptera larvae to raise their young can be affected by changes in Lepidoptera larvae abundance and distribution due to climate change, habitat alterations, and other factors. Breeding phenology for some songbirds can be closely linked to peaks in Lepidoptera larvae abundance. The timing of breeding for species such as the Great Tit is such that the peak nestling period occurs during peak Lepidoptera larvae abundance (Grieco 2002), whereas for other species such as the Wood Warbler (*Phylloscopus sibilatrix*), the peak in Lepidoptera larvae abundance coincides with its peak incubation period (Maziarz and Wesolowski 2010). Climate change can alter the timing of Lepidoptera larvae peaks; the response of birds to these changes is variable and some species exhibit greater plasticity in adjusting their timing than others (Visser et al. 2006, Both et al.

2006). Migratory species that use photoperiod as a cue to begin migration to breeding grounds may be more susceptible to mismatching since Lepidoptera larvae emergence is governed by local climatic changes (Strode 2003). Mismatches between peak energy demands of nestlings and peak Lepidoptera larvae abundance can cause lower reproductive output in terms of the number of fledglings per nest and the weights of nestlings and fledglings (Visser et al. 2006). Pied Flycatchers (*Ficedula hypoleuca*) were more susceptible to mismatching in forests dominated by oaks (*Quercus* spp.) than in other habitat types, indicating that habitat type can mediate or heighten mismatching effects. Habitat that was dominated by oaks had sharper Lepidoptera larvae peaks, whereas habitat that was not dominated by oaks had a more even abundance of Lepidoptera larvae for a longer period during the breeding season (Burger et al. 2012).

Studies on the relationships between tree species and Lepidoptera larvae indicate that abundance of Lepidoptera larvae can vary across tree species in springtime (Summerville et al. 2003, Foss and Riese 2003, Wagner 2012). Habitat structure and age can also affect arthropod abundance. For example, old growth forests can have higher insect abundance than early successional forests (Jeffries et al. 2006). Thus anthropogenic or natural forest habitat alterations could potentially affect songbird food supply.

Many Nearctic-Neotropical wood warbler species (family Parulidae) rely on Lepidoptera larvae as a food source for their young (Strode 2003, Knapton 1984, Holmes 1998). Information available on the diet of the Cerulean Warbler (*Setophaga cerulea*), a wood warbler that forages for arthropods high in the canopy of hardwood forests, is limited. The Cerulean Warbler is one of the fastest declining wood warblers in North America, with a population decrease of approximately 3% per year (Sauer et al. 2011) and is listed as vulnerable internationally (IUCN

2014), state-endangered in Indiana (IDNR 2012), and is a federal species of concern (USFWS 2012). Its breeding range encompasses portions of mid- and eastern United States and the southern edge of Ontario, Canada, and its winter range is in the Andes Mountains in northern South America (Buehler et al. 2013). It prefers large, mature trees, distinct zonation between the upper canopy and sub-canopy, and a mostly closed canopy (Lynch 1981), with the presence of some canopy gaps (Oliarnyk and Robertson 1996, Weakland et al. 2005). Loss of habitat may explain a portion of the decline in Cerulean Warblers; however, increasing forest cover in some areas within its range indicates that other mechanisms may be involved. In several regions, particularly those with landscapes fragmented by agriculture, reproductive success is low (Buehler et al. 2008) and this can contribute to population declines.

Knowledge of the Cerulean Warbler's diet is mostly limited to two studies describing the stomach contents of 14 adult birds in West Virginia (Sample et al. 1993) and four in Alabama (Howell 1924). In West Virginia, the primary insect orders of stomach contents were Homoptera (57%), Lepidoptera (37%), and Coleoptera (7%), and in Alabama they were Hymenoptera (42%), Lepidoptera (35%), and Coleoptera (23%). Oliarnyk and Roberston (1996) and Barg et al. (2006) described the nest provisioning behaviors of Cerulean Warblers in Ontario, and Boves (2011) reported results from Tennessee, although none of these studies included diet observations of young. Male Cerulean Warblers often bring food to incubating females and Barg et al. (2006) found that 100% of the prey items presented to females were Lepidoptera larvae. Allen and Islam (2004) reported nestling feeding rates in Big Oaks National Wildlife Refuge (BONWR) in southern Indiana, but other nest provisioning behaviors have not been published for this state. Foraging ecology of adults has been studied in Indiana, Illinois, and West Virginia, although prey items were not identified. Cerulean Warblers foraged most frequently in hickories

(*Carya* spp.), white oaks (*Quercus alba*), and tulip trees (*Liriodendron tulipifera*) in Indiana (MacNeil 2010), hickories in Illinois (Gabbe et al. 2002), and hickories, sugar maple (*Acer saccharum*), and chestnut oak (*Quercus prinus*) in West Virginia (George 2009). The warblers' primary foraging method is to glean arthropods off the leaves, but they will also catch prey in the air (MacNeil 2010).

Long-term monitoring data (K. Islam, unpub. data) indicate that Cerulean Warbler breeding phenology in Indiana is similar to this species' phenology in the central hardwood region (Buehler et al. 2013). Male Cerulean Warblers typically arrive in Indiana during the second two weeks of April and females arrive at the end of April and early May. Early May is when the majority of nest building occurs (see Chapter 2). New nests are initiated in late May and into June; however, many of these are likely re-nests instead of late arriving birds. Cerulean Warblers can re-nest several times if their first attempts fail but will only raise one brood per season (Buehler et al. 2013). A nesting cycle has on average five days of nest construction, four days of laying, 11 days of incubation, and a 10 day nestling period (Buehler et al. 2013). In Indiana, the nests are 18 m high on average and are located towards the distal end of the tree branch (Roth and Islam 2008, Wagner and Islam in press).

Studying the breeding biology of Cerulean Warblers is challenging in general due to difficulty in locating nests and inability to access nests because of their height. Nevertheless, substantial efforts have been made during the past decade to understand the Cerulean Warbler at its breeding grounds (e.g. Buehler et al. 2008, Barg et al. 2006, Roth and Islam 2008, Gabbe et al. 2002, Register and Islam 2008, Boves and Buehler 2012, Wagner and Islam in press). According to the United States Fish and Wildlife Service (2007), an important conservation action is to "investigate correlations between climate change, timing of spring arrival of Cerulean

Warblers on breeding grounds, and timing of emergence of insect prey populations." My study focused primarily on identifying important prey items and changes in the diet during the breeding season, knowledge of which can be used in future studies focusing on broader climate change questions.

I studied the diet of Cerulean Warbler young in Indiana with the primary goal of determining the major arthropod orders in their diet and determining prey preference of parents provisioning nestlings. I hypothesized that Cerulean Warblers have a preference for Lepidoptera larvae in that "preference" meant that the proportion of Lepidoptera larvae in the nestling diet would be higher than expected given the availability of Lepidoptera larvae. I also predicted that the proportion of Lepidoptera larvae in the diet of nestlings would be the highest during the peak nestling period and would decline during the breeding season. In conjunction with assessing changes in diet during the breeding season, I determined whether these changes corresponded to alterations of other feeding behaviors such as feeding rates, bill loads (total length of all prey items in the bill), and number of items in the bill. Another objective was to describe general nest provisioning behaviors of the Cerulean Warbler in Indiana including a) a comparison of female and male feeding behaviors with respect to rates, bill loads, and the number of prey items in the bill, b) average feeding rates and length of prey items, c) a comparison of the average size (by length) of prey items in the diet and in the environment, and d) the most common prey sizes (by length) in the diet. An additional objective was to assess reproductive success for Cerulean Warblers in relation to changes in diet among years and during the breeding season. This study occurred during spring 2011-2013 with a major portion of data collection occurring in 2013. In addition, a pilot study was conducted on fledgling diet in 2012 and results are reported herein.

METHODS

Study Area

Research was conducted in the Yellowwood and Morgan-Monroe state forests in southern Indiana, located approximately 30 kilometers east and north of the city of Bloomington, respectively (Figure 1). The landscape has a mixture of moderate to steep, mesic and dry-mesic slopes and is dominated by oaks (*Quercus* spp.), hickories (*Carya* spp.), maples (*Acer* spp.), and American beeches (*Fagus grandifolia*) (Homoya et al. 2013). My research was conducted as part of a larger study designed to measure ecosystem responses to silvicultural methods (Swihart et al. 2013), although I did not investigate silviculture effects on nest provisioning. There were five 225 ha plots in the Yellowwood State Forest and two in the Morgan-Monroe State Forest. There were two additional plots in the Morgan-Monroe State Forest that were not used due to their lack of Cerulean Warblers. The distance between the southernmost and northernmost plots was 25 kilometers which imposed logistical constraints for data collection. The majority of the data came from the treatment sites where clear-cuts, shelterwood cuts, group-cuts, and single tree selection occurred and very few data were from the control sites where no logging occurred.

Nest monitoring

To locate Cerulean Warblers, point counts were conducted in sampling grids within each of the nine plots during the months of May in 2011-2013 (Figure 1). Each grid encompassed 225 ha, with 49 points spaced 200 m apart with a 150 m buffer around the perimeter. Cerulean Warbler presence was documented at each of these points by broadcasting Cerulean Warbler vocalizations and recording Cerulean Warbler response. Upon arrival at a point, we listened for two minutes, broadcast vocalizations using a SanDisk Sansa Clip+ 4 GB MP3 Player attached to a RadioShack Mini Audio amplifier for one minute, then listened for two more minutes. The volume on the amplifiers was set as high as possible without distorting the broadcast. The number of Cerulean Warblers detected was recorded and direction and distance were estimated so that they could be relocated.

In May and June of 2011-2013, Cerulean Warbler nests were located by observing female and male behaviors (e.g. female brings nest material to nest). Nests were monitored every 2-4 days and on consecutive days when nestlings were close to fledging. Because nests are located high in the canopy, spotting scopes and binoculars were used to monitor behaviors and determine nesting stages. Nest monitoring time of day ranged from 0630 to 1830. There was typically one observer and one recorder. In 2011-2012, the standard observation time was 30 min. In order to maximize the number of prey items identified, I increased the observation session time to 1 hr at least once for each nest in 2013. Arrival and departure times of parents and their activities at the nest were recorded. In 2011 and 2012, prey deliveries to nestlings were filmed using a Sony Cybershot 53 zoom attached to a Nikon Prostaff RAIII 82-mm spotting scope equipped with a 20–60x eyepiece. In 2013, prey deliveries were filmed using a Canon Rebel T3i 50 mm camera attached to a Vortex RZR-A1 Razor HD 85 mm angled spotting scope equipped with a 20–60x eyepiece. I experimented with taking photographs of the prey deliveries; however, videos allowed for better prey identification so the majority of results are from prey deliveries that were filmed. Arthropods were identified to order and Lepidoptera larvae to family by viewing the videos and photographs. Heteroptera and Homoptera were grouped together into the category Hemiptera. I assessed the length of each prey item by comparing it to bill length and used the average bill length of Cerulean Warblers (Buehler et al. 2013) to calculate the length of the prey items. A nest was considered successful if there was at least one fledgling, or, for a small number of nests, if 9-10 day old nestlings were observed. The number of 9-10 day old nestlings was used as an estimate of the number of fledglings.

In 2012, fledglings were found opportunistically by listening for their begging calls and I filmed parents delivering food to them. One fledgling belonged to a nest I had monitored during the season, whereas the others were from nests I did not locate. Film times were not very structured and ranged from one to five hours between 0730 and 1600 hr during the month of June. In 2012, nest failure rate was high and I had fewer opportunities to film prey deliveries to nestlings. Therefore, I was able to spend time filming a small sample of fledglings. As such, these data should be viewed as preliminary findings that provide a rough indication of fledgling diet and feeding rates. More rigorous studies are needed to properly describe Cerulean Warbler fledgling diet.

Arthropod sampling

To evaluate the arthropod assemblage in the warblers' foraging habitat, I sampled the arthropods available to the parents during the latter portion of the nestling period to three days post-fledging. I sampled arthropods in both the upper and lower canopy which reflected the variation in Cerulean Warbler foraging heights. I used a branch sampling method similar to Johnson (2000). I constructed a ring pole and attached a 30 gal plastic bag with draw strings (Figure 2). I attached a rope to the draw strings so that the bag could be pulled tight. In one swift movement the bag was put over the end of a branch and closed tight by pulling down on the rope. I cut the branches off with a pole pruner at heights between 7-9 m. Tree species sampled were selected by observing where the parents were foraging which was typically in hickories and white oaks. I collected 30 branch clippings in the lower canopy for each nest and only from branches that had not been disturbed. Branch clippings were taken from between six to 10 different trees for each nest. In addition, the upper canopy (~20 m high) was sampled by climbing the trees with ropes. In the upper canopy, instead of using a pole, the bags were opened wide allowing air to fill the inside and then the end of the branch was covered with the bag, the bag was cinched closed and the branch was cut off with clippers. Ten samples were taken from each tree and 2-3 trees were sampled for each nest. To minimize disturbance to the nests, I did not sample trees immediately adjacent to nest trees, and instead sampled from trees directly outside those trees relative to the direction of the nest. The branch samples were frozen for 24 hours to euthanize the arthropods. The arthropods were removed from the branch clippings following freezing, preserved in 70% ethanol, identified to order (also to family and species for Lepidoptera larvae) and measured to the nearest 0.01 mm. Heteroptera and Homoptera were grouped together in the category Hemiptera. Specimens that were smaller than the smallest prey item in the Cerulean Warbler nestling diet were not included in the analysis.

Data Analysis

I analyzed prey preference using the software program PREFER 5.1 developed by Pankratz (1994) and modeled after a statistical analysis method described by Johnson (1980). The model uses a ranking system to determine the order of preference from most preferred to least preferred but does not infer avoidance of any prey type. I combined lower and upper canopy samples and pooled early season samples together and late season samples together. Specifically, I summed the number of individual prey items for each arthropod order across the samples separately for the two time periods and used the percentages of each order. By pooling the data, I was able to use larger sample sizes for prey availability in my analyses. For two nests that had no corresponding arthropod samples, I used the percentage calculated for other sites at the same time period.

I used linear regression analysis to determine the effect of time of year on Lepidoptera larvae proportion in the nestling diet, and to assess the relationship between the number of nests with nestlings and the proportion of Lepidoptera larvae in the nestling diet. Lepidoptera larvae proportion data were logit-transformed. Regression analyses were conducted using RStudio Version 0.98.490. Differences in feedings rates, bill loads, prey sizes, and number of items/feeding trip were analyzed using two-sample t-tests, paired t-tests, and Mann-Whitney U tests in Minitab 16.2.4. Because a large proportion of nests fledged during the end of May and the first week of June (see Chapter 2, Figure 6), I defined the "early" season as any date before 8 Jun and warblers that had fledglings after that date were considered part of the "late" season breeders. I used this cut-off date to compare changes in feeding rates, bill loads and number of items in the bill between birds nesting in the early season and those nesting in the late season. Feeding rates for songbird nestlings are typically higher for older nestlings. I excluded data for nestlings age 1-3 when comparing rates between the early and late season because I had more feeding observations for nestlings at that age during the early season than the late season. I used the average number of feeds per parent for sample values when analyzing feeding rates. I compared feeding rates between females and males over the entire nestling period. I also separated nestlings into two groups, age 1-5 days old and age 6-10 days old, and compared feeding rates between females and males for the two groups. To standardize data among the three years, I used only the first 30 mins of observations in analyses. Data were checked for normality and homogeneity of variance. Analyses were conducted using Minitab 16.2.4.

Nest survival probability was determined using a system developed by Mayfield (1975), which accounts for the fact that successful nests are found more frequently than nests that fail. To detect differences between survival probability for Cerulean Warblers nesting in the early and late season periods, I used the software program CONTRAST, a modified chi-square program developed by Hines and Sauer (1989). All statistical analyses were conducted using a significance level of $\alpha = 0.05$ and mean ± standard errors are reported.

RESULTS

Branch samples

Lower branch samples were collected for 10 nests in 2013. For six of these same nests, upper canopy samples were collected as well. The three most common groups of arthropods on the branch samples were Coleoptera (34%), Hemiptera (16%), and Lepidoptera larvae (14%) (Table 1). Among Lepidoptera larvae families, Notodontidae (33%), Noctuidae (21%), and Geometridae (19%) were the most common (Table 2). All but one of the Notodontidae specimens were early instar *Lochmaeus* spp.; however, this was the only dominant genus among the samples (Table 3). The mean length of Lepidoptera larvae (13.24 ± 0.91 mm) was greater than the mean length of all other arthropods types [(4.96 ± 0.11 mm) (Two-sample t-test; $t_{67} = 9.05$, $P < 0.001$)].

Diet samples and prey preferences

A total of 52 Cerulean Warbler nests were monitored during 2011-2013 and feeding data were collected from 25 nests. The number of arthropods fed to nestlings that were filmed or photographed in 2011, 2012, and 2013 was 23, 27 and 577, respectively. Prey items were visible in 73-85% of feeding events. Between 13-47% of prey items were only distinguished as "non-Lepidoptera larvae arthropods" meaning that it was apparent that they were not Lepidoptera larvae but could not be identified to a specific order (Table 1). In sum, the sample sizes of prey items used in analyses were 23 in 2011, 18 in 2012, and 366 in 2013. In all three years, Lepidoptera larvae were the most common arthropod order fed to nestlings (65% of prey items in 2011, 44% in 2012 and 53% in 2013). In 2013, Lepidoptera larvae constituted 83% of the diet during the early part of the season during the peak in nestlings (Figure 3). During this year, the proportion of Lepidoptera larvae in the diet decreased during the breeding season (r^2 = - 0.50, P = 0.002). The number of nests with nestlings was positively correlated with the proportion of Lepidoptera larvae in the nestlings diet (r^2 = 0.26, P = 0.001). The families of 37% of the Lepidoptera larvae were identified, and Notodontidae and Noctuidae were fed most frequently (Table 3). Cerulean Warblers fed their nestlings Lepidoptera larvae, Diptera, Lepidoptera adults, Orthoptera, and Opiliones more often relative to their availability (Program PREFER; F (8, 4) = 179.70, $P < 0.05$) (Table 4). However, no distinctions of preference level could be made among these five prey types. Araneae, Hemiptera, Hymenoptera, and Coleoptera were fed less often relative to their availability, but there were no significant differences among these prey types. The majority of Dipterans fed to nestlings were Tipulidae (crane flies).

Feeding rates and bill loads

The mean prey delivery rate (2011-2013) during the entire nestling period for parents combined was 4.31 ± 0.34 deliveries/30 min. Feeding rates early in the season (2011 and 2013) were not different from those later in the season (Square-root, pooled two-sample t-test; t_{17} = -

1.10, $P = 0.29$), however, because of low statistical power due, results are inconclusive. Feeding rates were higher in 2012 (x̄ = 4.93 ± 0.62 deliveries/30 min) than in 2013 (x̄ = 2.83 ± 0.32 deliveries/30 min) for nestlings ages 1-5 days old (Pooled two-sample t-test; $t_{16} = 3.31$, $P = 0.005$). I did not include data from older nestlings because there were so few data for 2012. I did not include 2011 data because the sample size of feeding rates for young nestlings was too small. I found that overall (2011-2013) males fed nestlings more frequently than females (Paired t-test; $t_{25} = 4.21$, $P < 0.001$). When I divided the data into age groups, males still fed more frequently (x̄ = 2.11 ± 0.26 deliveries/30 min) than females (x̄ = 1.27 ± 0.22 deliveries/30 min) when nestlings were 1-5 days old (Paired t-test; $t_{19} = 3.40$, $P = 0.003$). Results suggest that there was a difference in feeding rates between males (mean = 3.24 ± 0.53 deliveries/30 min) and females (x̄ = 2.42 ± 0.36 deliveries/30 min) when nestlings were 6-10 days old (Paired t-test; $t_{15} = 1.87$, $P = 0.08$) but further data are needed.

Bill loads were larger in the first half of the season (x̄ = 23.87 ± 1.1 mm) than in the second half of the season [(x̄ = 19.5 ± 1.0 mm) (Two-sample t-test; $t_{181} = 2.96$, $P = 0.004$)]. There was no difference between female and male bill load size (Pooled two-sample t-test; $t_{65} = -1.00$, $P = 0.32$). Mean length of prey in the diet (14.67 ± 0.43 mm) was greater than mean length of prey in the branch samples [(6.13 ± 0.21 mm) (Two-sample t-test; $t_{481} = 18.01$, $P < 0.001$)]. Food items less than one bill length constituted 24% of the diet, while those between one and three bill lengths were 68%, and items over three bill lengths constituted only 6%.

The proportion of prey deliveries with multiple items was higher in the second half of the breeding season (x̄ = 0.43 ± 0.098) than in the first half of the season [(x̄ = 0.212 ± 0.208) (Pooled two-sample t-test; $t_{10} = -2.35$, $P = 0.04$)]. There was no difference between the proportion of prey deliveries of multiple items for females ($\bar{x}$ = 0.22 ± 0.054) and males [($\bar{x}$ = 0.35 ± 0.079) (Paired t-test; t_{14} = -1.48, P = 0.16)].

In 2012, I filmed 255 feeding events for four sets of fledglings (seven individual fledglings). Prey items were visible in 154 of the events; 18 were unknown and 41 could only be distinguished as non-Lepidoptera larvae arthropods (items that could not be identified to order but were not Lepidoptera larvae). Non-Lepidoptera larvae, orthopterans and Lepidoptera larvae constituted 26%, 21% and 19% of the diet, respectively (Table 5). Of the 10 Lepidoptera larvae that could be identified to family, 7 were Geometridae and 3 were Notodontidae. Except for five feeding events on 31 May 2012, all data were collected after 13 Jun 2012. They were acquired by filming fledglings in shrubs and therefore close to the ground. I noted that the parents tended to forage at a similar level as their fledglings and observed two male parents forage on the ground for a brief time. Each fledgling was only fed by one parent. The mean feeding rate for both sexes was 14.75 ± 0.819 deliveries/hr and feeding rates between sexes did not differ (Mann-Whitney U test; P = 0.79).

Brooding females would typically get off the nest when males arrived to feed the nestlings. However, the females would often remain at the nest, especially when nestlings were young and stand at the edge while the male fed the nestlings, or the male would give the prey item to the female which she would then feed to the nestlings. I witnessed the female opening her bill towards the male several times, keeping it open for several seconds. The male usually responded by giving the prey to the female. Food was frequently put into a nestling's mouth several times before the nestling ate it and occasionally it would first be put in one nestling's mouth, removed and then fed to another nestling. The parents often pinched the Lepidoptera larvae with their bill in several places in between feeding attempts. I witnessed two incidents of parents ripping apart a Lepidoptera larva by each pulling on one end.

Nesting success

Mayfield (1975) nest success was 35% in 2011, 6% in 2012 and 33% in 2013. The average nest success across years was 24.7%. There was no difference in survival probability for birds nesting early and late in the season during 2011 and 2013 (Program CONTRAST; $\chi^2 = 0.23$, $P = 0.63$), however, because of low statistical power these results are inconclusive. I excluded 2012 in the early/late season analysis because I only found one nest after the first week in June during that year. The number of fledglings across years ranged from 2-3/nest.

DISCUSSION

Lepidoptera larvae were the primary food source for Cerulean Warbler nestlings particularly during the peak nestling period which occurred during the end of May and the first week of June. Studies of related species also showed Lepidoptera larvae as the principal food source for nestlings (e.g. Knapton 1984). Nashville Warblers (*Vermivora ruficapilla*) fed their nestlings Lepidoptera larvae 89% of the time, with the remaining diet proportion consisting of Diptera, Coleoptera, Araneae, and unknown prey items (Knapton 1984). Sample (1993) and Howell (1924) reported a much lower proportion of Lepidoptera larvae in the diet of adult Cerulean Warblers. In these studies, Homoptera and Hymenoptera had the highest proportions. Lepidoptera larvae were still a major component of the adults' diet (Sample 1993, Howell 1924); however, they may have been harder to identify than other prey types because of their softer body. Likewise, parents may be more selective about the food they bring to their nestlings than the food they themselves consume.

When diet and prey availability were compared, Lepidoptera larvae, Diptera, Lepidoptera adults, Orthoptera, and Opiliones were preferred over Araneae, Hemiptera, Hymenoptera, and Coleoptera. Although Dipterans had the second highest proportion in the diet, Diptera availability may have been underestimated due to my sampling technique since Cerulean Warblers often catch prey in the air (MacNeil 2010, Buehler et al. 2013) and my technique did not specifically target flying insects. Many of the Dipterans fed to nestlings were crane flies, which have long, cylindrical, soft bodies similar to Lepidoptera larvae. Another potential bias in our results could have occurred because certain prey were harder to identify in the videos and photographs (e.g. Hemiptera) than others (e.g. Araneae) and would therefore, be distinguished only as non-Lepidoptera larvae arthropods more frequently than other prey types. There were a number of items that could only be identified as non-Lepidoptera larvae arthropods, and diet assessments in future studies would have greater accuracy if more items could be identified to order. Although I used high quality equipment in my study, identification of arthropods could be improved by using an even higher quality digiscope set-up. Likewise, video quality would improve if a camera system could be installed close to the nests. However, these options are considerably more expensive. Other techniques for studying nestling diet include fecal sac analysis, throat ligatures, and forced regurgitation but these are only viable options for species with accessible nests.

I found that the proportion of Lepidoptera larvae in the diet decreased during the course of the season in 2013, as it did in other similar studies (e.g. García-Navas and Sanz 2011). Due to low statistical power, I was unable to conclude whether survival probability differed between warblers nesting in the early versus late season. I did not investigate how the decrease may have affected nestling growth rates or the number of fledglings per nest or their weight. However, I found that the number of items in each bill load increased in the second half of the season which may have at least partially compensated for the lower proportion of Lepidoptera larvae. The non-Lepidoptera larvae arthropods available in the canopy were generally smaller than the Lepidoptera larvae available, and therefore, Cerulean Warbler parents would have had to capture more of them to maintain comparable amounts of food brought to the nestlings later in the season. Despite having more items in their bill during food delivery events, the bill load decreased in the late season indicating that the parents may not have been able to compensate completely. Blue Tits (*Cyanistes caeruleus*) on mainland Spain increased their feeding rates to compensate for poorer food quality later in the breeding season (García-Navas and Sanz 2011), whereas Blue Tits in Corsica, France compensated by bringing larger items (Tremblay et al. 2005). The feeding rate of Blue Tits in Corsica was higher in areas where Lepidoptera larvae were more abundant than in areas of low abundance; however, the tits brought back larger Lepidoptera larvae in the latter areas so that the biomass fed per nestling was not different between areas. Overall, the Cerulean Warblers were selecting larger items in the environment compared to what was available. Bill loads with multiple items often had one Lepidoptera larvae (usually near the base of the bill indicating it was found first) plus one or more smaller non-Lepidoptera larvae arthropods. It is possible that the warbler parents would find a Lepidoptera larva first and gather additional items on their return journey to the nest.

The average feeding rate in 2011-2013 was similar to what Boves (2011) found in Tennessee but higher than what Allen and Islam (2004) found in BONWR and Barg et al. (2006) and Oliarnyk and Robertson (1996) found in Ontario. I found that feeding rates were higher in

2012 than in 2013. In 2012, leaf-out occurred earlier than normal and there was a drought during the spring and summer. If there were fewer Lepidoptera larvae available due to these conditions, the warblers may have increased their feeding rates to offset lower quality food deliveries. However, higher feeding rates in 2012 may have contributed to higher predation rates adding to the high failure rate. I did not have enough data to compare the bill load or number of items in the bill between the years.

I documented two predation events during the three years. I observed a Red-bellied Woodpecker (*Melanerpes carolinus)* remove a Cerulean Warbler nestling from a nest in 2012 (Auer et al. 2013), and I recorded an unknown species of bird, about the same size as a woodpecker, prey on another nest during incubation. The latter event was captured by a trail camera aimed at a nest when I was experimenting with trail cameras in 2012. The species could not be identified because the image was not clear enough. In 2011, a failed nest was observed partially torn at the bottom. Another nest failed after a hail storm and disappeared. Except for these incidents when direct cause could be inferred, sources for the remaining nest failures are unknown but likely due to predation which is the leading cause of nest failure in passerines (Martin 1995).

Females fed significantly less frequently than males during the first half of the nestling stage; this difference was not as apparent for older nestlings but results were inconclusive. Lower feeding rates for females when nestlings were young was likely due to the considerable amount of time females spend brooding younger nestlings which decreases as the nestlings get older (Barg et al. 2006). Females spend more time brooding younger nestlings because altricial nestlings do not develop endothermy until at least 4.5 days post-hatching (Dunn 1975). Other researchers found no difference in feeding rates between female and male Cerulean Warblers

(Oliarnyk and Robertson 1996, Barg et al. 2006, Boves 2013). Allen and Islam (2004) reported a higher feeding rate for females when nestlings were six days old but no comparisons were made for the entire nestling period and sample size was small.

Average nesting success was very similar in 2011 and 2013 and much lower in 2012. Spring 2011 had above average rainfall whereas spring 2012 had very dry conditions. Drought can negatively affect songbird reproduction (George et al. 1992) and likely contributed in large part to the low nest success in 2012. In 2012, spring temperatures were relatively high especially in March (NOAA 2013) and trees leafed out earlier than normal (S. Auer pers. obs.). Although I was not tracking Lepidoptera larvae phenology, peaks in abundance were likely earlier that year since Lepidoptera larvae emergence is largely influenced by temperature cues (Strode 2003). Drought is known to negatively affect Lepidoptera larvae abundance (Shure et al. 1998) and if there was a lack of Lepidoptera larvae during the nestling period it may have affected the warbler's nest success in a number of ways. The drought and early leaf-out may have affected the food sources of predators, causing the predators to feed more heavily on Cerulean Warbler eggs and young. In years when there is a superabundance of Lepidoptera larvae, songbird nest predation is lower because generalist nest predators such as corvids and rodents shift the focus of their foraging more to Lepidoptera larvae (Ostfeld and Keesing 2000); prey switching in general is a common phenomenon (Murdoch 1969). Cerulean Warbler nestlings may have had a less nutritious diet and survived at a lower rate, although we did not see any evidence of weakened nestlings. The higher rate of feeding trips may have been related to a reduced availability of Lepidoptera larvae. Higher frequency of feeding trips to the nest can increase predator detection (Skutch 1949, Mayfield 1975) and may have contributed to higher predation rates in 2012 which was probably the major cause of nest failure. Likewise, there may have been higher predation rates due to increased time spent foraging versus defending young due to a drought induced food shortage (Duncan Rastogi et al. 2006).

The majority of the fledgling diet data were from the latter portion of the 2012 breeding season and probably do not represent the typical fledgling diet, especially during peak fledging which occurs earlier. Orthopterans and Lepidoptera larvae were fed most frequently to the fledglings. The most noteworthy difference between the fledgling and nestling diet was the high proportion of Orthopterans in the fledglings' diet. Many of these were in the Oecanthinae (tree crickets) subfamily of the family Gryllidae. Further studies are needed to assess fledgling diet adequately.

The relationship between Cerulean Warblers and Lepidoptera larvae warrants further investigation, particularly with respect to the effects of climate and habitat. Long-term studies on Lepidoptera larvae peaks and Cerulean Warbler breeding phenology could provide information on potential climate change effects. If certain tree species have a greater abundance of Lepidoptera larvae, it follows that Cerulean Warbler pairs with more of these trees in their territories could potentially increase their reproductive success. Moreover, habitat structure could also have an effect on Lepidoptera larvae supply and therefore affect reproductive success. Studying diet in conjunction with weighing and counting fledglings could further elucidate the effects of food on breeding success.

LITERATURE CITED

Allen, J., and K. Islam. 2004. Gender differences in parental feeding effort of cerulean warbler parents at Big Oaks National Wildlife Refuge, Indiana. Proceedings of the Indiana Academy of Science 113:162-165.

Auer, S. A., K. Islam, K. W. Barnes, and J. A. Brown. 2013. Documentation of predation of a nestling cerulean warbler by a red-bellied woodpecker. Wilson Journal of Ornithology 125:642-646.

Barg, J. J., J. Jones, M. K. Girvan, and R. L. Robertson, R. 2006. Within-pair interactions and parental behavior of cerulean warblers breeding in eastern Ontario. Wilson Journal of Ornithology 118:316-325.

Biermann, G. C., and S. G. Sealy. 1982. Parental feeding of nestling yellow warblers in relation to brood size and prey availability. Auk 99:332-341.

Both, C., S. Bouwhuis, C. M. Lessells, and M. E. Visser. 2006. Climate change and population declines in a long-distance migratory bird. Nature 441:81-83.

Boves, T. 2011. Multiple responses by cerulean warblers to experimental forest disturbance in the Appalachian Mountains. Ph. D. dissertation, University of Tennessee, Knoxville, TN.

Boves, T. J., and D. A Buehler. 2012. Breeding biology, behavior, and ecology of *Setophaga cerulea* in the Cumberland Mountains, Tennessee. Southeastern Naturalist 11:319-330.

Buehler, D. A., J. J. Giocomo, J. Jones, P. B. Hamel, C. M. Rogers, T. A. Beachy, D. W. Varble, C. P. Nicholson, K. L. Roth, J. Barg, R. J. Robertson, J. R. Robb, and K. Islam. 2008. Cerulean warbler reproduction, survival, and models of population decline. Journal of Wildlife Management 72:646-653.

Buehler, D. A., P. B. Hamel, and T. J. Boves. 2013. Cerulean warbler (*Setophaga cerulea*). In Birds of North America Online (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, New York, NY, USA. <http://bna.birds.cornell.edu/bna/species/511/>. Accessed 2 Mar 2014.

Burger, C., E. Belskii, T. Eeva, T. Laaksonen, M. Mägi, R. Mänd, A. Qvarnström, T. Slagsvold, T. Veen, M. E. Visser, K. L. Wiebe, C. Wiley, J. Wright, and C. Both. 2012. Climate change, breeding date and nestling diet: How temperature differentially affects seasonal changes in pied flycatcher diet depending on habitat variation. Journal of Animal Ecology 81:926–936.

Duncan Rastogi, A., L. Zanette, and M. Clinchy. 2006. Food availability affects diurnal nest predation and adult antipredator behaviour in song sparrows (*Melospiza melodia*). Animal behaviour 72:933-940.

Dunn, E. H. 1975. The timing of endothermy in the development of altrical birds. Condor 77:288-293.

Foss, L. K., and L. K. Rieske. 2003. Species-specific differences in oak foliage affect preference and performance of gypsy moth caterpillars. Entomologia Experimentalis et Applicata 108:87-93.

Gabbe, A. P., S. K. Robinson, and J. D. Brawn. 2002. Tree species preferences of foraging insectivorous birds: implications for floodplain forest restoration. Conservation Biology 16:462-470.

García-Navas, V., and J. J. Sanz. 2011. The importance of a main dish: nestling diet and foraging behaviour in Mediterranean blue tits in relation to prey phenology. Oecologia 165:639-649.

George, G. A. 2009. Foraging ecology of male cerulean warblers and other Neotropical migrants. Ph.D. dissertation, West Virginia University, Morgantown, West Virginia.

George, T. L., A. C. Fowler, R. L. Knight, and L. C. McEwen. 1992. Impacts of a severe drought on grassland birds in western North Dakota. Ecological Applications 2:275-284.

Goodbred, C. O. N., and R. T. Holmes. 1996. Factors affecting food provisioning of nestling black-throated blue warblers. Wilson Bulletin 108:467-479.

Grieco, F. 2002. Time constraint on food choice in provisioning blue tits, *Parus caeruleus*: the relationship between feeding rate and prey size. Animal Behaviour 64:517-526.

Hines, J. E., and J. R. Sauer. 1989. Program CONTRAST—a general program for the analysis of several survival or recovery rate estimates. Fish and Wildlife Technical Report 24:1–7.

Holmes, S. B. 1998. Reproduction and nest behaviour of Tennessee warblers *Vermivora peregrina* in forests treated with Lepidoptera-specific insecticides. Journal of Applied Ecology 35:185-194.

Homoya, M. A., D. B. Abrell, J. A. Aldrich, and T. W. Post. 2013. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94:245-268.

Howell, A. 1924. Birds of Alabama. Bureau of Biological Survey. US Department of Agriculture and Department of Game and Fisheries, Brown Printing Company, Montgomery, Alabama.

Indiana Department of Natural Resources (IDNR). 2012. Indiana’s state endangered species. http://www.in.gov/dnr/fishwild/files/fw-State_Endangered_Species_list.pdf. Accessed 01 Jan 2013.

International Union for Conservation of Nature (IUCN). 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. Accessed 25 Mar 2014.

Jeffries, J. M., R. J. Marquis, and R. E. Forkner. 2006. Forest age influences oak insect herbivore community structure, richness, and density. Ecological Applications 16:901-912.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Johnson, M. D. 2000. Evaluation of an arthropod sampling technique for measuring food availability for forest insectivorous birds. Journal of Field Ornithology 71:88-109.

Karasov, W. H. 1990. Digestion in birds: chemical and physiological determinants and ecological implications. Studies in Avian Biology 13:391-415.

Knapton, R. W. 1984. Parental feeding of nestling Nashville warblers: the effects of food type, brood-size, nestling age, and time of day. Wilson Bulletin 96:594-602.

Lack, D. 1950. The breeding seasons of European birds. Ibis 92:288-316.

Lynch, J. M. 1981. Status of the cerulean warbler in the Roanoke River Basin of North Carolina. Chat 45:29-35.

MacNeil, M. M. 2010. Does timber harvesting affect cerulean warbler foraging ecology? M.Sc. thesis, Ball State University, Muncie, IN.

Martin, T. E. 1987. Food as a limit on breeding birds: a life-history perspective. Annual Review of Ecology and Systematics 18:453-487.

Martin, T. E. 1995. Avian life history evolution in relation to nest sites, nest predation, and food. Ecological Monographs 65:101-127.

Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bulletin 87:456-466.

Maziarz, M., and T. Wesołowski. 2010. Timing of breeding and nestling diet of wood warbler *Phylloscopus sibilatrix* in relation to changing food supply. Bird Study 57:540-552.

Murdoch, W. W. 1969. Switching in general predators: experiments on predator specificity and stability of prey populations. Ecological Monographs 39:335-354.

National Oceanic and Atmospheric Administration (NOAA). 2013. Quality Controlled Local Climatological Data. < http://cdo.ncdc.noaa.gov/qclcd/QCLCD?prior=N />. Accessed 20 Dec 2013.

Oliarnyk, C. J., and R. J. Robertson. 1996. Breeding behavior and reproductive success of cerulean warblers in southeastern Ontario. Wilson Bulletin 108:673-684.

Ostfeld, R. S., and F. Keesing. 2000. Pulsed resources and community dynamics of consumers in terrestrial ecosystems. Trends in Ecology and Evolution 15:232-237.

Pankratz, C. 1994. PREFER—Preference assessment v5.1 (Windows, OS2). Northern Prairie Science Center, North Dakota.

Raley, C. M., and S. H. Anderson. 1990. Availability and use of arthropod food resources by Wilson's warblers and Lincoln's sparrows in southeastern Wyoming. Condor 92:141-150.

Redford, K. H., and J. G. Dorea. 1984. The nutritional value of invertebrates with emphasis on ants and termites as food for mammals. Journal of Zoology 203:385-395.

Register, S. M., and K. Islam. 2008. Effects of silvicultural treatments on cerulean warbler (*Dendroica cerulea*) abundance in southern Indiana. Forest Ecology and Management 255: 3502-3505.

Roth, K. L., and K. Islam. 2008. Habitat selection and reproductive success of cerulean warblers in Indiana. Wilson Journal of Ornithology 120:105-110.

Sample, B. E., R. J. Cooper, and R. C. Whitmore. 1993. Dietary shifts among songbirds from a diflubenzuron-treated forest. Condor 95:616-624.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American breeding bird survey, results and analysis 1966-2010. Version 12.07.2011. USGS Patuxent Wildlife Research Center, Laurel, Maryland, USA. <http://www.mbr-pwrc.usgs.gov/bbs/bbs.html>.

Seki, S. I., and H. Takano. 1998. Caterpillar abundance in the territory affects the breeding performance of great tit *Parus major minor*. Oecologia 114:514-521.

Shure, D. J., P. D. Mooreside, and S.M. Ogle. 1998. Rainfall effects on plant-herbivore processes in an upland oak forest. Ecology 79:604-617.

Skutch, A. F. 1949. Do tropical birds rear as many young as they can nourish? Ibis 91:430-45.

Strode, P. K. 2003. Implications of climate change for North American wood warblers (Parulidae). Global Change Biology 9:1137-1144.

Summerville, K. S., T. O. Crist, J. K. Kahn, and J. C. Gering. 2003. Community structure of arboreal caterpillars within and among four tree species of the eastern deciduous forest. Ecological Entomology 28:747-757.

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. General Technical Report NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 350 p.

Tremblay, I., D. Thomas, J. Blondel, P. Perret, and M. M. Lambrechts. 2005. The effect of habitat quality on foraging patterns, provisioning rate and nestling growth in Corsican Blue Tits *Parus caeruleus*. Ibis 147:17-24.

United States Fish and Wildlife Service (USFWS). 2007. A conservation action plan for the cerulean warbler (*Dendroica cerulea*). Produced for the USFWS Division of Migratory Bird Management Focal Species Program. <http://www.fws.gov/midwest/eco_serv/soc/birds/cerw/documents/cerw_Action%20Plan_28June07.pdf>. Accessed 25 Mar 2014.

United States Fish and Wildlife Service (USFWS). 2012. Species of concern. <http://www.fws.gov/midwest/es/soc/>. Accessed 01 Jan 2013.

Visser, M. E., L. J. M. Holleman, and P. Gienapp. 2006. Shifts in caterpillar biomass phenology due to climate change and its impact on the breeding biology of an insectivorous bird. Oecologia 147:164-172.

Wagner, J. R. 2012. Cerulean warbler population and breeding response to recent silviculture and influences of prey availability on avian nesting ecology. M.Sc. thesis, Ball State University, Muncie, IN.

Wagner, J. R., and K. Islam. In press. Nest-site selection and breeding ecology of the cerulean warbler in southern Indiana. Northeastern Naturalist.

Weakland, C. A., P. B. Wood, and R. Holberton. 2005. Cerulean warbler (*Dendroica cerulea*) microhabitat and landscape-level habitat characteristics in southern West Virginia. Auk 122:497-508.

FIGURES

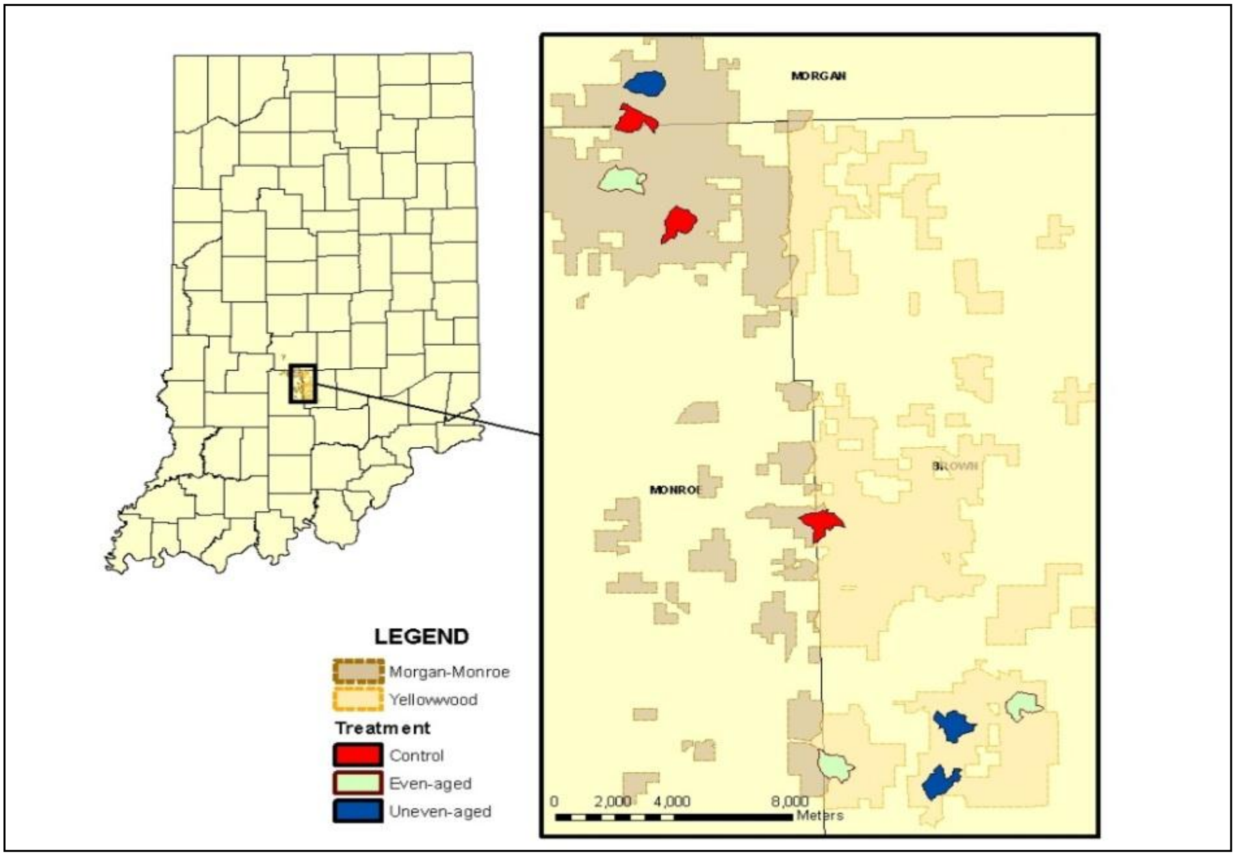

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Figure 1. The Hardwood Ecosystem Experiment study design in Yellowwood and Morgan-Monroe state forests in Indiana.

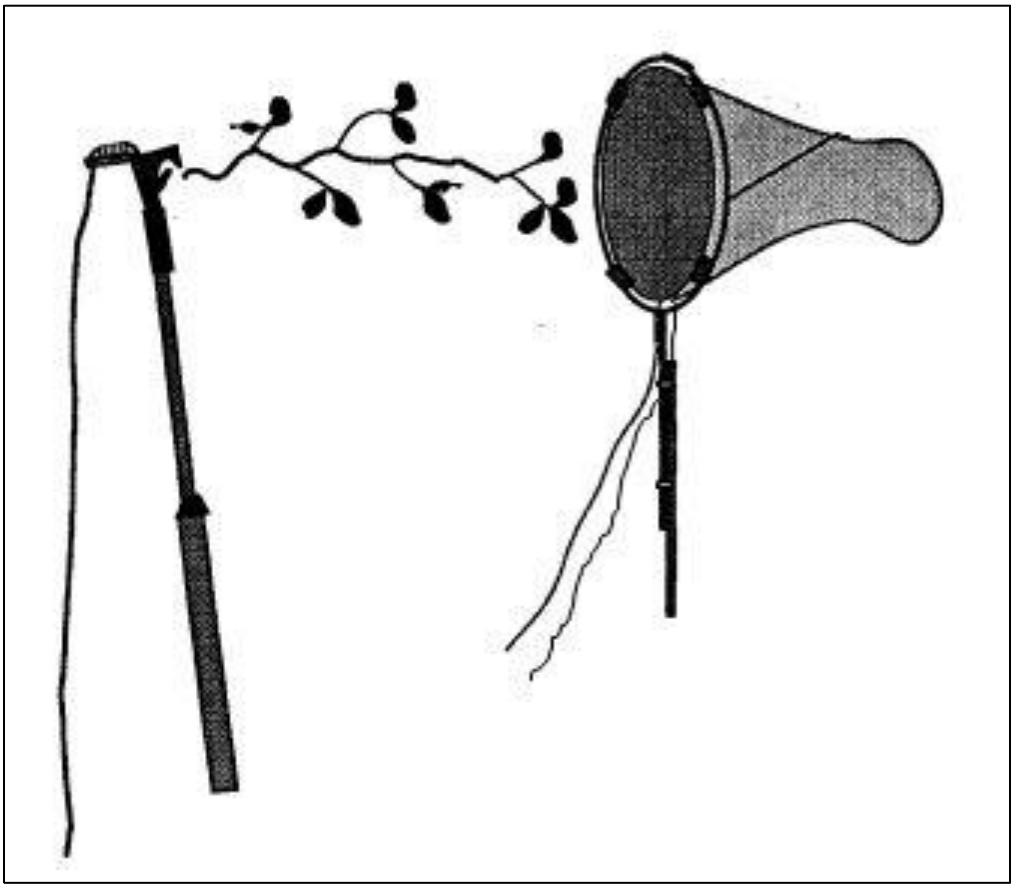

Figure 2. Branch sampling design adapted from Johnson (2000) was used to sample arthropods in south-central Indiana. A 30 gal plastic bag was attached to a ring at the end of a pole and pinned to the ring with plastic clamps. A drawstring was used to pull the bag tight over the end of branches and then a pole pruner was used to clip off the branch.

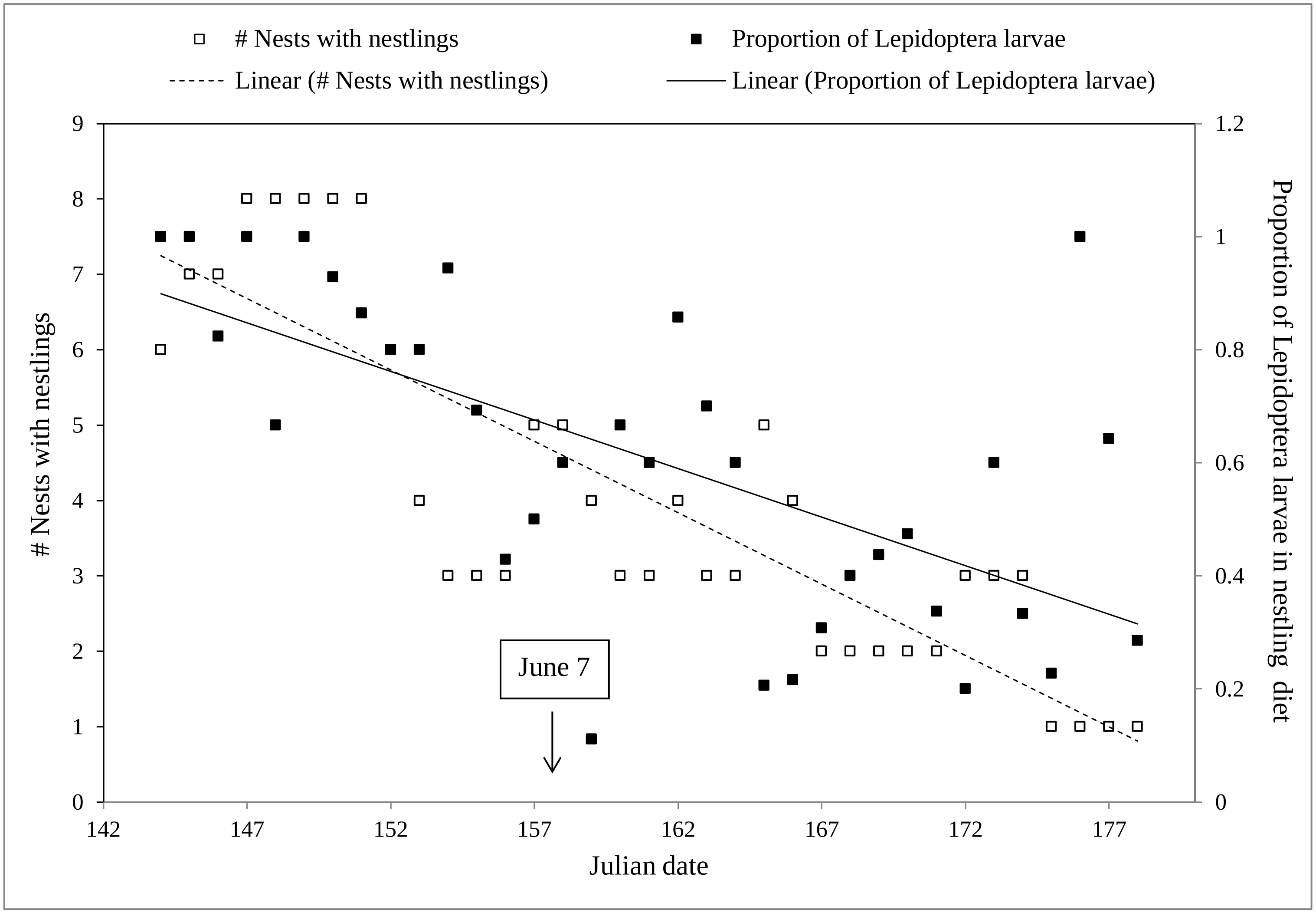

Figure 3. Number of Cerulean Warbler nests with nestlings and the proportion of Lepidoptera larvae in the diet of Cerulean Warbler nestlings in Yellowwood and Morgan–Monroe state forests in 2013. Lepidoptera larvae decreased from May 24 to June 27, 2013 ($r^2 = 0.50$).

TABLES

Table 1. Prey items in branch samples (2013) and diet of nestlings (2011-2013) in Yellowwood and Morgan-Monroe state forests in Indiana.

	2013				2012		2011	
Arthropod Order	Individuals in branch samples	%	Individuals in diet	%	Individuals in diet	%	Individuals in diet	%
Coleoptera	157	34.06	12	3.28	0	0	0	0
Hemiptera	76	16.49	8	2.19	0	0	0	0
Lepidoptera larvae	66	14.32	194	53.01	8	44.44	15	65.00
Araneae	58	12.58	5	1.37	0	0	0	0
Hymenoptera	39	8.46	2	<1.00	0	0	0	0
Orthoptera	23	4.99	6	1.64	0	0	1	4.00
Diptera	14	3.04	37	10.11	2	11.11	0	0
Ixodida	7	1.52	0	0.00	0	0	0	0
Opiliones	4	<1.00	2	<1.00	0	0	0	0
Plecoptera	3	<1.00	0	0	0	0	0	0
Neuroptera	3	<1.00	0	0	0	0	0	0
Mecoptera	3	<1.00	0	0	0	0	0	0
Psocoptera	3	<1.00	0	0	0	0	0	0
Plecoptera	3	<1.00	0	0	0	0	0	0
Isoptera	1	<1.00	0	0	0	0	0	0
Strepsitera	1	<1.00	0	0	0	0	0	0
Phasmida	0	0	1	<1.00	0	0	2**	9.00
Adult Lepidoptera	1	0	3	<1.00	0	0	2	9.00
Unknown	0	0	56	NA	2	NA	9	NA
Other*	NA	NA	96	26.23	8	44.44	3	13.00

*Prey items that were not Lepidoptera larvae but could not be identified to order
**One of these prey items was not actually consumed by the nestling.

Table 2. Lepidoptera larvae families in branch samples and diet of Cerulean Warbler nestlings in Yellowwood and Morgan-Monroe state forests in Indiana during May and June, 2013. Only 37% of the Lepidoptera larvae in the diet were identified to family and the remaining 63% were not distinguishable.

Lepidoptera family	Individuals in branch samples	%	Individuals in diet	%
Noctuoidea*	NA	NA	8	11.00
Notodontidae	21	33.33	22	31.00
Noctuidae	13	20.63	21	30.00
Geometridae	12	19.05	14	20.00
Tortricidae	7	11.11	5	7.00
Gelechiidae	3	4.76	1	1.00
Erebidae	3	4.76	0	0
Gelechioidea**	2	3.17	0	0
Limacodidae	1	1.59	0	0
Sphingidae	1	1.59	0	0

*Noctuoidea is a superfamily that includes Notodontidae, Noctuidae and Erebidae

**Gelechioidea is a superfamily that includes Gelechiidae

Table 3. Lepidoptera larvae species in branch samples. Branch samples were collected near Cerulean Warbler nests in Yellowwood and Morgan-Monroe state forests in Indiana in 2013.

Species	# individuals
Acronicta sp.	1
Amorpha juglandis	1
Amphipyra pyramidoides	1
Besma quercivoraria	1
Choristoneura rosaceana	1
Choristoneura spp.	3
Cleora spp.	2
Dichomeris ligulella	2
Dichomeris sp.	1
Ennominae sp.	1
Himella intractata	1
Hypagirtis unipuncta	1
Hypena madefactalis	1
Hyphantria cunea	1
Iridopsis humaria	1
Speranza pustularia	1
Lithophane antennata	1
Lithophane sp.	2
Lochmaeus spp. (early instars)	21
Olethreutes sp.	1
Paectes spp.	1
Panopoda sp.	1
Peridea basitriens	1
Pero sp.	1
Protoboarmia porcelaria	1
Unknown	12

Table 4. Ranking of prey types in Cerulean Warbler nestling diet in Yellowwood and Morgan-Monroe state forests in Indiana in 2013. Prey types are ranked from most to least preferred. Samples were collected in the upper and lower canopy. Preference was significantly different between the top five ranked items and the items ranked 6-9; however, there was no difference among items within these two groups.

Rank	Prey type	Mean difference in ranks
1	Diptera	-2.83
2	Lepidoptera larvae	-2.75
3	Adult Lepidoptera	-2.54
4	Orthoptera	-1.29
5	Opiliones	-1.20
6	Hymenoptera	1.87
7	Araneae	2.2
8	Hemiptera	3.04
9	Coleoptera	3.50

Table 5. Diet of Cerulean Warbler fledglings in Yellowwood and Morgan-Monroe state forests in Indiana in 2012. N = 7 fledglings.

Arthropod order	Individuals in diet	%
Other*	42	31.11
Orthoptera	33	24.44
Caterpillars	30	22.22
Diptera	10	7.41
Neuroptera	7	5.19
Araneae	5	3.7
Adult Lepidoptera	4	2.96
Coleoptera	2	1.48
Phasmida**	2	1.48

*Arthropods that were not Lepidoptera larvae but could not be identified to order
**Not actually consumed by fledgling.

CHAPTER 2. CERULEAN WARBLER BREEDING BIOLOGY AND THE EFFECTS OF SILVICULTURE ON NESTING SUCCESS

ABSTRACT

I studied Cerulean Warbler (*Setophaga cerulea*) breeding biology and the effects of silviculture on Cerulean Warblers in the hardwood forests of southern Indiana. Silviculture treatments were applied in fall 2008 and nest monitoring occurred in 2011-2013. Nest monitoring was conducted in three even-aged, three uneven-aged, and three control units that were each 225 ha. Even-aged units received clear-cut and shelterwood harvests, uneven-aged units received group-cuts and single tree selection harvests, and control units received no harvest. Mayfield (1975) nesting success was 35% in 2011, 6% in 2012 and 33% in 2013 with an average of 24.7% across the three years. Due to the small sample size of nests, results for silviculture treatment effects on nesting success were inconclusive. Cerulean Warblers nested most often in white oaks (*Quercus alba*); on northeast facing slopes, ridgetops, and in riparian areas; and on the south side of the nest tree.

INTRODUCTION

The Cerulean Warbler (*Setophaga cerulea*), once a common spring migrant of eastern hardwood forests, is one of the fastest declining songbirds in North America, decreasing at a rate of approximately 3% per year (Sauer et al. 2011). It is considered a species of concern in the United States (USFWS 2012), vulnerable to extinction internationally (IUCN 2014), and endangered in Indiana (IDNR 2012). Despite the recent regeneration of hardwood forests in central and northern United States, some forest interior birds such as the Cerulean Warbler have declined (Sauer et al. 2011). The reason for this species' decline is not straightforward, and multiple studies indicate that its population decrease is likely caused by a combination of factors. First, an increase in habitat fragmentation and a lack of preferred structural features, such as a heterogeneous canopy, may be reducing the amount of appropriate Cerulean Warbler habitat (Buehler et al. 2013). Cerulean Warblers prefer areas with large mature trees (Robbins et al. 1992), distinct zonation between the upper canopy and sub-canopy, and a mostly closed canopy (Lynch 1981), with the presence of some canopy gaps (Oliarnyk and Robertson 1996, Weakland et al. 2005). Second, lower rates of disturbance events such as fire, which occurred frequently prior to European settlement, may diminish the overall quality of forest habitat for Cerulean Warblers (Saab and Powell 2005). Third, Cerulean Warblers have lost a significant amount of habitat at their wintering grounds in the Andes Mountains in South America (Buehler et al. 2013). Fourth, although habitat loss and fragmentation are believed to be leading causes of the decline in Cerulean Warblers, low reproductive success is likely an important contributor. In some regions, especially those with landscapes fragmented by agriculture, reproductive success is low and range-wide reproductive rates are not high enough to offset adult mortality (Buehler et al. 2008, Rogers 2013).

Multiple studies across the Cerulean Warbler's breeding range have been conducted to identify preferred habitat features and the effects of habitat on fecundity (Oliarnyk and Robertson 1996, Stoleson 2004, Weakland et al. 2005, Wood et al. 2005, Wood et al. 2006, Bakermans and Rodewald 2009, Bakermans et al. 2012, Wood and Perkins 2012, Boves et al. 2013a, Boves et al. 2013b, Sheehan et al. 2013). Most studies have focused on the effect of habitat on settlement decisions and breeding distributions while fewer have examined the effects on reproductive success. Yet information on Cerulean Warbler breeding response to forest management practices can serve to improve conservation management strategies. Further research on habitat selection and its effect on reproductive success could help forest managers define optimal habitat features and identify priority areas to protect for the Cerulean Warbler. In addition to land protection for this species, forest management practices can be modified to improve habitat conditions. Forest logging techniques that mimic natural disturbances and create heterogeneous forest canopies may be an effective strategy for Cerulean Warblers; however, few studies have been conducted on the effects of silviculture on Cerulean Warbler reproductive success. Logging is common throughout the eastern hardwood forests, and therefore, determining its effects on this vulnerable species may be crucial for the warbler's preservation. Hamel (2000) identified the need to assess silvicultural effects on Cerulean Warblers as a research priority.

Results from previous studies on the effects of silvicultural treatments on Cerulean Warbler reproductive success are varied. In Ohio, nesting success was not influenced by adjacency to recent clear-cuts (< 10 years old) ranging in size from 5.7 to 15.6 ha (Bakermans and Rodewald 2009). Newell and Rodewald (2012) found no difference between Cerulean Warbler nesting success in 10-30 ha first phase shelterwood cuts (reduced to 50% of original stocking one to two years before study) and unharvested sites in Ohio. Conversely, Boves et al. (2013) found that Cerulean Warblers in Tennessee were attracted to harvest sites but had lower reproductive success in these areas than at control sites. Basal area and canopy cover reductions at harvest sites varied by a little more than a factor of 3, from 20-75% (Boves et al. 2013). Silviculture that is intended to mimic natural disturbances may have attracted Cerulean Warblers but reduced their nesting success, indicating that harvested areas may have become ecological traps. Ecological traps occur when species select low quality habitat and incur lower productivity rates than they would in higher quality habitat (Battin 2004, Arlt and Pärt 2007). For example, Olive-sided Flycatchers (*Contopus cooperi*) in Montana preferred to nest in selectively harvested forests more than burned forests (mostly high severity burns) yet had lower reproductive success in the harvested areas (Robertson 2012). A reduction in habitat quality can be caused by human activity or natural events, and these areas can become population sinks.

Research on the effects of local habitat features on Cerulean Warbler nesting success has also produced inconsistent results. Nesting success increased in Ohio in areas with higher numbers of large trees and grapevines and with greater canopy openness (Bakermans and Rodewald 2009). Bakermans et al. (2012) found that nest success increased with canopy openness and decreased with increasing understory vegetation. In Tennessee, Boves et al. (2013a) found that daily survival rate increased with distance to nest tree foliage edge. They also found that nesting in white oak (*Quercus alba*) was negatively related to daily nest survival rate and was maladaptive. Other habitat features such as tree size had no effect on nesting success at this study site. In Ontario, Cerulean Warbler nesting success increased with greater foliage cover and was much lower after a major ice storm reduced the canopy coverage (Jones et al. 2001). Jones et al. (2001) reported that Cerulean Warblers increased their territory size following the spring during which they incurred low nesting success. This adjustment indicated that the warblers were able to modify their behavior in response to major habitat disturbance.

My research objectives were to determine a) whether silvicultural treatments had an effect on Cerulean Warbler reproductive success, and b) to describe Cerulean Warbler breeding biology in southern Indiana. Specifically, I investigated the effects of even-aged and uneven-aged forest harvest techniques on Cerulean Warbler reproductive success. Even-aged and uneven-aged treatments in this study included multiple harvesting techniques; to assess the effects of these individual components, I compared reproductive success of Cerulean Warblers nesting in first phase shelterwood cuts to those in non-shelterwood areas and reproductive success for warblers nesting near clear-cuts and group-cuts to those further away from the harvests. Breeding biology parameters measured in this study were a) overall Cerulean Warbler reproductive success, b) interannual variation in reproductive success, c) breeding phenology, and d) nest microhabitat characteristics.

METHODS

Study area and initial silviculture treatments

Research was conducted during spring 2011-2013 in the Yellowwood and Morgan-Monroe state forests in southern Indiana (Figure 1). Yellowwood State Forest (8700 ha) is in Brown and Monroe counties (39˚50'N, 86˚30'W) and is similar in forest composition to Morgan-Monroe State Forest (9430 ha), which is in Morgan and Monroe counties (39˚25'N, 86˚25'W) (Jenkins and Parker 1998). Oaks (*Quercus* spp.), maples (*Acer* spp.), hickories (*Carya* spp.), and American beeches (*Fagus grandifolia*) are the dominant tree species of a secondary-growth forest matrix that stretches across mesic and dry-mesic slopes (Homoya et al. 2013). There are numerous ephemeral streams in the valleys, and small historic conifer plantations (*Pinus strobus* and *P*. v*irginiana*) are present throughout the area. My research was one of several studies that were conducted as part of the Hardwood Ecosystem Experiment (HEE), a large research study on the effects of silviculture on multiple taxa in south-central Indiana (Swihart et al. 2013). The goal of the HEE was to evaluate commercial logging methods over 100 years, particularly those that encourage oak and hickory regeneration. Forest management strategies included four commonly used tree harvest techniques, and information from the HEE can be used to promote sustainable logging practices and forest biodiversity. The four techniques included shelterwood, clear-cuts, group-cuts and single-tree selection; the first two promote an even-aged forest structure and the latter two promote uneven-aged forest structure. Since the 1960s, parts of the Yellowwood and Morgan-Monroe state forests were logged using single-tree and group-cut methods (Jenkins and Parker 1998). In 2006, nine units were delineated in Yellowwood and Morgan-Monroe state forests ranging from 365-405 ha in size, and core areas (78.31-110.44 ha) within the units were randomly selected to receive even-aged, uneven-aged, or no harvest treatments (controls). In fall 2008, three even-aged units received two 4-ha clear-cuts and two 4-ha first phase shelterwood cuts; three uneven-aged units received eight group cuts (four 0.4 ha, two 1.2 ha and two 2 ha cuts with 50 m buffers) plus single-tree selection of basal areas of 16.1 to 23.0 m^2/ha; and three control units received no harvesting (Figure 2). For the initial stage preparatory cut in the shelterwood treatment areas, most mid- and under-story non-oak trees ≤ 25.4 cm diameter at breast height (DBH) were removed. In addition, Swihart et al. (2013) stated that “a few small overstory culls were removed, neither lowering basal areas below 13.8 m2/ha nor creating large canopy gaps”. Five to 10 years after the preparatory cut occurred, a second stage cut will occur to reduce stocking to a basal area of 13.8 to 16.1 m/ha^2. Harvests will be focused on non-oak and hickory trees, especially those with poorly formed canopies, and trees such as oaks and hickories will be left standing to provide seed sources. Five to 10 years after the second stage cut, the remaining large trees will be removed to allow the understory to mature. Buffer areas surrounding the core areas were subject to single-tree selection harvesting and group cuts (> 100 m from core); however, very few buffer areas incurred harvests during this study.

Point Counts

To locate Cerulean Warblers, we conducted 100 m fixed-radius point counts in sampling grids within each of the nine units during the month of May. The grids were established in 2007, and each encompassed 225 ha, with 49 points spaced 200 meters apart with a 50 m buffer around the perimeter (Figure 2). The grids extended beyond the treatment cores and into the buffer areas. We documented Cerulean Warbler presence at each of these points by broadcasting Cerulean Warbler vocalizations and recording Cerulean Warbler response. Upon arrival at a point, we listened for two minutes, broadcast male vocalizations using a SanDisk Sansa Clip+ 4 GB MP3 Player attached to a RadioShack Mini Audio amplifier for one minute, then listened for two more minutes. The volume on the amplifiers was set as high as possible without distorting the broadcast. We recorded the number of Cerulean Warblers detected, in addition to their direction and distance.

Territory mapping

During the second two weeks of May and all of June, we recorded the coordinates of singing males with a Global Positioning System (GPS) unit (Garmin GPSMAP 62S). Male songbirds defend their territory by singing from trees at territory boundaries (Falls 1981). From 7 to 12 song perches were recorded per male (Kaminski and Islam 2013). We used the *minimum convex polygon* tool in ArcGIS v. 10.0 (Environmental Systems Research Institute, Inc., Redlands, CA) to delineate each territory and the *feature to point* tool to determine the centroid of each territory, which was subsequently used as the location for conducting vegetation surveys.

Nest monitoring

We started searching for nests in the beginning of May when the majority of Cerulean Warblers in Indiana begin their nesting cycle. In order to maximize the nest sample size, we targeted areas that had larger numbers of warblers and searched for nests in even-aged, uneven-aged, and control units. In 2013, during the first week of May, we concentrated our efforts in the control units where nests were more difficult to find. Finding nests was especially challenging in the control units because the vegetation was thicker and there were fewer Cerulean Warblers present than in other treatment units. We located nests by observing both male and female behaviors (e.g. female brings nest material to nest or male makes a "zeet" call note after feeding young). We monitored each nest every other day for 30 min at random times between 0630 to 1800 hrs. We used binoculars and spotting scopes (Nikon Prostaff RAIII 82-mm spotting scope (2011-2012) and a Vortex Razor HD 85 mm angled spotting scope (2013) both equipped with 20–60x eyepieces) to monitor nests. Occasionally we found inactive nests. Inactive nests were found within Cerulean Warbler territories near singing males and were presumably from an earlier failed nesting attempt, or they were nests that we found after finding fledglings below them.

In 2012-2013, we conducted 1 hr observation sessions, usually two times per nest, to collect information on continuous length of incubation bouts. We did not count the number of fledglings but used the number of nestlings present in the nest during the last observation to estimate the number that fledged. Our view of the nest was not always conducive to observing all the nestlings, and therefore, for some nests we may not have been able to count all of the nestlings. The nests are 18 m high on average and often obscured by vegetation. We used parental behaviors to determine the stage of nesting and approximate age of young; we also used nestling morphology and behavior to determine nestling age. We considered a nest to be in the laying stage by using a combination of factors: a) when a female was observed arriving at the nest without nesting material and leaving without sitting on the nest or without sitting on the nest for extended periods, b) the female neglecting the nest for extended periods, and c) timing of building and/or incubation assuming an average incubation period of 11 days and an average laying period of four days (Buehler et al. 2013). When a nest failed, we returned at least twice to the area to attempt to find the re-nest. Since the Cerulean Warblers were not banded, we could not confirm reattempts at nesting, although there were four nests monitored in 2013 that we suspected were re-nests. We recorded the coordinates of nest locations and plotted them in ArcGIS.

Vegetation and topographic surveys

In 2011-2013, we surveyed vegetation in male territories and in random sites following methods in James and Shugart (1970). We used ArcGIS to generate random points in unused areas within the units. We used a meter tape to measure 11.3 m in each cardinal direction from those points forming a 0.04 ha circular plot. We recorded the number, species, and DBH of all trees. For each nest, we recorded the nest tree species, height and DBH, nest height, distance of nest to the nest tree bole and to the distal end of the nest branch (excluding 2011 nests), aspect, nest orientation, presence of grapevines (*Vitis sp.*) on the tree, and presence of Virginia creeper (*Parthenocissus quinquefolia*) over the nest. Tree and nest height were estimated using rangefinders. To estimate distance of the nest to the nest tree bole, we measured the distance between the bole and an observer standing directly under the nest. To estimate the distance from the nest to the distal end of the branch, we combined this same method with using our eye to estimate the distance. Nest orientation was determined by standing at the nest bole and finding the direction of the nest with a compass. Aspect was measured by creating a 10 m buffer around nest points in ArcGIS and calculating the mean aspect of that area.

Weather

I used weather data from the National Oceanic and Atmospheric Administration (NOAA) collected at the Monroe County Airport weather station in Bloomington, Indiana and available online (NOAA 2013). I used cooling degree days to compare monthly and annual variation in temperature. Cooling degree days provide an index of both the number of warm days and how warm the temperatures were during a period of time. To be classified as a cooling degree day, the average daily temperature has to be above 18 °C. I calculated the number of cooling degree days by subtracting 18 °C from the average temperature for each day and totaling the amounts for each month from March-June excluding negative numbers (similar to Boves and Buehler 2012).

Data analysis

I analyzed daily nest survival probability using Mayfield's (1975) method which accounts for the lower probability of finding nests that fail due to a shorter active period. I calculated nest success rates by raising the survival probability to the 25^{th} power which corresponds to 25 days in the nesting cycle excluding the building stage (Buehler et al. 2008). Nests were considered successful if they produced ≥1 fledgling. I used the program CONTRAST (Hines and Sauer 1989) to conduct a modified chi-square analysis to identify differences in survival probability among years and treatments. I determined proximity to clear-cuts and group-cuts using ArcGIS *generate near table* tool, and compared daily survival rates between nests located ≤ 100 m of a cut and nests > 100 m of a cut using CONTRAST. I chose 100 m in order to maximize sample size but still be relatively close to the cuts. Manolis et al. (2002) reported lower success rates for birds nesting within 100 m of clear-cuts and other avian researchers classified forested areas that were at least 100 m from the forest edge as interior forest (Duguay et al. 2001, Battin and Sisk 2011). I also compared survival probability between nests in shelterwood areas and nests outside of these areas. If a nest tree was abutting a shelterwood area and the corresponding territory was in the shelterwood area, then I grouped the nest with shelterwood nests. To assess whether the warblers were nesting in white oaks in higher proportion to white oak availability, I conducted a Chi-square goodness-of-fit test in Minitab 1.16.0 using data from vegetation surveys at random points and in territories. All statistical analyses were conducted using a significance level of $\alpha = 0.05$ and mean ± standard errors are reported. To assess nesting phenology, I back- and forward-dated all nests except for those that failed before we could collect sufficient data. I used published average nesting stage lengths (Buehler et al. 2013) which were five days for building, four days for laying, 11 days for incubation, and 10 days for the nestling period. I could not separate first nesting attempts from re-nests because the warblers were not banded, and therefore, summaries were made for all nests.

RESULTS

Nesting success

During May and June 2011-2013, we found 52 active Cerulean Warbler nests in Yellowwood and Morgan-Monroe state forests (Figures 3-11). The overall mean number of fledglings was 2.5/nest. Nest success across treatments was 58% in 2011, 8% in 2012, and 57% in 2013. Mayfield (1975) nesting success was 35% in 2011, 6% in 2012, and 33% in 2013. The average Mayfield nest success across years was 24.7%. When I compared daily survival rates in CONTRAST, I found no differences among years when all three years were analyzed together ($\chi^2 = 4.50$, P = 0.11) likely due to low statistical power. However, when only two years were analyzed, survival probability in 2012 was lower than in 2013 ($\chi^2 = 4.07$, P = 0.04) and results suggest it was also lower than in 2011 ($\chi^2 = 3.84$, P = 0.05). There was no difference in reproductive success between even-aged and uneven-aged units (χ^2 = 0.03, P = 0.86, n = 21 nests in uneven-aged units and 24 nests in even-aged units; Table 1). In addition, there was no difference in survival probability between nests within 100 m of group-cuts and clear-cuts, and all other nests ($\chi^2 = 0.16$, P = 0.52, n = 8 nests within 100 m of cuts and 41 nests outside 100 m of cuts). There was no difference in survival probability between nests within shelterwood areas and outside of shelterwood areas (χ^2 = 0.19, P = 0.36, n = 9 nests within shelterwood areas and 40 nests outside of shelterwood areas). It should be noted that for the analyses between silviculture treatments, there was low statistical power.

In 2011, failure for all unsuccessful nests (n = 5) occurred during the incubation phase. In 2012, 55% of unsuccessful nests failed during the nestling stage, 36% during incubation, 9% during laying, and zero during building (n = 11 total failed nests). In 2013, 64% of unsuccessful nests failed during incubation, 9% during building, 18% during laying, and 9% during the nestling stage (n = 11 total failed nests). The nest that failed during the nestling stage in 2013 was in an area with an unusually open canopy. These numbers should be viewed cautiously since not all nests were found during the building stage.

The causes of nest failure for most nests were unknown. Two predation events were witnessed during 2011-2013. I observed a Red-bellied Woodpecker (*Melanerpes carolinus)* remove a Cerulean Warbler nestling from a nest in 2012 (Auer et al. 2013), and I observed an unknown species of bird (approximately the same size as the woodpecker) prey on another nest during the incubation stage. The latter event was captured by a trail camera aimed at a nest when I was experimenting with trail cameras in 2012. The predator species could not be identified because the image was not clear enough. In 2011, a failed nest was observed partially torn at the bottom. Another nest failed after a hail storm and disappeared. Except for these incidents when we could infer a direct cause, sources for the remaining nest failures are unknown but likely due to predation which is the leading cause of nest failure in passerines (Martin 1995). Blue Jays (*Cyanocitta cristata*), American Crows (*Corvus brachyrhynchos*), squirrels (*Sciurus* spp.), and chipmunks (*Tamius* spp.) appear to be some of the most common Cerulean Warbler nest predators (Buehler et al. 2008, Boves and Buehler 2012). In 2013, I witnessed a gray squirrel (*Sciurus carolinensis*) foraging on a branch ~2 m above an incubating female Cerulean Warbler. The female remained frozen in position for ~5 min watching the squirrel until it left. In 2012, I observed a black rat snake (*Elaphe obsoleta obsoleta*) moving along the ground directly under a

Cerulean Warbler fledgling that was perched ~ 2 m high in a sapling. The male parent that had been feeding the fledgling chipped frequently while the snake was in close proximity.

The only successful nest in 2012 (there was one nest with an unknown fate that was likely unsuccessful), had a Brown-headed Cowbird (*Molothrus ater*) nestling in it. The cowbird nestling disappeared from the nest when the Cerulean Warbler nestlings were 5-7 days old and subsequently all three nestlings fledged (although one was less developed than the other two). Cowbird nestlings are larger than Cerulean Warbler nestlings and are known to beg more aggressively than other passerine nestlings in general (Briskie et al. 1994) and a predator may have taken the largest, loudest item in the nest without returning for the remaining nestlings. Cowbirds were common throughout the research site, but due to the inaccessibility of nests, the rates of parasitism were unknown. During 2011-2013, in addition to the one cowbird nestling, we saw one cowbird fledgling fed by a Cerulean Warbler (2011) and no other incidents of cowbird parasitism.

Breeding phenology and weather

The first nest was found on 8 May in 2011, 1 May in 2012, and 3 May in 2013. In 2011, we did not begin conducting research until 3 May, whereas in 2012 and 2013, we began nest searching on 29 April. Mean nest initiation was 11 May for 2011 and 2013, and 12 May for 2012. Peak nest building occurred between the first and second weeks of May for all three years (Figure 12). The peak nestling period occurred during the end of May into early June for all three years (Figure 13). In 2011, 2012, and 2013, the last active nests were found on 12 June (building stage), 15 June (building stage), and 21 June (feeding), respectively. The former two failed during the building and incubation stages, respectively, and the latter nest was successful. The last fledglings were observed on 26 June in 2011, 29 June in 2012, and on 30 June in 2013. The mean date of fledging was 5 June in 2011, 8 June in 2012, and 10 June in 2013.

Weather patterns for the breeding seasons during 2011-2013 were varied; 2011 was an extremely wet year, 2012 was a drought year, and 2013 had no extreme weather but springtime was relatively cooler (Figures 14 and 15). In 2012, there were 18.57 cooling degree days in March, whereas in 2011 and 2013, there were less than four (NOAA 2014). The number of cooling degree days in April was similar during the three years. During the month of May, there were 85.7 cooling degree days in 2012 versus 62.89 in 2011 and 60.11 in 2013. Precipitation was unusually high in spring 2011 and was low in 2012.

Incubation and foraging bouts

Mean incubation time per 30 min was 24.67 ± 0.48 min (n = 45 observation sessions, 19 nests). The mean length of continuous incubation bouts was 28.42 ± 2.92 min (n = 33 observation sessions, 17 nests). The mean continuous foraging bout for females was 5.9 ± 0.46 min. We did not measure brooding times. The parents were frequently seen removing fecal sacs, occasionally ingesting them.

Nest microhabitat

In addition to the active nests, we found 10 inactive nests and recorded nest site characteristics for these as well. In 2011-2013, 25% of nests were in areas where the mean aspect was between 0-90 degrees, 18% of nests were located on a ridge, 16% were in flat streambed areas and 23% were in areas where the mean aspect was between 91-359 degrees (n = 67 nests). Fifty-one percent of nests were located SE to SW of the nest tree bole, 32% were NW to NE of the bole and the remainder were evenly divided between locations E and W of the bole (n = 59 nests). Mean nest tree height was 26.18 ± 0.66 m (n = 58). Mean nest height was 19.92 ± 0.60 (n = 59). Mean distance of nests to the distal end of the branch was 2.06 ± 0.17 m (n = 37). Mean nest tree DBH was 42.99 ± 2.03 m (n = 57). Mean distance from the nest to the nest tree bole was 4.50 ± 0.339 m (n = 59). Sample sizes differed due to the addition of certain measurements after 2011 or missed measurements in the field.

Cerulean Warbler nests were found in 13 different tree species (Table 2), 44% of which were white oaks. The warblers nested in white oaks in greater proportion to their availability ($\chi^2 = 42.42$, df = 1, $P < 0.001$). In 2013, the approximate date of tree leaf-out was later compared to most years and we observed that the earliest nests were located in trees that already had leaves. Grapevines were recorded on six nest trees and five nests were covered by Virginia creeper (n = 59).

DISCUSSION

Nest success

Average nesting success was very similar in 2011 and 2013 and lower in 2012. Spring 2011 had excessive rainfall whereas spring 2012 had very dry conditions. Drought can negatively affect songbird reproduction (George et al. 1992) and likely contributed in large part to the low nest success in 2012. In 2012, spring temperatures were relatively high especially in March and trees leafed out earlier than normal (S. Auer pers. obs.). Although we were not tracking Lepidoptera larvae phenology, peaks in Lepidoptera larvae abundance were likely earlier that year since Lepidoptera larvae emergence is largely influenced by temperature cues (Strode 2003). Drought is known to negatively affect Lepidoptera larvae abundance (Shure et al.

1998) and a lack of Lepidoptera larvae during the nestling period during the drought year may have affected the warbler's nesting success since Lepidoptera larvae are their main food source (see Chapter 1). The drought and early leaf-out may have affected the food sources of predators, causing the predators to feed more heavily on Cerulean Warbler eggs and young. In years when there is a superabundance of Lepidoptera larvae, songbird nest predation is lower because generalist nest predators such as corvids and rodents shift the focus of their foraging more to Lepidoptera larvae (Ostfeld and Keesing 2000); prey switching in general is a common phenomenon (Murdoch 1969). Cerulean Warbler nestlings may have had a less nutritious diet and survived at a lower rate, although we did not see any evidence of weakened nestlings. The higher rate of feeding trips (see Chapter 1) may have been related to reduced availability of Lepidoptera larvae. Higher frequency of feeding trips to the nest can increase predator detection (Skutch 1949, Mayfield 1975) and may have contributed to higher predation rates which were probably the major cause of nest failure.

We found that a disproportionate number of nests failed during incubation versus the nestling stage in 2011 and 2013. Beachy (2008) also found higher nest failure during the incubation stage versus nestling stage; however, Boves and Buehler (2012) found that nests failed roughly equally during the two stages. Higher survival rates during the nestling period are common for passerines (Best and Stauffer 1980) and may be explained a number of ways. For example, parents are more invested in their nestlings than at previous nest stages and will defend the nest more rigorously. Also, nests that are more susceptible to predation will be found earlier during the nesting cycle and those that survive to the nestling stage are typically less detectable (Best and Stauffer 1980). However, if detectability increases during the nestling period due to the increase in parental trips to the nest then this should increase predation risk for nestlings (Skutch 1949, Mayfield 1975).

Mean Mayfield (1975) nesting success at the HEE site was 24.7%. Mean Mayfield (1975) nesting success for Cerulean Warblers at Big Oaks National Wildlife Refuge (BONWR) in southeast Indiana was 15.8% during 2002-2005 with a range from 8.2% to 28.8% (Buehler et al. 2008). Buehler et al. (2008) reported mean Mayfield (1975) nesting success as 27.4% in Michigan, 20.8% in the Mississippi Alluvial Valley (MAV), 46.2 % in the Cumberland Mountains in Tennessee, and 40.5% in Ontario, Canada. They attributed the lower success rates of Indiana, Michigan and MAV potentially to higher cowbird parasitism rates and higher predation rates due to forest cover of < 50% within a 10-km radius. Many studies (e.g. Bayne and Hobson 1997) have shown that songbirds in highly fragmented forests in agricultural dominated landscapes tend to have lower reproductive rates. At the HEE sites, cowbird parasitism rates appeared to be very low, although without observing the actual nest contents we could not accurately determine how many nests were abandoned due to the presence of cowbird eggs.

An assessment of the effects of silviculture on nesting success at the HEE site was limited by sample size and results were inconclusive. The sample of nests in control units was especially low; however, the potentially high success rates for control nests denote the importance of investigating this further and attaining a larger sample of nests. Boves et al. (2013b) found higher nesting success in control areas than in harvest treatments areas in Tennessee, although the treatment types differed from those at my study sites. It is unfortunate that at my study site, the control units that were randomly selected had substantially lower numbers of Cerulean Warblers than treatment units. This shortage coupled with the thicker vegetation in control units made nest searching even more difficult for an already inherently difficult bird species. I recommend concentrating nest searching efforts in control units early in the season when vegetation conceals nests to a lesser degree.

In general, obtaining large sample sizes annually at the HEE site is difficult for several reasons including the extensive acreage of the HEE units, the distance between units, distance between Cerulean Warbler pairs, and limited personnel. I believe that only continued monitoring over the long-term will yield reliable results on the effects of silviculture treatments on Cerulean Warbler nesting success in this area.

Breeding phenology

There appeared to be very little variation in nesting phenology among the years with mean nest initiation occurring on almost exactly the same date each year. Conversely, weather conditions were quite varied among the three years, indicating a potential lack of plasticity in Cerulean Warblers with respect to nest initiation. As a species that uses photoperiod cues to migrate, warmer spring temperatures would not influence the arrival of the warblers at the breeding grounds but would speed up leafing-out of trees and emergence of Lepidoptera larvae. Climate change in general is likely causing mismatches in the timing of breeding birds and Lepidoptera larvae peaks, especially with respect to migratory species (Both et al. 2006). Both et al. (2006) determined that the Pied Flycatcher (*Ficedula hypoleuca*), a long-distance migratory bird, suffered population declines due to mismatched timing. Non-migratory Great Tits (*Parus major*) in Europe showed some plasticity in their laying dates as spring temperatures increased; however, synchrony with Lepidoptera larvae peaks was disrupted and parents produced fewer and lighter fledglings (Visser et al. 2006). The results from my study indicate that warmer spring temperatures combined with drought conditions during one year likely had adverse effects on reproductive success; however, further research is required to assess the relationships between climate conditions, tree and leaf phenology, and Cerulean Warbler breeding success. Mean nest initiation date for Cerulean Warblers in Tennessee was earlier in 2010 than in 2008-2009 (Boves and Buehler 2008). Spring of 2010 was warmer at the Tennessee study site than it was during the spring in 2008-2009, and the earlier nest initiation date suggested that Cerulean Warblers were exhibiting plasticity in contrast to our findings. Decreases in nesting success for Cerulean Warblers have also been attributed to occasional extreme cold spells such as occurred at BONWR during 2003 (Roth and Islam 2008).

Incubation and feeding bouts

Mean incubation times for females were similar to those in Ontario, Canada which were 50 ± 5.3 min/hr (Oliarnyk and Robertson 1996) and 25.7 ± 0.27 min/30 min (Barg et al. 2006). Likewise, mean length of continuous incubation bouts was slightly lower than the rate for females in Ontario which was 32.6 ± 3.5 min (Barg et al. 2006).

Nest microhabitat

Nest height, nest tree height, nest tree DBH, and distance of nest to bole and the distal end of the nest branch was generally consistent with Cerulean Warbler microhabitat features in other areas of their range (Oliarnyk and Robertson 1996, Boves et al. 2013a, Rogers 2006, Bakermans and Rodewald 2009, Roth and Islam 2008). At our study site, Cerulean Warblers nested in a variety of tree species but white oaks were the most common nest tree species. Cerulean Warblers in Ohio preferred to nest in white oaks (Bakermans 2008), and at BONWR, white oaks and black walnuts (*Juglans nigra*) were the dominant nest tree species (Roth and Islam 2008). The most commonly used nest trees in other areas across the Cerulean Warbler range were sugar maple in Canada (Oliarnyk and Robertson 1996), and black oak (*Quercus velutina*) and black locust (*Robinia pseudoacacia*) in Michigan (Rogers 2006). White oaks, sugar maples, and cucumber magnolias (*Magnolia acuminate*) were preferred by Cerulean Warblers in the Cumberland Mountains, Tennessee (Boves et al. 2013a). Boves et al. (2013a) found that nesting in white oaks was negatively related to daily survival rate and was maladaptive. I did not assess reproductive success in relation to tree species. Affinity for nesting in white oaks could be attributed to a high insect abundance in the canopy (Jeffries et al. 2006, Summerville et al. 2003). Wagner (2012) demonstrated that white oaks and hickories in the area had more Lepidoptera larvae activity than other dominant tree species such as maples and tulip trees (*Liriodendron tulipifera*). However, we found very few nests in hickories considering they are a dominant tree species which likely means that other characteristics of white oaks are desirable. There may be specific structural features that Cerulean Warblers favor such as long lateral limbs or the color and texture of white oak bark. Cerulean Warblers in Indiana regularly foraged in white oaks and tulip trees, although hickories were their preferred tree species (MacNeil 2010). Cerulean Warbler settlement at our study site was positively associated with hickory abundance; white oaks were a dominant species but were not more abundant in territories than random sites (K. Barnes unpub. data). A tendency to nest in white oaks and forage in hickories in the area highlights the potential importance of these tree species for Cerulean Warblers in Indiana. However, given the diversity of nest and foraging tree species across their breeding range, the Cerulean Warblers may be adaptable to changes in forest landscape.

Cerulean Warblers frequently nested on north to northeast to east (0-90) facing slopes and on ridgetops and streambeds. Cerulean Warblers in some other regions showed a preference for northeast facing slopes (Wood et al. 2006, Hartman et al. 2009, Newell and Rodewald 2012, Boves et al. 2013a). Northeast facing slopes are typically more productive in the central hardwood region (Lopez et al. 2008). Yellowwood and Morgan-Monroe state forest aerial photographs from mid-April in 2011 showed that northeast facing slopes at the time had more foliage cover which could induce settlement in these areas for Cerulean Warblers arriving during peak arrival time in the second half of April. Likewise, Cerulean Warblers may be selecting northeast facing slopes because of their higher insect abundance (Cramp 1998). Cerulean Warbler settlement is associated with ridgetops in West Virginia and Tennessee (Weakland and Wood 2005, Buehler et al. 2006) and riparian areas in Alabama and Mississippi (Hamel et al. 2004, Carpenter et al. 2011). Nests were most often located on the south sides of the nest tree, consistent with Cerulean Warbler nests at BONWR (Roth 2004, Varble 2006). Cerulean Warblers may be selecting southerly nest exposures to take advantage of warmer temperatures which allow for reduced energy costs for parents (Ardia et al. 2006).

MANAGEMENT IMPLICATIONS AND FUTURE STUDIES

Logging will likely continue in Indiana’s forested lands for many years, necessitating further research on its effects on Cerulean Warbler reproductive success. Likewise, it is important to determine how specific logging methods affect Cerulean Warbler reproduction. Almost all forested land in Indiana was cleared for agriculture after European settlement (Evans and Kelly 2008). Following the regrowth of forests, they currently cover approximately 20% of Indiana (reduced from 85% pre-European settlement). Cerulean Warblers tend to have lower reproductive success in agriculturally dominated regions such as Indiana (Buehler et al. 2008), and improving the quality of the remaining forests could help offset this phenomenon. Regional differences in forest habitat exist across the Cerulean Warbler's range and a prescription for forest management in one area may not be as beneficial to the warbler in another area. Therefore, it is important to obtain information on local landscape effects on reproductive success. Almost half of the warbler's nests were in white oaks at the HEE site and further research into the effects of this choice on fecundity is warranted. The Cerulean Warblers favored northeast facing slopes, and though research should be conducted to assess the adaptiveness of selecting these slopes, this finding could be valuable information for forest managers. In addition to further research on silviculture effects, I recommend assessing how microhabitat and macrohabitat features affect reproductive success with respect to nesting success and the number of fledglings per nest (and potentially weight of fledglings). A comprehensive study could be conducted using regression models to analyze the effects of nest site, nest patch (habitat immediately surrounding the nest), and territory vegetation characteristics on reproductive success. This type of multi-level study of silviculture and habitat effects on Cerulean Warbler reproductive success would serve to benefit conservation management for this species in Indiana.

LITERATURE CITED

Ardia, D. R., J. H. Pérez, and E. D. Clotfelter. 2006. Nest box orientation affects internal temperature and nest site selection by tree swallows. Journal of Field Ornithology 77:339-344.

Arlt, D., and T. Pärt. 2007. Nonideal breeding habitat selection: a mismatch between preference and fitness. Ecology 88:792-801.

Auer, S. A., K. Islam, K. W. Barnes, and J. A. Brown. 2013. Documentation of predation of a nestling cerulean warbler by a red-bellied woodpecker. Wilson Journal of Ornithology 125:642-646.

Bakermans, M. H. 2008. Demography and habitat use of cerulean warblers on breeding and wintering grounds. Doctoral dissertation, Ohio State University, Columbus, OH.

Bakermans, M. H. and A. D. Rodewald. 2009. Think globally, manage locally: The importance of steady-state forest features for a declining songbird. Forest Ecology and Management 258:224-232.

Bakermans, M. H., A. D. Rodewald, and A. C. Vitz. 2012. Influence of forest structure on density and nest success of mature forest birds in managed landscapes. Journal of Wildlife Management 258:224-232.

Barg, J. J., J. Jones, M. K. Girvan, and R. L. Robertson. 2006. Within-pair interactions and parental behavior of cerulean warblers breeding in eastern Ontario. Wilson Journal of Ornithology 118:316-325.

Battin, J. 2004. When good animals love bad habitats: ecological traps and the conservation of animal populations. Conservation Biology 18:1482-1491.

Battin, J. and T. D. Sisk. 2011. One-sided edge responses in forest birds following restoration treatments. Condor 113:501-510.

Bayne, E. M., and K. A. Hobson. 1997. Comparing the effects of landscape fragmentation by forestry and agriculture on predation of artificial nests. Conservation Biology 11:1418-1429.

Beachy, T. A. 2008. Cerulean Warbler (*Dendroica cerulea*) breeding ecology and habitat selection, initial response to forest management, and association with anthropogenic disturbances in the Cumberland Mountains of Tennessee. M.Sc. thesis, University of Tennessee, Knoxville, USA.

Best, L. B., and F. Stauffer. 1980. Factors affecting nesting success in riparian bird communities. Condor 82:149-158.

Both, C., S. Bouwhuis, C. M. Lessells, and M. E. Visser. 2006. Climate change and population declines in a long-distance migratory bird. Nature 441:81-83.

Boves, T. J., and D. A Buehler. 2012. Breeding biology, behavior, and ecology of *Setophaga cerulea* in the Cumberland Mountains, Tennessee. Southeastern Naturalist 11:319-330.

Boves, T. J., D. A. Buehler, J. Sheehan, P. B. Wood, A. D. Rodewald, J. L. Larkin, P. D. Keyser, F. L. Newell, A. Evans, G. A. George, and T. B. Wigley. 2013a. Spatial variation in breeding habitat selection by Cerulean Warblers (*Setophaga cerulea*) throughout the Appalachian Mountain. Auk 130:46-59.

Boves, T. J., D. A. Buehler, J. Sheehan, P. B. Wood, A. D. Rodewald, J. L. Larkin, P. D. Keyser, F. L. Newell, G. A. George, M. H. Bakersman, A. Evans, T.A. Beachy, M. E. McDermott, K. A. Perkins, M. White, T. B. Wigley. 2013b. Emulating natural disturbances for declining late-successional species: a case study of the consequences for cerulean warblers (*Setophaga cerulea*). PloS one 8:e52107.

Briskie, J. V., C. T. Naugler, and S. M. Leech. 1994. Begging intensity of nestling birds varies with sibling relatedness. Proceedings of the Royal Society of London. Series B: Biological Sciences 258:73-78.

Buehler, D. A., J. J. Giocomo, J. Jones, P. B. Hamel, C. M. Rogers, T. A. Beachy, D. W. Varble, C. P. Nicholson, K. L. Roth, J. Barg, R. J. Robertson, J. R. Robb, and K. Islam. 2008. Cerulean warbler reproduction, survival, and models of population decline. Journal of Wildlife Management 72:646-653.

Buehler, D. A., P. B. Hamel, and T. Boves. 2013. Cerulean warbler (*Setophaga cerulea*). In Birds of North America Online (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, New York, NY, USA. <http://bna.birds.cornell.edu/bna/species/511/.> Accessed 13 April 2014.

Carpenter, J. P., Y. Wang, C. Schweitzer, and P. B. Hamel. 2011. Avian community and microhabitat associations of cerulean warbler in Alabama. Wilson Journal of Ornithology 123:206-217.

Cramp, S. 1998. The complete birds of the western palearctic on CD-ROM. Oxford University Press, Oxford.

Duguay, J. P., P. B. Wood, and J. V. Nichols. 2001. Songbird abundance and avian nest survival rates in forests fragmented by different silvicultural treatments.Conservation Biology 15:1405-115.

Evans, T. P., and H. Kelley. 2008. Assessing the transition from deforestation to forest regrowth with an agent-based model of land cover change for south-central Indiana (USA). Geoforum 39:819-832.

Falls, J. B. 1981. Mapping territories with playback: an accurate census method for songbirds. Studies in Avian Biology 6:86-91.

Foss, L. K., and L. K. Rieske. 2003. Species-specific differences in oak foliage affect preference and performance of gypsy moth caterpillars. Entomologia Experimentalis et Applicata 108:87–93.

George, T. L., A. C. Fowler, R. L. Knight, and L. C. McEwen. 1992. Impacts of a severe drought on grassland birds in western North Dakota. Ecological Applications 2:275-284.

Hamel, P. B. 2000. Cerulean warbler status assessment. United States Fish and Wildlife Service, Fort Snelling, MN.

Hamel, P. B., D. K. Dawson, and P. D. Keyser. 2004. How we can learn more about the cerulean warbler (*Dendroica cerulea*). Auk 121:7-14.

Hartman, P. J., D. S. Maehr, and J. L. Larkin. 2009. Habitat selection by cerulean warblers in eastern Kentucky. Wilson Journal of Ornithology 121:469-475.

Hines, J. E., and J. R. Sauer. 1989. Program CONTRAST—a general program for the analysis of several survival or recovery rate estimates. Fish and Wildlife Technical Report 24:1–7.

Homoya, M. A., D. B. Abrell, J. A. Aldrich, and T. W. Post. 2013. The natural regions of Indiana. Proceedings of the Indiana Academy of Science 94:245-268.

Indiana Department of Natural Resources (IDNR). 2012. Indiana's state endangered species. <http://www.in.gov/dnr/fishwild/files/fw-State_Endangered_Species_list.pdf>. Accessed 01 Jan 2013.

International Union for Conservation of Nature (IUCN). 2013. IUCN Red List of Threatened Species. Version 2013.2. <www.iucnredlist.org>. Accessed 25 Mar 2014.

James, F. C., and H. H. Shugart Jr. 1970. A quantitative method of habitat description. Audubon Field Notes 24:727-736.

Jeffries, J. M., R. J. Marquis, and R. E. Forkner. 2006. Forest age influences oak insect herbivore community structure, richness, and density. Ecological Applications 16:901-912.

Jenkins, M. A., and G. R. Parker. 1998. Composition and diversity of woody vegetation in silvicultural openings of southern Indiana forests. Forest Ecology and Management 109:57–74.

Jones, J., R. D. DeBruyn, J. J. Barg, and R. J. Robertson. 2001. Assessing the effects of natural disturbance on a Neotropical migrant songbird. Ecology 82:2628-2635.

Kaminski, K. J., and K. Islam. 2013. Effects of silviculture on abundance and spatial characteristics of cerulean warbler territories. American Midland Naturalist 170:111-120.

Lopez, O. R., K. Farris-Lopez, R. A. Montgomery, and T. J. Givnish. 2008. Leaf phenology in relation to canopy closure in southern Appalachian trees. American Journal of Botany 95:1395-1407.

Lynch, J. M. 1981. Status of the cerulean warbler in the Roanoke River Basin of North Carolina. Chat 45:29-35.

MacNeil, M. M. 2010. Does timber harvesting affect cerulean warbler foraging ecology? M.Sc. thesis, Ball State University, Muncie, IN.

Manolis, J. C., D. E. Andersen, and F. J. Cuthbert. 2002. Edge effect on nesting success of ground nesting birds near regenerating clearcuts in a forest-dominated landscape. Auk 119:955-970.

Martin, T. E. 1995. Avian life history evolution in relation to nest sites, nest predation, and food. Ecological Monographs 65:101-127.

Mayfield, H. F. 1975. Suggestions for calculating nest success. Wilson Bulletin 87:456-466.

Murdoch, W. W. 1969. Switching in general predators: experiments on predator specificity and stability of prey populations. Ecological Monographs 39:335-354.

National Oceanic and Atmospheric Administration (NOAA). 2013. Quality Controlled Local Climatological Data. < http://cdo.ncdc.noaa.gov/qclcd/QCLCD?prior=N />. Accessed 20 Dec 2013.

Newell, F. L., and A. D. Rodewald. 2012. Management for oak regeneration: short-term effects on the bird community and suitability of shelterwood harvests for canopy songbirds. Journal of Wildlife Management 262:739-749.

Oliarnyk, C. J., and R. J. Robertson. 1996. Breeding behavior and reproductive success of cerulean warblers in southeastern Ontario. Wilson Bulletin 108:673-684.

Ostfeld, R. S., and F. Keesing. 2000. Pulsed resources and community dynamics of consumers in terrestrial ecosystems. Trends in Ecology and Evolution 15:232-237.

Robbins, C. S., J. W. Fitzpatrick, and P. B. Hamel. 1992. A warbler in trouble: *Dendroica cerulea*. Pages 549-562 in J. M. Hagan III and D.W Johnston, editors. Ecology and conservation of neotropical migrant landbirds. Smithsonian Institution, Washington, D.C., USA.

Robertson, B. A. 2012. Investigating targets of avian habitat management to eliminate an ecological trap. Avian Conservation and Ecology 7:2.

Rogers, C. M. 2006. Nesting success and breeding biology of cerulean warblers in Michigan. Wilson Journal of Ornithology 118:145-151.

Rogers, C. M. 2013. Minimum annual survival estimates of male cerulean warblers (*Setophaga cerulea*) in southwestern Michigan. Wilson Journal of Ornithology 125:370-375.

Roth, K. L. 2004. Cerulean warbler breeding biology in Big Oaks National Wildlife Refuge, Madison, Indiana. M.Sc. thesis, Ball State University, Muncie, IN.

Roth, K. L., and K. Islam. 2008. Habitat selection and reproductive success of cerulean warblers in Indiana. Wilson Journal of Ornithology 120:105-110.

Saab, V. A., and H. D. W Powell. 2005. Fire and avian ecology in North America: process influencing pattern. Studies in Avian Biology 30:1-13.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American breeding bird survey, results and analysis 1966-2010. Version 12.07.2011. USGS Patuxent Wildlife Research Center, Laurel, Maryland, USA. <http://www.mbr-pwrc.usgs.gov/bbs/bbs.html>. Accessed 12 Dec 2013.

Sheehan, J., P. B. Wood, D. A. Buehler, P. D. Keyser, J. L. Larkin, A. D. Rodewald, T. B. Wigley, T. J. Boves, G. A. George, M. H. Bakermans, T. A. Beachy, A. Evans, M. E. McDermott, F. L. Newell, K. A. Perkins, and M. White. 2013. Avian response to timber harvesting applied experimentally to manage cerulean warbler breeding populations. Forest Ecology and Management online <http://www.sciencedirect.com/science/article/pii/S0378112713004799>. (verified 05 May 2014)

Shure, D. J., P. D. Mooreside, and S. M. Ogle. 1998. Rainfall effects on plant-herbivore processes in an upland oak forest. Ecology 79:604-617.

Skutch, A. F. 1949. Do tropical birds rear as many young as they can nourish? Ibis 91:430-45.

Stoleson, S. H. 2004. Cerulean warbler habitat use in an oak-northern hardwoods transition zone: implications for management. Pp 535 *in* Proceedings of the 14th Central Hardwood Forest Conference (D.A.Yaussy, D. M. Hix, R. P Long, and P. C. Goebel, editors). United States Department of Agriculture Forest Service General Technical Report NE-316. Newtown Square, Pennsylvania, USA.

Strode, P. K. 2003. Implications of climate change for North American wood warblers (Parulidae). Global Change Biology 9:1137-1144.

Summerville, K. S., T. O. Crist, J. K. Kahn, and J. C. Gering. 2003. Community structure of arboreal caterpillars within and among four tree species of the eastern deciduous forest. Ecological Entomology 28:747-757.

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. General Technical Report NRS-P-108. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 350 p.

United States Fish and Wildlife Service (USFWS). 2007. A conservation action plan for the cerulean warbler (*Dendroica cerulea*). Produced for the USFWS Division of Migratory Bird Management Focal Species Program. <http://www.fws.gov/midwest/eco_serv/soc/birds/cerw/documents/cerw_Action%20Plan_28June07.pdf>. Accessed 25 Mar 2014.

United States Fish and Wildlife Service (USFWS). 2012. Species of concern. <http://www.fws.gov/midwest/es/soc/>. Accessed 01 Jan 2013.

Varble, D. W. 2006. The effects of a periodic cicada emergence on forest birds and the ecology of cerulean warblers at Big Oaks National Wildlife Refuge, Indiana. M.Sc. thesis, University of Tennessee, Knoxville, TN.

Visser, M. E., L. J. M. Holleman, and P. Gienapp. 2006. Shifts in caterpillar biomass phenology due to climate change and its impact on the breeding biology of an insectivorous bird. Oecologia 147:164-172.

Wagner, J. R. 2012. Cerulean warbler population and breeding response to recent silviculture and influences of prey availability on avian nesting ecology. M.Sc. thesis, Ball State University, Muncie, IN.

Weakland, C. A., and P. B. Wood. 2005. Cerulean warbler (*Dendroica cerulea*) microhabitat and landscape-level habitat characteristics in southern West Virginia. Auk 122:497-508.

Weakland, C. A., P. B. Wood, and R. Holberton. 2005. Cerulean warbler (*Dendroica cerulea*) microhabitat and landscape-level habitat characteristics in southern West Virginia. Auk 122:497-508.

Wood, P. B., S. B. Bosworth, and R. Dettmers. 2006. Cerulean warbler abundance and occurrence relative to large-scale edge and habitat characteristics. Condor 108:154-165.

Wood, P. B., J. P. Duguay, and J. V. Nichols. 2005. Cerulean warbler use of regenerated clearcut and two-age harvests. Wildlife Society Bulletin 33:851-858.

Wood, P. B. and K. A. Perkins. 2012. Behavioral activities of male cerulean warblers in relation to habitat characteristics. Wilson Journal of Ornithology 124:497-50.

FIGURES

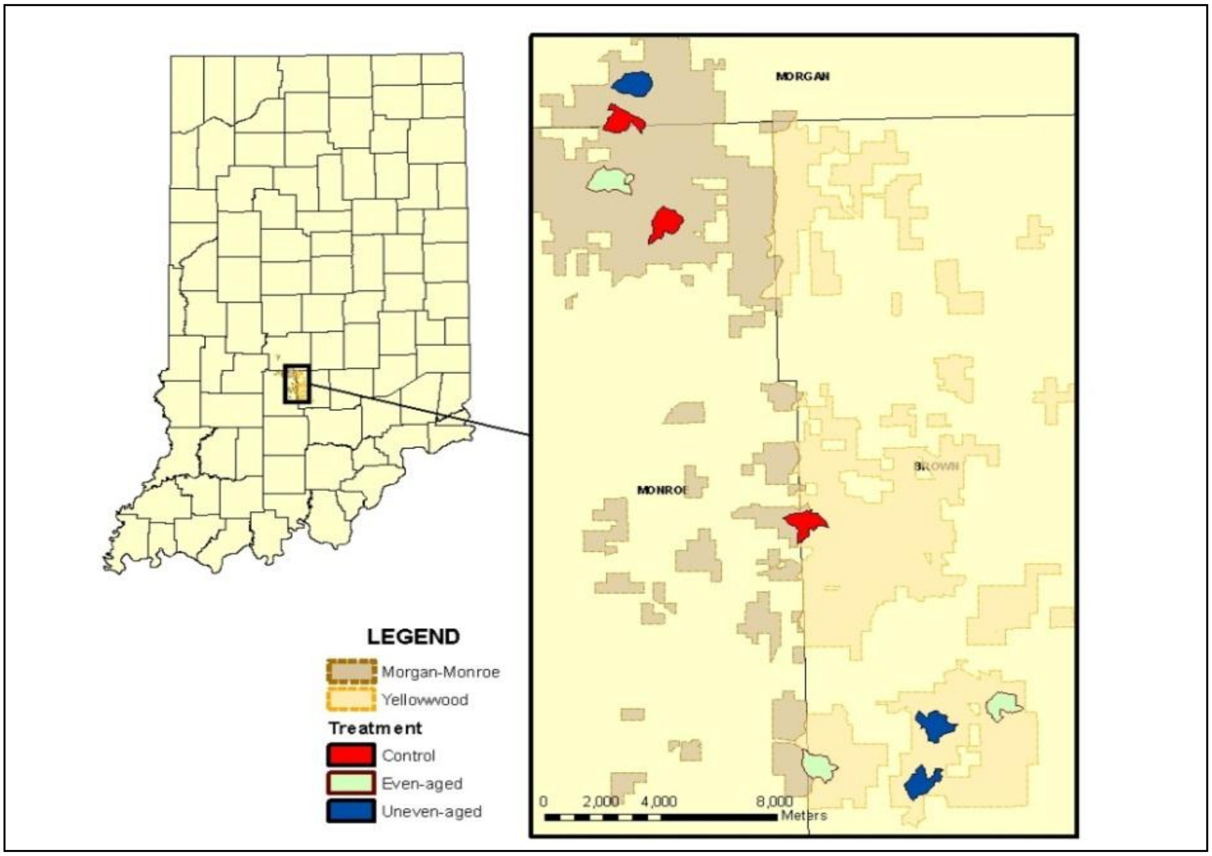

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Figure 1. The Hardwood Ecosystem Experiment study design in Yellowwood and Morgan-Monroe state forests in Indiana.

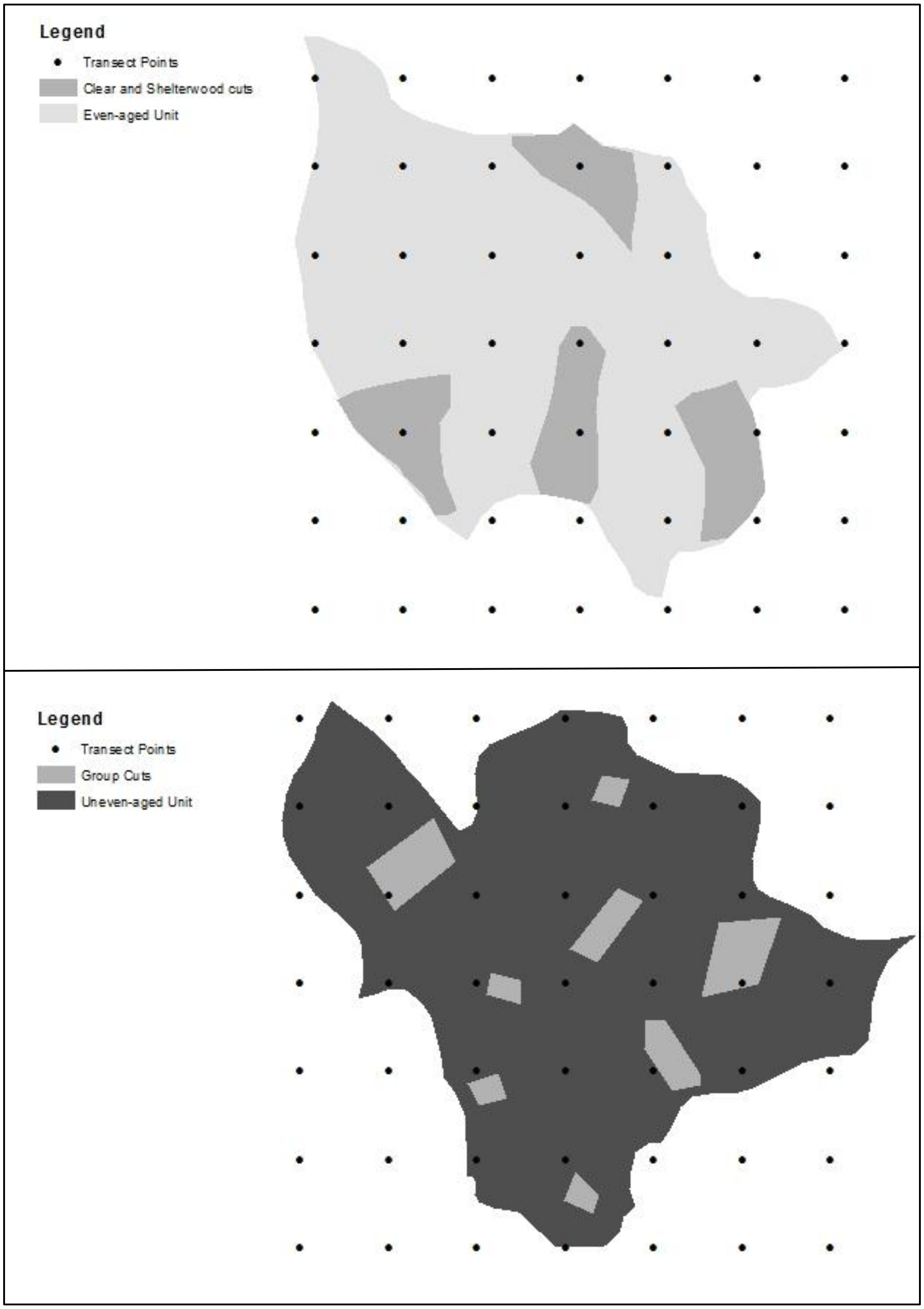

Figure 2. Examples of even- and uneven-age treatment units in Yellowwood and Morgan-Monroe state forests in Indiana. A grid with 49 points was superimposed onto each core research area. Each grid plus a 50 m buffer encompassed 225 ha. Uneven-age units incurred single-tree selection cuts in addition to group cuts.

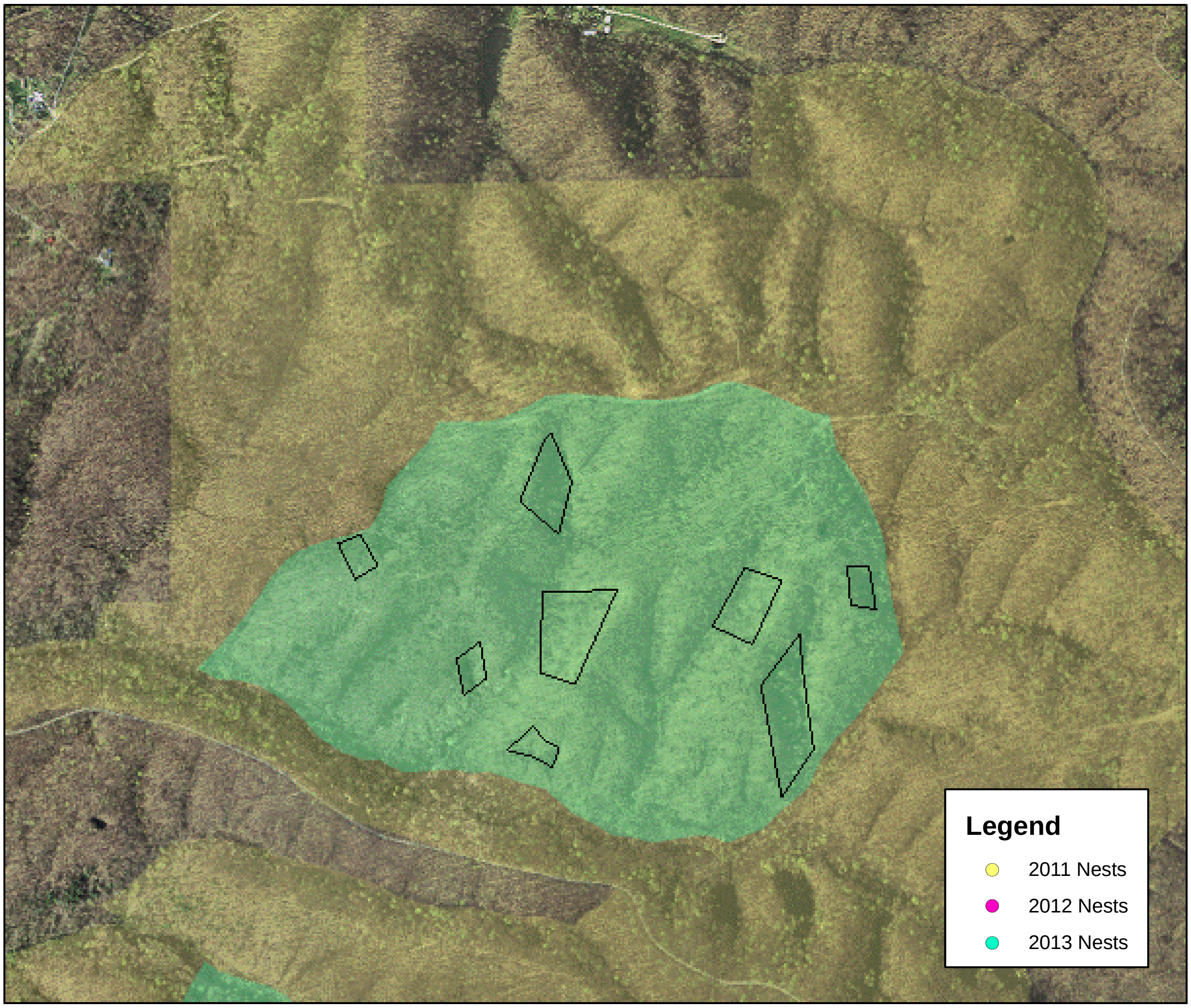

Figure 3. Hardwood Ecological Experiment research unit 1 (uneven-aged) in Morgan County, Indiana. There were no Cerulean Warbler (*Setophaga cerulea*) nests during 2011-2013. The core research area (transparent green) received group-cuts (polygons outlined in black) and single-tree selection cuts. The buffer area (transparent yellow) was subject to single-tree selection cuts, but no harvest occurred in areas with nests.

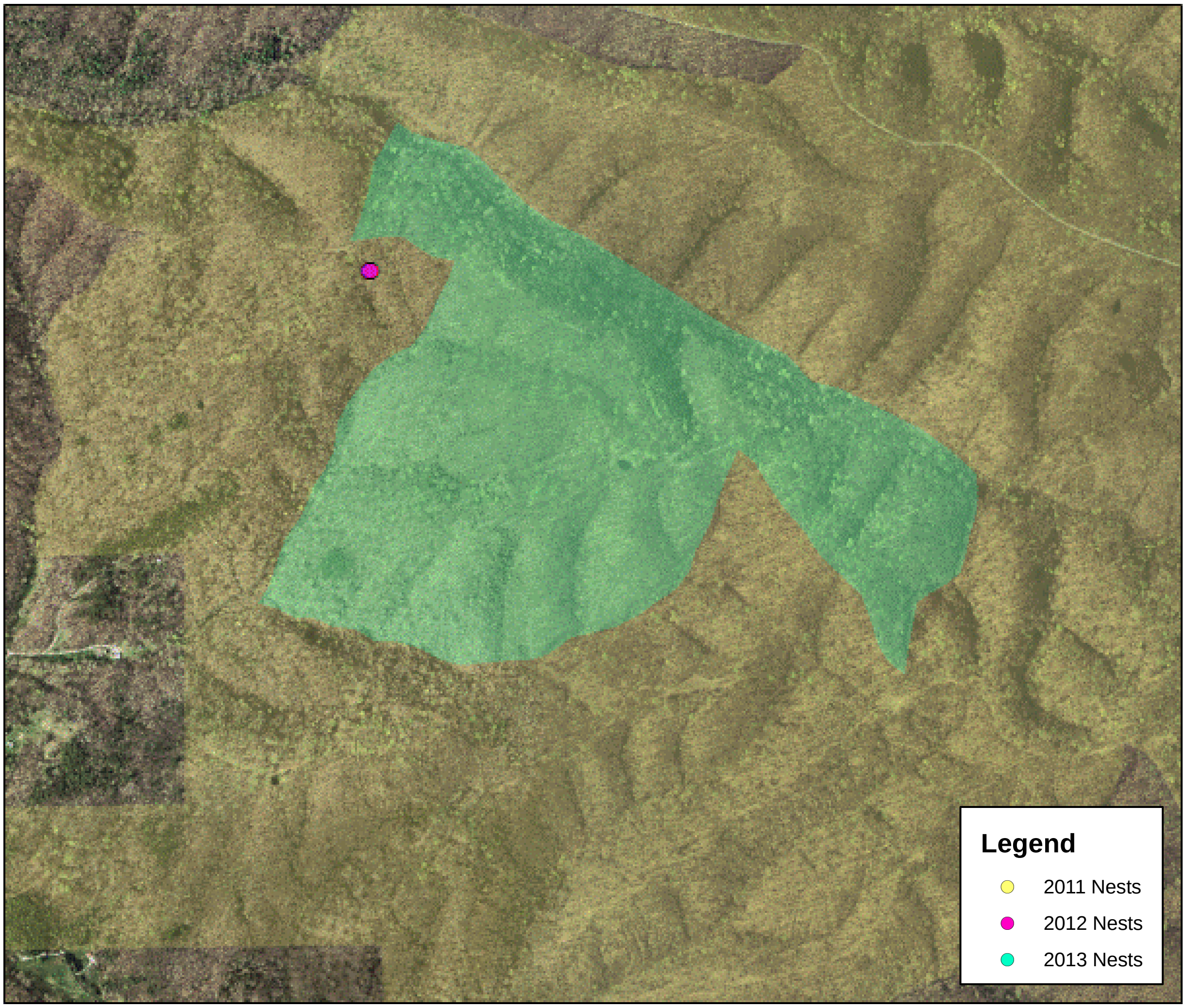

Figure 4. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 2 (control) in Morgan and Monroe counties, Indiana. The core research area (transparent green) received no harvests. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

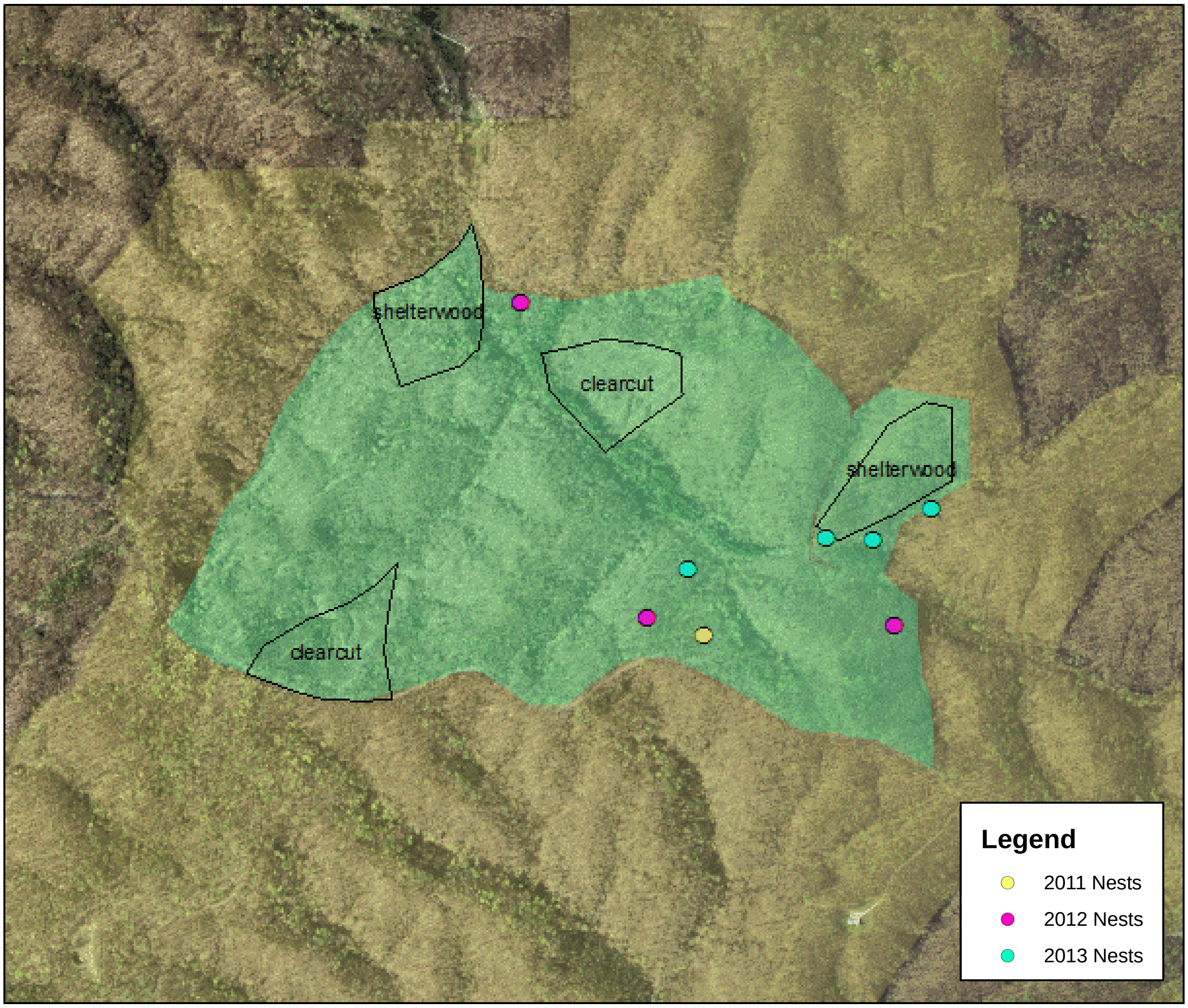

Figure 5. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 3 (even-aged) in Monroe County, Indiana. The core research area (transparent green) received two clearcuts and two shelterwood cuts. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

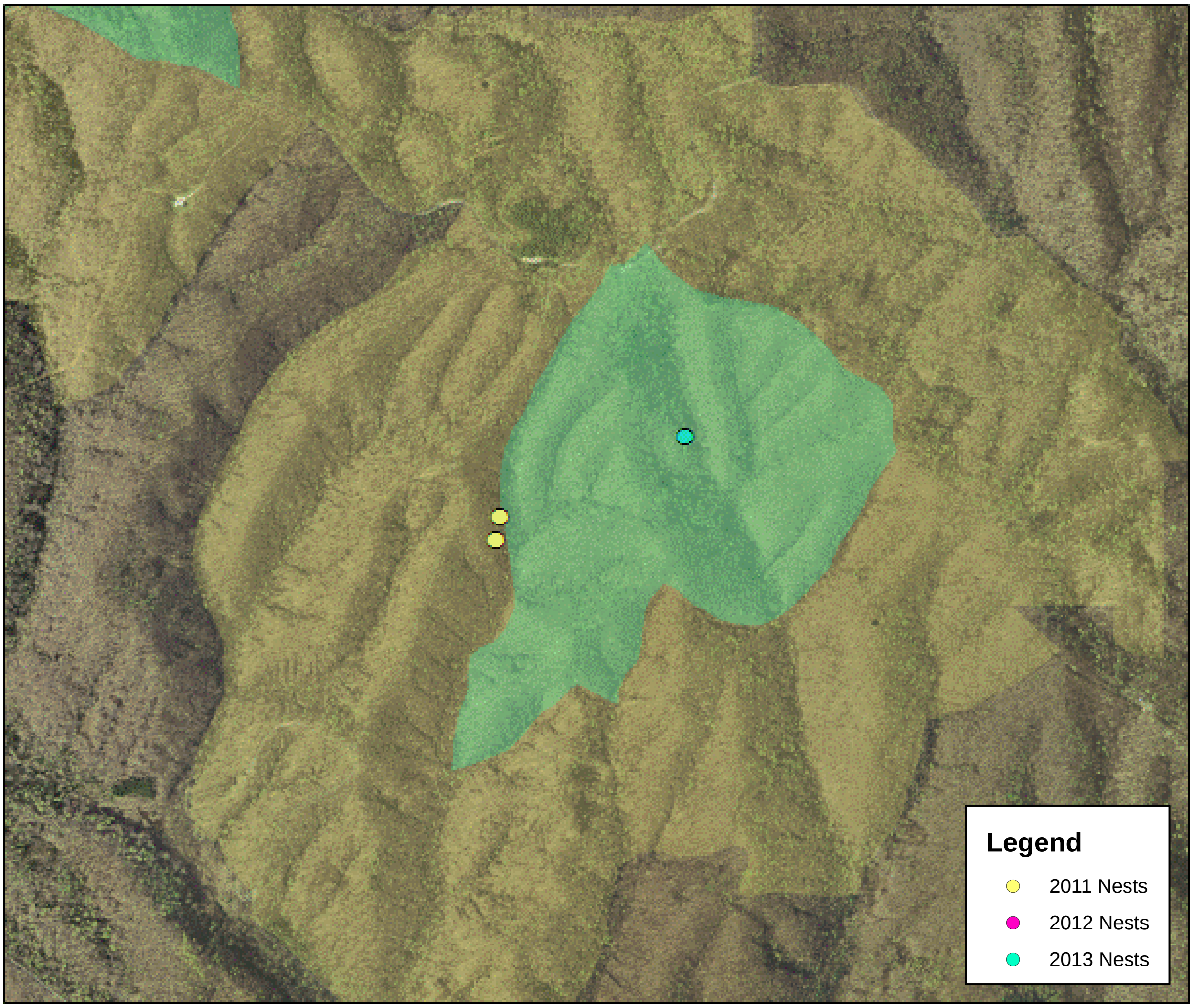

Figure 6. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 4 (control) in Monroe County, Indiana. The core research area (transparent green) received no harvests. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

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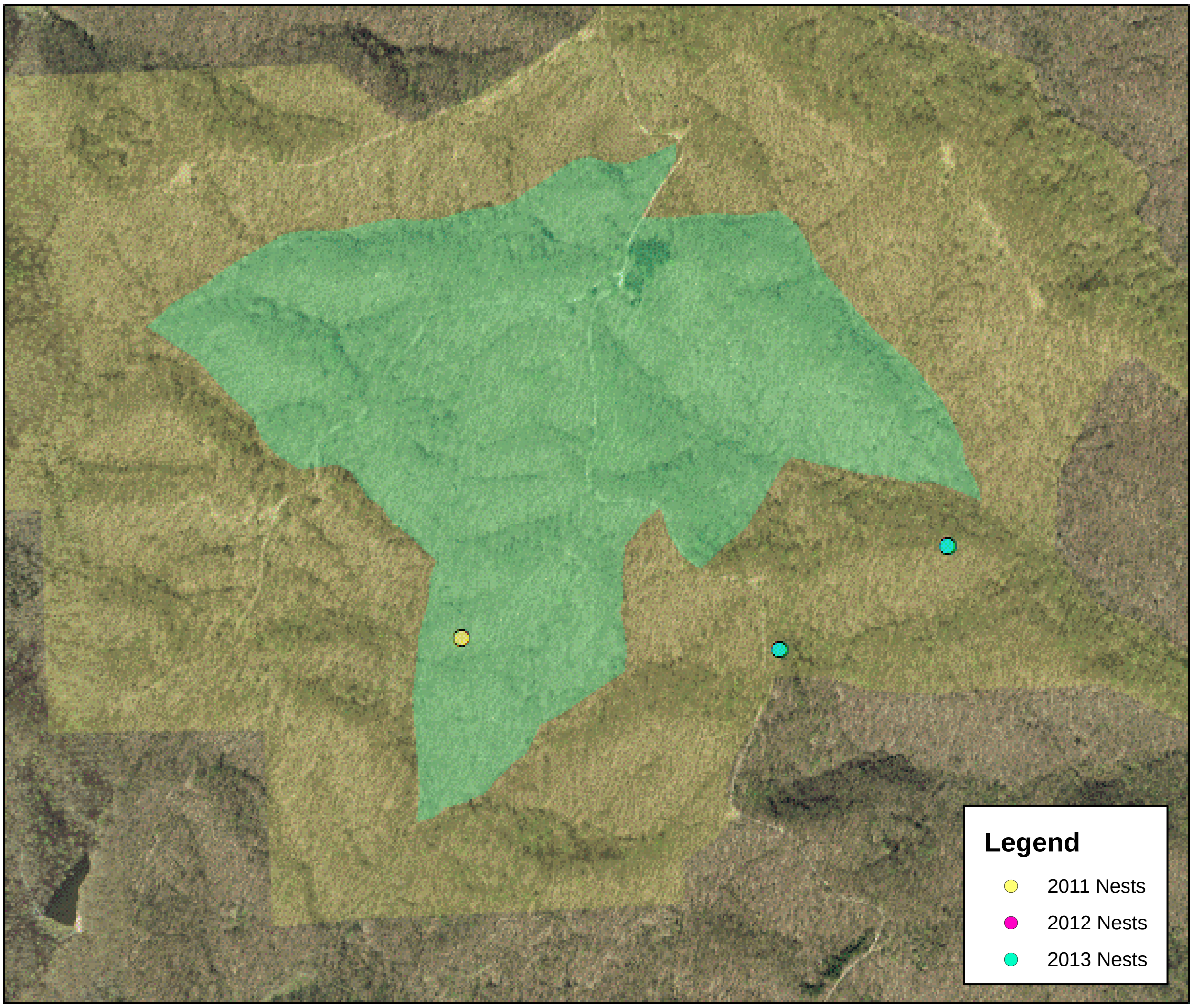

Figure 7. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 5 (control) in Monroe and Brown counties, Indiana. The core research area (transparent green) received no harvests. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

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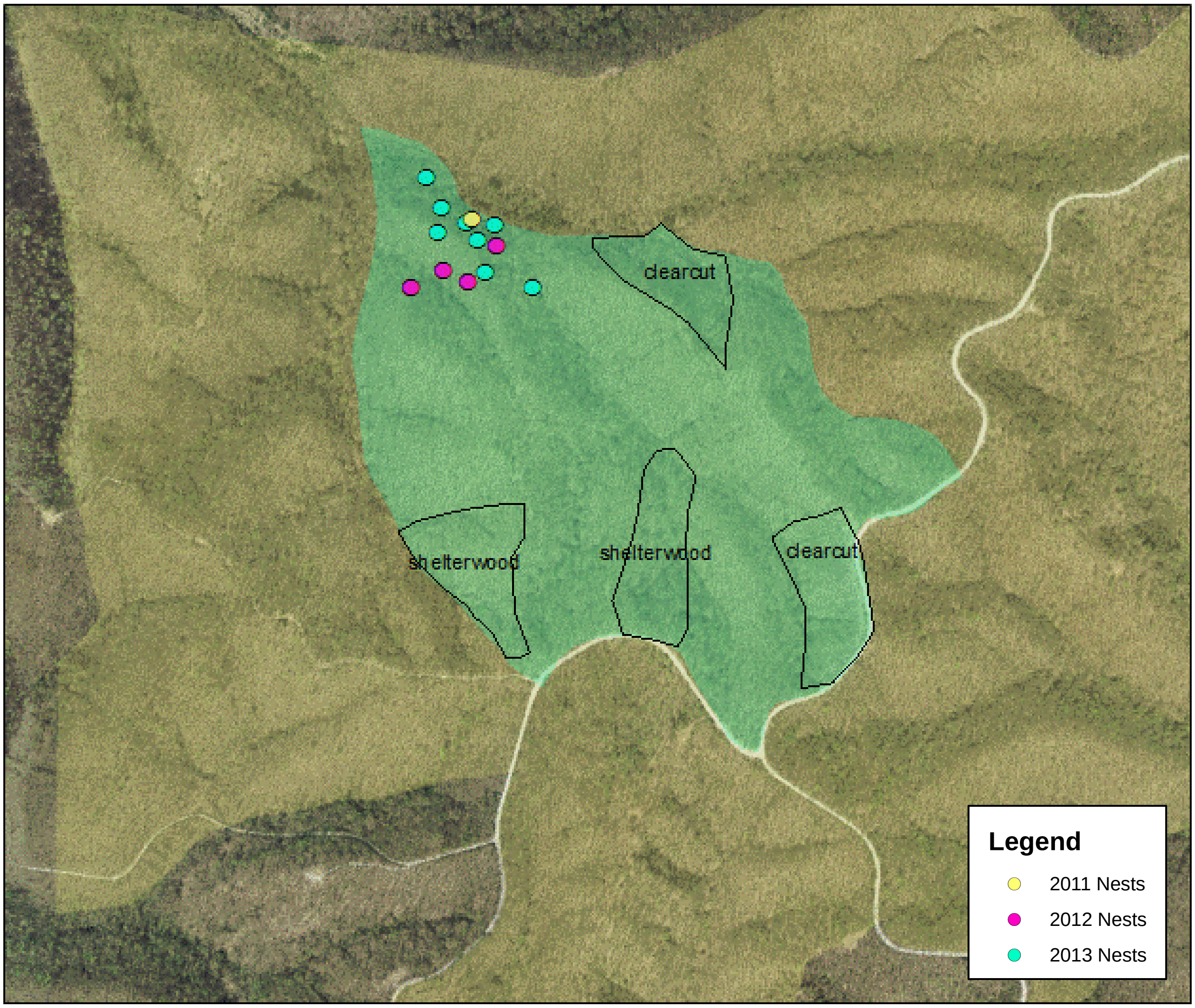

Figure 8. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 6 (even-aged) in Monroe and Brown counties, Indiana. The core research area (transparent green) received two clearcuts and two shelterwood cuts. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

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Figure 9. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 7 (uneven-aged) in Brown County, Indiana. The core research area (transparent green) received group-cuts (polygons outlined in black) and single-tree selection cuts. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

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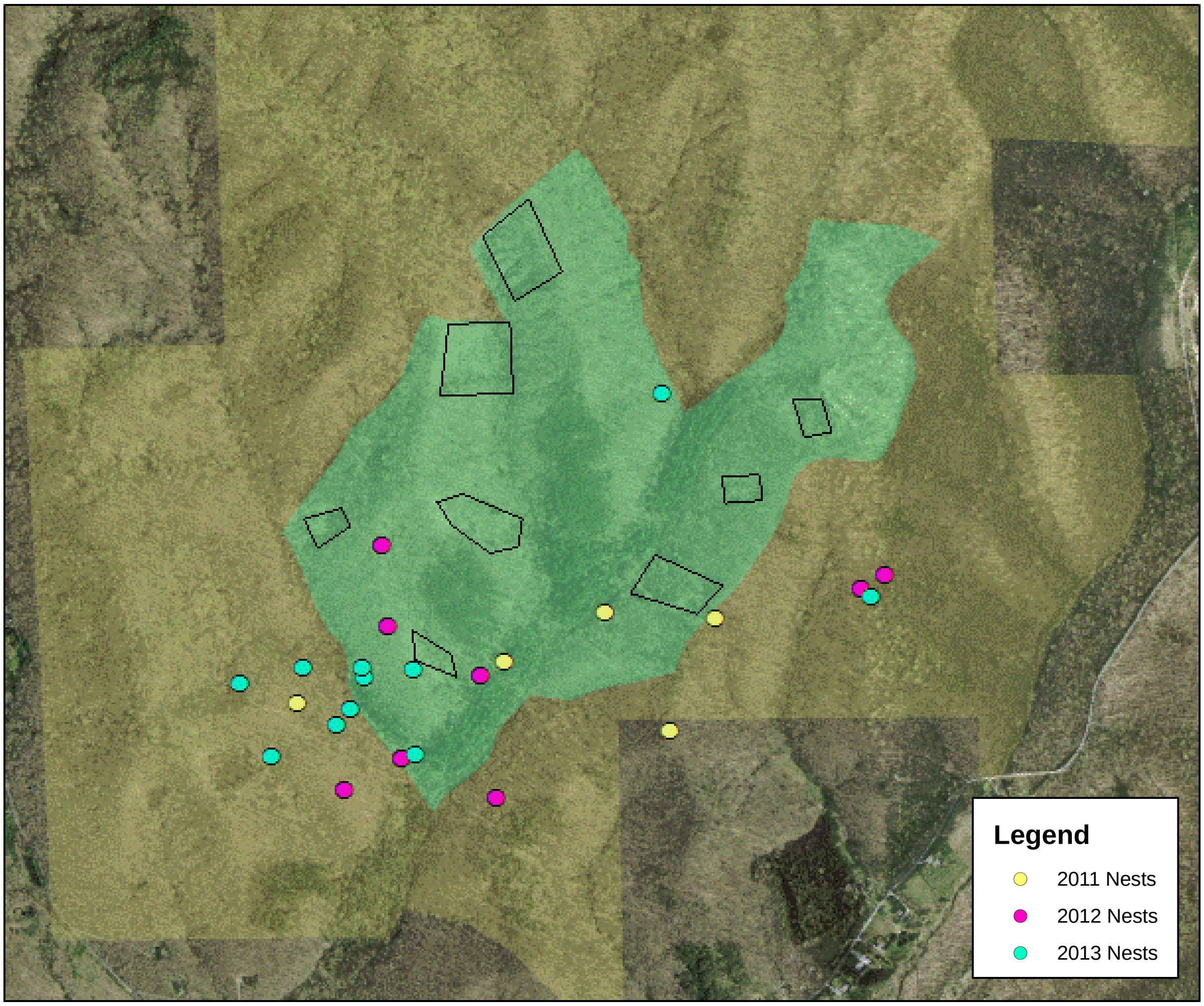

Figure 10. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 8 (uneven-aged) in Brown County, Indiana. The core research area (transparent green) received group-cuts (polygons outlined in black) and single-tree selection cuts. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests.

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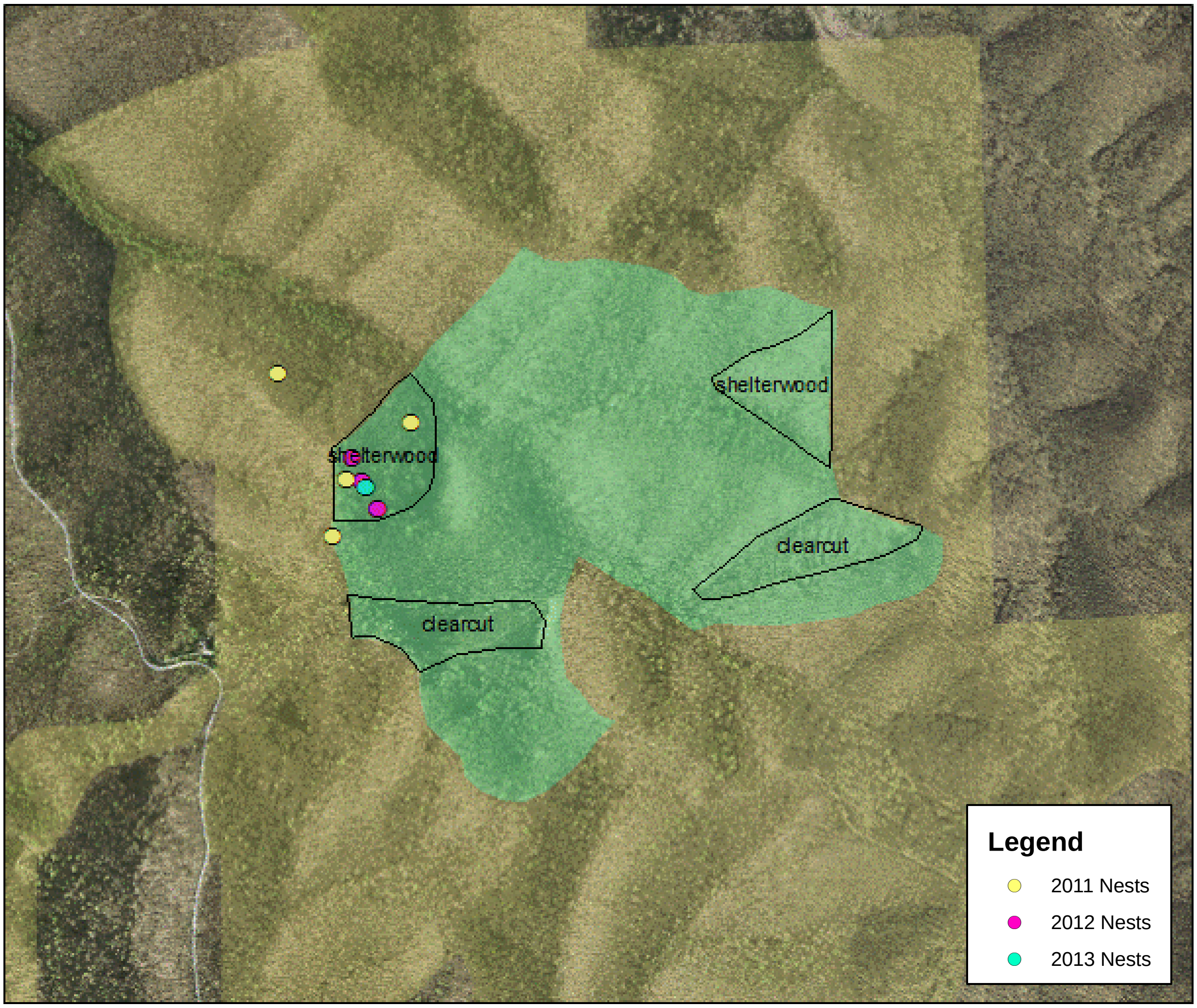

Figure 11. Cerulean Warbler (*Setophaga cerulea*) nest locations during 2011-2013 in the Hardwood Ecological Experiment research unit 9 (even-aged) in Brown County, Indiana. The core research area (transparent green) received two clearcuts and two shelterwood cuts. The buffer area (transparent yellow) was subject to single-tree selection cuts but no harvest occurred in areas with nests

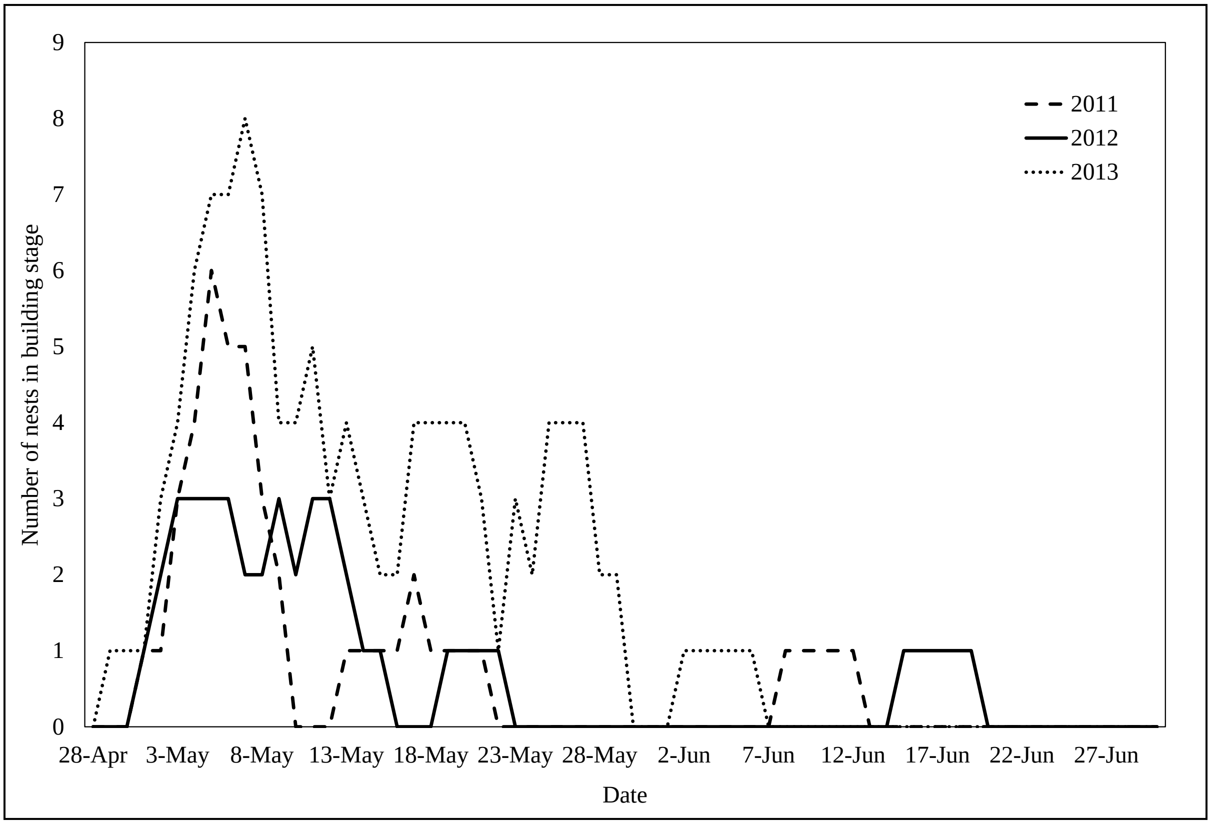

Figure 12. The number of Cerulean Warbler nests in the nest building phase in Yellowwood and Morgan-Monroe state forests during spring 2011-2013.

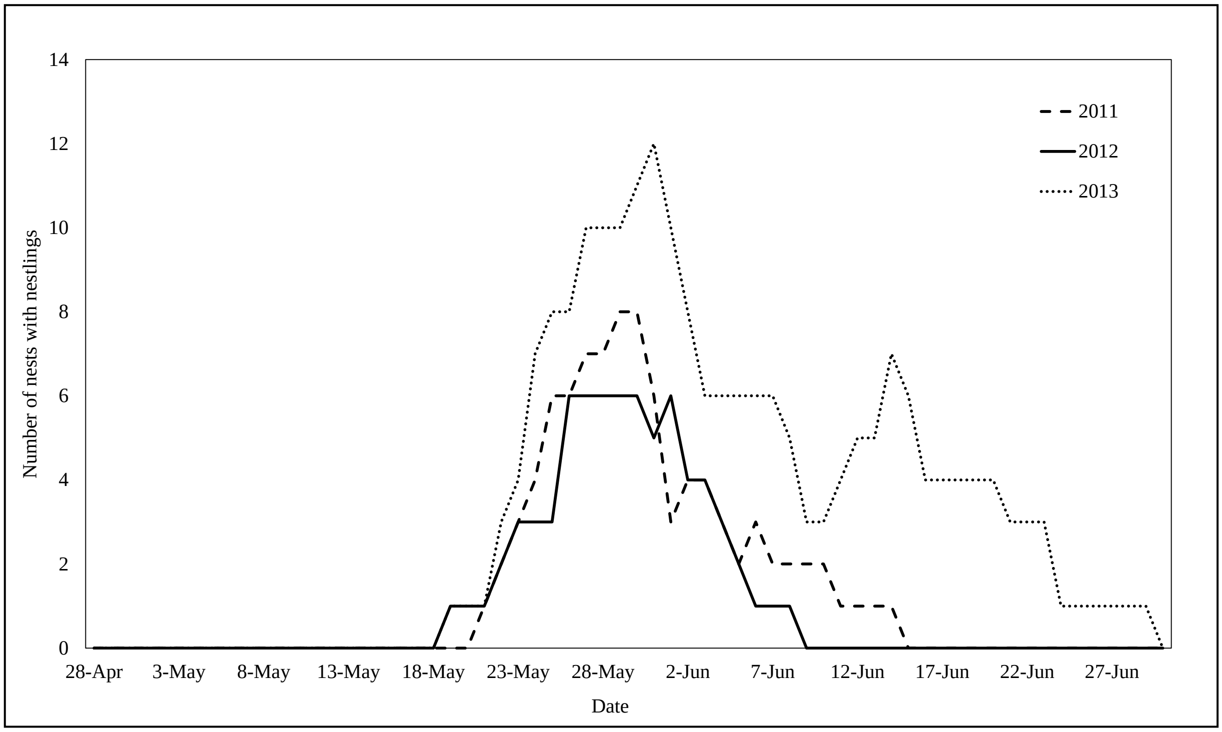

Figure 13. The number of Cerulean Warbler nests with nestlings in Yellowwood and Morgan-Monroe state forests during spring 2011-2013

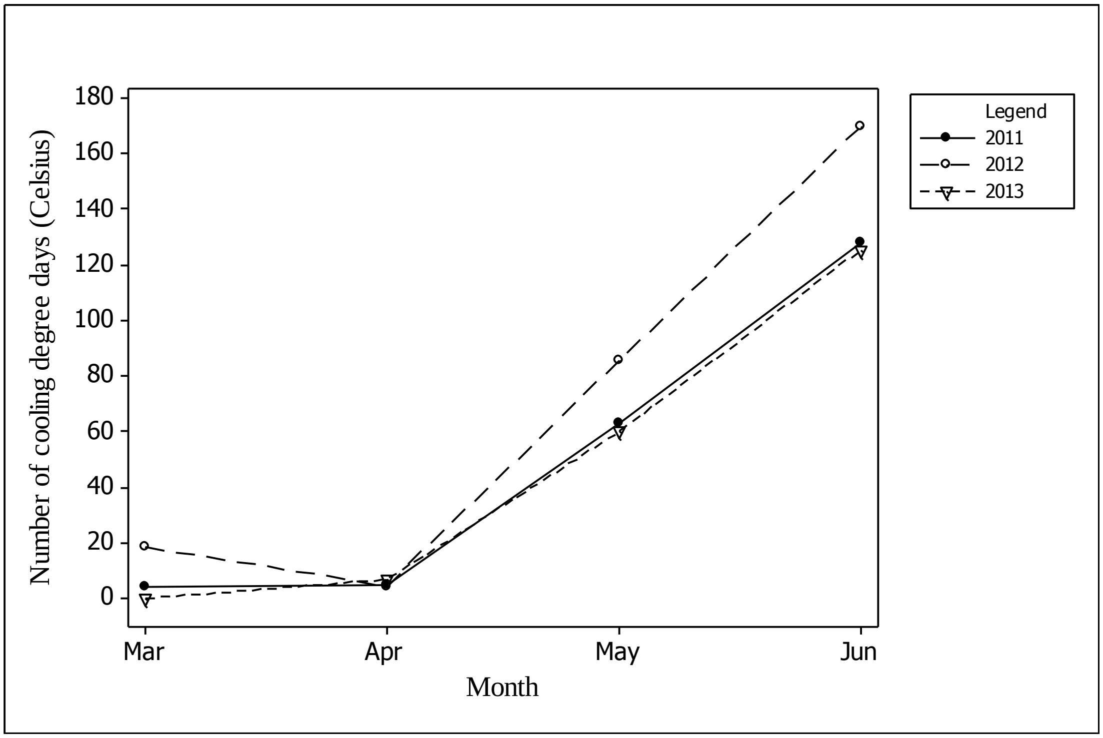

Figure 14. The number of cooling degree days during March-June in 2011-2013 at the Monroe County Airport weather station in Bloomington, IN. Cooling degree days indicate the number of warm days and how high the temperatures were during that time.

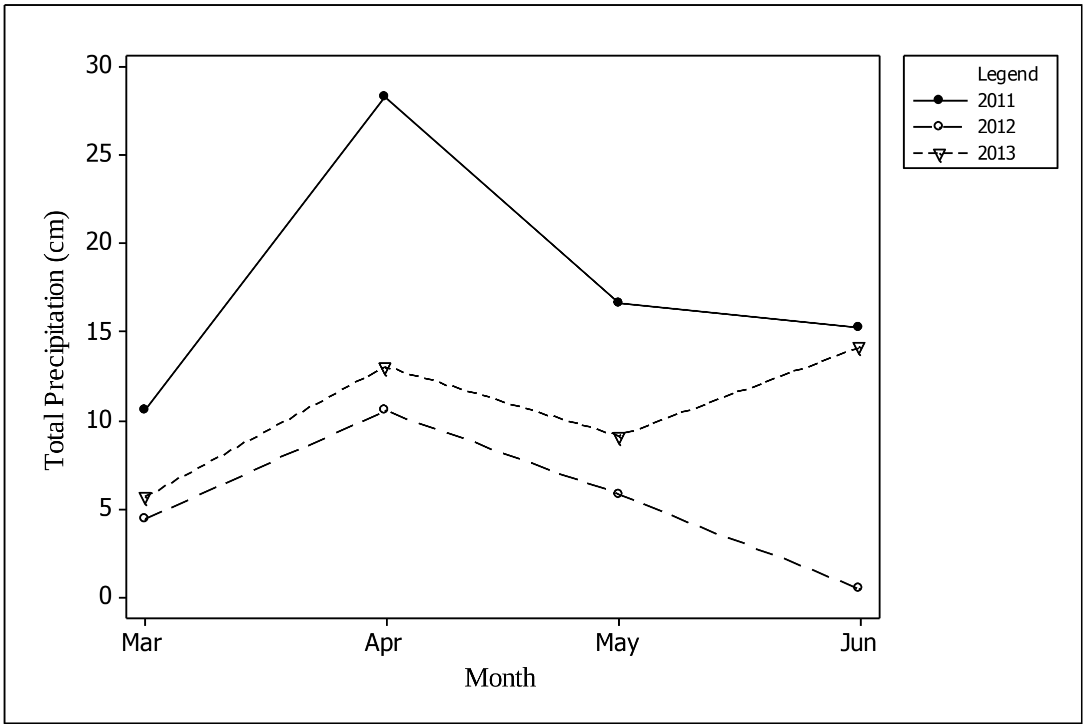

Figure 15. The amount of precipitation during March-June in 2011-2013 at the Monroe County Airport weather station in Bloomington, IN.

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TABLES

Table 1. Mayfield (1975) survival rates for select groupings of Cerulean Warbler nests in Yellowwood and Morgan-Monroe state forests during 2011-2013. Control = research unit with no harvest, even-aged = unit with even-aged harvesting, uneven-aged = unit with uneven-aged harvesting, <100 m = < 100 m from a clear- or group-cut, ≥100 m = ≥100 m from a clear- or group-cut, shelterwood = in an area where first-stage shelterwood harvest occurred, non-shelterwood = outside of areas in which first-stage shelterwood cuts occurred. Nests that failed during the building stage (1) and nests that had unknown fates (2) are not included in this table.

Type	Exposure days	Failures	Daily survival rate	DSR SE	Nesting success %	Nests
Control	67	0	1.000	0	100.0	4
Even-aged	192.5	13	0.932	0.024	17.2	24
Uneven-aged	209	13	0.938	0.019	20.2	21
<100 m	76	5	0.934	0.028	18.1	8
≥100 m	392.5	18	0.954	0.011	30.8	41
Shelterwood	105.5	5	0.960	0.02	36.0	9
Non-shelterwood	363	21	0.939	0.012	20.7	40

Table 2. Nest tree species for Cerulean Warblers during 2011-2013 in Yellowwood and Morgan-Monroe state forests, Indiana.

Tree species	# nests	% nests
Quercus alba (white oak)	27	43.55
Acer saccharum (sugar maple)	9	14.52
Liriodendron tulipifera (tulip tree)	5	8.06
Quercus sp. (oak hybrid)	3	4.84
Carya glabra (pignut hickory)	3	4.84
Quercus prinus (chestnut oak)	3	4.84
Ulmus rubra (slippery elm)	3	4.84
Carya ovata (shagbark hickory)	2	3.23
Platanus occidentalis (American sycamore)	2	3.23
Carya cordiformis (Bitternut hickory)	1	1.61
Quercus rubrus (red oak)	1	1.61
Quercus velutina (black oak)	1	1.61
Fagus grandifolia (American beech)	1	1.61
Juglans nigra (black walnut)	1	1.61