Establishing Regional Mentor Sites for the Management of the Cerulean Warbler and other Mature Forest Avifauna

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TABLE OF CONTENTS

Abstract.....i

Acknowledgments.....iii

Introduction.....1

Objectives.....4

Methodology and Study Design.....5

Methodology development and study site selection……..5

Study Area.....5

Bird Survey….....6

Territory Mapping….....7

Nest Monitoring…….....7

Analysis of Landscape Features……..……..….....8

Results.....11

Relative Abundance Estimate.....11

Territory Sizes.....11

Nest Monitoring …….....11

Analysis of Landscape Features …….…..….12

Discussion.....14

Relative Abundance Estimates …….....14

Territory Sizes...…….15

Nest Monitoring …….....15

Analysis of Landscape Features …….....19

Forest Management Recommendations.....22

Territory-level Selection……...……..22

Landscape-level Selection……..24

Future Research Direction…….25

Long-term Monitoring at NSA Crane…….....27

Surveys to Follow Trends in Population ……....27

Reproductive Monitoring for Source/Sink Modeling……..27

Banding for Survivorship and Site Fidelity……....28

Literature Cited.....29

LIST OF TABLES

Table 1 - Extents of study units 1-6.....34

Table 2 - Habitat features of study sites.....35

Table 3 - Relative abundance estimates & number of mapped territories 36

Table 4 - Nest site characteristics…….....37

Table 5 - Nest tree aspect and orientation……..……..….....38

Table 6 - Trees ≥ 10 cm DBH near nest tree.....39

Table 7 - Distribution of territories 40

Table 8 – Spatial distribution of territories……...41

Table 9 – Selection of tree species……...42

Table 10 – Spatial attributes……..…...43

LIST OF FIGURES

Figure 1 - Study area…….....44

Figure 2 - Survey Protocol.....45

Figure 3 – Unit 1…….....46

Figure 4 – Unit 2…….....47

Figure 5 – Unit 3…….....48

Figure 6 – Unit 4…….....49

Figure 7 – Unit 5…….....50

Figure 6 – Unit 6…….....51

ABSTRACT

Cerulean Warblers (*Setophaga cerulea*) are small Neotropical migrant songbirds that have experienced population declines for several decades. They are globally listed as vulnerable and endangered in the state of Indiana. We examined relative abundance, territory sizes, spatial attributes of territories to landscape features, and reproductive ecology at six study sites within the Naval Support Activity Crane (NSA Crane) installation in southern Indiana. Data were collected from 2 May to 6 July during the 2014 breeding seasons. A total of 101 male Cerulean Warblers were detected at the six study sites. Relative abundance estimates ranged from 2.55-14.80 males/km² with an average of 8.59 males/km². The number of territories demarcated at each study site ranged from 9-30 with a mean territory size of 0.30 ha. The majority of territories (67%) were randomly distributed across the study sites. Cerulean Warbler territories were characterized by tall and closed canopies that displayed denser vertical canopy structure compared to random points where birds were not located. Territories were established on steeper slopes, closer to perennial streams, and at greater distance from the nearest canopy gaps (≥ 70 m^2) than random points, and Cerulean Warblers appeared to select northeast-facing slopes to establish their territories. There was no significant difference in distance of territories to roads or elevation compared to non-use sites. Cerulean Warbler territories had larger diameter trees (20.54 cm DBH) than non-use (19.12 cm DBH) sites, and greater abundance of hickories. Cerulean Warblers selected stands that were harvested more often than predicted based on harvest site availability, and avoided non-harvested stands more often than predicted based on non-harvest site availability. Of the 16 Cerulean Warbler nests that were found, 11 failed (nest

success was 21%). Nest success was much lower than at similar study sites in southern Indiana. The average nest height (17.38 m), nest tree height (24.53 m), diameter of nest tree (37.17 cm) were all lower than those reported at other sites in Indiana. Cerulean Warblers are selective foragers. Several recent studies in Indiana have documented the importance of oaks and hickories as preferred foraging trees, and as sources of abundant lepidopteran larvae that are important in the diet of Cerulean Warbler nestlings. To provide preferred foraging and nesting habitat for this warbler in the future, forests should be managed to increase oak and hickory regeneration, while at the same time maintaining shade-tolerant species such as sugar maples that appear to be important nesting trees at NSA Crane. Prescribed burns, in combination with small openings through patch and group selection cuts, will create openings necessary for the regeneration of oak seedlings.

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Introduction

The Cerulean Warbler (*Setophaga cerulea*) is one of many forest-nesting Neotropical migrants of conservation concern with long-term population declines documented on breeding grounds (Robbins *et al*. 1992). This species breeds in North America, primarily throughout the northeastern and midwestern deciduous forested areas, and winters in northern South America. Based on long-term data analyses (1966-2012) from the North American Breeding Bird Survey (BBS), the Cerulean Warbler showed an annual decline of 3.03 %, which is the most precipitous decline of any North American wood warbler (Sauer *et al*. 2014). Since 1968, the overall population of Cerulean Warblers has declined by 70% primarily due to habitat loss and fragmentation of mature deciduous forests. Hamel (2000b) estimated that the Cerulean Warbler population size would diminish to 8% of the 1966 level if population declines continue over the next 30 years. The species has received high ratings for vulnerability by Partners in Flight for threats to its breeding and nonbreeding habitats, and overall population trend within North America. The Office of Migratory Bird Management listed the species as a migratory nongame bird of management concern in 1987 (USFWS 1987). Public and scientific concern over Cerulean Warbler population declines initiated a petition to list this species as threatened under the Endangered Species Act (USFWS 2002); however, the petition to list was later denied (USFWS 2006). The Cerulean Warbler is listed as Vulnerable by the IUCN (Birdlife International 2004).

Although Butler (1898) considered the species a common migrant and summer resident in Indiana, the Cerulean Warbler was listed as a “species of special concern” in the mid-1990’s (Bruner 1998) and more recently as endangered in the state

(http://www.in.gov/dnr/naturepreserve/files/np_brown.pdf). This designation does not offer specific added protection, but does indicate an urgent need to monitor populations closely, and for research to support the management and conservation of this declining species. Indiana displayed the lowest relative abundance estimate of 0.27 Cerulean Warblers/route from BBS data among states for which an estimate could be calculated (Hamel 2000b). From 1966-2012, the annual decline for Cerulean Warblers in Indiana was 3.92 (http://www.mbr-pwrc.usgs.gov/cgi-bin/atlasa12.pl?06580&1&12&csrfmiddlewaretoken=3YKakk7LxT2ki6NSpl4mstudYCqdW02C).

Department of Defense (DoD) Natural Resource Managers support the military mission objectives and activities, and manage the habitat needs of declining species. This project proposal from Ball State University was initially presented to Mr. Steven Andrews, Natural Resources Manager at Naval Support Activity Crane (NSA Crane). He communicated approval for the research proposal within the context of current and future versions of the Installation's Natural Resources Management Plan (INRMP). This project advances the work of DoD Legacy Resource Management supported project #09-429 titled "Cerulean Warbler Occurrence Atlas for Military Installations". Project 09-429 evaluated the occurrence of Cerulean Warbler populations by mailing questionnaires to military installations within the species breeding range.

NSA Crane encompasses a major area of contiguous forest in Indiana, has a viable Cerulean Warbler population, and implements a science-based forest management program which allows for the comparison of forest treatments. NSA Crane in Indiana served as one of three mentor sites, representative of Bird Conservation Region (BCR)

24, for military installations with actively managed forests that have Cerulean Warbler populations, and data at this site were collected by Ball State University. The other two mentor sites were Leavenworth (BCR 22) and Fort Custer Training Center (BCR23), and these sites were developed as mentor sites by Kalamazoo Nature Center. Case studies and best practices constructed from this mentor site will be disseminated to other sites in BCR 24 with information on the implementation of similar practices. This project will benefit the military mission by maintaining unrestricted access to areas for training, testing, and other critical activities by developing the best forest management practices to maintain Cerulean Warbler populations and halt population decline to avoid land and activity restrictions.

This project assessed the relative abundance of Cerulean Warblers and the spatial characteristics of territories in relation to the landscape during the breeding season at NSA Crane. Project products, with transferable application, include forest management guidance for Cerulean Warblers, geographic interface of Cerulean Warbler data, and protocols for long-term monitoring. This project supports the State of Indiana Comprehensive Wildlife Strategy and complements the Cerulean Warbler research component of the Hardwood Ecosystem Experiment (HEE) in two southern Indiana state forests. HEE is a research partnership with the Indiana Department of Natural Resources, multiple universities including Ball State University, The Nature Conservancy, and private stakeholders.

Objectives

Task 1: Develop project methodology and select/confirm study sites at NSA Crane.

Task 2: Conduct Cerulean Warbler point count surveys and demarcate territories at selected sites.

Task 3: Create Geographic Information System (GIS) layers with Cerulean Warbler territories and point count data.

Task 4: Analyze landscape features of territories using GIS.

Task 5: Develop forest management guidance and protocols for long-term monitoring of Cerulean Warblers.

Task 6: Complete Progress Report on Legacy website.

Methodology and Study Design

Develop project methodology and select/confirm study sites at NSA Crane

Project methodologies (size of study units, point count surveys, territory demarcation, nest monitoring, and analyses of landscape features) were based on long-term protocols developed since 2000 by the PI and applied to the following study areas in Indiana: Big Oaks National Wildlife Refuge (BONWR), Morgan-Monroe and Yellowwood state forests, and Hoosier National Forest. To select specific study sites at NSA Crane, the PI made reconnaissance trips on 15 August 2011, 14 June 2012, and 21 June 2013. Areas of NSA Crane, where a previous researcher (Harmon P. Weeks, Jr., Purdue University, West Lafayette, Indiana) and a long-term monitoring program (Erin Rowan, Monitoring Avian Productivity and Survivorship [MAPS] station coordinator, The Institute of Bird Populations) had detected Cerulean Warblers, were visited to confirm presence of the species. Once the continued presence of Cerulean Warblers was confirmed at these historic sites, final selection of the 6 study sites was determined on 10 July 2013 (Fig. 1).

Study Area

NSA Crane comprises 25,337 ha, of which 19,829 ha are forested. The forest matrix consists largely of oak-hickory forested stands, mixed hardwoods, and bottomland hardwoods. Forest tracts have been managed using a variety of silvicultural techniques, including group selection, improvement cuts, crop tree release, timber stand improvement, prescribed burning, and grapevine removal. Six 225 ha units were

delineated using ArcGIS v. 10.0 in areas where Cerulean Warblers had previously been recorded. Table 1 shows the extents of units 1-6 and Table 2 shows several descriptive features of these units. We conducted Cerulean Warbler (*Setophaga cerulea*) surveys between 2 May, 2014 and 6 July, 2014.

Bird Survey

Point counts were conducted from 2 May, 2014 to 28 May, 2014. Each unit had 49 points spaced 200 m apart with a 150 m buffer around the perimeter (Fig. 2). We used a 100-m fixed radius for our point counts to minimize the likelihood of double counting; the effective distance that a male Cerulean Warbler can be heard is 90 m (Hamel *et al*. 2009, Jones *et al*. 2000). Cerulean Warbler presence was documented at each of these points by broadcasting Cerulean Warbler vocalizations and recording Cerulean Warbler response. We surveyed each point for a total of five minutes. After arriving at a particular sampling 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 (Falls 1981). The volume on the amplifiers was set as high as possible without distorting the broadcast. We recorded the number of Cerulean Warblers detected, and their direction and distance. Direction was determined using a compass and distance was determined using our assessment of the volume of Cerulean Warbler vocalizations. Surveys were not conducted during rainy or windy conditions. Sampling point locations were recorded in Universal Transverse Mercators (UTM) using Global Positioning System (GPS) units. The total number of

males detected at each study site was divided by the total area aurally sampled for each study site (1.96 km^2) to calculate number of males/km^2 for each unit.

Territory Mapping

During May and June, we recorded the coordinates of singing males. Whenever a male Cerulean Warbler was observed in a tree perched and singing, we marked the tree with flagging tape. A territory is defined as the area within the perimeter of song-perch trees. Global Positioning System (GPS) coordinates of the trees were recorded with NAD 83 Universal Transverse Mercator (UTM) using a Garmin GPSMAP 62S unit. Whenever possible, we revisited known territories multiple times before final demarcation was determined. We attempted to record at least five song perches. However, we were not always able to attain five song perches. Therefore, between 1 and 12 song perches were recorded per male. The species of tree from which the male sang was recorded for each song perch. We created polygons in ArcGIS for territories with 3 or more song perches. These territory layers were superimposed over a map of the study area to provide an image of the spacing of the territories (Figs. 3-8).

Nest Monitoring

We located Cerulean Warbler nests during point count and territory surveys (Figs. 3-8) by observing parental behaviors (e.g. female Cerulean Warbler carrying nest material to nest). Nest searching was conducted only as incidental observations during other activities because it did not fulfill any of the research objectives outlined in the research proposal. Nests were monitored to determine whether they failed or succeeded

and were visited very infrequently until the last few days of the nestling stage. Nests that survived until the nestling stage were monitored every day when the nestlings were between 6 and 10 days old, and fledglings were located. We considered a nest successful if at least one nestling fledged. We recorded nest site characteristics, including nest height, nest tree height, distance of nest to trunk and distal end of nest branch, nest tree diameter at breast height (DBH), nest tree species, nest orientation in relation to nest tree, and aspect of nest tree. We also recorded the number of each tree species within a 11.3 m radius around the nest (James and Shugart 1970).

Analysis of Landscape Features

Distances between the centroids of each territory and the nearest neighboring territory were used as part of a nearest neighbor analysis (Krebs 1989), which was performed using the Spatial Analyst Tool “Average Nearest Neighbor” tool in ArcMap. We calculated if Cerulean Warblers' territory centers were clustered using centers derived from territories containing 3-12 points. Distance was calculated using the straight line method, “Euclidean Distance” and the encompassing area of the research unit was entered as one of the tool options to define the extent that was surveyed.

We statistically compared the spatial characteristics of use and non-use sites. We selected non-use sites by importing the coordinates of each point count location where no Cerulean Warblers were detected. We filtered non-use points by removing all points that were within 100 m of a mapped territory. This reduced the total number of points from 294 to188, and of these, 98 points were selected randomly as non-use points. Random extents were created around these points by essentially copying and randomly pasting the Cerulean Warbler territories around non-use points. These coordinates were used to

compare spatial characteristics of Cerulean Warbler use sites to non-use sites. Light detecting and ranging (LiDAR) data layers were derived using methodology detailed in Barnes (2014) and data made available through IndianaMap Framework Data (http://opentopo.sdsc.edu/gridsphere/gridsphere?gs_action=lidarDataset&cid=geonlidarframeportlet&opentopoID=OTLAS.062012.4326.1). LiDAR-derived variables we selected for comparisons included aspect, canopy height, % canopy height < 12 m, % canopy height ≥ 24 m, slope, vertical distribution ratio, elevation, distance to nearest canopy gap ≥ 20 m^2, and distance to nearest canopy gap ≥ 70 m^2. National hydrography data (http://maps.indiana.edu/layerGallery.html) were used in comparisons between territory centroids and random non-use points for distance to perennial streams, distance to intermittent streams, and distance to all streams (perennial, intermittent, and streams without an identification combined). Data from Indiana Department of Transportation (INDOT) were used to compare distance to nearest road between territory centroids and random non-use sites (http://opentopo.sdsc.edu/gridsphere/gridsphere?gs_action=lidarDataset&cid=geonlidarframeportlet&opentopoID=OTLAS.062012.4326.1). The analysis tool "Generate Near Table" was used to calculate distance to nearest feature, and the spatial analyst tool "Zonal Statistics As Table" was used to calculate statistics within use and non-use polygons. Independent-sample *t*-tests were used for all landscape-level comparisons between territory locations and random non-use sites.

Kalamazoo Nature Center hired foresters to collect basal area (BA) and trees per acre (TPA) using current methods from the Timber Cruising Handbook. Point surveys with a fixed length angle gauge at basal area factor (BAF) 10 was used at 50 points

located at the study sites at NSA Crane (25 at randomly selected Cerulean Warbler use sites and 25 at randomly located non-use sites; Reding and Vormwald 2014) and the diameter (cm) at breast height (DBH) was measured for all "in" trees. A Logistic Regression was performed in 'R' to determine if Cerulean Warbler territories were characterized by specific tree species compared to non-use sites. Tree species selected were as follows: all hickories (*Carya* spp.) combined, sugar maple (*Acer saccharum*), white oak (*Quercus alba*), tulip tree (*Liriodendron tulipifera*), and red oak family. A 2-sample t-test was used to determine if there was any significant different in DBH of trees $\geq$ 10 cm between Cerulean Warbler territories and non-use sites. Normality and variance were checked and DBH was cube root transformed to obtain normality. A Chi-square analysis was performed to compare counts of Cerulean Warbler territory centers in each harvest treatment type (use) to the proportion of each harvest treatment type available. The amount of area was calculated as m^2 for each harvest treatment type for all forest stands within the 6 study sites (using the most recent harvest treatment type). Many stands had multiple treatment types over the last 50+ years. All statistical tests were performed at $\alpha = 0.05$ level of significance.

Results

Relative Abundance Estimates

We recorded a total of 101 detections of male Cerulean Warblers during point count surveys (Figs. 3-8, Table 3). The number of birds detected at each study unit ranged from 5 to 29 or 2.55 to 14.80 birds/km^2, respectively. Study sites 2 and 5 had the highest number of detections (Table 3). The mean relative abundance was 8.59 ± 3.90 birds/km^2.

Territory Sizes

We mapped a total of 110 Cerulean Warbler territories (12 territories with 1 to 2 song perches recorded, 9 with 3 to 4 song perches, and 89 with 5 to 12 song perches; Figs. 3-8, Table 3). The number of territories delineated at each study site ranged from 9 to 30 with study sites 2 and 5 containing the greatest number of territories. In general, the number of male Cerulean Warbler detections during point count surveys corresponded well with the number of territories that were demarcated at each study site (Table 3). These data suggest that birds detected earlier during the point count surveys stayed and established territories rather than migrating through the area. Average territory size (using only territories with 5 or more points) was 0.30 ± 0.17 ha.

Nest Monitoring

We monitored 16 Cerulean Warbler nests of which 5 were successful and 11 failed (Figs. 3-8). Of the 5 that were successful, 2 were found by locating a fledgling underneath the nest and then searching above for the nest which contained nestlings. Of

the nests that failed, 1 was found torn apart, 1 disappeared from the tree limb, and 10 were still intact. We did not observe Brown-headed Cowbird (*Molothrus ater*) nestlings in any of the nests although cowbird parasitism of Cerulean Warbler nests has been observed in other parts of southern Indiana. We recorded nest site characteristics for all 16 nests (Table 4, 5 and 6). Mean nest height was 17.38 m with a mean nest tree diameter of 37.17 cm and a mean nest tree height of 24.53 m. Mean distance of nest to the tree trunk was 4.25 m and mean distance of nest to end of branch was 2.2 m (Table 4). The majority (43.75%) of nests were oriented in a northwest direction (Table 5). Nest tree species were sugar maple (6 nests), white oak (3 nests), slippery elm (*Ulmus rubra*; 2 nests), black tupelo (*Nyssa sylvatica*; 2 nests), ash (*Fraxinus sp.*; 1 nest), American sycamore (*Platanus occidentalis*; 1 nest), and scarlet oak (*Quercus coccinea*; 1 nest).

Analysis of Landscape Features

Mean distance of territories to the nearest neighboring territories was 152 m. Based on a nearest neighbor analysis, Cerulean Warbler territories were distributed randomly in four study sites (units 2, 3, 4 & 6), one study site exhibited clustered territories (unit 5), and territories in one study site (unit 1) were somewhat clustered (Table 7).

Cerulean Warblers consistently established territories in stands with a tall (19 m; $p < 0.001$) and closed canopy ($p < 0.001$), more dense vertical canopy structure ($p = 0.007$), greater distance to nearest canopy gap ≥ 70 m^2 ($p = 0.03$), greater slope (11º; $p < 0.001$), and closer to perennial streams ($p = 0.004$) than corresponding random points

where no birds were located (Table 8). Data suggest that Cerulean Warblers selected territories with a northeast-facing aspect ($p = 0.07$). There was no significant difference between distance to roads ($p = 0.518$) and elevation of territories ($p = 0.574$) to random points. Moreover, there was no significant difference between territories and random points when intermittent streams ($p = 0.556$) were compared. Cerulean Warbler territories were located significantly further away when perennial, intermittent, and streams with no identification were combined ($p < 0.030$) than random points.

Cerulean Warbler occurrence had a moderately strong positive association with hickory abundance ($n = 51$ in use and $n = 21$ in non-use; $\beta = 0.497$, S.E. = 0.209, $p = 0.0176$; Table 9). Data suggest that Cerulean Warbler territories (20.541 ± 7.092 cm DBH) were characterized by larger diameter trees than non-use sites (19.107 ± 5.479 cm DBH) but more data are needed ($p = 0.059$). Cerulean Warblers selected stands that were harvested (especially improvement cuts) more often than predicted based on harvest site availability, and avoided non-harvested stands more often than predicted based on non-harvest site availability ($p < 0.000$; Table 10).

Discussion

Relative Abundance Estimates

Our one-year average of 8.6 males/km² is higher compared to more recent relative abundance estimates of breeding Cerulean Warblers in Indiana. For example, the average relative abundance estimate derived from data collected from 2007-2014 at our long-term monitoring sites at the HEE in Morgan-Monroe and Yellowwood state forests is 6.54 males/km^2. However, we caution that our one-year study at NSA Crane does not take into account inter-year variation. At our long-term study sites at the HEE, annual relative abundance averages ranged from a low of 4.36 to a high of 8.27. In other studies, Islam and Roth (2004) calculated the relative abundance of Cerulean Warblers at BONWR in southeast Indiana at 2.35 males/km² over a 2 year period. Islam and Basile (2002) and Islam *et al*. (2006) detected 1.95 males/ km² in the Hoosier National Forest, Yellowwood State Forest, and Morgan-Monroe State Forest in 2000 and 2001, and 3.58 males/km² in 2004 & 2005, respectively. Despite recent dramatic declines, at least some areas still indicate relatively high Cerulean Warbler densities. Hamel (1992) reported a density of 24.2 pairs/km² in the Mississippi Alluvial Valley. Cerulean Warbler density in four plots in south-central Ohio was reported as 22.25 pairs/km² (Artman *et al*. 2001). In West Virginia, which has historically contained a high proportion of the Cerulean Warbler population, Cerulean Warbler density was reported as 46 territories/km² in intact forest, but only 7 territories/ km² in fragmented forest (Weakland and Wood 2005).

Territory Sizes

Average territory size at NSA Crane (0.30 ha) was similar to that recorded by Barg *et al.* (2005) in Ontario, Canada. However, Oliarnyk (1996) mapped 18 territories in Ontario that ranged from 0.38 to 2.40 ha, with a mean of 1.04 ha. At our long-term study sites at the HEE, mean territory sizes ranged from a minimum of 0.09 ha to a maximum of 0.86 ha with an overall mean of 0.26 ha from 2007-2014 (n = 563 territories). Mean territory size of 51 territories at BONWR in southeast Indiana was 0.21 ha, ranging from 0.03 ha to 0.53 ha (Islam and Roth 2004). Territories (n = 59) in the Hoosier National Forest, Yellowwood State Forest, and Morgan-Monroe State Forest in 2000 and 2001 ranged in size from 0.04 - 1.43 ha, with a mean of 0.34 ha (Islam and Basile 2002), and a mean territory size of 0.34 ha in 2004 & 2005 (Islam *et al*. 2006). Our average territory size of 0.30 ha at NSA Crane is within the range of previous measurements in the same general locations but much smaller than those reported by Oliarnyk (1996) in Ontario. Barg *et al.* (2005) noted a number of factors that may influence territory size, including habitat quality variation, resource distribution, paired or unpaired males, and bird age.

Nest Monitoring

Although not part of our research objectives, we located 16 nests at NSA Crane of which 11 failed and two were found only after locating fledglings beneath them. Excluding the latter two nests (including nests that are found this way biases calculations), overall nest success was 21%. This success rate is very low compared to rates at our long-term HEE study sites. During 2011-2014, nest success was 58% in

2011, 8% in 2012, 58% in 2013 and 40% in 2014. During the 2012 breeding season, severe drought conditions drastically reduced nest success; therefore this low rate was atypical. In general, nest success at the HEE was lower than nest success in Ontario and Tennessee but comparable to rates in Michigan.

Brood parasitism by Brown-headed Cowbirds may play an important role in the decline of Cerulean Warblers (Robbins *et al*. 1992), although there has been much variation in occurrence of parasitism throughout the breeding range (Hamel 2000a). No cases of brood parasitism were documented in an Ontario study site (Oliarnyk 1996) or in 40 nests in southeast Indiana (Islam and Roth 2004). Fourteen percent of 57 nests in Ontario (Peck and James 1997), 2% of 52 nests in the Cumberland Mountains of Tennessee (Hamel 2000a), and 14% of 66 nests in the Mississippi Alluvial Valley were parasitized by cowbirds. Two of three nests located at BONWR in 2004 contained a Brown-headed Cowbird (*Molothrus ater*) nestling, in addition to a single Cerulean Warbler nestling (Islam et al. 2006). Despite the parasitism, both of these nests successfully fledged one Cerulean Warbler along with each cowbird. Considering the relative success of the two parasitized nests at BONWR (each fledging one Cerulean Warbler), it is unclear what role brood parasitism may play in the decline of Cerulean Warblers in this part of the breeding range. We did not observe any nests parasitized at NSA Crane although Brown-headed Cowbirds were commonly observed. At our long-term reproductive study at the HEE, <5 nests have been parasitized by cowbird chicks.

Predation is considered a major source of nest failure, although camera monitoring of nests is necessary for confirmation. Prominent nest predators of Cerulean Warbler include, American Crow (*Corves brachyrhynchos*), Blue Jay (*Cyanocitta*

cristata), eastern chipmunk (*Tamius striatus*), and squirrels (*Sciurus* spp.) in Indiana, Michigan, Mississippi, Tennessee, and Ontario, Canada (Boves and Buehler 2012, Buehler *et al*. 2008, Rogers 2006). At the BONWR study site, one nest was observed to be predated by an American Crow and another failed nest had remains of a torn wing with pinfeathers directly underneath (Islam and Roth 2004). Suspected nest predators such as American Crows, Blue Jays, and rat snakes (*Elaphe obsoleta*) were common near Cerulean Warbler nesting areas at BONWR (Islam and Roth 2004). At our HEE study sites, predation of a Cerulean Warbler nestling by a Red-bellied Woodpecker (*Melanerpes carolinus*) was recorded on video camera (Auer *et al*. 2012) and an unknown species of bird (approximately the same size as the woodpecker) was observed preying on another nest during the incubation stage (Auer 2014). At the NSA Crane sites, one nest was found torn apart and a second one disappeared from the tree suggesting predation. American Crows and Blue Jays were commonly observed at the NSA Crane study sites.

At NSA Crane, average Cerulean Warbler nest height was 17.38 m. This value is lower than most values reported for other parts of Indiana and elsewhere in its distribution (see Wagner and Islam 2014 for a summary of nest site characteristics throughout its range). For example, nest heights at other study sites in Indiana (BONWR and HEE) averaged 18.4 m. Actual nest tree height (mean 24.53 m) at NSA Crane was lower than at the HEE sites (mean 25.7 m). Average nest tree diameter at NSA Crane (37.17 cm) was less than the average diameter at BONWR (50.4 cm) and at the HEE study sites (41.9 cm) suggesting that trees at NSA Crane are harvested on shorter rotations. Mean distance of nest to the trunk of the tree was similar between NSA Crane

(4.25 m) and other sites in Indiana (BONWR = 4.8 m and HEE = 4.4 m; Wagner and Islam 2014). The majority (43.75%) of nests found at NSA Crane were oriented in a northwest direction. In contrast, 51% of nests at the HEE study sites during the 2011-2013 breeding season were located SE to SW of the nest tree bole, while 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; Sasha 2014).

The most frequently used nest tree at NSA Crane was sugar maple (38%) followed by white oak (19%). In contrast, white oak was the predominant nest tree (46%) at the HEE sites and both black walnut (*Juglans nigra*) and white oak made up 53% of nest trees at BONWR (see Wagner and Islam 2014). In other parts of its distribution, black locust (*Robinia pseudoacacia*; 57%) and black oak (*Quercus velutina*; 50%) were the dominant nesting trees in Michigan, white oak in Ohio (60%), and sugar maple in southeastern Ontario (67%) and the Cumberland (39%) and Appalachian (% not stated) mountains of Tennessee (see Wagner and Islam 2014),

The importance of preferred tree species cannot be overlooked in habitat restoration and management, especially for uncommon bird species and selective foragers such as Cerulean Warblers (Gabbe *et al*. 2002). Unfortunately, important foraging trees are currently in decline in the breeding range of the Cerulean Warbler. Several recent studies in Indiana have demonstrated the importance of oaks and hickories as preferred foraging trees, and as sources of abundant lepidopteran larvae that are important in the diet of Cerulean Warbler nestlings (Auer 2014, Wagner 2012, MacNeil 2010). Oaks and hickories currently have very little recruitment due to an understory that has become increasingly dominated by sugar maple (Pierce *et al*. 2006). Oaks and hickories are

tolerant of fire and disturbances, and the recent suppression of fire in the last century has altered the landscape by promoting shade tolerant species. Important mast producers such as oaks and hickories are currently in decline and will decrease to a few large individuals (Shotola *et al*. 1992, Pierce *et al*. 2006). Harvesting and disturbance is currently needed to increase recruitment and help decrease the effects of maples and beeches. While studies show that disturbance can have immediate negative effects on certain bird species, it is important to note that natural disturbances are an integral component of managing forests and need to be substituted in some way (Rodewald & Smith 1998). Prescribed burning that reduces shrubs and saplings may not negatively affect bird communities or reproductive success depending on the frequency of burns (Artman *et al*. 2001). By reducing seedlings of shade tolerant trees and creating canopy openings, uneven-aged harvesting, as well as monitoring forest composition, can be used to increase the abundance and regeneration of preferred tree species for Cerulean Warblers.

Analysis of Landscape Features

Cerulean Warblers are known to exhibit clustered territoriality (Roth and Islam 2007). At NSA Crane, territories were clustered in unit 5 and somewhat clustered in unit 1, while the majority of territories (4 of 6 units or 67%) were randomly distributed across the landscape. At our long-term study sites at the HEE, 82.8% of all territories were clustered in 2007, and 85.5% were clustered in 2009. Only 51.8% of all territories were clustered in 2008. Still, there was no apparent change in the overall amount of clustering from 2007 to 2009.

At NSA Crane, Cerulean Warbler territories were characterized by tall and closed canopies that displayed denser vertical canopy structure than randomly selected non-use sites. In addition, territories were located on steeper slopes, closer to perennial streams, and at greater distances from the nearest canopy gaps that were ≥ 70 m^2 than non-use sites. There is some evidence to suggest that Cerulean Warblers selected northeast-facing slopes to establish territories but more data are needed. There was no significant difference in distance to roads or elevation between territories and non-use sites. At our HEE study sites, we found that Cerulean Warblers appear to prefer placing their territories on northeast slopes (Barnes 2014). In addition, territories were near streams, roads, and/or coniferous forest patches (Kaminski and Islam 2013). Some of these findings have been documented by other researchers. For example, in West Virginia, Cerulean Warblers showed a preference for north to east facing slopes (Weakland and Wood 2005). Cerulean Warbler association with an eastern aspect could be attributed to the fact that forest growth in the northern hemisphere is frequently greatest on east facing slopes (Beers *et al.* 1966). Consequently, eastern facing slopes could be more productive and possess greater structural diversity. At BONWR in Indiana, Cerulean Warblers selected areas with greater slope than at random sites (Roth and Islam 2008). Our observation that the species prefers slopes to flat land also matches the findings of Buehler *et al.* (2006).

Based on ground measurements of trees, Cerulean Warbler territories had slightly larger diameter trees with a greater occurrence of hickories than non-use sites. In addition, Cerulean Warblers selected stands that were harvested more than predicted based on availability, and avoided non-harvested stands more often than predicted based

on non-harvested stand availability. Stands with improvement cuts had the greatest number of Cerulean Warbler territories (70) compared to expected availability of those harvested stands (48; Table 10). In contrast, no treatment sites had fewer Cerulean Warbler territories (15) than expected (29; Table 10). However, we only used the most recent harvest to identify harvest type for each forest stand and more complex analyses should be completed to better understand settlement response in harvested stand types.

Forest Management Recommendations

Conservation and management of Cerulean Warblers on their breeding grounds will require research and implementation of research findings at two very different scales of analyses: the level of the territory and the landscape.

Territory-level Selection

Cerulean Warblers maintain all-purpose territories during the breeding season. In Indiana, territories are generally small (average values of 0.21-0.34 ha). These territories are used to a) attract mates, b) provide protection from predators, c) find food to support mated pairs and their offspring, and to d) provide nesting trees and nest materials to construct nests and raise young. The following are some recommendations to consider when creating an ideal suite of territory characteristics: The presence of large-sized trees within territories is a common theme throughout our studies, including NSA Crane. Male Cerulean Warblers select significantly larger (mean = 43 cm dbh) and taller (mean = 27 m) trees within their territories to broadcast their song (Jones and Islam 2006). Nest trees selected are generally large in size (mean values of 41.9 and 50.4 cm dbh at different study areas) with an average nest height of 18.4 m (Roth and Islam 2008, Wagner and Islam 2014). Maintaining large-sized trees within stands will insure that nesting, foraging, and singing trees are available to Cerulean Warblers. Longer harvest rotations (> 30 years) will allow for mature forest components to develop.

A favored component of Cerulean Warbler nests are fibers from grapevines (*Vitis spp*.). In Ohio, Cerulean Warbler nest success was positively associated with the density of grapevines available in territories (Bakermans and Rodewald 2009), and in the

Cumberland Mountains of Tennessee, grapevine bark was a common material incorporated in nests (Beachy 2008, Boves and Buehler 2012). At our long-term study sites at the HEE, grapevines were present in most territories (83%; Wagner and Islam 2012). Nests at NSA Crane were constructed with grapevine fiber and females were observed peeling grapevine bark for nests on several occasions (S. Auer and K. Barnes, personal observations). We recommend that current forest management practice of cutting all grapevines prior to harvest is modified so that a certain percentage of the grapevines are retained at the stand level.

Based on our current findings on foraging ecology and Cerulean Warbler nestling diet (Auer 2014, Wagner 2012, MacNeil 2010), both male and female Cerulean Warblers forage in tall (mean - male = 25.48 m; female = 23.33 m), mature (mean - male 41.3 cm dbh; female = 36 cm dbh) trees. However, males were observed foraging more often in the upper canopy than females (77% versus 59%), and females used the mid-story more than males (35% versus 14%). Thus, vegetation structure is also an important component of territories. Maintaining multi-aged forest stands will provide the needs for both sexes. Bitternut hickory, the most common foraging tree at our HEE study sites, was used by both sexes, and males used this species as a perch tree for singing as well (MacNeil 2010, Jones and Islam 2006). However, bitternut hickory accounted for only 6% of the trees and 7% of the basal area within territories. Other trees selected for foraging were white oak and tulip tree (Gabbe *et al*. 2002, George 2009, MacNeil 2010). At NSA Crane, Cerulean Warbler territories had a moderately strong positive association with hickories. Wagner (2012) demonstrated the importance of oaks and hickories as food trees for lepidopteran larvae, which are the primary prey type fed to Cerulean Warbler nestlings

and fledglings. To provide preferred foraging habitat for this warbler, forests must be managed to increase oak and hickory regeneration. Shade-tolerant trees such as sugar maples seem to be important as nest trees at NSA Crane, and some maples should be maintained at the stand level. Prescribed burning in combination with timber stand improvement can be implemented in forest stands that have received patch and group selection cuts. These small harvests will create openings necessary for the regeneration of oak and hickory seedlings. An integrated forest management plan that strives to maintain an oak-hickory dominated landscape through uneven-aged management, such as at NSA Crane (Andrews et al. 2010), will provide the components that are selected by Cerulean Warblers when establishing territories at the level of the forest stand.

Landscape-level Selection

The placement of male Cerulean Warbler territories within the context of the landscape can also be characterized by a number of landscape features. Based on LiDAR-derived metrics, Barnes (2014) found that at the long-term HEE study sites, the top predictors of Cerulean Warbler territories were northeast-facing slopes, lower elevations, and steeper slopes. Other predictors were habitats with greater hickory (*Carya* sp.) basal area (m^2/ha), taller canopy, greater total basal area (m^2/ha), and greater tulip tree basal area (m^2/ha). The top models suggested that high-use areas were characterized with less total basal area (m^2/ha), large trees ($\geq$ 53 cm DBH), greater white oak (*Quercus alba*) basal area (m^2/ha), and contained a homogeneous horizontal and vertical canopy structure.

At these same study sites, Cerulean Warbler territories were associated with streams and secondary roads (Kaminski and Islam 2013). Many of these secondary roads were old logging roads that created openings in the canopy. Of the 76 Cerulean Warbler territories demarcated in 2009, 58% had one or more canopy openings based on ground surveys (Kaminski 2010). Based on LiDAR-derived metrics, 54% of Cerulean Warbler territories were associated with canopy gaps (Barnes 2014). The majority of these openings were small averaging 0.06 ha from ground-based surveys and 0.01 ha based on LiDAR data. The creation of small canopy openings through forest management practices may mimic openings created through natural tree falls. At NSA Crane, the primary forest management plan adopted is uneven-aged management (single and group-tree harvests; Andrews et al. 2010), which does provide openings in the forest canopy attractive to Cerulean Warblers.

Future Research Direction

Additional research is needed to evaluate the effects of different forest harvest regimes on the reproductive success of Cerulean Warblers in Indiana and at other sites within the Central Hardwoods Region (BCR 24). Specific questions to address are 1) how do differing forest practices affect productivity, and 2) how do these forest practices affect prey abundance? Our understanding and assessment of source/sink dynamics in Cerulean Warbler populations is hampered because of the limited survivorship estimations available from a few long-term banding studies. A comprehensive long-term banding effort across BCR 24 will allow us to determine return rates for Cerulean

Warbler populations that exhibit site fidelity. Current and future MAPS stations across the Central Hardwoods Region can play a significant role in this effort.

Long-term Monitoring of Cerulean Warblers at NSA Crane

Surveys to Follow Trends in Population

Based on relative abundance estimates at other sites in Indiana, there is considerable variation in annual estimation of bird detections. Therefore, our one-year estimate of relative abundance at NSA Crane does not account for inter-year variation. We recommend that our established six sites at NSA Crane serve as a baseline for comparison with future surveys at these six sites conducted every 2-3 years. These follow-up surveys will determine overall trend in Cerulean Warbler population within the NSA Crane installation.

An alternative survey protocol, though not as comprehensive, would be to conduct shortened Breeding Bird Surveys along easily accessible roads. The surveyor would stop at every half mile interval and count the number of Cerulean Warblers heard/seen during a three minute period. All six study sites that were surveyed during 2014 at NSA Crane, had roads through portions of each unit.

Reproductive Monitoring for Source/Sink Modeling

Relative abundance estimates allow us to monitor trends in population size but they do not provide any information on reproductive fitness. To assess the effects of different forest harvest regimes on Cerulean Warbler productivity, intensive reproductive studies need to be undertaken to determine if the population at NSA Crane is a source (high quality habitat producing large populations with positive growth rates) or a sink (low quality habitat with small populations with negative growth rates) population.

Although limited data suggest that Cerulean Warbler populations in Indiana may be part of a sink population (Buehler et al. 2008), estimates for survivorship are lacking for the state. Populations of species that occur on the periphery of their distributional range, such as the Cerulean Warbler in Indiana, may become very important source populations as a result of shifts in distribution due to climate change. It is predicted that many species of songbirds, that currently have their stronghold in the southern part of the U.S., will move northwards (Hitch and Leberg 2007). Other factors can also result in distributional changes. For example, Hamel et al. (2004) documented a northeastward shift in Cerulean Warbler populations, likely a result of loss of bottomland forests in the south and an increase in mature forests in the northeast.

Banding for Survivorship and Site Fidelity

A comprehensive banding study at NSA Crane, targeted specifically at Cerulean Warblers, will help us determine if a) the same individual Cerulean Warblers return to NSA Crane each year establishing site fidelity in the population, and b) allow us to calculate survivorship based on band returns. These survival estimates are essential in the calculations of growth models. In 1989, a MAPS study was established at NSA Crane and bird populations are monitored through mist-netting efforts annually (Andrews et al 2010). Banding efforts in early May in areas of Cerulean Warbler presence, such as the six study sites established for this study, will enable us to determine if the Cerulean Warbler population that breeds at NSA Crane exhibits site fidelity.

Literature Cited

Andrews, S., T. Hobson, T. Osmon, B. Miller, P. Sczerzenie, and M. Blevins. 2010. Final Integrated Natural Resources Management Plan: Naval Support Activity Crane, Indiana. Natural Resource Office, NAVFAC Midwest, PWD Crane.120 pp.

Artman, V. L., E. K. Sutherland, and J. F. Downhower. 2001. Prescribed burning to restore mixed-oak communities in southern Ohio: Effects on breeding-bird populations. Conservation Biology 15:1423-1434.

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.

Auer, S. A. 2014. Cerulean Warbler (*Setophaga cerulea*) nest provisioning behaviors and the effects of forest management practices on nest success in southern Indiana. M.Sc. Thesis, Ball State University, Muncie, IN. 82 pp.

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.

Barg, J. J., J. Jones, and R. J. Robertson. 2005. Describing breeding territories of migratory passerines: suggestions for sampling, choice of estimator, and delineation of core areas. Journal of Animal Ecology 74:139-149.

Barnes, K.W. 2014. Assessing the influence of social information and habitat structure on Cerulean Warbler breeding habitat in southern Indiana. M.Sc. Thesis, Ball State University, Muncie, IN. 118 pp.

Beachy, T.A. 2008. Cerulean Warbler (*Dendroica cerulea*) breeding ecology, 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, TN. 169 pp.

Beers, T. W., P. E. Dress, and L. C. Wensel. 1966. Aspect transformation in site productivity research. American Scientist 54:691-692.

Birdlife International. 2004. Threatened birds of the world 2004. CD-ROM. Birdlife International, Cambridge, U.K.

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.

Bruner, A. W. 1998. Cerulean Warbler. Pages 260-261 *in* Atlas of breeding birds of

Indiana (Castrale, J. S., E. M. Hopkins, and C. E. Keller, Eds.). Indianapolis: Nongame and Endangered Wildlife Program, Indiana Department of Natural Resources.

Buehler, D. A., M. J. Welton, and T. A. Beachy. 2006. Predicting Cerulean Warbler habitat use in the Cumberland Mountains of Tennessee. Journal of Wildlife Management 70:1763-1769.

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.

Butler, A. W. 1898. Birds of Indiana. Indiana Department of Geology and Natural Resources. Annual Report 22:515-1187.

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

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.

George, G.A. 2009. Foraging ecology of male Cerulean Warblers and other Neotropical migrants. Ph.D. Dissertation, West Virginia University, Morgantown.

Hamel, P. B. 1992. Cerulean warbler, *Dendroica cerulea.* P. 385-400. *In*: K. J. Schneider and D. M. Pence (eds.). Migratory nongame birds of management concern in the Northeast. U.S. Dept. Interior Fish and Wildlife Service, Newton Corner, Massachusetts, USA.

Hamel, P. B. 2000a. Cerulean Warbler (*Dendroica cerulea*). *In* The Birds of North America, no. 511 (A. Poole and F. Gill, Eds.). The Birds of North America, Inc., Philadelphia.

Hamel, P. B. 2000b. Cerulean Warbler status assessment. U.S. Fish and Wildlife Service, Minneapolis, Minnesota.

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

Hamel, P. B., M. J. Welton, C. G. Smith III, and R. P. Ford. 2009. Test of Partners in Flight effective detection distance for Cerulean Warbler. Pp. 328–333, *In* T.D. Rich, C. Arizmendi, D.W. Demarest, and C. Thompson (Eds.). Tundra to Tropics: Connecting Birds, Habitats, and People. Proceedings of the 4th international Partners in Flight conference 13–16 February 2008, McAllen, TX. American Press, University of Texas-Pan, Edinburgh, TX. 712 pp.

Hitch, A. T., and P. L. Leberg. 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conservation Biology 21:534-539.

Islam, K., and C. Basile. 2002. Relative abundance and habitat selection of Cerulean Warblers in southern Indiana. Final report submitted to U.S. Fish and Wildlife Service, Fort Snelling, MN, December 2002. Department of Biology Technical Report No. 1, Ball State University, Muncie, Indiana 76 pp.

Islam, K., and K. L. Roth. 2004. Habitat selection and r reproductive success of Cerulean Warblers in southern Indiana. Final Report submitted to U.S. Fish & Wildlife Service, Fort Snelling, MN, December 2004. Department of Biology Technical Report No. 4, Ball State University, Muncie, Indiana 51 pp.

Islam, K., K. L. Roth, and K. C. Jones. 2006. Landscape analysis of habitat suitability and breeding biology of the Cerulean Warblers. Final Report submitted to U.S. Fish & Wildlife Service, Fort Snelling, MN, June 2006. Department of Biology Technical Report No. 5, Ball State University, Muncie, Indiana 43 pp.

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

Jones, J., W. J. McLeish, and R. J. Robertson. 2000. Density influences census technique accuracy for cerulean warblers in eastern Ontario. Journal of Field Ornithology 71:46-56.

Jones, K. and K. Islam. 2006. Selection of song perches by Cerulean Warblers. Proceedings of the Indiana Academy of Science 115:37-43.

Kaminski, K. J. 2010. Cerulean Warbler initial response to silvicultural treatments in southern Indiana. M.Sc. Thesis, Ball State University, Muncie, IN 66 pp.

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.

Krebs, C. J. 1989. Ecological methodology. Harper and Row, New York, U.S.A.

MacNeil, M. M. 2010. Does timber harvesting affect Cerulean Warbler foraging ecology? M.Sc. thesis, Ball State University, Muncie, IN. 38 pp.

Oliarnyk, C. J. 1996. Habitat selection and reproductive success in a population of cerulean warblers in southeastern Ontario. Master's Thesis, Queen's University, Kingston, ON. 42 pp.

Peck, G. K. and R. D. James. 1987. Breeding birds of Ontario: nidiology and distribution. Vol. 2: passerines. Toronto, ON: Royal Ontario Museum. 290 pp.

Pierce, A. R., G. Parker, and K. Rabenold. 2006. Forest succession in an oak-hickory dominated stand during a 40-year period at the Ross Biological Reserve, Indiana. Natural Areas Journal 26:351-359.

Reding S. and L. M. Vormwald. 2015. Establishing Regional Mentor Sites for the Management of the Cerulean Warbler and other Mature Forest Avifauna. Final Report submitted to the Department of Defense Legacy Resource Management Program, Department of the Army, Champaign, IL, March 2015. Kalamazoo Nature Center, Kalamazoo, Michigan.

Robbins, C. S., J. W. Fitzpatrick, and P. B. Hamel. 1992. A warbler in trouble: *Dendroica cerulea*. Pages 549-562 *in* Ecology and conservation of Neotropical migrant landbirds (Hagan, J.M. III. and D.W. Johnston, Eds.). Smithsonian Institute Press, Washington, D.C. University of Wisconsin Press, Madison Wisconsin.

Rodewald, P. G., and K. G. Smith. 1998. Short-term effects of understory and overstory management on breeding birds in Arkansas oak-hickory forests. Journal of Wildlife Management 62:1411-1417.

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

Roth, K. L., and K. Islam. 2007. Do Cerulean Warblers (*Dendroica cerulea*) exhibit clustered territoriality? American Midland Naturalist 157:345-355.

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

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2014. The North American Breeding Bird Survey, Results and Analysis 1966 - 2012. Version 02.19.2014 *USGS Patuxent Wildlife Research Center*, Laurel, MD.

Shotola, S. J., G. T. Weaver, P. A. Robertson, W. C. Ashby. 1992. Sugar maple invasion of an old-growth oak-hickory forest in southwestern Illinois. American Midland Naturalist 127:125-138.

U.S. Fish and Wildlife Service, Office of Migratory Bird Management. 1987. Migratory nongame birds of management concern in the United States: The 1987 list. Washington, DC: U.S. Fish and Wildlife Service.

U.S. Fish and Wildlife Service**.** 2002. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the cerulean warbler as threatened with critical habitat. Federal Register 67(205):65083-65086.

U.S. Fish and Wildlife Service. 2006. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the cerulean warbler (*Dendroica cerulea*) as threatened with critical habitat. Federal Register 71(234):70717-70733.

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

Wagner, J. 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. 173 pp.

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.

Table 1. Extents of units 1-6 using geographic coordinate system NAD83, projection UTM 16N at NSA Crane, Indiana.

Unit	Xmin	Ymin	Xmax	Ymax
1	521204.3487	4303812.2671	522704.3487	4305312.2671
2	522578.0827	4300707.8387	524078.0827	4302207.8387
3	524173.4362	4302670.9806	525673.4362	4304170.9806
4	514161.9878	4292644.6771	515661.9878	4294144.6771
5	516833.5460	4298065.6742	518333.5460	4299565.6742
6	512389.3694	4295199.3847	513889.3694	4296699.3847

Table 2. Habitat features of Cerulean Warbler research units at NSA Crane, Indiana in 2014. These data are derived from LiDAR data retrieved from IndianaMap Framework Data.

Unit	Mean Canopy Height (m)	% Open Canopy (≤ 12 m)	% Tall Canopy (> 24 m)	Mean Beers Aspect	Mean Elevation (m)	Mean Slope (degrees)
1	17.3	0.29	0.29	0.99	210	10
2	14.8	0.41	0.22	0.85	190	11
3	18.5	0.26	0.35	0.90	221	11
4	15.8	0.35	0.25	0.95	192	11
5	17.5	0.29	0.32	1.00	204	11
6	14.5	0.40	0.21	0.98	178	9

Table 3. Cerulean Warbler point count detections and territories detected at NSA Crane, Indiana, 2014.

Unit	Detections	R.A. (Detections/km2)	Territories mapped
1	16	8.16	19
2	29	14.80	30
3	15	7.65	14
4	5	2.55	9
5	23	11.73	23
6	13	6.63	15
Total	101	8.59	110

Table 4. Nest site characteristics for Cerulean Warblers at NSA Crane, Indiana, 2014.

Mean Nest Height (m)	Mean Nest Tree Height (m)	Mean Nest Tree DBH (cm)	Mean distance of nest to trunk (m)	Mean distance of nest to end of branch (m)
17.38	24.53	37.17	4.25	2.2

Table 5. Cerulean Warbler nest tree aspect and nest orientation at NSA Crane, Indiana, 2014.

Azimuth Bin	Nest Tree Aspect	Nest Orientation
0-90°	31.50%	25%
91-180°	31.50%	12.50%
181-270°	18.75%	18.75%
271-359°	18.75%	43.75%

Table 6. Trees ≥ 10 cm DBH within 11.3 m of Cerulean Warbler nests at NSA Crane, Indiana, 2014.

Tree Species	#
Acer saccharum	43
Carya glabra	25
Carya ovata	14
Liriodendron tulipifera	8
Quercus coccinea	7
Quercus alba	7
Nyssa sylvatica	7
Fagus grandifolia	7
Snag	7
Fraxinus spp.	6
Ulmus spp.	6
Carya spp.	5
Sassafras albidum	4
Platanus occidentalis	3
Cercis canadensis	3
Juglans nigra	2
Fraxinus americana	2
Quercus velutina	2
Acer rubrum	2
Cornus spp.	2

Table 7. Distribution of Cerulean Warbler territories at NSA Crane, Indiana, 2014.

Unit	Mean Distance (m) Observed	Mean Distance (m) Expected	Nearest Neighbor Ratio	Z	P	Distribution
1	147.2	192.8	0.76	-1.75	0.078	Somwhat Clustered
2	122.3	146.5	0.84	-1.61	0.835	Random
3	163.7	207.1	0.79	-1.45	0.148	Random
4	119.4	249	0.48	-2.99	0.003	Random
5	177.8	163	1.09	0.8	0.426	Clustered
6	182.3	199.6	0.91	-0.62	0.536	Random

Table 8. Comparison of Cerulean Warbler territories to landscape features at NSA Crane, Indiana, 2014.

Variable	Mean Use	Mean SD	Mean Non-Use	Mean SD	t	P
Beers	1.129819	0.5814182	0.9808433	0.5875946	1.7841	0.07597
CH	19.06474	4.637822	15.50963	5.981671	4.6497	<0.001
CH.std	8.029957	1.783212	7.554172	2.025204	1.7455	0.08248
CH12	0.2455374	0.157643	0.3671003	0.2471169	-4.1056	<0.001
CH24	0.3933468	0.2289813	0.2467284	0.215827	4.6127	<.001
SLOPE	11.920463	4.374212	9.439464	3.763928	4.2561	<0.001
VDR	0.7843909	0.05603963	0.7470207	0.1230458	2.736	0.00705
VDRstd	0.2302249	0.05471759	0.2603012	0.07048992	-3.3366	0.00103
ELEV	199.4792	23.13566	201.4223	25.17493	-0.5626	0.5744
PER	522.5494	348.7781	682.1947	415.8537	-2.9118	0.00403
INT	246.3662	174.3596	260.628	164.7407	-0.5886	0.5568
HYDRO	111.58286	66.31107	92.98827	59.33841	2.0686	0.03991
GAPS	1.759663	1.313043	1.397461	1.31207	1.9317	0.05486
GAPS70	2.365568	1.798037	1.81011	1.773785	2.1771	0.03068
ROADS	161.7333	102.3532	151.8184	112.2388	0.6462	0.5189

Table 9. Comparisons of selected tree species between Cerulean Warbler territories and non-use sites at NSA Crane, Indiana, 2014.

Variable	**β**	**se**	**z**	**p**
Carya spp.	0.497	0.209	2.375	0.0176
Acer saccharum	0.01	0.153	0.062	0.95
Quercus alba	-0.015	0.098	-0.155	0.877
Liriodendron tulipifera	-0.04	0.097	-0.409	0.682
Quercus rubra group	0.107	0.177	0.601	0.548

Table 10. Comparisons of observed versus expected counts of Cerulean Warbler territory centers in each harvest treatment site at NSA Crane, Indiana, 2014.

Category	**# CERW Observed**	**Proportion Expected**	**# CERW Expected**	**Contribution to Chi-Sq.**	
No treatment	15	0.299543	29.3552	7.01993	N =98
Improvement cut	70	0.492556	48.2705	9.7818	Df = 3
Crop tree release	1	0.040824	4.0008	2.25075	Chi-sq. = 20.2207
Group selection	12	0.167077	16.3735	1.16822	P < 0.00

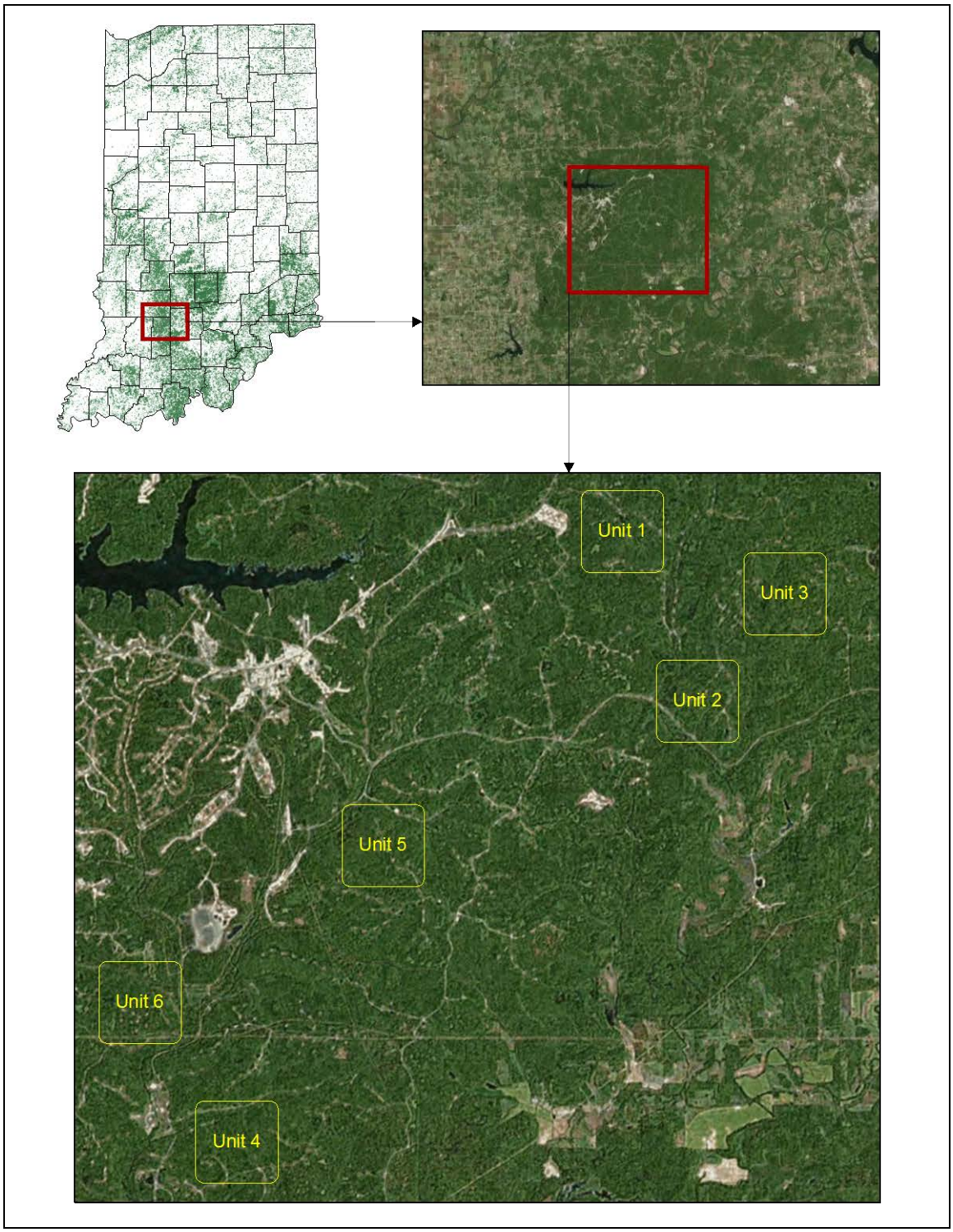

Figure 1. Map of six Cerulean Warbler research units at NSA Crane, 2014.

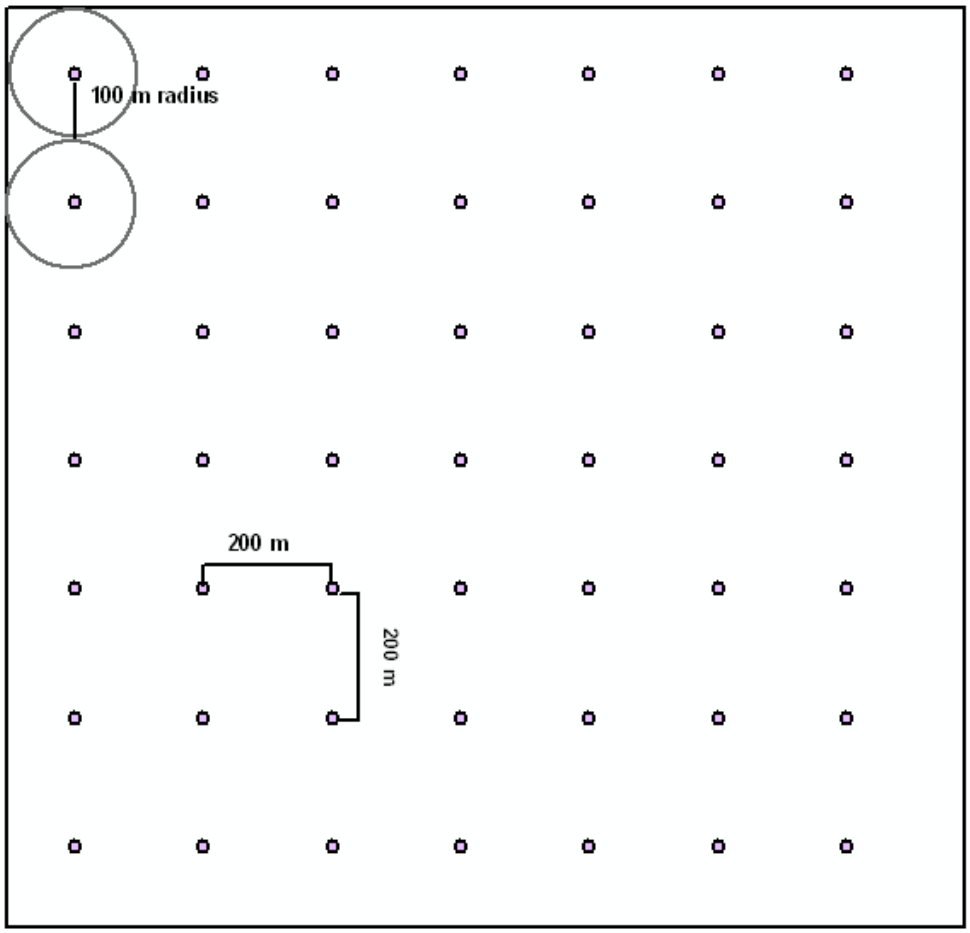

Figure 2. Protocol utilized for Cerulean Warbler surveys within six study sites at NSA Crane in southern Indiana. Seven transects, 200 m apart, were surveyed. Each transect consisted of seven survey points.

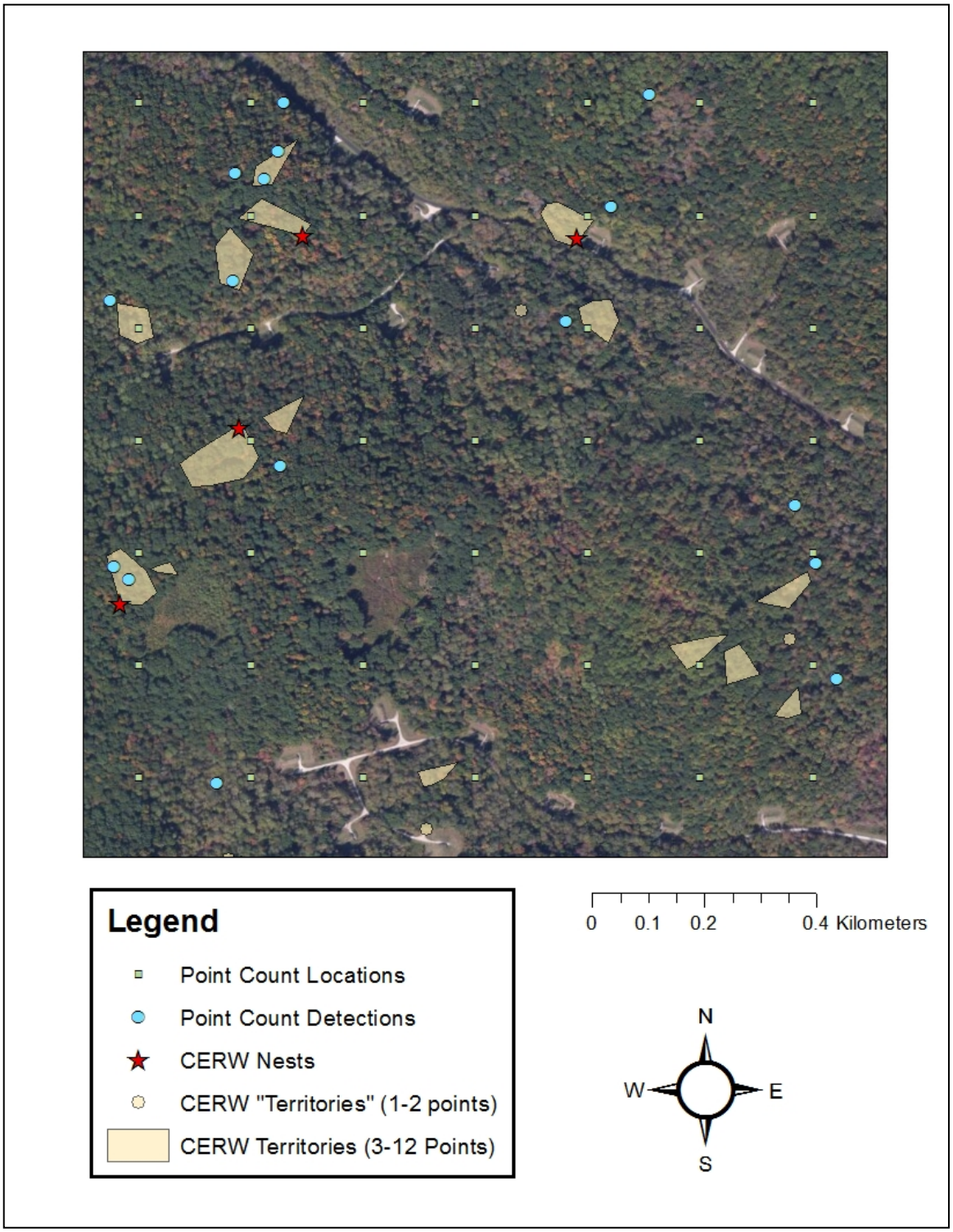

Figure 3. Cerulean Warbler research unit 1 with point count detections, territories, and nest locations at NSA Crane, Indiana, 2014.

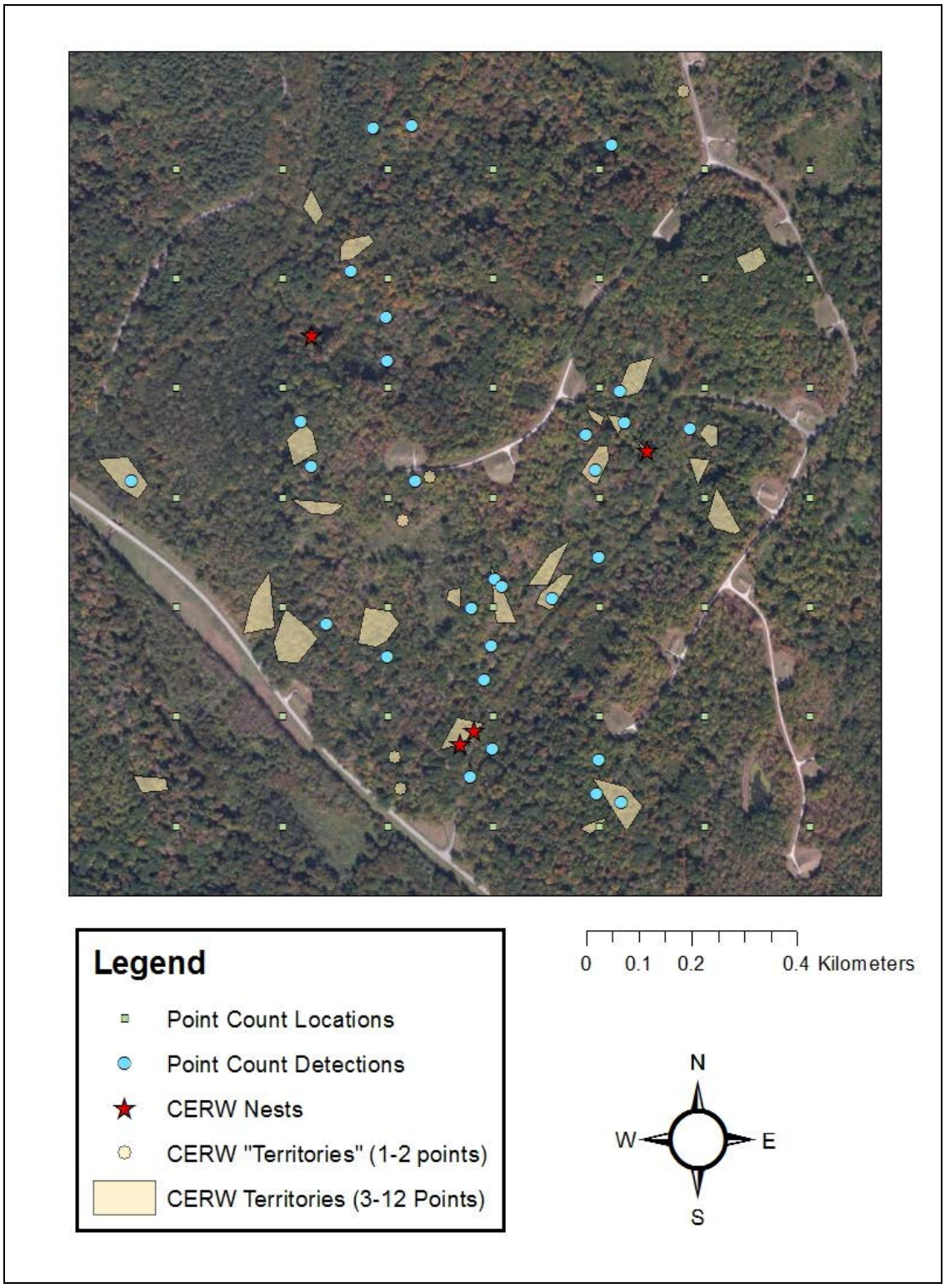

Figure 4. Cerulean Warbler research unit 2 with point count detections, territories, and nest locations at NSA Crane, Indiana, 2014.

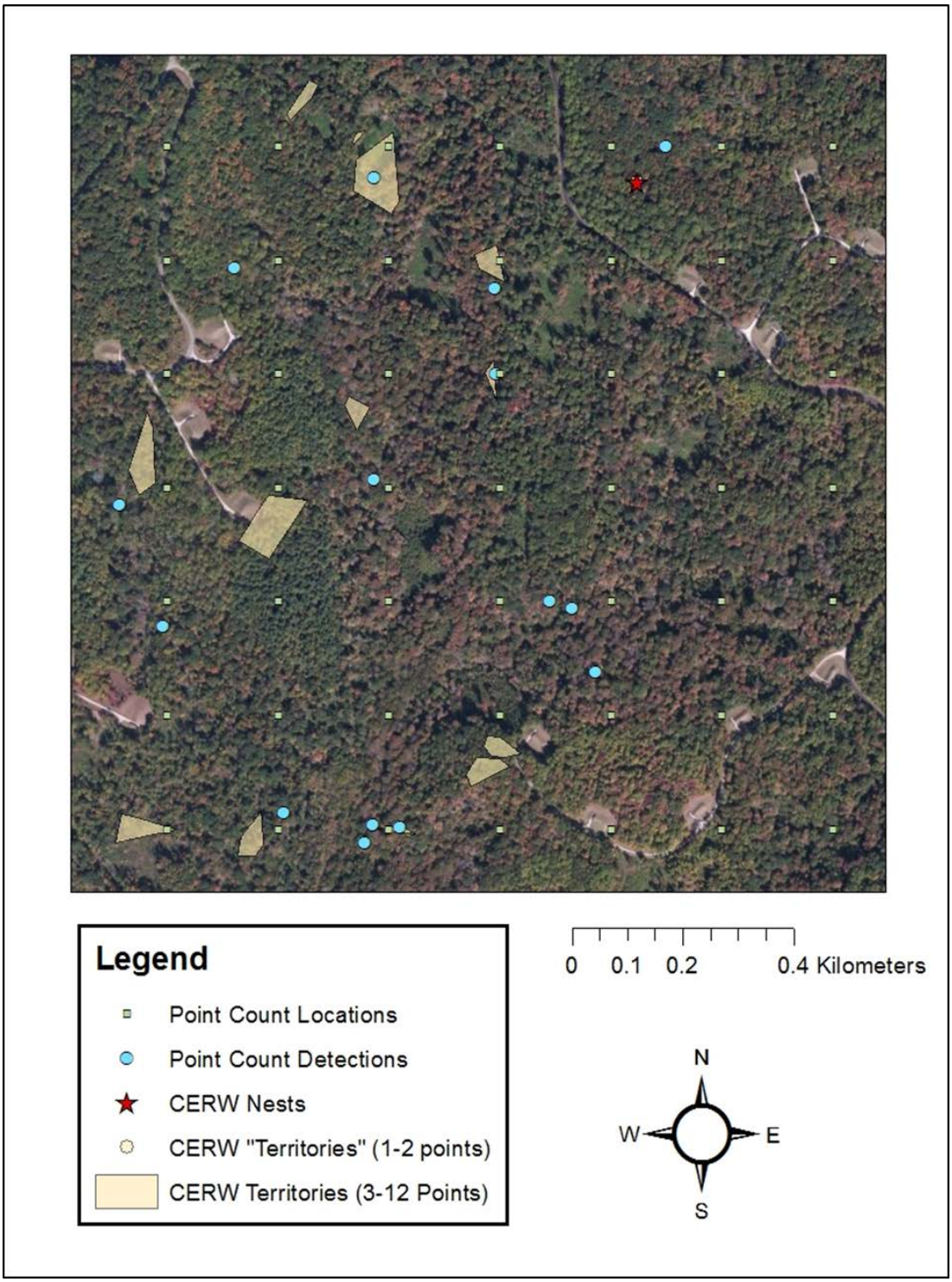

Figure 5. Cerulean Warbler research unit 3 with point count detections, territories, and nest locations at NSA Crane, Indiana, 2014.

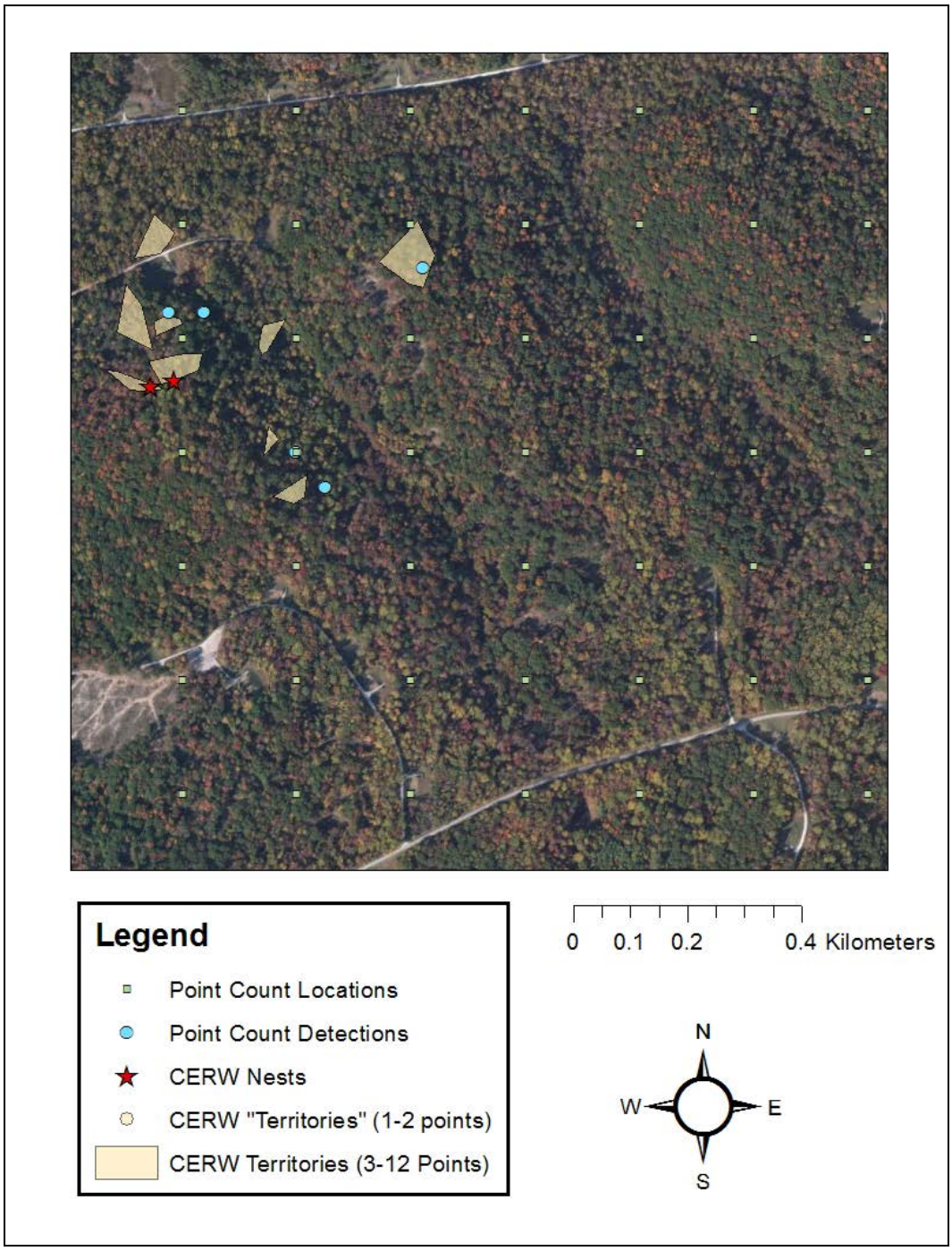

Figure 6. Cerulean Warbler research unit 4 with point count detections, territories, and nest locations at NSA Crane, Indiana, 2014.

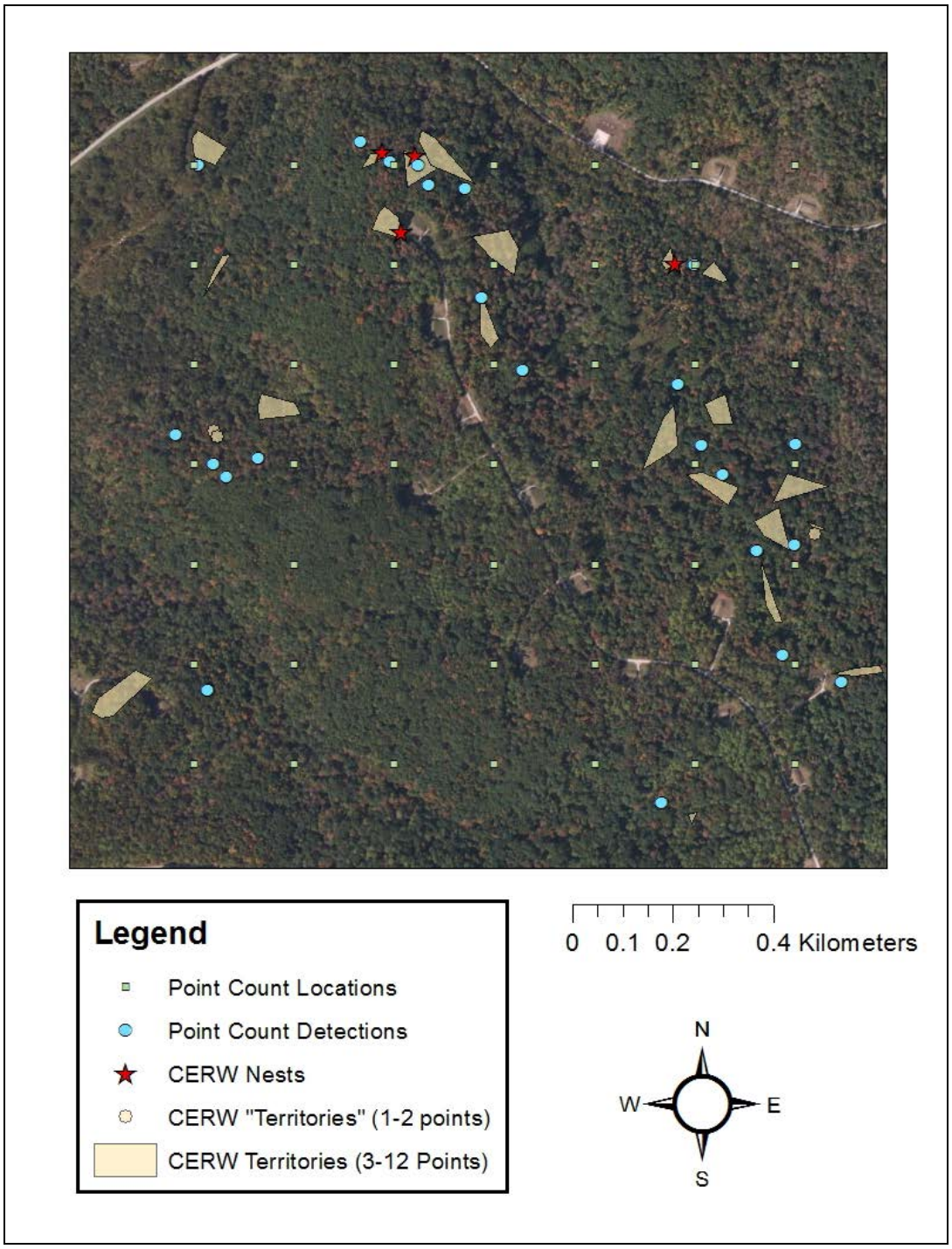

Figure 7. Cerulean Warbler research unit 5 with point count detections, territories, and nest locations at NSA Crane, Indiana, 2014.

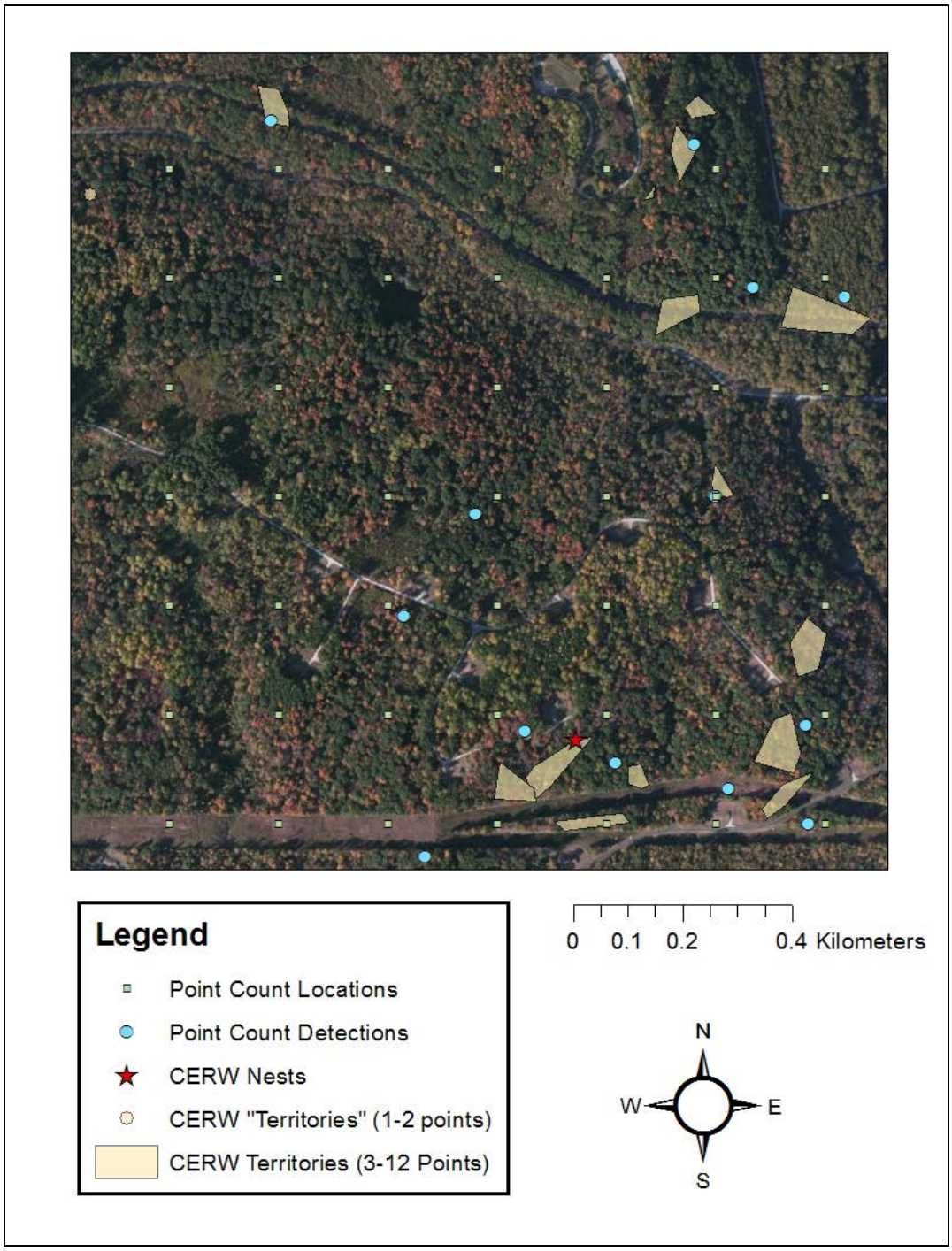

Figure 8. Cerulean Warbler research unit 6 with point count detections, territories, and nest locations at NSA Crane, Indiana, 2014.