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Survival and Habitat Selection of Golden-Winged Warblers (*Vermivora chrysoptera*) during Nesting and Post-fledging Periods at North Cumberland Wildlife Management Area, Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Justin Andrew Lehman entitled "Survival and Habitat Selection of Golden-Winged Warblers (*Vermivora chrysoptera*) during Nesting and Post-fledging Periods at North Cumberland Wildlife Management Area, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

David A. Buehler, Major Professor

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Survival and Habitat Selection of Golden-Winged Warblers (*Vermivora chrysoptera*) during Nesting and Post-fledging Periods at North Cumberland Wildlife Management Area, Tennessee

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Acknowledgments

One of the main reasons I entered the wildlife field was because I learned that a career in wildlife biology is guaranteed to be perpetually stimulating; there is no possible way to know everything about wildlife species, their interactions, and their habitat. I have worked with Golden-winged Warblers for eight summers now and learned something new about them seemingly every day I studied them. I owe my thanks to the many people that have helped me get to where I am and will hopefully continue to offer their guidance and support as I continue my career.

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Abstract

Golden-winged Warbler (*Vermivora chrysoptera*) populations in the Appalachian Mountains have declined precipitously over the past 50 years. To better understand the decline, I studied two important aspects of the reproductive cycle: the nesting and post-fledging periods on reclaimed surface mines and recent timber harvest sites at North Cumberland Wildlife Management Area (NCWMA), Tennessee from 2013 to 2015. Nestlings were radio-marked with a 30-day transmitter two days before their scheduled fledge date and monitored daily once they fledged. Vegetation data were collected at the nest site and daily fledgling locations points along with paired random points. Vegetation characteristics most important during nest site selection were percent mature forest within 250 m of nest (selected against), percent *Rubus* spp. within 1m of nest (selected for) and vertical vegetation density (selected for). Fledglings did not select for or against any vegetation types during their first 3 days post-fledging. Shrub/sapling vegetation was most selected for during days 4-25. Fledglings avoided mature forest vegetation and herbaceous vegetation during the same time period. Nest survival over a 23-day nesting cycle was 0.354 ± 0.058 (SE) across all years. Vegetation characteristics most closely related to daily nest survival were percent forbs within 1 m of nest (positive relationship) and percent *Rubus* spp. within 1 m of nest (negative relationship). Fledgling survival for the entire 25-day post-fledging period was 0.289 ± 0.066, with most of the mortality occurring in the first 3 days (0.736 ± 0.039 daily survival rate). Snake predation accounted for 52% (16/31) of known deaths. The best supported model when individual habitat covariates were added included percent shrub-sapling vegetation within 250 m of post-fledging location (negative relationship). All other individual covariates had a delta AICc >2 when compared to the top model. Managing for Golden-winged Warbler reproduction must be a balance between meeting the needs for

nesting and ensuring fledgling survival. Compared to values reported elsewhere across the northern parts of the breeding range of the species, full season productivity at NCWMA of 0.66 offspring/pair may be insufficient to sustain populations without significant sources of immigration.

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CHAPTER 1: INTRODUCTION

Golden-winged Warblers (*Vermivora chrysoptera*) are Nearctic-Neotropical migrant songbirds that have garnered conservation attention recently because of their population decline (-2.8% / year, Sauer et al. 2017), their hybridization with Blue-winged Warblers (*Vermivora cyanoptera*), and as a symbol of the need for early successional plant communities. Precipitous declines in Golden-winged Warbler populations have occurred in the Appalachians, including Tennessee (8.4% yr^{-1} [95% CI 5.4 – 12.1]), Pennsylvania (7.6% yr^{-1} [5.7 – 9.6]), West Virginia (8.6% yr^{-1}, [6.5 – 10.3]), and North Carolina (11.5% yr^{-1} [6.6 – 16.2]; Sauer et al. 2017). The species was petitioned to be listed for protection under the Endangered Species Act in 2010 and the U. S. Fish and Wildlife Service determined that there was substantial merit to the petition and initiated a species status review (Federal Register 2011). Several factors are thought to be driving the decline of this species across most of its historic breeding range, including habitat loss in both the breeding and wintering range, hybridization with the Blue-winged Warbler, and Brown-headed Cowbird (*Molothrus ater*) parasitism (Buehler et al. 2007). Of these factors, loss of quality breeding habitat (young forest embedded in extensively forested landscape) may be the most significant (Buehler et al. 2007). Many studies have observed the nesting period of Golden-winged Warblers (Klaus and Buehler 2001, Bulluck and Buehler 2008, Confer et al. 2010, Percy 2012, Aldinger et al. 2015) but only one study has studied the post-fledging period (Streby et al 2016).

The post-fledging period historically has been understudied in songbirds because of the lack of appropriate technology, such as radio transmitters small enough to use on songbird fledglings. The ability to successfully fledge young is important; survival during the post-fledging stage may be of equal or even greater importance in seasonal productivity. In a 2-year study on Ovenbirds (*Seiurus aurocapilla*), seasonal productivity (number of young surviving to independence per breeding female) was greater in the year with lesser daily nest survival This result was caused by greater daily fledgling survival off-setting the effects of lesser daily nest survival (Streby and Andersen 2011).

Given these considerations, the goals of my thesis research was to document the factors that were important in nest-site selection and daily nest survival (Chapter 2) and compare those factors to factors that were important in post-fledging habitat selection and daily survival (Chapter 3). Understanding the key determinants of success during both of these critical stages should shed light on how best to manage for reproduction in this species (Chapter 4).

CHAPTER 2: NEST SURVIVAL AND NEST-SITE SELECTION OF GOLDEN-WINGED WARBLERS (*VERMIVORA CHRYSOPTERA*) AT NORTH CUMBERLAND WILDLIFE MANAGENENT AREA, TENNESSEE

Abstract

Nest survival is an important aspect of fitness for avian species. I monitored Golden-winged Warbler nesting ecology in the North Cumberland Wildlife Management Area, Tennessee during 2013-2015. I documented nesting vital rates, determined vegetation characteristics selected for during nest-site selection, identified which nest-site vegetation characteristics were most closely related to nest survival, and ultimately determined if there was a connection between vegetation characteristics for nest-site selection and nest survival. We found and monitored 65 nests from 2013 to 2015. Clutch size was 4.5 ± 0.1 (SE) eggs and young fledged per successful nest was 3.9 ± 0.2 fledglings. The vegetation covariate most important during nest-site selection was mature forest vegetation within 250 m of nest, which was negatively related to nest-site selection. No other vegetation models were < 2 ΔAICc from our top nest-site selection model; the next two best-supported models included *Rubus* spp. within 1 m of nest (selected for) and vertical vegetation density (selected for). Daily nest survival did not vary by year from 2013-2015, at 0.956 ± 0.067. I observed a 23-day nesting period with nest daily survival rate (DSR) 0.354 ± 0.058 across all years. Vegetation characteristics most closely related to daily nest survival were percent forbs within 1 m of nest (positive relationship) and percent *Rubus* spp. within 1 m of nest (negative relationship). Covariates important in nest-site selection were not strongly linked with daily nest survival. Possible explanations for this lack of a linkage are that I did not measure the appropriate vegetation characteristics, my population was a sink population in which nest-site selection was maladaptive for unknown reasons, or Golden-winged Warblers on my study sites were balancing nest-site selection with another fitness component, potentially juvenile survival. The

lack of a linkage between nest-site selection and nest survival makes recommendations for improving nesting habitat problematic.

Introduction

The Golden-winged Warbler (*Vermivora chrysoptera*) is one of the most critically threatened, non-federally listed vertebrates in eastern North America (Buehler et al 2007). It is a Nearctic-Neotropical migrant songbird that breeds in southeastern Canada, northeastern and Great Lakes regions of the United States, and at higher elevations of the southern Appalachian Mountains (Figure 2.1). Golden-winged Warblers nest in early successional communities such as abandoned farmland, reclaimed surface mines, alder swamps, forests 3-10 years after timber harvests, and utility rights-of-ways (Hands et al. 1989). This species has become rare and patchily-distributed in its Appalachian breeding range, and many populations are in danger of extirpation. Precipitous declines in Golden-winged Warbler populations have occurred in the Appalachians, including Tennessee (-8.4% yr^{-1} [95% CI 5.4 – 12.1]), Pennsylvania (-7.6% yr^{-1} [5.7 – 9.6]), West Virginia (-8.6% yr^{-1}, [6.5 – 10.3]), and North Carolina (-11.5% yr^{-1} [6.6 – 16.2]; Sauer et al. 2017). Several factors are thought to be driving the decline of this species across most of its historic breeding range. These include habitat loss in both the breeding and wintering range, hybridization with the Blue-winged Warbler (*Vermivora cyanoptera*), and Brown-headed Cowbird (*Molothrus ater*) parasitism (Buehler et al. 2007). Of these factors, loss of cover used for nesting (early successional communities embedded in forested landscape) may be most significant (Buehler et al. 2007).

In 2010, the Golden-winged Warbler was petitioned to be listed under the federal Endangered Species Act (Federal Register 2011). The U.S. Fish and Wildlife Service reviewed the petition and determined that it had substantial merit and initiated a review of the species' status. Thus, the implementation of management prescriptions that promote Golden-winged Warbler habitat during the breeding season is a conservation priority. Recently, science-based guidelines for creating Golden-winged Warbler breeding habitat were developed (Bakermans et al. 2011, Roth et al. 2012), and we are faced with the challenge of large-scale implementation of these habitat management guidelines to stabilize and reverse Golden-winged Warbler population declines. In 2012, the USDA-Natural Resource Conservation Service (NRCS) and the U.S. Fish and Wildlife Service initiated a collaborative effort to create habitat on private lands for 7 imperiled wildlife species including the Golden-winged Warbler (USDA 2016).

The nesting period is a critical component of the breeding biology of birds (Dinsmore et al. 2002). Much research has been done on the nesting ecology of Golden-winged Warblers. In the Great Lakes region, where populations are relatively stable, Wisconsin had a 24-day nest survival of 0.45 and Minnesota had 25.5-day nest survival of 0.392 (Streby and Andersen 2013, Roth et al. 2014). In North Carolina during 1997 and 1998, 25-day nest survival was 0.725 (Klaus and Buehler 2001). In New York, Confer et al. (2010) had a 25-day nest survival of 0.37 in upland study areas. Aldinger at al. (2015) studied populations in seven different states (Minnesota, Wisconsin, New York, North Carolina, Pennsylvania, Tennessee, and West Virginia). They estimated a mean nest DSR of 0.960 ± 0.003 (0.360 25-day nest survival) but that survival varied between states and within the nesting season. Two other studies have researched Golden-winged Warbler nesting in the North Cumberland Wildlife Management Area, with most nests being on the same study areas as my research project. In 2004-2006, Bulluck (2007) estimated nest DSR as 0.973 ± 0.004 (0.360 25-day nest survival). In 2009-

2011, Percy (2012) estimated nest DSR as 0.961 ± 0.007 (0.367 ± 0.006 25-day nest survival) however survival varied greatly with a high 25-day nest survival of 0.575 in 2010 and a low of 0.108 in 2009.

To promote and increase habitat for Golden-winged Warblers, it is necessary to understand the vegetation characteristics associated with nest-site selection and successful breeding. Several researchers have used habitat and weather covariates when modeling nest survival for Golden-winged Warblers. The comprehensive study of Aldinger et al. (2015) in Minnesota, Wisconsin, New York, North Carolina, Pennsylvania, and West Virginia reported the percent grass within 1 m of nest was included in the top model. Survival was relatively constant until grass cover reached 50%; daily nest survival declined for greater levels of grass cover. Other habitat variables with minor biological importance were percent *Rubus* spp. within 1 m of nest and distance to forest edge. On my study areas at North Cumberland Wildlife Management Area, Tennessee, Bulluck (2007) provided evidence that nest DSR decreased as daily minimum temperature increased, increased with increasing shrub cover, and decreased with increasing sapling cover. Percy (2012) reported that nest survival decreased with the presence of *Rubus* spp. in the nest substrate and also decreased with increasing percent cover of *Rubus* spp. within 1 m and 11.3 m of the nest. Nest survival also decreased with an increase in distance to forest edge.

Building on previous research conducted in the region, my first objective was to continue to find and monitor nests on my study areas in the North Cumberland Wildlife Management Area. I wanted to determine the length of the nesting period and estimate nest survival. Secondly, I wanted to determine which vegetation characteristics female Golden-winged Warblers were selecting for when selecting nest sites. Thirdly, I wanted to determine which vegetation covariates were most closely related to survival. Lastly, I wanted to examine if there was a relationship between selection of nest-site vegetation characteristics and vegetation characteristics most closely related to survival to allow for the development of effective nesting habitat management recommendations.

Methods

Study Sites

My study sites were located in the Royal Blue Unit of the North Cumberland Wildlife Management Area (NCWMA), which consists of 60,000 ha of public land spanning four counties (Scott, Anderson, Campbell and Morgan) in the northeastern portion of Tennessee (Percy 2012). The predominant land cover of the study sites was a combination of mixed-mesophytic and oak (*Quercus* spp.)-hickory (*Carya* spp.) forests, with ~15% of the area in early stages of succession because of timber harvest and surface mining for coal (<5% area suitable for Golden-winged Warbler nesting). The NCWMA was in the Cumberland Mountains region and managed by the Tennessee Wildlife Resources Agency. This area was comprised of steep, mountainous terrain with elevations peaking at ~1200 m. The mean elevation of my study sites was 780 m (range = 431 – 996 m).

Experimental management for Golden-winged Warblers occurred on 3 study sites during 2010-2012: Anderson (~55 ha), Burge (~25 ha), and Red Oak (~40 ha) mountains. These sites were managed with timber harvest and subsequent combinations of broadcast herbicide and prescribed fire treatments. Three additional study sites were on reclaimed coal surface mines: Ash Log (~160 ha), Burge (~55 ha), and Massengale (~160 ha) mountains. All study sites were located in the southwestern portion of NCWMA and were located within 20 km of each other (Figure 2.2). Golden-winged Warblers had been documented previously on all of these sites (Buehler et al., unpublished data). Coal surface-mine reclamation occurred from about 1980–1990 on the mine sites. Reclamation involved planting black locust (*Robinia psuedoacacia*), tall fescue (*Schedonorus phoenix*), orchard grass (*Dactylis glomerata*), timothy grass (*Phluem pretense*), sericea lespedeza *(Lespedeza cuneata)*, and autumn olive (*Elaeagnus umbellata*). Yellow-poplar (*Liriodendron tulipifera*), maples (*Acer* spp.), oaks, blackberry (*Rubus* spp.), and a few forbs (e.g., *Solidago* spp., *Aster* spp.) have since colonized the reclaimed mine sites.

On Massengale, three burn units measuring 40 ha, 115 ha, and 145 ha, were on a one- to three-year fire-return rotation from 2007 to 2011. All of Massengale Mountain was managed with prescribed fire in spring 2013. A single unit, measuring 35 ha, was burned on Ash Log Mountain in 2007, but logistical constraints prevented subsequent prescribed burning. All burns were conducted during the dormant season. Prescribed burns were of low-moderate intensity with flame lengths generally 1-2 m.

Field Methods

During May-July 2013-2015, we located and monitored nests of Golden-winged Warblers and hybrids on 5 sites using methods outlined in Martin and Geupel (1993). I considered nests attended to by male and female Golden-winged Warbler phenotypes as Golden-winged Warbler nests and nests attended to by male or female hybrid phenotypes as hybrid nests. I included these hybrid nests with the rest of the Golden-winged Warbler nests in the analysis. *Vermivora* spp. raise one brood per season and generally renest up to two times after nest failure (Bulluck 2007). I minimized the potential bias of discovering a disproportionate number of nests in open vegetation types by following female behavioral cues

(Ficken and Ficken 1968), nest material or food carries, and inconspicuous movements to areas with nesting cover to locate nests rather than by systematic searching. In 2015, 6 females were radio-tagged and some of the nests were located by following radio-tagged females. We were careful not to disrupt nesting activity because Golden-winged Warbler females may abandon nests if disturbed during construction or egg-laying (Confer et al. 2010). We checked nests every 2–4 days initially and more frequently as fledging approached to maximize accuracy of nestling age while minimizing potential negative impacts of visiting nests. I defined complete clutch size as the number of Golden-winged Warbler eggs present after the onset of incubation. I defined the number of young fledged as the number of nestlings observed on the last day I monitored the nest prior to fledging. If ≥1 Golden-winged Warbler nestling fledged, I classified a nest as "successful." To decrease bias associated with misidentification of nest fate (Streby and Andersen 2013), I used a combination of nest condition, fate of radio-marked juveniles (Chapter 3), and the presence and behavior of color-marked adults to verify nest fate.

I measured vegetation characteristics at nests within 30 days after nests either fledged or failed. To sample vegetation, I used a nested plot design (1-m, 5-m, and 11.3-m radius) centered on nest sites. I visually estimated vegetation cover (±5%) for 7 different classes (leaf/woody litter, grass, forbs, woody plant species, vines, *Rubus* spp., and other [i.e. bare ground, large woody debris, etc.]) within a 1-m radius circle around plot center and at a 0.5 m height above ground. I estimated vertical vegetation density above 1.5 m using a densiometer in 4 cardinal directions 5 m from plot center. I also estimated basal area using a 2.5 m^2/ha wedge prism. I used a density board with a 2-cell wide x 10-cell tall array of squares (20-cm x 20-cm squares) to estimate horizontal vegetation density to the nearest 5%. The density board was placed at plot center and the observer stood 5 m from plot center in each cardinal direction. The observer recorded the number of density board squares (out of 20) that were >50% covered from a height of 1 m. I used a rangefinder to delineate an 11.3-m radius circle around plot center. In this circle, I estimated the average height of shrubs and tree saplings (+/- 0.25 m), and counted the number of snags. We collected the same vegetation data at a paired random point 25-50 m from the nest to assess vegetation availability within the territory for Resource Selection Functions analysis.

Vegetation Type Mapping

In ArcGIS (Environmental Systems Research, Inc., Redlands, California, USA) I digitized a polygon vegetation cover map using 1-m resolution ortho-imagery (2012 US Geological Survey), topo maps, and historic mining records. I ground-truthed the map in polygons where I was unsure of the classification. The five vegetation types contained in the map were 1) herbaceous dominated, 2) shrub/sapling, 3) human-developed (roads and buildings), 4) mature forest, and 5) pole-sized forest. Human-developed class occurred infrequently and Golden-winged Warblers never used it so I excluded it from any analyses. We differentiated pole-sized forest from mature forest because the tree diameters and understory structure differed. Pole-sized forests in TN are more similar to the forests of the Great Lakes region than mature forests in TN, which have closed canopies with little to no understory cover. The herbaceous and shrub/sapling vegetation classes included areas from both reclaimed mines and timber harvest, even though they differed in composition and structure. The pixel size classified was 10 m x 10 m. I buffered each individual nest location by 250 m to include the male territory and potential territories of predators such as Eastern Chipmunk (*Tamius striatus*) and Black Rat Snake (*Elaphe obsoletus*) (Blair 1942, Durner and Gates 1993, Streby et al. 2012). I then overlaid the buffered points with the cover class shapefile to get the percentage of each cover type within a 250-m radius. I also overlaid a buffered point of an adjacent 250-m radius circle 500 m from nest for Resource Selection Functions analysis. I measured in ArcGIS the distance of each nest site to mature forest edge, pole-sized forest edge, and any forest edge. Points located within mature or pole-sized forest vegetation were given a negative value for distance to forest edge.

Statistical Analyses

I used Resource Selection Functions in Program R (R Development Core Team 2017) to test which vegetation covariates were most important during nest-site selection (Boyce et al. 2002). I tested the same vegetation covariates used in my nest survival analysis (see below) except basal area and vertical vegetation density due to lack of data. Paired random points were between 25-50 m from the nest for all vegetation covariates except for broad scale cover types (250-m radius circle). Random cover type points were 500 m from the nest.

I estimated daily survival rate (DSR) for *Vermivora* spp. nests and evaluated competing DSR models using the nest survival model in Program MARK (White and Burnham 1999). I modeled the binomially distributed data with the user-defined, logit-link function while simultaneously considering associations with covariates. I used standard coding for data analysis in MARK (Dinsmore et al. 2002, Rotella et al. 2004). To estimate the probability of surviving the nesting period, I used the actual nest observations to estimate the number of days associated with each stage. I assumed one egg was laid per day and that incubation started on the day the last egg was laid. Therefore, the days required for egg-laying was clutch size minus one. I censored nests that I could not conclusively determine hatch date or fledge date when estimating days for incubation and brooding.

I used Akaike's Information Criterion adjusted for small sample bias (AIC_c) for model selection (Burnham and Anderson 2002). I used 3 groups (Year) in the modeling process. I modeled time as daily variables (t), a linear variable (T), as a quadratic (T^2), and as several groupings of days. I used 22 covariates in my models (Table 2.1) including management history (mine site or timber harvest), elevation (m), brood size, vertical vegetation density, horizontal vegetation density, percent vegetation composition within 1 m of nest, number of snags within 11.3 m of nest, average sapling and shrub height (m) within 11.3 m, basal area using a 2.5-m^2/ha wedge prism, and percent cover of vegetation types within 250 m of nest. A correlation analysis yielded no correlation of $R > 0.7$ between these covariates. I considered the model with the lowest AIC_c value the best-supported model given the data and models with $\Delta AIC_c \leq 2$ to be plausible, competing models (Burnham and Anderson 2002). I assessed the relative plausibility of each model in the model suite by comparing model weights (w_i). I presented β coefficients and their standard errors (SE) and 95% confidence intervals (CI) for covariates in supported models to infer the biological importance of covariates.

Results

Nest Monitoring

We found and monitored 65 nests during the 2013-2015 breeding seasons (2013, n = 18; 2014, n = 29; and 2015, n = 18). Of these, 24 survived the entire nesting period and had at least one juvenile Golden-winged Warbler fledge the nest. Average clutch size was 4.5 ± 0.1 (SE) eggs per nest (range 3-5) with a generally negative relationship relative to time of season. Average number of young fledged per nest was 3.9 ± 0.2 for successful nests and 1.4 ± 0.2 for all nesting attempts. I observed that 9.2% (10/109) of the eggs from successful nests did not hatch. I also observed that 5.5% (6/109) of eggs from successful nests hatched but were depredated or were otherwise missing from the nests before a typical fledging date. I did not find any nests of Blue-winged Warbler and recorded 2 nests each year (6 total nests) in which 1 parent was a Blue-winged Warbler x Golden-winged Warbler hybrid (Brewster's Warbler). No nests had hybrids for both parents. The first active nest (first egg laid) during the entire 3-year study period was May 5. The last day I recorded an active nest was June 30, resulting in an estimated 56-day nesting study period (*i* in Program MARK). The majority of the nests in the sample were first attempts (62/67, 92.5%), even though I searched for renests after nest failure. I did not record any females attempting 3 nests or double brooding. The average laying period (n = 59) was 3.54 ± 0.08 (SE) days to lay a clutch. On average, the incubation period (n = 15) was 11.67 ± 0.13 days and the nestling period (n = 10) was 8.10 ± 0.18 (SE) days. As a result, the entire nest period was 23.1 ± 0.39 (SE) days.

Nest-site Selection

The Resource Selection Functions yielded several vegetation covariates that were either selected for or against during nest-site selection. The vegetation covariate most important during nest-site selection was mature forest within 250 m of nest, which was selected against (Tables 2.2 & 2.3). No other models were < 2 ΔAICc from our top model, however the next two best-supported models included *Rubus* spp. within 1 m of nest (selected for) and vertical vegetation cover (selected for).

Characteristics of Successful Nests

Successful nests were at an average elevation of 865.9 ± 14.9 (SE) m (Table 2.4). Vertical cover >1.5 m was 60.1 ± 6.0 % and horizontal vegetation density averaged 68.9 ± 4.3 % 5 m from nest. For vegetation classes within 1 m of nest, litter cover was 5.8 ± 1.4 %, grass cover was 11.1 ± 2.6 %, forb cover was 58.8 ± 4.8 %, woody cover was 1.4 ± 0.5 %, vine cover was 5.4 ± 2.4 %, and *Rubus* spp. cover was 16.0 ± 4.3 %. The number of snags within 11.3 m of the nest averaged 1.5 ± 0.4, average sapling height was 3.7 ± 0.3 m, and average shrub height was 0.8 ± 0.3 m and tree basal area was 8.0 ± 2.8 m^2/ha. The distance to mature forest edge averaged 38.4 ± 6.8 m, the average distance to pole-sized forest edge was 56.8 ± 23.7 m, and the average distance to any forest edge (mature or pole-sized) was 10.1 ± 5.7 m. Vegetation cover within 250 m of nest averaged 4.2 ± 1.0 % herbaceous, 57.1 ± 3.4 (SE) % mature forest, 19.6 ± 2.6 (SE) % pole-sized forest, and 17.8 ± 2.7 (SE) % shrub-sapling.

Nest Survival

The n = 65 nests generated a total of 911 exposure days (14 exposure days/nest) in the Program Mark analysis. The best survival model using temporal covariates only, was based on constant survival by year but survival within each year grouped into four equal two-week intervals (1-14, 15-28, 29-42, 43-56) (Table 2.5). Daily nest survival was 0.956 ± 0.067 (SE). Nest survival for the entire 23.1-day nesting period was 0.354 ± 0.058. If I assumed a 25-day nesting period (nesting length used by many Golden-winged Warbler nesting studies), survival was 0.324 ± 0.059.

The best supported model when adding vegetation covariates to our base temporal model included forb cover within 1 m of nest (β-coefficient = 0.016, CI= 0.002 – 0.030, Figure 2.3). No other supported models were ΔAICc < 2 from our top model. The only other model that was better supported than our base temporal model was one that included *Rubus* spp. cover within 1 m of nest (β-coefficient = -0.012, CI= -0.028 – 0.003).

Discussion

Vital Rates

My estimate of clutch size (4.54 ± 0.08 [SE] eggs) was similar to that reported in earlier studies at North Cumberland Wildlife Management Area, Tennessee. These estimates are somewhat lower than those from greater latitudes, which is consistent with that of most passerines (Ashmole 1963, Bulluck et al. 2013). Bulluck (2007) estimated clutch size as 4.30 ± 0.09 from 2004-2006 and Percy (2012) estimated a clutch size as 4.46 from 2009-2011. Mean young fledged per successful nest was also similar during 2013-2015 (3.88 ± 0.12 fledglings) compared to 2004-2006 (4.06 ± 0.13 fledglings) and 2009-2011 (4.3 fledglings). I could not find any other Golden-winged Warbler studies that reported percentage of unhatched eggs but unhatched eggs during my study (9.2 %) was similar to Koenig (1982), who reported the mean percentage of unhatched eggs for passerines at 8.8%.

Many Golden-winged Warbler nesting studies assumed a 25-day nesting period with 4 days for egg laying, 11 days for incubation, and 10 days for brooding (Ehrlich et al. 1988). However, the only other Golden-winged Warbler study that actually reported an estimated nesting period (Streby and Andersen 2013) illustrates that nesting periods may differ (Tennessee: 23.1-day nesting period, Minnesota 25.5-day nesting period) and generally increases as latitude increases (Martin 1995). The estimate of nesting survival would be biased low 3% if I assumed a 25-day nesting period and nest survival could be biased high in studies in northern sites if the nesting period was greater than 25 days. Although the variation in the length of the nesting period is not great across the breeding range, individual studies should measure the length of the nesting period directly and use it in the nest survival estimates to improve accuracy.

Golden-winged Warbler nest survival estimates have varied considerably across the breeding range and from year to year. Nest survival estimates ranged from 0.108 during 2009 in Tennessee (Percy 2012) to 0.725 during 1998 in North Carolina (Klaus and Buehler 2001). Nest survival estimates during my study (0.354 ± 0.058 [SE]) were average compared to a comprehensive nest-survival study of Golden-winged Warblers across their breeding range ($\bar{x}$ = 0.360, Aldinger et al. 2015) . My estimate also was slightly lower than a review of passerine nesting which estimated nest survival in early successional communities as 0.444 ± 0.026 for ground-nesting birds (Martin 1995). Because I used radio-telemetry to more accurately determine fate of the nestlings, my estimate of nest survival may be lower than other nesting studies, which are often biased high (Streby et al. 2013).

Nest-Site Selection

Golden-winged Warblers at North Cumberland Wildlife Management Area, Tennessee, nested at 600-1,000 m elevation in forested landscapes that contained a mosaic of other vegetation types, including herbaceous and shrub-sapling patches. At the scale of a male territory (~250 m scale), nests were still in forest-dominated (pole-sized and mature) vegetation but contained even more herbaceous and shrub-sapling vegetation. Nests were typically located within these shrub-sapling and/or herbaceous vegetation types and were usually near (11.5 m on average) a deciduous forest edge. Horizontal vegetation density was typically dense within 5 m of the nest (mean vertical cover = 68%). Vertical vegetation above the nest was also fairly dense (mean woody cover = 59%), consisting mostly of saplings and shrubs. Vegetation within 1 m of the nest was about half forbs (mean forb cover = 51%), with *Rubus* spp. and grass comprising most of the remaining vegetation. Successful nests typically had less grass cover, more forb cover, and less *Rubus* spp. cover within 1 m of the nest than unsuccessful nests.

Many of the vegetation covariates associated with nest sites were above the null model in the RSFs (Table 1.3), suggesting that habitat selection was occurring for these covariates. To summarize, the vegetation characteristics most important during nest-site selection were mature forest within 250 m of nest (selected against), *Rubus* spp. within 1 m of nest (selected for), and vertical vegetation cover (selected for). These patterns of nest-site selection are largely consistent with other studies from the Cumberland Mountains (Buehler and Bulluck 2008, Percy 2012), and elsewhere in the Appalachian Mountains region (Aldinger and Wood 2014). Furthermore, these patterns of nest-site selection are largely consistent with nest-site selection studies from the Great Lakes region (Roth et al. 2014, Streby et al. 2014).

Vegetation Characteristics Related to Nest Survival

The habitat covariates linked to nest survival in this study appear to be consistent with important habitat covariates from studies elsewhere in the Appalachian Mountain region. Aldinger (2015) determined that percent grass cover within 1 m of nests, percent *Rubus* spp. cover within 1 m of nests, and distance to forest edge were the habitat covariates that were negatively related to nest survival across most of the breeding range and across a variety of management types. Bulluck and Buehler (2008) determined that percent forb cover within 1 m of nests was positively related while average sapling height and woody cover within 1 m of nests were negatively related to nest survival. Percy (2012) determined that percent *Rubus* spp. cover within 1 m and 11.3 m of nests, and distance to forest edge were negatively related to nest survival. In my study, forb cover within 1 m of nest was positively related and *Rubus* spp. cover within 1 m of nest was negatively related to nest survival, similar to Bulluck and Buehler (2008) and Percy (2012) on the same study sites. Although I did not have the exact same vegetation covariates represented in the top models as the covariates in the top models from other studies, the vegetation covariates important in other studies still showed the same relationships to nest survival in my study. Distance to forest edge was less for successful nests than for unsuccessful nests in my study. Also, average sapling height and woody cover around the nests were less for successful nests than for unsuccessful nests. No other Golden-winged Warbler nesting studies looked at broader-scale vegetation characteristics so I could not compare results from other studies on vegetation covariates within 250 m of nests.

Nest Survival Related to Nest-Site Selection

Theoretically, selection of certain vegetation characteristics and cover types for nesting should lead to nest survival benefits, ultimately linked to fecundity (Martin 1995). This relationship was not evident for the vegetation covariates measured in my study. The most important vegetation characteristic related to nest survival was forb cover within 1 m of nest and Golden-winged Warblers did not appear to select for areas with greater forb cover. Also, nest survival had a negative relationship with *Rubus* spp. cover within 1 m of nest but Golden-winged Warblers actually selected nests sites with greater *Rubus* spp. cover than at random sites. Although nest survival had a negative relationship with *Rubus* spp. cover, the pattern of selection for greater *Rubus* spp. cover suggests that there may be a minimum amount of *Rubus* spp. cover needed around the nest.

There are a few plausible explanations as to why I observed a disconnect between nest-site selection and nest survival in terms of vegetative characteristics. First, I may not have measured the correct vegetation or other covariates to clearly show a connection between nest-site selection and nest survival. However, I did measure vegetation characteristics that were plausibly linked to nest survival and I measured these characteristics at several different scales. Second, recent changes in landscape or vegetative cover from human disturbance may have caused Golden-winged Warblers to nest in lesser-quality cover. This is commonly known as the ecological trap theory (Dwernychuk and Boag 1972). This concept is similar to the source-sink theory and is simply a sink habitat (low quality habitat that cannot maintain a population without immigration) that is preferred rather than avoided. Many other studies have observed this pattern for avian taxa ranging from passerines to waterfowl and birds of prey (Battin 2004, Robertson and Hutto 2007, Boves et al. 2013). Lastly, habitat selection during different life stages can be in conflict, resulting in a balancing of an individual's total fitness at the expense of individual components of fitness (Price and Grant 1984, Schluter et al. 1991). Streby et al. (2014) observed that female Golden-winged Warbler nest-site selection was the result of selection pressure of two opposing fitness components, nest survival and juvenile survival. These opposing selection pressures gave the appearance that nest-site selection was maladaptive, when in fact, it was balancing nest survival with selection for proximity to quality post-fledging habitat that enhanced juvenile survival. For this reason, management recommendations that are solely based on nest-site selection and nest survival, may be misguided in terms of maximizing seasonal productivity (Streby et al. 2014).

CHAPTER 3: POST-FLEDGING SURVIVAL AND HABITAT SELECTION OF GOLDEN-WINGED WARBLERS (*VERMIVORA CHRYSOPTERA*) AT NORTH CUMBERLAND WILDLIFE MANAGENENT AREA, TENNESSEE

Abstract

Understanding post-fledging survival and habitat use relationships is critical to inform management strategies to conserve populations of declining avian species, such as Golden-winged Warbler (*Vermivora chrysoptera*). We radio-tracked Golden-winged Warbler fledglings at North Cumberland Wildlife Management Area, Tennessee from 2013 to 2015. I wanted to document post-fledging survival, movement patterns, and vegetation type selection. The maximum travel distance recorded for a 1-day old fledgling was 31.4 m. Maximum travel distances/day for the remaining 24 days were 64.4 m (day 2), 127.5 m (day 3), 172.6 m (days 4-11), 371.7 m (days 12-13), and 411.5 m (days 14-25). Fledglings did not select for or against any vegetation types during their first 3 days post-fledging. Shrub/sapling vegetation was most selected for during days 4-25. Juveniles avoided mature forest and herbaceous vegetation during the same time period. Snake predation accounted for 52% (16/31) of known deaths with the remaining mortalities attributed to small mammals (26%), birds of prey (9%), and exposure/abandonment (13%). Survival models were split into 2 time intervals. Daily survival rate (DSR) was 0.736 ± 0.039 (SE) during the initial first 3 days post-fledging. Survival for the entire three-day interval was 0.399 (n = 57 fledglings). Daily survival increased considerably for days 4-25 post-fledging, DSR = 0.986 ± 0.007 (n = 25). Fledgling survival for the entire 25-day post-fledging period was 0.289 ± 0.066. The best supported model when vegetation covariates were added included percent shrub-sapling vegetation within 250 m of fledgling location (β-coefficient = -6.849, CI= -11.017 – -2.681). All other individual covariates had a ΔAICc > 2 when compared to the top model. Relatively low post-fledging survival for Golden-winged Warblers in the Cumberland Mountains may limit the ability to sustain populations without significant immigration.

Introduction

Golden-winged Warblers (*Vermivora chrysoptera*) are Nearctic-Neotropical migrant songbirds that have garnered conservation attention recently because of their population decline (-2.8% / year, Sauer et al. 2017), their hybridization with Blue-winged Warblers (Vermivora cyanoptera), and as a symbol for the need for early successional plant communities. The rate of population decline has been extremely steep in the Appalachian Mountains portion of the Golden-winged Warbler breeding range (-8.56% / year [95% CI 7.3-9.8], Sauer et al. 2017). In 2010, Golden-winged Warblers were petitioned to be listed under the federal Endangered Species Act. The U.S. Fish and Wildlife Service determined there was substantial merit to the petition and initiated a species status review.

Nesting success and the number of young fledged have been used as indices of reproductive success and habitat quality in countless avian studies. Although the ability to successfully fledge young is important, survival during the post-fledging stage may be of equal or greater importance in determining seasonal productivity. In a 2-year study on Ovenbirds (*Seiurus aurocapilla*), seasonal productivity (number of young surviving to independence per breeding female) was greater in the year with lesser daily nest survival. This result was caused by greater daily fledgling survival off-setting the effects of lesser daily nest survival (Streby and Andersen 2011).

The post-fledging period has been historically understudied in songbirds because of the lack of appropriate technology, such as radio transmitters small enough to use on songbird fledglings. Most previous estimates of juvenile survival have been obtained from mark/recapture or resighting studies (Woolfenden 1978, Dhondt 1979, Thomson et al. 1999). The mark/recapture method may work reasonably well for resident birds but works poorly for

Nearctic-Neotropical migrants because of their general lack of natal site fidelity (Anders et al. 1997).

Studying the post-fledging period is important for more than survival. Attaching transmitters to nestlings before they fledge can give more accurate estimates of nest survival (Streby and Andersen 2013). Radio-tracking fledglings can lead to a better understanding of habitat requirements because vegetation used in the post-fledging period can be quite different than vegetation used in the nesting period (Marshall et al. 2003, Vitz 2008). Management plans are often created to maximize nesting potential; if different vegetation types are required for fledgling survival, management must focus equally on post-fledging vegetation as well.

In this study, I seek to address several specific objectives. First, I will document daily survival rates for Golden-winged Warbler fledglings from fledging to independence from their parents (defined in this study as 25 days post-fledging). Second, I will determine which vegetation types are being selected during the post-fledging period. Third, I will assess whether covariates are related to daily survival rates, including temporal and spatial covariates, as well as specific vegetation covariates. Finally, I will use models of daily survival rates to infer how Golden-winged Warbler habitat might be managed to improve post-fledging survival.

Methods

Study Sites

My study sites were located in the Royal Blue Unit of the North Cumberland Wildlife Management Area (NCWMA), which consists of 60,000 ha of public land spanning four counties (Scott, Anderson, Campbell and Morgan) in the northeastern portion of Tennessee (Percy 2012). The predominant land cover of the study sites was a combination of mixed-mesophytic and oak (*Quercus* spp.)-hickory (*Carya* spp.) forests, with ~15% of the area in early stages of succession because of timber harvest and surface mining for coal (<5% area suitable for Golden-winged Warbler nesting). The NCWMA was in the Cumberland Mountains region and managed by the Tennessee Wildlife Resources Agency. This area was comprised of steep mountainous terrain with elevations peaking at ~1200m. The mean elevation of my study sites was 780 m (range = 431– 996 m).

Experimental management for Golden-winged Warblers occurred on 3 study sites during 2010-2012: Anderson (~55 ha), Burge (~25 ha), and Red Oak (~40 ha) mountains. These sites were managed timber harvest and subsequent combinations of broadcast herbicide and prescribed fire treatments. Three additional study sites were on reclaimed coal surface mines: Ash Log (~160 ha), Burge (~55 ha), and Massengale (~160 ha) mountains. All study sites were located in the southwestern portion of NCWMA and were located within 20 km of each other (Figure 2.2). Golden-winged Warblers had been documented previously on all of these sites (Buehler et al., unpublished data). Coal surface-mine reclamation occurred from about 1980–1990 on the mine sites. Reclamation involved planting black locust (*Robinia psuedoacacia*), tall fescue (*Schedonorus phoenix*), orchard grass (*Dactylis glomerata*), timothy grass (*Phluem pretense*), sericea lespedeza *(Lespedeza cuneata)*, and autumn olive (*Elaeagnus* *umbellata*). Yellow-poplar (*Liriodendron tulipifera*), maples (*Acer* spp.), oaks, blackberry (*Rubus* spp.), and a few forbs (e.g., *Solidago* spp., *Aster* spp.) have since colonized the reclaimed mine sites.

On Massengale, three burn units measuring 40 ha, 115 ha, and 145 ha, were on a one- to three-year fire-return rotation from 2007 to 2011. All of Massengale Mountain was managed with prescribed fire in spring 2013. A single unit, measuring 35 ha, was burned on Ash Log Mountain in 2007, but logistical constraints prevented subsequent prescribed burning. All burns were conducted during the dormant season. Prescribed burns were of low-moderate intensity with flame lengths generally 1-2 m.

Field Methods

We searched for nests by observing predominantly female behavior leading to nest location. Once nests were located, we monitored nest activity every 2-4 days until nests either fledged or failed (Chapter 2). When nestlings were approximately 7-8 days old (1-2 days prior to the anticipated fledge-date), I removed them from the nest, placed them in a cloth sack, and moved them to a work area ≥ 10 m from the nest for processing. Each nestling had its mass recorded and I then attached a numbered US Geological Survey band and one color band to each nestling (UT IACUC #561). I randomly selected 1-3 nestlings from each nest and attached a radio transmitter using the method described below (Figure 3.1). Most transmitters were placed on birds as nestlings, but 2 individuals (3, and 11 days post-fledging) were opportunistically captured by hand or mist-net and equipped with a transmitter after fledging. The combined mass of radio transmitter, harness, and leg band was about 0.41g and < 5% of nestling mass at fledging. The attachment of leg bands and radio transmitter resulted in ~5 min of total handling time after which the nestlings were returned to their nest.

I attached radio transmitters using a figure-eight harness around the pelvic girdle of the bird (Rappole and Tipton 1991). The harnesses were made from a 1-mm elastic thread (Gütermann GmbH, Baden-Württemberg, Germany) which eventually deteriorated and detached from the radio-marked bird (Streby et al. 2013). In 2014 and 2015, radio transmitters were purchased from Blackburn Transmitters (Nacogdoches, Texas, USA) and had a battery life of approximately 30 d. In 2013, 1 to 2-year-old old radio transmitters were gifted to my project and had a battery life of 0-25 d. Radio transmitters were re-used on multiple birds if they were recovered post-deployment and were still in a usable condition (i.e., 10+ d of predicted battery life remaining, antenna not kinked or coiled).

Similar to Streby et al. (2016), I checked the nest each day after radio-transmitter attachment. If the nest was empty, I radio-tracked each radio-marked fledgling from that nest. If I found a radio-transmitter not attached to a bird, I closely examined the radio-transmitter for signs of predation (bite marks on harness, antenna, or battery). If I did not observe any signs of predation, I concluded the bird slipped from the harness and the bird was censored from the analysis from that point forward. If I determined that a bird died from predation, I looked for parental and sibling activity nearby to determine if the predation happened before or after fledging. If I observed any sign of a surviving sibling nearby (adults angrily chipping, adults feeding a sibling, begging from sibling), I concluded that the nest fledged. If I did not observe any surviving sibling, I concluded that the entire nest failed and I censored those radio-marked birds from my post-fledging analysis. I tracked each radio-marked fledgling daily between 0700 and 1300 EDT until the individual was recovered dead or the radio transmitter battery failed. I determined approximate location using triangulation and then made visual contact with the target individual using homing to determine if it was alive or dead and to record location with a GPS and evaluate habitat.

I determined the cause of death of each mortality event based on the field evidence present where the radio transmitter was found. For snake predation, I assumed a snake was responsible for the predation event if the radio transmitter was in the digestive tract of the snake (black rat snake [*Elaphe obsolete*], northern copperhead [*Agkistrodon contortrix*] and corn snake [*Pantherophis guttatus*]). I assigned predation events to small mammals (mainly thought to be Eastern Chipmunk [*Tamius striatus*]) if there was visual damage to the transmitter and/or the transmitter/carcass was slightly buried or there were other remains of the dead juvenile bird. I assigned a predation event to an avian predator (mainly thought to be Sharp-shinned Hark [*Accipiter striatus*] and Cooper's Hawk [*Accipiter cooperii*]) if the carcass had been plucked leaving the transmitter amidst a pile of feathers. Fledglings that were found whole, with no visual damage to them or the transmitter, were presumed dead to exposure/abandonment. If I found a transmitter on top of vegetation with no visible damage, I assumed the fledgling slipped out of the harness (Streby et al. 2016).

The collected habitat measurements were designed to conform to the Golden-winged Warbler Working Group habitat sampling protocol (Aldinger and Wood 2014). Vegetation measurements were collected at each daily location the bird was first observed (defined as plot center), one day after the actual use of a given site if necessary to avoid disturbing the bird. At each point I recorded 1) the fledgling's location (+/- 10 m) using a handheld global positioning system (Garmin Etrex and Garmin GPSMap60, Olathe, Kansas, USA), 2) habitat characteristics (described below), 3) which parent(s) was present, 4) fledgling's perch-height from ground (m), and 5) parental activity. I estimated vertical vegetation density cover using a densiometer in four cardinal directions 5 m from plot center. I also measured basal area using a 2.5 m^2/ha-factor wedge prism.

I visually estimated vegetation cover to the nearest 5% for seven different classes (litter, grass, forbs, woody, vines, *Rubus* spp., and other [i.e. bare ground, large woody debris, etc.]) in a 1-m radius circle around plot center and at 0.5 m above ground. I used a density board with a 2-cell wide x 10-cell tall array of squares (20-cm x 20-cm squares) to estimate horizontal vegetation density to the nearest 5%. The density board was placed at plot center and the observer stood 5 m from plot center in each cardinal direction. The observer recorded the number of density board squares (out of 20) that were >50% covered from a height of 1 m. I used a combination of a rangefinder, tape measure, and a visual estimate to delineate an 11.3-m radius circle around plot center. In this circle, I visually estimated the average height of shrubs (+/- 0.25 m), the average height of saplings (+/- 0.25 m), and counted the number of snags (standing dead tree > 5 in dbh and > 4.5 ft tall). Correlation Analysis yielded no correlation between these vegetation covariates of $r > 0.7$.

Vegetation Type Mapping

In ArcGIS (Environmental Systems Research, Inc., Redlands, California, USA) I digitized a polygon vegetation cover type map using 1-m resolution ortho-imagery (2012 US Geological Survey), topo maps, and historic mining records. I ground-truthed the map in polygons where I was unsure of the classification. The five vegetation types contained in the map were 1) herbaceous, 2) shrub/sapling, 3) human-developed (roads and buildings), 4) mature forest, and 5) pole-sized forest. Human-developed class occurred infrequently and Golden-winged Warblers never used it so I excluded it from any analyses. We differentiated pole-sized forest from mature forest because the understory structure and tree diameters differed. Pole-sized forests in TN are more similar to the forests of the Great Lakes region than mature forests in TN, which have closed canopies with little understory cover. The herbaceous and shrub/sapling vegetation classes included areas from both reclaimed mines and timber harvest, even though they may have differed slightly in composition and structure. The pixel size classified was 10 m x 10 m. I buffered each daily juvenile location by 250 m to include the male territory and potential territories of predators such as Eastern Chipmunk and Black Rat Snake (Blair 1942, Durner and Gates 1993, Streby et al. 2012). I then overlaid the buffered points with the cover class shapefile to get the percentage of each cover type within a 250-m radius. I also measured with ArcGIS the distance of each daily juvenile location to mature forest edge, pole-sized forest edge, and any forest edge. Points located within mature or pole-sized forest vegetation were given a negative value for distance to forest edge.

Statistical Analysis

I estimated cover-class use and availability for two time intervals after fledging (days 1-3 and days 4-25; based on differences in survival) for four vegetation cover types (grass/forbs, shrub/sapling, pole-sized forest, mature forest). I used Resource Selection Functions in Program R (R Development Core Team 2017) to test which vegetation covariates were most important during post-fledging habitat selection (Boyce et al. 2002). I used ArcGIS to calculate the straight-line distance (m) between consecutive daily points of each fledgling as they aged. I then determined the maximum distance traveled each day by all fledglings. I assumed that if a fledgling traveled a certain distance one day, they could travel an equal distance every subsequent day, so that all maximum daily travel estimates were the same or greater than the previous day. I used the digitized cover-class map to determine use of the four cover classes by extracting the cover class type associated with each observed fledgling point.

I buffered each observed fledgling point by a radius determined as the daily maximum travel distance for all fledglings. I extracted the cover-class polygons for each buffered point and converted to percentage to determine cover-class availability.

Fledgling survival was estimated using program MARK's Known Fate model (White and Burnham 1999). I used 3 groups (Year) in the modeling process. I modeled time as daily variables (t), a linear variable (T), as a quadratic (T^2), and as several groupings of days (i.e. days 1-2, 3-4, 5-25, days 1-3, 4-25, etc.). I had 26 individual covariates that I analyzed in relation to juvenile survival (Table 3.1). Four were general covariates: treatment (mine and forest management), fledge date, number of siblings that fledged, and daily distance from ground (m). I included 3 weather covariates: average precipitation, average high temperature, and average low temperatures for the first three days post-fledging. I also included daily vegetation covariates: vertical vegetation density, basal area, horizontal vegetation density, average sapling height, average shrub height, and number of snags. I also included the six vegetation estimates within 1 m of fledgling location (litter, grass, forbs, woody plant species, vines, and *Rubus* spp.). Finally, I included the four vegetation types within 250 m of fledgling location (herbaceous, shrub/sapling, pole-sized forest, mature forest), as well as distance to forest edge for pole, mature, and any forests. I modeled an interaction variable between the top individual covariates and treatment, to test for a treatment effect. I used the vegetation data from the nest site for the first survival interval (day 1) and vegetation measured at each daily location thereafter.

Results

Post-fledging Monitoring

I placed transmitters on 73 nestlings during the 2013, 2014, and 2015 breeding seasons (2013, n = 18; 2014, n = 35; and 2015, n = 20). Of these, 56 survived the nestling stage, had their transmitter stay on during fledging (we determined n = 3 dropped their transmitter during fledging), and were subsequently monitored as fledglings. In 2015, 2 additional individuals were opportunistically captured and equipped with a transmitter 3 and 11 days after fledging. As such, a total of 58 fledglings were radio-tracked during all 3 years of this post-fledging study (2013, n = 10; 2014, n = 31; and 2015, n = 17) on 4 of the 5 study sites (Ashlog, n = 25, Burge, n = 5, Massengale, n = 21, Red Oak, n = 7).

Post-fledging Site Selection

The maximum observed travel distance for a 1-day old fledgling was 31.4 m (Table 3.2). Maximum observed travel distances for the remaining 24 days were 64.4 m (day 2), 127.5 m (day 3), 172.6 m (days 4-11), 371.7 m (days 12-13), and 411.5 m (days 14-25).

The null model was our top model when comparing vegetation type selection for the first 3 days, suggesting that there wasn't any significant pattern of habitat selection during this time interval (Tables 3.3 & 3.4). For days 4-25, shrub/sapling vegetation within 250 m of juvenile location was most selected for. No other models were < 2 ΔAICc from our top model. Two other models scored above the null model including mature forest vegetation within 250 m of juvenile location (selected against) and herbaceous vegetation within 250 m of juvenile location (selected against).

Post-fledging Survival

Of the 58 fledglings tracked, 21 (36%) were tracked until the transmitter battery expired or the fledgling could not be found on the study area. The other 37 fledglings died during the study. I was able to determine the cause of death for 31 fledglings (Table 3.5). Six fledglings went missing within the first three days and were presumed dead from unknown causes. Of the known mortalities, snakes accounted for 52% (16/31), small mammals accounted for 26% (8/31), birds accounted for 9% (3/31), and 13% (4/31) died to exposure and/or abandonment. Of the 16 snake predations, 8 were by Black Rat Snakes, 6 were by Northern Copperheads, and 2 were by Corn Snakes.

Based on analysis of a total of 402 survival days, the best survival model (with temporal covariates) held group (year) constant and grouped into two intervals (days 1-3 and days 4-25, Table 3.6). Daily survival rate was low during the initial first 3 days post-fledging with a daily survival of 0.736 ± 0.039 (SE) across all study sites. Survival for the entire three-day interval was 0.40 (n = 57 fledglings). Daily survival increased considerably for days 4-25 post-fledging, DSR = 0.986 ± 0.007 (n = 25). Fledgling survival for the entire 25-day post-fledging period was 0.29 ± 0.066. Post-fledging survival for the entire period appeared to differ by management type; survival was 0.000 (n = 7) on recent timber harvest sites managed with prescribed fire and 0.312 ± 0.059 (n = 51) on reclaimed mine sites.

The best supported model when individual habitat covariates were added included shrub-sapling cover at 250 m (negative effect) and improved when I just modeled the covariate during the first 3 days (β-coefficient = -6.849, CI= -11.017 – -2.681, Table 3.6). All other individual covariates had a ΔAICc > 2 when compared to the top model. The next best supported model included sapling height at 11.3 m (positive effect), which was improved when just modeling the vegetation covariate during the first 3 days (β-coefficient = 0.340, CI = 0.037 – 0.642). Several other individual habitat covariates improved the base model but were not strongly supported in that β-coefficients overlapped zero (i.e., mature forest vegetation within 250 m [positive effect], distance to forest edge [negative effect], average shrub height within 11.3 m [negative effect], and grass within 1 m [negative effect]). There was no treatment effect on the top covariates.

Discussion

Vital Rates

Juvenile survival over the first 25 day period post-fledging was 0.29 ± 0.066 (SE), which was actually a conservative estimate. My survival estimate was potentially biased high if the fledglings that were censored for dropping their transmitter (n = 3) were actually predated. Cox et al (2014) used 45 studies, equating 53 data points (some studies observed more than one species), to compare juvenile survival of 35 Nearctic-Neotropical migrant songbird species for the first 21 days post-fledging. Most survival estimates were generated from radio-telemetry data (n = 31), but others also used banded individuals (n = 17) or both methods (n = 5). Survival rates ranged from 23-87% but most were above 40%. Cox et al. (2014) concluded that a post-fledging survival less than 40% (TN 21-day nest survival = 30.6%) requires an unrealistically high overwinter survival to prevent population decline unless adult survival rates and seasonal fecundity are high. Golden-winged Warblers have a relatively small clutch size and are single-brooded (Chapter 2) compared to other songbirds. A relatively low juvenile survival rate for Golden-winged Warblers in the Cumberland Mountains paired with an average nest survival and single-broodedness (Chapter 2) suggest that poor recruitment into the population is one of the likely factors linked to the local population decline. Recent genetic studies (Toews et al. 2016) further complicate Golden-winged Warbler conservation planning because Golden-winged and Blue-winged Warblers have hybridized to such a great extent based on full genomic nuclear DNA analyses. In my study, 9% (6/67) of the nesting pairs monitored had at least 1 hybrid parent. The effects of this level of hybridization on recruitment into the local population further exacerbates the decline of the Golden-winged phenotype.

Predator Communities

In most if not all passerines, predator communities ultimately determine nest survival rates (Rangen et al. 1999, Fontaine and Martin 2006), as well as juvenile survival rates (Sunde 2005, Schmidt et al. 2008). Streby et al. (2016) in a presumably stable population in Minnesota attributed 86% of fledgling Golden-winged Warblers mortalities to small mammal predation and only 9% to snake predation. Golden-winged Warbler fledglings during the 2014 breeding season in Pennsylvania also had no snake predation (0/17) compared with 88% (15/17) small mammal predation (J. Larkin et al., unpub. data). Because Tennessee had 52% snake predation compared with 26% small mammal predation, there is likely a major difference in predator communities in Tennessee compared with the other two areas where Golden-winged Warbler post-fledging period have been studied. Golden-winged Warbler juvenile survival was estimated at 52% in Minnesota (Streby et al. 2016) and 45.5% in Pennsylvania (J. Larkin et al., unpub. data), possibly because of the lack of snake predation.

Black rat snakes, northern copperheads and corn snakes were documented with fledgling radio transmitters in their gut. Snakes show little to no territorial behavior during the summer months (Seigel et al. 2001), and therefore density of snakes may be only limited by food and cover availability. Although I did not directly measure snake abundance on the study sites, I frequently encountered snakes during the course of field activities. Not only were snakes relatively abundant, their daily movements may have covered several Golden-winged Warbler territories. Male copperheads in the Connecticut River Valley had a relatively small home range (2.7 ha) and daily movements of only 20.7 m during the summer months (Smith et al. 2009). Male black rat snakes in Ontario had much larger home ranges (7.6 ha) and greater average daily movements (69.3 m; (Weatherhead and Hoysak 1989). These home ranges and daily movements were generally greater than the distance a Golden-winged Warbler fledgling moved during the first 3 days post-fledging (when 89% of the predation events occurred). Also, during the first few days, fledglings are usually close to the ground, which makes them more vulnerable to snakes at night when thermal contrast is the greatest. All 3 species of snakes are almost exclusively nocturnal during the summer months (Smith et al. 2009, DeGregorio et al. 2014). In years of good mast availability and small mammal population increases, snake populations may respond in kind, such that Golden-winged fledglings could be susceptible to elevated levels of snake and small mammal predation. Given that I observed constant survival among years in this study, wide fluctuations in small mammal and snake populations and/or predation pressures were not seen. Mast cycles during the monitoring period (2013-15) were undocumented.

Habitat Use and Linkages to Survival

Juvenile Golden-winged Warblers used vegetation types similar to their nest sites during the most critical early period (days 1-3) post-fledging. This pattern reflects their limited daily movements, such that the nest site determined the vegetation type used during early post-fledging. The pattern of habitat use changed over time as daily movements led to departure from the nest site into different vegetation types (i.e., shrub/sapling, pole timber, and mature forest). This change in vegetation use was similar to what was reported by Streby et al. (2016) in Minnesota, where Golden-winged Warblers post-fledging moved from patches of herbaceous and shrub/sapling cover types used for nesting into adjacent forest. In Streby et al.'s (2016) study, such movements were critically linked to improved survival. In my study, fledglings used the forested areas more as they aged but still selected against mature forests and selected for *Rubus* spp. when compared to what was available for them to use.

Survival of fledglings on my study sites was most strongly linked to intermediate-scale vegetation cover. I had three covariates which improved my base model by at least 2 ΔAIC. The amount of shrub-sapling cover had a negative relationship with survival. Predators (snakes and/or small mammals) may have either greater densities in shrub-sapling cover types or at least greater activity, thus increasing the chance for a predation event. Alternatively, the vulnerability of the fledglings themselves to predation may have been greater, regardless of predator density or activity. The increased vulnerability to predation in shrub-sapling cover types was apparently unrelated to the structure of the cover that was present to hide in because juvenile survival appeared to be unrelated to the horizontal vegetation density covariate. The positive relationship with average sapling height suggests that predation risk decreased as forest and mineland succession advanced on these sites as tracked by sapling height. Again this effect could be related to reduced predator density/activity or reduced vulnerability from the predators that were there or both. Surprisingly, the height at which the fledgling perched did not appear to be directly related to survival; thus the reduced predation risk in sites with taller saplings was not simply a result from fledglings perching higher off the ground.

My mine sites fit the description of what copperheads and other snakes often use. Of the 58 fledglings studied during this project, 52 were from previously mined areas that were maintained as herbaceous openings with scattered shrubs and tree saplings. Some snakes are known to prefer areas with rock outcroppings for cover (Blouin-Demers and Weatherhead 2001). A study of snakes and nest predation found that snake habitats were characterized by greater shrub cover and that nest success decreased with increasing shrub height (Klug et al. 2010). Copperheads were found more often in herbaceous openings than mature forest in Indiana (Carter 2012). Even though shrub-sapling vegetation is important for nesting, too much of it may support a predator community that is detrimental to juvenile survival. The opposite is true with mature forest and sapling height. Although Golden-winged Warbler nesting was not associated with mature forests, this vegetation type may have a different predator community that is less detrimental to juvenile survival.

CHAPTER 4: CONCLUSION

Full season productivity (FSP) is the number of offspring raised to independence per breeding pair. I wanted to estimate FSP to illustrate how nest productivity (number of young fledged per breeding pair) and post-fledging survival determine FSP and to compare those values with the only other published values calculated for the species from Minnesota (Peterson 2016). I calculated FSP as follows (Peterson 2016):

$$FSP = NP * FS$$

where NP is nest productivity and FS is fledgling survival to independence (first 25-days after fledging). I calculated NP as follows:

$$NP = (NS + (1 – NS) * NS) * NF$$

where NS was nest survival and NF was the number fledged per nest. I assumed all females attempted two nesting attempts if the first one failed. NS in Tennessee was 0.354, NF was 3.9, NP was 2.27 (Chapter 2), FS was 0.289 (Chapter 3) and FSP was calculated as 0.66 offspring/pair.

FSP must be paired with survival rate data from the breeding and non-breeding periods to be able to calculate population growth rates. In absence of the accompanying survival rate data, direct comparison of FSP among breeding populations is still a meaningful way to assess how reproduction is contributing to population sustainability. For Golden-winged Warblers, the only other population that had FSP estimates was from Minnesota (Peterson 2016). In the Minnesota study, NS was 0.392, NF was 4.35, NP was 2.74 and FS was 0.52 for Golden-winged Warblers (Peterson 2016) and FSP was 1.43 offspring/pair or over twice the level of productivity measured from Tennessee. These results are consistent with the 2005-2015 Breeding Bird Survey population trend data (MN = +0.83%/year [-0.326 - 4.98% CI], TN = -7.99%/year [-

18.21 - 2.96% CI], (Sauer et al. 2017)), suggesting that part of the decline in Golden-winged Warblers in Tennessee is correlated with poor reproduction.

Lesser nest productivity and significantly lesser fledgling survival are accounting for the differences in FSP when compared with Minnesota. The main difference in the predator communities between Tennessee and Minnesota is the general lack of snakes in Minnesota. It is likely that this one difference is responsible for driving the differences in FSP between these two regions since the avian and mammalian predator communities are similar between these regions.

The key vegetation covariates related to nest-site selection, nest survival, juvenile-site selection, and juvenile survival were forbs and *Rubus* spp. within 1 m of point (nest or fledgling daily location), average sapling height, and shrub/sapling vegetation and mature forest within 250 m of point (Table 4.1).

Management for Golden-winged Warbler breeding habitat is challenging because there are potentially different vegetation conditions for attracting breeding pairs in the first place (nest-site selection) and for ensuring nest and fledgling survival (Table 4.1). To attract territory establishment and nesting in the first place there must be open patches of grasses and forbs, mixed with patches of shrubs and saplings in a forested landscape. The range of conditions that are attractive for territory establishment (Table 2.2) set the stage for potential reproduction. Nesting habitat can be created by converting mature forest via timber harvest to adjacent 1-10 ha patches of early successional communities. Fortunately, timber harvest in the NCWMA during the past 10 years has created many such openings of early successional communities. Based on a more detailed study of plant response to management at North Cumberland Wildlife Management Area (Nanney 2016), herbicide and fire treatments can convert these young forests into herbaceous-dominated openings that are more attractive for Golden-winged Warbler territory establishment than timber harvest alone. The real management challenge, however, is to take sites that are suitable for territory establishment and to manage them to ensure greater levels of productivity than what was report in my study. The key to this appears to be having high-quality post-fledgling habitat juxtaposed with nesting habitat, because most of the fledgling mortality occurred near the nest site. Because the amount of mature forest within 250 m of the juvenile locations was positively related but amount of shrub/sapling cover was negatively related to juvenile survival, having nest sites juxtaposed with more mature forest cover and less shrub/sapling cover may lead to increased juvenile survival. Early successional herbaceous-dominated nesting patches surrounded by mature forest may ultimately create this condition.

Ultimately, predator communities, mainly snake populations, are the most likely factor affecting the Golden-winged Warbler population in Tennessee. If snakes are the reason for Tennessee being near the southern limit of their breeding range, a warming climate may actually create more predation pressure during the nesting and post-fledging periods (Blouin-Demers and Weatherhead 2001, Change 2014). To decrease the predation pressure, other studies have suggested transitioning mature forest to 1-10 ha of mixed herbaceous and woody early successional communities to minimize snake predation. Mature forest is not a preferred habitat of black rat snakes or northern copperheads (Durner and Gates 1993, Sutton et al. 2017). Converting mature forest to new patches of early successional communities might create a window for Golden-winged Warblers to nest before snake populations have time to respond. Also, late spring burns, when snakes have recently come out of hibernation and are lethargic, may be particularly effective as they could help control snake populations (Lyon 1978, Erwin and Stasiak 1979).

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APPENDIX

Tables

Table 2.1 - List and description of covariates used in modeling nest survival and for nest site selection of Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

Variable Name	**Description**
Treatment	Treatment type (timber harvest or reclaimed surface mine)
Elev	Elevation (m) of nest
ClutchSize	Number of eggs laid per nest
Litter1m	Visual estimate of percent detritus cover in a 1 m radius circle centered on nest
Grass1m	Visual estimate of percent grass cover in a 1 m radius circle centered on nest
Forbs1m	Visual estimate of percent forb cover in a 1 m radius circle centered on nest
Woody1m	Visual estimate of percent woody vegetation cover in a 1 m radius circle centered on nest
Vine1m	Visual estimate of percent vine cover in a 1 m radius circle centered on nest
Rubus1m	Visual estimate of percent *Rubus* spp. cover in a 1 m radius circle centered on nest
VertCover	Percent vegetation cover above 1.5 m using a densiometer in four cardinal directions
HorizCover	Percent vertical vegetation cover 5 m from nest in four cardinal directions using 20-squared density board
Snags	Number of snags in a 11.3 m radius circle centered on nest
SapHt	Visual estimate of average sapling height in a 11.3 m radius circle centered on nest
ShrubHt	Visual estimate of average shrub height in a 11.3 m radius circle centered on nest
BasalArea	Basal area (m^2/ha) using a 2.5 m^2/ha-factor wedge prism
DFEMature	Distance (m) of nest to mature forest edge using cover type maps

Table 2.1 Continued

Variable Name	**Description**
DFEPole	Distance (m) of nest to pole-sized forest edge using cover type maps
DFEAny	Distance (m) of nest to any forest edge using cover type maps
Herbac250m	Percent herbaceous/grass (<25% shrub-sapling) cover type in 250 m radius circle centered on nest
ShrubSap250m	Percent shrub-sapling (<25% herbaceous) cover type in 250 m radius circle centered on nest
Mature250m	Percent mature forest cover type in 250 m radius circle centered on nest
Pole250m	Percent pole-sized forest cover type in 250 m radius circle centered on nest

Table 2.2 - Vegetation characteristics for nest site and paired random sample 25-50 m from nest for Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

		Nests		**Random**	
Covariate	**N**	**Mean**	**SE**	**Mean**	**SE**
Elev	65	872.4	8.5	867.7	8.5
Litter1m	65	6.7	1.4	13.1	2.3
Grass1m	65	15.3	1.9	18.8	2.7
Forbs1m	65	50.6	3.2	41.1	3.4
Woody1m	65	2.3	0.6	5.9	1.7
Vines1m	65	5.2	1.3	5.9	1.7
Rubus1m	65	18.9	2.6	8.6	1.9
VertCover	65	58.6	3.3	42.7	4.1
HorizCover	47	68.1	2.7	52.7	3.9
Snags	65	1.1	0.2	1.2	0.2
SapHt	65	3.8	0.2	3.7	0.2
ShrubHt	65	0.9	0.2	0.6	0.1
BasalArea	37	21.1	4.5	56.9	10.1
DFEMature	65	34.0	4.4	28.5	5.0
DFEPole	65	60.7	12.7	61.4	12.5
DFEAny	65	11.5	3.4	9.5	3.4
Herbac250m	65	4.7	0.6	2.6	0.4
ShrubSap250m	65	18.4	1.6	12.4	1.7
Mature250m	65	55.0	2.2	70.7	2.5
Pole250m	65	20.6	1.6	13.6	2.0

Table 2.3 –Resource Selection Function results for nest site selection/avoidance for Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

Model	**Selection**	**K**	**AICc**	**ΔAICc**	**AICc Weight**
Mature250m	–	3	166.7	0	0.98
Rubus1m	+	3	176.2	9.5	0.01
VertCover	+	3	177.6	10.9	0
Herbac250m	+	3	179.0	12.3	0
Pole250m	+	3	179.0	12.3	0
ShrubSap250m	+	3	180.1	13.4	0
Litter1m	–	3	180.6	13.9	0
Woody1m	–	3	181.6	14.9	0
Forbs1m	+	3	182.3	15.6	0
Null		2	184.3	17.6	0
ShrubHt	0	3	184.9	18.2	0
Grass1m	0	3	185.3	18.6	0
DFEMature	0	3	185.7	19.0	0
DFEAny	0	3	186.2	19.5	0
Elev	0	3	186.3	19.6	0
Snags	0	3	186.3	19.6	0
SapHt	0	3	186.3	19.6	0
Vines1m	0	3	186.3	19.6	0
DFEPole	0	3	186.4	19.7	0

Table 2.4 - Mean and standard error for nest site characteristics for all nests and successful nests of Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

		Successful Nests			**Unsuccessful Nests**	
Variable	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**
Elev	24	865.9	14.9	41	876.3	10.2
Litter1m	24	5.8	1.4	41	7.2	2.0
Grass1m	24	11.1	2.6	41	17.7	2.6
Forbs1m	24	58.8	4.8	41	45.8	4.0
Woody1m	24	1.4	0.5	41	2.8	0.8
Vines1m	24	5.4	2.4	41	5.1	1.5
Rubus1m	24	16.0	4.3	41	20.5	3.2
VertCover	24	60.1	5.7	41	57.7	4.0
HorizCover	20	68.9	4.3	29	69.5	3.5
Snags	24	1.5	0.4	41	0.9	0.3
SapHt	24	1.0	0.3	41	0.8	0.2
ShrubHt	24	3.7	0.3	41	3.9	0.2
BasalArea	16	8.0	2.8	22	8.8	2.4
DFEMature	24	38.4	6.8	41	31.5	5.7
DFEPole	24	56.8	23.7	41	63.0	14.6
DFEAny	24	10.1	5.7	41	12.4	4.2
Herb250	24	4.2	0.9	41	5.0	0.8
ShrubSap250	24	17.8	2.7	41	18.8	2.0
Mature250	24	57.1	3.4	41	53.7	2.9
Pole250	24	19.6	2.6	41	21.2	2.1

Table 2.5 – Model selection results in program MARK for the effects of temporal, site, and vegetation covariates on daily nest survival rates for Golden-winged Warbler (Vermivora chrysoptera) in the North Cumberland Wildlife Management Area, Tennessee, 2013-2015.

Model Name	K	AICc	ΔAICc	AICc Weight
$S_{(2Weeks + Forbs1m)}$	5	241.9	0.0	0.27
$S_{(2Weeks + Rubus1m)}$	5	244.7	2.8	0.07
$S_{(2Weeks)}$	4	244.9	3.0	0.06
$S_{(2Weeks + Snags)}$	5	245.5	3.6	0.04
$S_{(2Weeks + Grass1m)}$	5	245.6	3.7	0.04
$S_{(2Weeks + DFEMature)}$	5	246.2	4.3	0.03
$S_{(1Week)}$	8	246.2	4.3	0.03
$S_{(.)}$	1	246.4	4.5	0.03
$S_{(2Weeks + Pole250m)}$	5	246.6	4.6	0.03
$S_{(2Weeks + Woody1m)}$	5	246.7	4.8	0.03
$S_{(2Weeks + Stand)}$	5	246.7	4.8	0.02
$S_{(2Weeks + ClutchSize)}$	5	246.7	4.8	0.02
$S_{(2Weeks + VertCover)}$	5	246.7	4.8	0.02
$S_{(2Weeks + ShrubHt)}$	5	246.7	4.8	0.02
$S_{(2Weeks + DFEAny)}$	5	246.8	4.9	0.02
$S_{(2Weeks + Vine1m)}$	5	246.8	4.9	0.02
$S_{(2Weeks + Mature250m)}$	5	246.8	4.9	0.02
$S_{(2Weeks + Herbac250m)}$	5	246.9	4.9	0.02
$S_{(2Weeks + HorizCover)}$	5	246.9	5.0	0.02
$S_{(2Weeks + Litter1m)}$	5	246.9	5.0	0.02
$S_{(2Weeks + SapHt)}$	5	246.9	5.0	0.02
$S_{(2Weeks + DFEPole)}$	5	246.9	5.0	0.02
$S_{(2Weeks + Elev)}$	5	246.9	5.0	0.02
$S_{(2Weeks + BasalArea)}$	5	246.9	5.0	0.02
$S_{(2Weeks + ShrubSap250m)}$	5	246.9	5.0	0.02
$S_{(4 Weeks)}$	2	247.1	5.2	0.02
$S_{(Year)}$	3	249.6	7.7	0.01
$S_{(t)}$	56	318.6	76.7	0.00

Table 2.5 Continued

Model Name	**K**	**AICc**	**ΔAICc**	**AICc Weight**
$S_{(T)}$	1	381.3	139.4	0.00
$S_{(T2)}$	1	576.4	334.5	0.00
$S_{(Year*Daily)}$	168	586.9	345.0	0.00

K is the number of parameters modeled, AICc is Akaike's Information Criterion for small samples, and ΔAICc is the scaled value of AICc. $S_{(.)}$ is the constant survival model. $S_{(Year)}$ is an annual grouping. $S_{(1Week,\ 2Weeks,\ 4Weeks)}$ are temporal groupings based on 1-week, 2-week, or 4-week intervals.

Table 3.1 - List and description of covariates collected during each time a juvenile was tracked (usually daily) and used in modeling post-fledging survival of Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

Variable Name	**Description**
Treatment	Treatment type (timber harvest or reclaimed surface mine)
FledgeDate	Fledge date based on the earliest known fledge date during the project (1=May 29)
NumFledge	Number of nestlings that survived the nesting period for each successful nest (including the radio-marked juvenile)
Precip	Average rainfall (cm) during the first 3 days after fledging
TempH	Average high temperature (°F) during the first 3 days after fledging
TempL	Average low temperature (°F) during the first 3 days after fledging
GroundDist	Visual estimate (m) of the fledglings distance above ground
Litter1m	Visual estimate of percent detritus cover in a 1 m radius circle centered on the point the fledgling was first observed
Grass1m	Visual estimate of percent grass cover in a 1 m radius circle centered on the point the fledgling was first observed
Forbs1m	Visual estimate of percent forb cover in a 1 m radius circle centered on the point the fledgling was first observed
Woody1m	Visual estimate of percent woody vegetation cover in a 1 m radius circle centered on the point the fledgling was first observed
Vine1m	Visual estimate of percent vine cover in a 1 m radius circle centered on the point the fledgling was first observed
Rubus1m	Visual estimate of percent *Rubus* spp. cover in a 1 m radius circle centered on the point the fledgling was first observed
VertCover	Percent vegetation cover above 1.5 m using a densiometer in four cardinal directions, centered on the point the fledgling was first observed
HorizCover	Percent vertical vegetation cover 5 m from the point the fledgling was first observed in four cardinal directions using a 20-squared density board

Table 3.1 Continued

Variable Name	**Description**
Snags	Number of snags in a 11.3 m radius circle centered on the point the fledgling was first observed
SapHt	Visual estimate of average sapling height in a 11.3 m radius circle centered on the point the fledgling was first observed
ShrubHt	Visual estimate of average shrub height in a 11.3 m radius circle centered on the point the fledgling was first observed
BasalArea	Basal area (m^2/ha) using a 2.5 m^2/ha-factor wedge prism centered on the point the fledgling was first observed
DFEMature	Distance (m) of fledgling to mature forest edge using cover type maps
DFEPole	Distance (m) of fledgling to pole-sized forest edge using cover type maps
DFEAny	Distance (m) of fledgling to any forest edge using cover type maps
Herbac250m	Percent herbaceous/grass (<25% shrub-sapling) cover type in 250 m radius circle centered on the point the fledgling was first observed
ShrubSap250m	Percent shrub-sapling (<25% herbaceous) cover type in 250 m radius circle centered on the point the fledgling was first observed
Mature250m	Percent mature forest cover type in 250 m radius circle centered on the point the fledgling was first observed
Pole250m	Percent pole-sized forest cover type in 250 m radius circle centered on the point the fledgling was first observed

Table 3.2 – Daily distance traveled for juvenile Golden-winged Warblers, North Cumberland Wildlife Management Area, Tennessee, 2013-2015.

	N	**Max**	**Mean**	**SE**	**Max2**	**Mean2**
Day 1	38	31.5	9.5	1.2	31.5	9.5
Day 2	30	64.4	18.2	2.9	64.4	18.2
Day 3	23	127.5	32.7	6.6	127.5	32.7
Day 4	18	172.6	37.8	9.4	172.6	37.8
Day 5	16	95.3	38.7	7.4	172.6	38.7
Day 6	17	137.6	46.6	11.3	172.6	46.6
Day 7	15	125.4	57.2	8.3	172.6	57.2
Day 8	14	167.8	71.4	13.8	172.6	71.4
Day 9	14	95.3	43.1	8.3	172.6	71.4
Day 10	13	143.6	47.0	11.8	172.6	71.4
Day 11	13	163.3	57.3	15.5	172.6	71.4
Day 12	16	371.7	63.3	21.4	371.7	71.4
Day 13	12	144.6	63.9	14.0	371.7	71.4
Day 14	10	411.5	119.7	50.5	411.5	119.7
Day 15	12	334.7	105.3	33.8	411.5	119.7
Day 16	11	81.4	36.0	8.6	411.5	119.7
Day 17	11	64.6	30.5	6.0	411.5	119.7
Day 18	8	94.5	31.6	10.5	411.5	119.7
Day 19	4	87.2	24.7	20.9	411.5	119.7
Day 20	6	127.9	42.4	18.0	411.5	119.7
Day 21	8	186.7	59.1	22.2	411.5	119.7
Day 22	7	121.7	59.4	15.0	411.5	119.7
Day 23	6	167.2	56.4	22.5	411.5	119.7
Day 24	5	191.5	86.3	35.9	411.5	119.7
Day 25	4	153.6	63.8	32.5	411.5	119.7

Max is the maximum distance traveled by all juveniles of a certain age and Max2 is the maxium distance traveled of juveniles of a certain age, including all previous distances of younger ages. Mean is the average distance traveled of all juveniles of a certain age (plus standard deviation and standard error) and Mean2 is the average distance traveled of any age class up to a certain age.

Table 3.3 – Vegetation type selection during days 1-3 and 4-25 post-fledging for Golden-winged Warblers (Vermivora chrysoptera) in North Cumberland Wildlife Management Area, Tennessee, 2013-2015.

Days 1-3					
Model	**Selection**	**K**	**AICc**	**ΔAICc**	**Weight**
Null		2	248.1	0	0.39
Herbac250	0	3	249.7	1.7	0.17
Mature250	0	3	249.8	1.8	0.16
ShrubSap250	0	3	250.0	2.0	0.14
Pole250	0	3	250.1	2.0	0.14
Days 4-25					
Model		**K**	**AICc**	**ΔAICc**	**Weight**
ShrubSap250	+	3	735.7	0	1
Mature250	–	3	746.7	11.0	0
Herbac250	–	3	750.2	14.5	0
Null		2	755.4	19.7	0
Pole250		3	757.2	21.5	0

Table 3.4 - Mean and standard error for vegetation characteristics for first three days post-fledging for Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

Covariate	**N**	**Mean**	**SE**
GroundDist	81	0.5	0.1
Litter1m	80	14.0	2.2
Grass1m	78	5.8	1.7
Forbs1m	80	34.1	3.4
Woody1m	79	10.6	2.4
Vines1m	79	11.1	2.1
Rubus1m	79	21.9	3.3
VertCover	77	0.5	0.1
HorizCover	65	71.1	2.9
Snags	80	1.1	0.2
SapHt	80	4.1	0.2
ShrubHt	80	0.8	0.1
BasalArea	76	18.4	2.8
Grass250m	88	0.04	0.01
Mature250m	88	0.59	0.02
Pole250m	88	0.19	0.01
Shrub250m	88	0.16	0.01
DFEAny	88	3.8	3.4
DFEMature	88	30.7	3.7
DFEPole	88	64.7	12.1

Table 3.5 - The number and percent of Golden-winged Warbler (Vermivora chrysoptera) fledgling deaths by 3 different predator groupings (small mammals, snakes, and avian predators) and by exposure. North Cumberland Wildlife Management Area, Tennessee, 2013-2015

	2013		2014		2015		Total	
Snake	5	100%	9	50%	2	25%	16	52%
Sm Mammal	0	0	4	22%	4	50%	8	26%
Exposure	0	0	2	11%	2	25%	4	13%
Avian	0	0	3	17%	0	0%	3	9%
Total	5		18		8		31	

Table 3.6 - Model selection results in program MARK for the effects of temporal, site, weather, and habitat covariates on daily juvenile survival rates for Golden-winged Warbler (Vermivora chrysoptera) in the North Cumberland Wildlife Management Area, Tennessee, 2013-2015.

Model	**K**	**AICc**	**ΔAICc**	**AICc Weights**
$S_{\text{(Days 1-3, 4-25 + ShrubSap250m [Days 1-3])}}$	3	180.5	0.0	0.48
$S_{\text{(Days 1-3, 4-25 + ShrubSap250m)}}$	3	180.9	0.5	0.38
$S_{\text{(Days 1-3, 4-25 + SapHt [Days 1-3])}}$	3	186.6	6.1	0.02
$S_{\text{(Days 1-3, 4-25 + SapHt)}}$	3	186.8	6.3	0.02
$S_{\text{(Days 1-3, 4-25 + Mature250m [Days 1-3])}}$	3	188.4	8.0	0.01
$S_{\text{(Days 1-3, 4-25 + Mature250m)}}$	3	188.7	8.2	0.01
$S_{\text{(Days 1-3, 4-25 + DFEAny)}}$	3	188.9	8.4	0.01
$S_{\text{(Days 1-3, 4-25 + Stand)}}$	3	189.1	8.6	0.01
$S_{\text{(Days 1-3, 4-25 + DFEPole)}}$	3	189.2	8.7	0.01
$S_{\text{(Days 1-3, 4-25 + ShrubHt)}}$	3	189.7	9.2	0.00
$S_{\text{(Days 1-3, 4-25 + Grass1m)}}$	3	190.0	9.6	0.00
$S_{\text{(Days 1-3, 4-25)}}$	2	190.2	9.7	0.00
$S_{\text{(Days 1-3, 4-25 + Rubus1m)}}$	3	190.2	9.7	0.00
$S_{\text{(Days 1-3, 4-25 + TempL)}}$	3	190.4	10.0	0.00
$S_{\text{(Days 1-3, 4-6, 7-25)}}$	3	190.4	10.0	0.00
$S_{\text{(Days 1-3, 4, 5-25)}}$	3	190.9	10.4	0.00
$S_{\text{(Days 1-3, 4-25 + Forbs1m)}}$	3	191.0	10.5	0.00
$S_{\text{(Days 1-3, 4-25 + BasalArea)}}$	3	191.1	10.6	0.00
$S_{\text{(Days 1-3, 4-7, 8-25)}}$	3	191.1	10.7	0.00
$S_{\text{(Days 1-3, 4-25 + HorizCover)}}$	3	191.5	11.0	0.00
$S_{\text{(Days 1-3, 4-25 + Precip)}}$	3	191.5	11.1	0.00
$S_{\text{(Days 1-3, 4-25 + Grass250m)}}$	3	191.7	11.2	0.00
$S_{\text{(Days 1-3, 4-25 + Pole250m)}}$	3	191.8	11.4	0.00
$S_{\text{(Days 1-3, 4-25 + Woody1m)}}$	3	191.8	11.4	0.00
$S_{\text{(Days 1-3, 4-25 + Snags)}}$	3	191.8	11.4	0.00
$S_{\text{(Days 1-3, 4-5, 6-25)}}$	3	191.8	11.4	0.00
$S_{\text{(Days 1-3, 4-25 + Litter1m)}}$	3	192.0	11.6	0.00
$S_{\text{(Days 1-3, 4-25 + NumFledge)}}$	3	192.1	11.6	0.00

Table 3.6 Continued

Model	**K**	**AICc**	**ΔAICc**	**AICc Weights**
$S_{(Days\ 1\text{-}3,\ 4\text{-}25\ +\ Vine1m)}$	3	192.2	11.7	0.00
$S_{(Days\ 1\text{-}3,\ 4\text{-}25\ +\ GroundDist)}$	3	192.2	11.7	0.00
$S_{(Days\ 1\text{-}3,\ 4\text{-}25\ +\ TempH)}$	3	192.2	11.7	0.00
$S_{(Days\ 1\text{-}3,\ 4\text{-}25\ +\ FledgeDate)}$	3	192.2	11.8	0.00
$S_{(Days\ 1\text{-}3,\ 4\text{-}25\ +\ DFEMature)}$	3	192.2	11.8	0.00
$S_{(Days\ 1\text{-}2,\ 3\text{-}4,\ 5\text{-}25)}$	3	193.7	13.3	0.00
$S_{(Days1\text{-}4,5\text{-}25)}$	2	194.1	13.7	0.00
$S_{(Days\ 1,2,3,\ 4\text{-}25)}$	4	194.2	13.8	0.00
$S_{(Days\ 1\text{-}5,\ 6\text{-}25)}$	2	203.2	22.8	0.00
$S_{(Days\ 1\text{-}5,\ 6\text{-}10,\ 11\text{-}15,\ 16\text{-}20,\ 21\text{-}25)}$	5	207.6	27.1	0.00
$S_{(Days\ -\ Trend)}$	1	208.0	27.5	0.00
$S_{(Days)}$	25	226.9	46.5	0.00
$S_{(Year)}$	3	248.4	68.0	0.00
$S_{(.)}$	1	249.0	68.6	0.00
$S_{(Days\ -\ Quadratic)}$	1	269.9	89.5	0.00
$S_{(Year*Days)}$	75	346.1	165.7	0.00

K is the number of parameters modeled, AICc is Akaike's Information Criterion for small samples, and ΔAICc is the scaled value of AICc. $S_{(.)}$ is the constant survival model. $S_{(Year)}$ is an annual grouping. $S_{(Days\ X\text{-}X)}$ are temporal groupings based on days after fledging. Shrub-sapling land cover at 250m had a negative relationship, while mature forest land cover at 250m and average sapling height at 11.3m had a positive relationship.

Table 4.1 – The 5 key vegetation characteristics related to nest-site selection, nest survival, juvenile- site selection, and juvenile survival of Golden-winged Warblers (Vermivora chrysoptera), North Cumberland Wildlife Management Area, Tennessee, 2013-2015

	Nest Selec.	Nest Surv.	Juv. Selec. 1-3	Juv. Selec. 4-25	Juv. Surv.
Forbs1m	0	+ +	0	0	0
Rubus1m	+	−	0	0	0
SapHt	0	0	0	0	+
ShrubSap250	0	0	0	+ +	− −
Mature250	− −	0	0	−	+

Figures

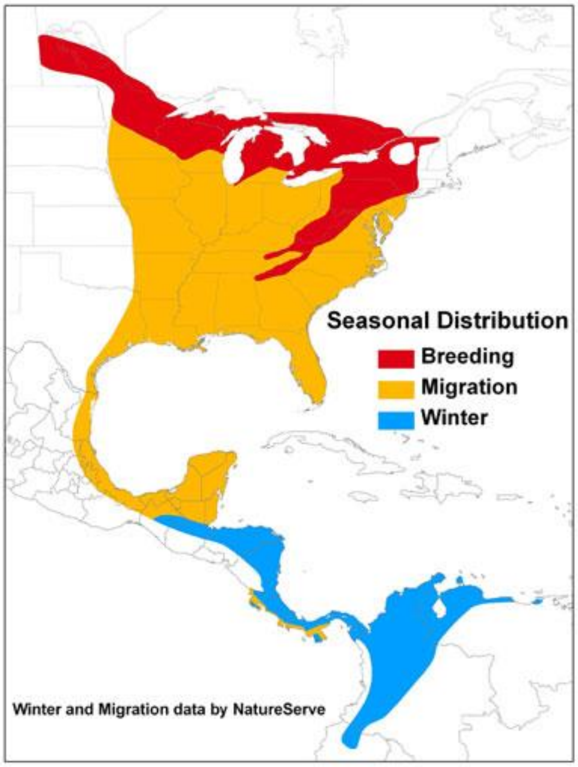


Figure 2.1 - Golden-winged Warbler (Vermivora chrysoptera) breeding distribution (Golden-winged Warbler Working Group 2009)

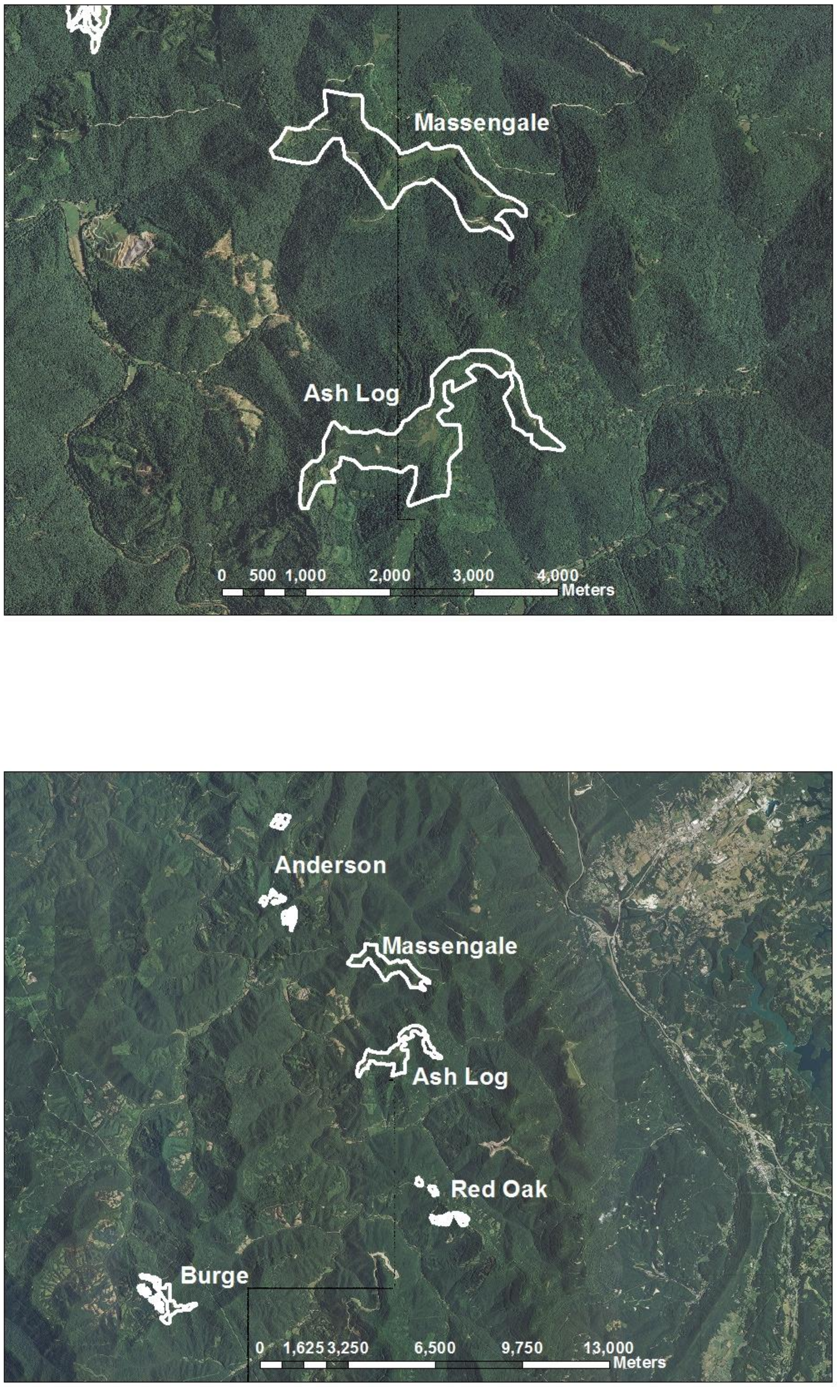
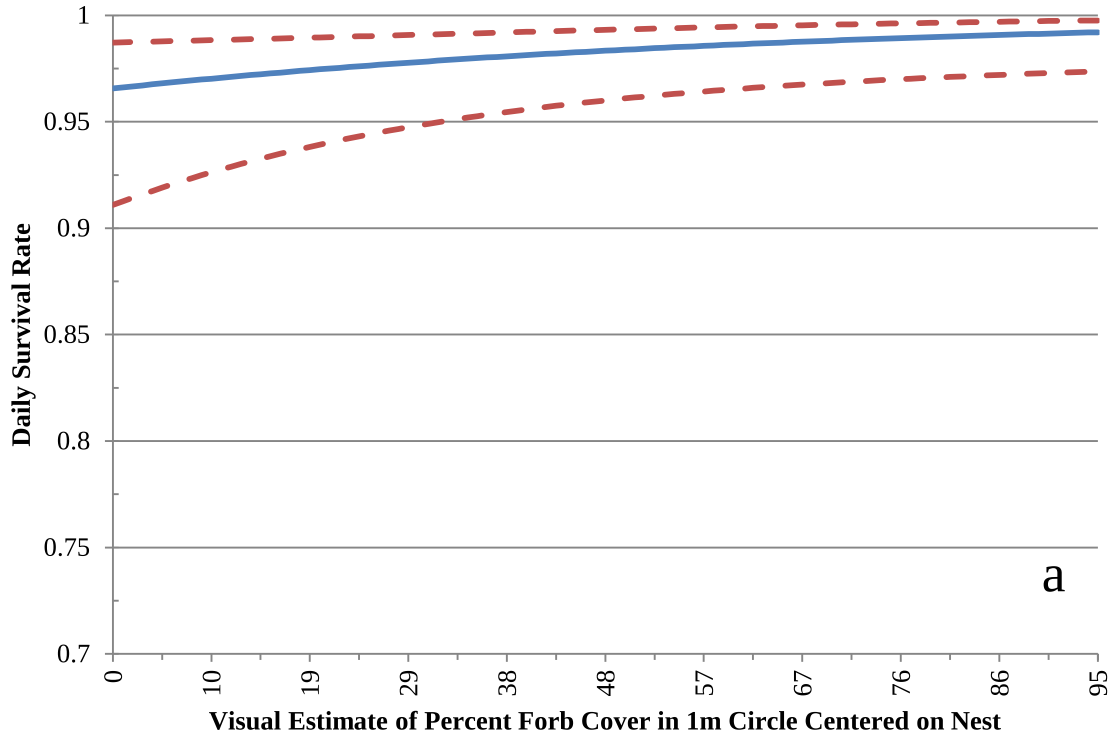


Figure 2.2 – Location of Golden-winged Warbler (Vermivora chrysoptera) study sites, North Cumberland Wildlife Management Area, Tennessee, 2013-2015.

Figure 2.3 – Golden-winged Warbler (Vermivora chrysoptera) nest daily survival rate (DSR) as a function of percent forb cover in 1 m circle around nest during days 1-14 (a), 15-28 (b), 29-42 (c) and 42-56 (d) since first nest initiation of study (May 5), North Cumberland Wildlife Management Area, Tennessee, 2013-2015



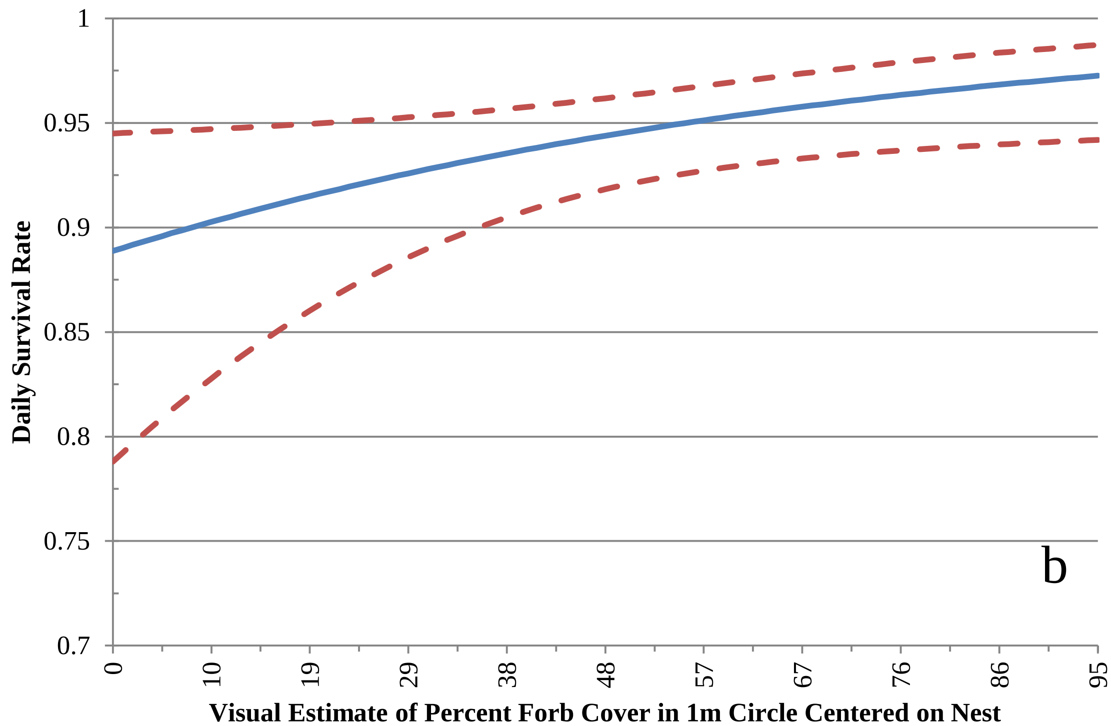
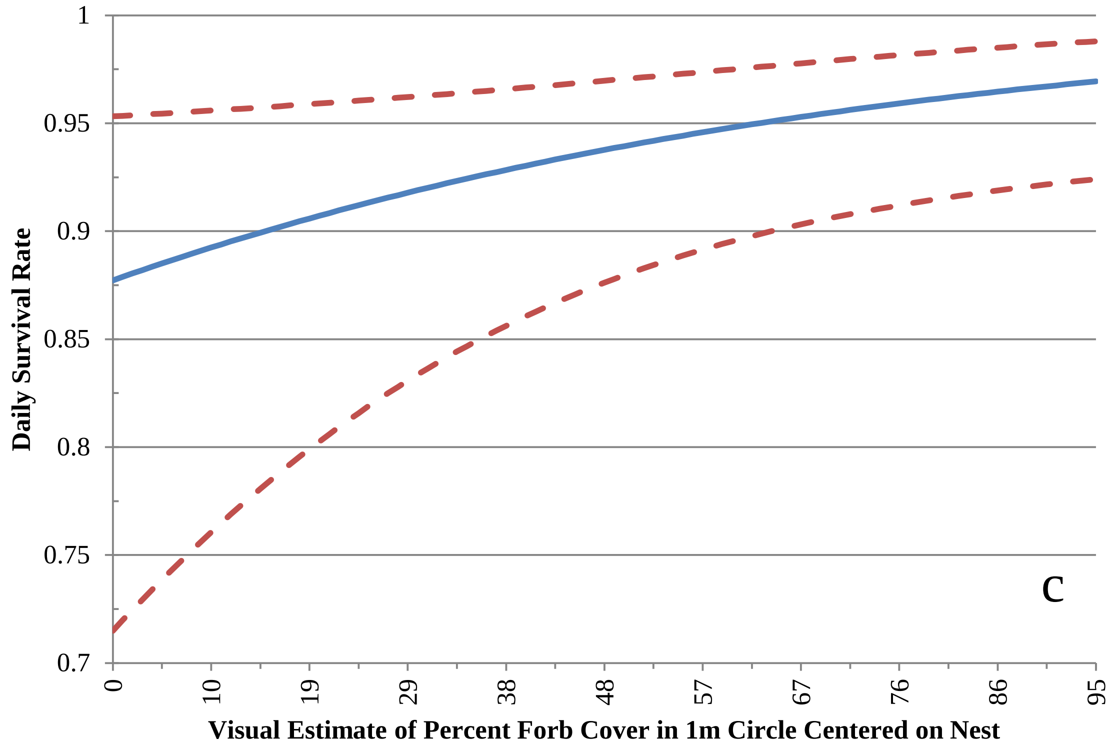


Figure 2.3 Continued



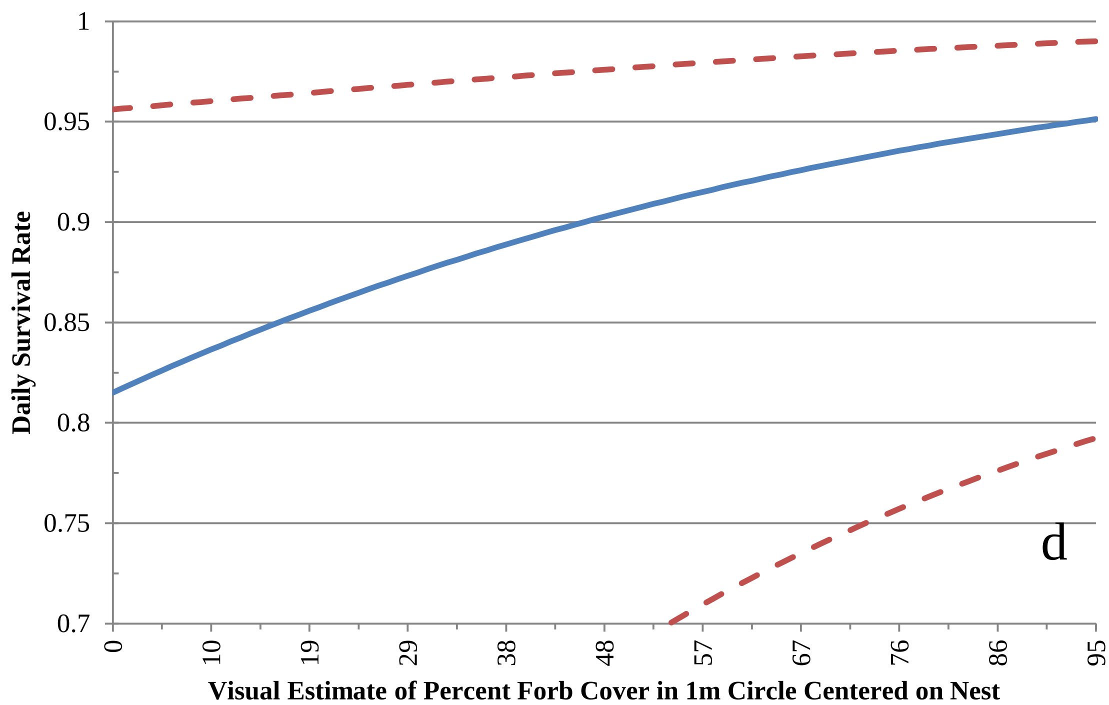
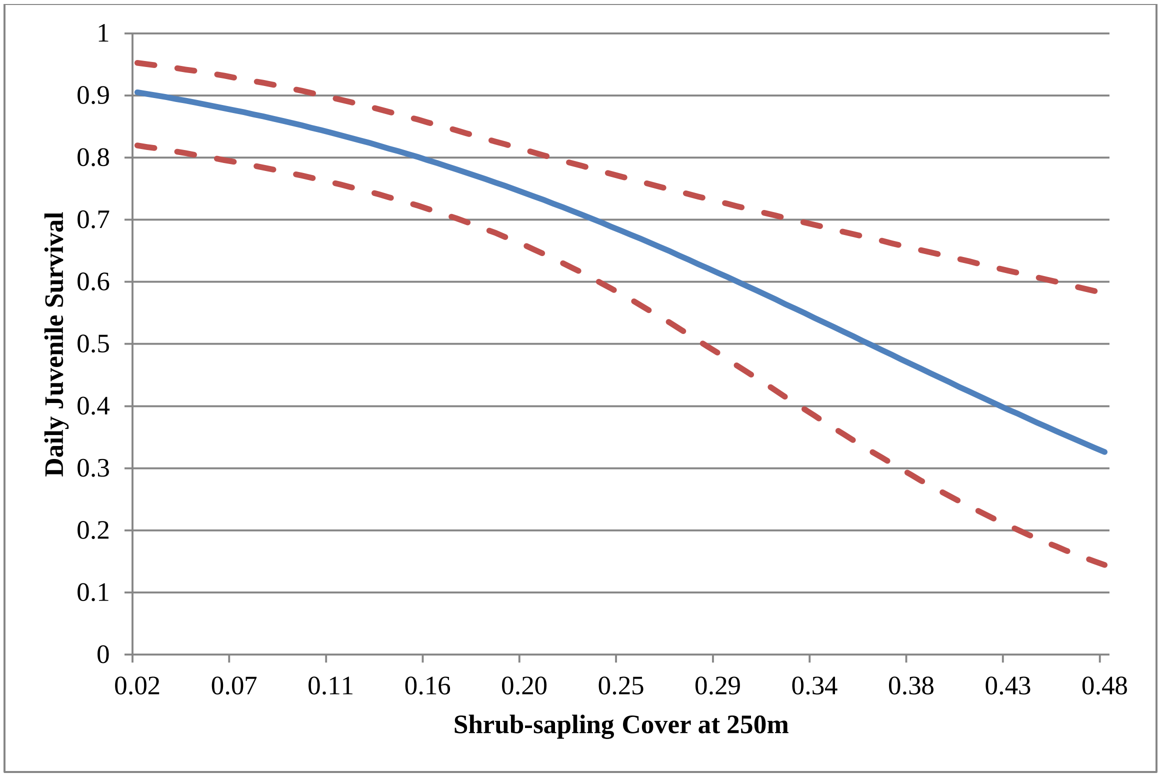


Figure 2.3 Continued

Figure 3.1 - A 7 day old nestling Golden-winged Warbler with a numbered USGS band and a 0.41 g radio-transmitter (left photo). Nestlings were placed back in the nest after banding and had 1-3 days to adjust to the radio-transmitter before fledging. A young fledgling Golden-winged Warbler (2 days post-fledging) with a 0.41 g radio-transmitter (right photo).

Figure 3.2 - Juvenile Golden-winged Warbler daily survival rate (solid line) and upper and lower 95% confidence intervals (dashed lines) over the first day in relation to shrub-sapling land cover in a 250m radius (top), mature forest land cover in a 250m radius (middle), and average sapling height (bottom).



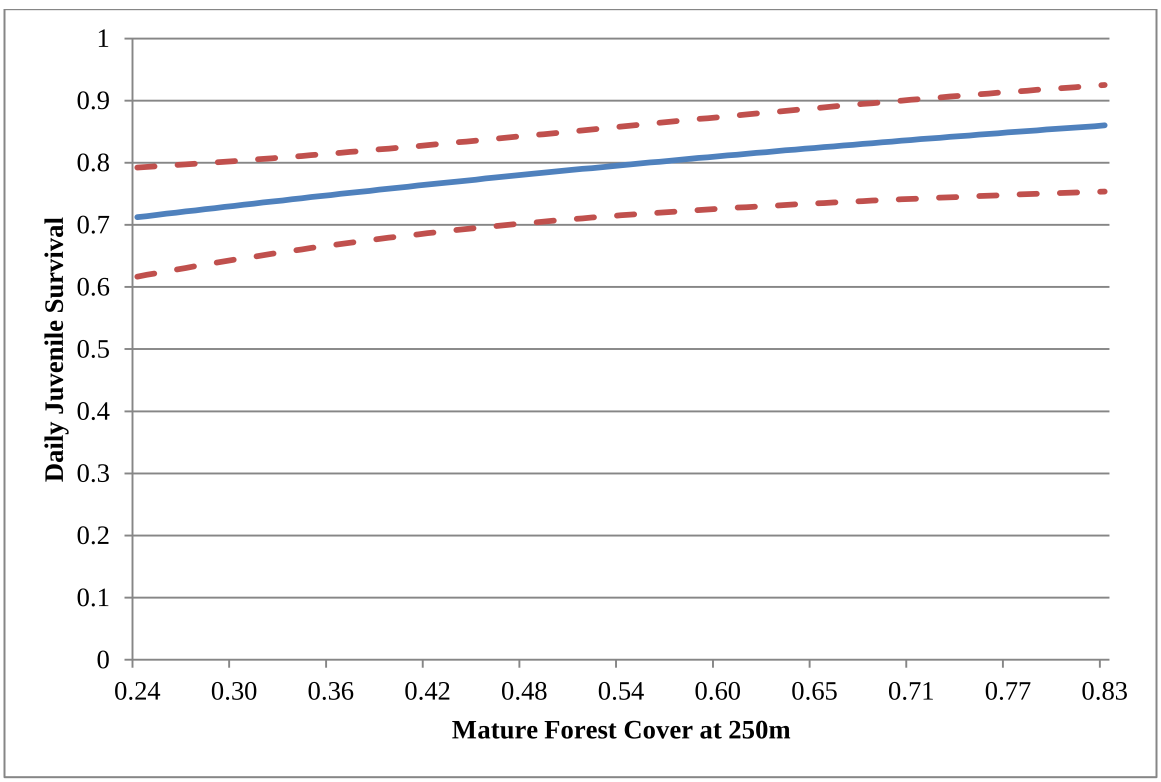


Figure 3.2 Continued

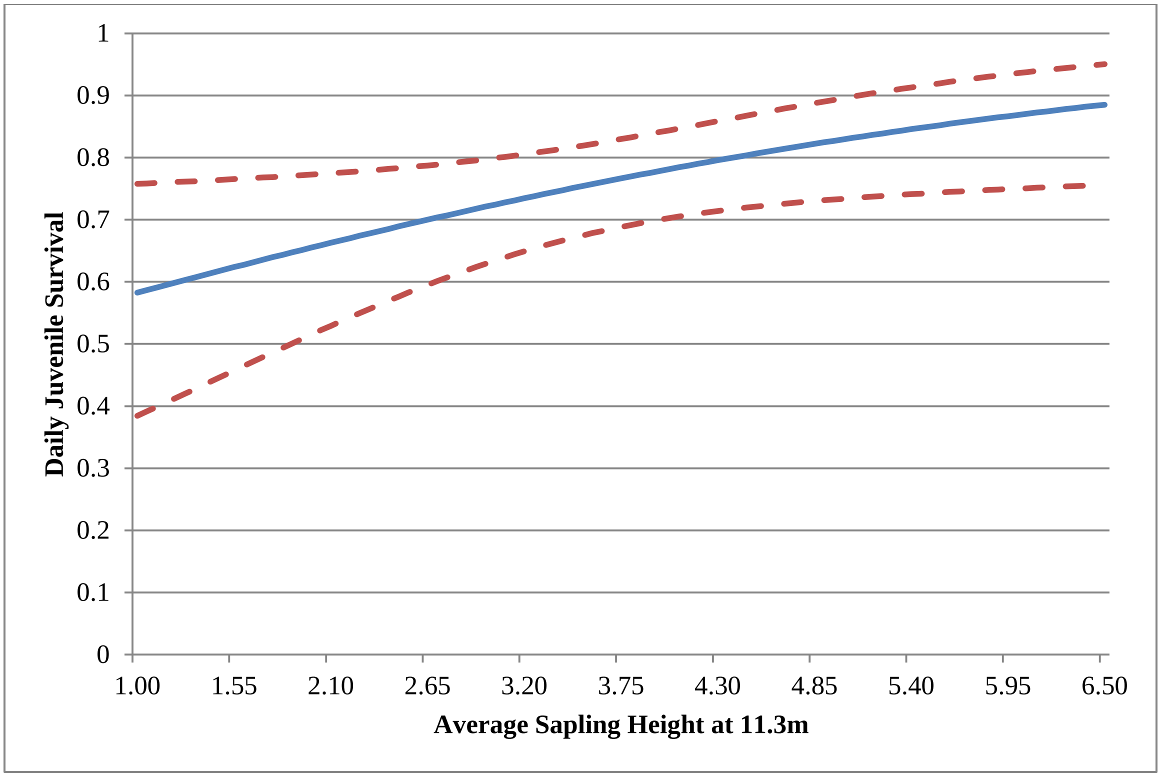


Figure 3.2 Continued

VITA

Justin Lehman, son of Richard and Joyce Lehman, was born in Rochester, MN on June 9, 1989. He graduated from John Marshall High School in 2007, and earned his Bachelor of Science Degree in Wildlife Biology at the University of Minnesota in May 2010. In April 2013 he entered graduate school at the University of Tennessee seeking a master's degree in Wildlife and Fisheries Science. Under the advisement of his major professor, Dr. David A. Buehler, Justin studied the population of Golden-winged Warblers located at North Cumberland Wildlife Management Area for his thesis research detailed in this document. Since first pursuing his bachelor's degree, he has gained invaluable experience studying populations of wild birds in a diverse array of ecosystems, including young aspen and jack pine forests in Minnesota, floodplains in Illinois and Indiana, forests fragmented by lava in Hawaii, managed wetlands in Missouri, and reclaimed surface mines in Tennessee.