Monitoring and Evaluating Golden-winged Warbler Use of Breeding Habitat Created by the Natural Resources Conservation Service Practices

A Conservation Effects Assessment Project (CEAP)

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Contents

STUDY OVERVIEW

Report Layout

This report describes each aspect of the Conservation Effects Assessment Project (CEAP) research conducted by Golden-winged Warbler Working Group partners in the Appalachian Mountains over the past three years (i.e., 2012 - 2014). The report begins with a background discussion, brief overview of the CEAP project, and an explicit summary of the objectives of this study. These introductory sections not only inform the reader about this project as a whole, but outline the importance of this work and conservation efforts for the Golden-winged Warbler, in general. The sections that follow are the finer components of this CEAP study that are each laid out in detail. Each aspect of study is subdivided into independent sections, each complete with a short **summary** presenting background and rationale, **methods** describing how the work was conducted, and **results** which describes the important findings of each component of study. Within each component of this study (n = 9 components), all figures and tables are shown (referenced within the text). Finally, an overall discussion of this study is presented in the "Project Discussion" section at the conclusion of this document. All citations for literature referenced within this document are listed at the end of this report. For more details regarding navigation of this document, see the Table of Contents (page 2).

Project Summary

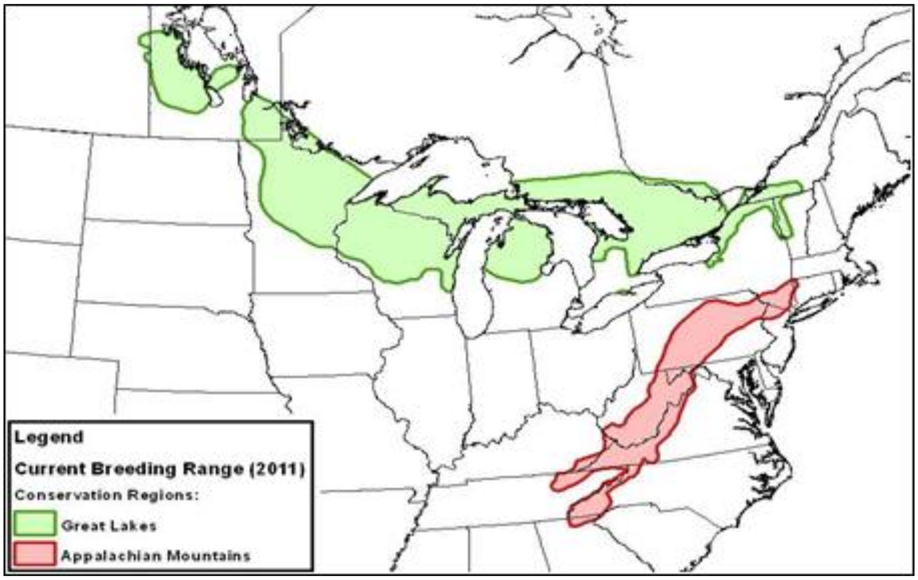
The Golden-winged Warbler (*Vermivora chrysoptera*) is a Neotropical migrant bird that breeds in young forest habitats and is experiencing steep population declines throughout the Appalachian Mountains breeding range (8.5% year^{-1} [95% CI 7.1 – 9.8], Sauer et al. 2014). One cause of population decline is loss of breeding habitat, and conservation of this species requires active habitat management. In this study, we monitored and evaluated Golden-winged Warbler response to habitat management using conservation practices suggested by the Natural Resource Conservation Service's (NRCS) *Working lands For Wildlife (WLFW): Golden-winged Warbler Habitat Initiative* in the southern and central Appalachian states. We examined density, nest success, juvenile survival and movements, adult condition and survival, and habitat selected by Golden-winged Warblers at study sites placed into five NRCS management systems groupings: timber harvest, prescribed fire- young forest, prescribed fire- old field, grazing management, and old field management. In 2012-2014, we conducted 864 point count surveys, banded 800 birds, mapped 739 territories, and monitored nesting success of 337 Golden-winged, Blue-winged (*Vermivora cyanoptera*), and hybrid Warbler nests across 95 sites in North Carolina, Pennsylvania, Tennessee, and West Virginia. Further, we analyzed the plumage of 135 individual males, radio-tracked 7 adult males on territory, and radio-tracked 89 fledglings. We also collected vegetation data to characterize each site (n = 2,347 vegetation plots), Golden-winged Warbler nest plot (n = 317), and associated random plot (n = 317).

Analyses from 2012-2014 indicated that many of the measured metrics (e.g., density and nesting survival) did not differ among the 5 management systems, thus indicating similar capabilities to support breeding Golden-winged Warblers. At the same time, this report identifies vegetation characteristics that can be manipulated to improve habitat within management systems. For example, across management systems, increased attention to attaining preferred levels of grass cover (5-25%/1-m radius) from the Golden-winged Warbler Breeding Season Conservation Plan (Roth et al 2012) may result in increased availability of nest sites. Furthermore across management systems, increased attention to attaining levels of *Rubus* spp. cover (13-48%/1-m radius) consistent with high-quality nest sites may result in increased nest survival. On average, managed sites supported 1.51 males/10 ha, where males had a 0.58 (± 0.04) minimum annual survival rate and produced 0.51 (± 0.05) fledglings/ha. Predicted Golden-winged Warbler density from point counts increased with elevation at southern sites but decreased with elevation at northern sites. Telemetry data on juvenile and adult Golden-winged Warbler movements and habitat use demonstrated that birds use multiple stages of succession (i.e., early, mid, and late successional forest) during the breeding and post-breeding periods. Additionally, promoting low-growing shrubs may increase juvenile survival by providing protection from predators. Data on male plumage ornamentation demonstrated that birds breeding in southern sites are less ornamented and of lighter mass compared to the other regions, and this was unlikely to be related to management systems. In addition, we documented high numbers of bird species (i.e., 126 species) using early successional habitat, and 34% of these are experiencing significant population declines (Sauer et al. 2104, Cooper and Rau 2014). Collectively, our study reinforces that a highly forested landscape with multiple age-classes of forests is critical for breeding and post-breeding Golden-winged Warblers.

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 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 1). It nests in abandoned farmlands, shrublands, scrub barrens, beaver glades, swamp forests with partial canopies and other areas maintained by fire, timber harvesting, and utility rights-of-ways management (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 before effective conservation measures can take place. Precipitous declines in Golden-winged Warbler populations have occurred in the Appalachians, including Tennessee (8.0% yr^{-1} [95% CI 4.8 – 11.8]), Pennsylvania (7.3% yr^{-1} [5.4 – 9.3]), West Virginia (8.8% yr^{-1}, [6.6 – 10.6]), and North Carolina (10.8% yr^{-1} [5.3 – 16.2]; Sauer et al. 2014). Several factors may 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 (see Appendix 1 for all scientific names), and Brown-headed Cowbird parasitism (Buehler et al. 2007). Of these factors, loss of quality breeding habitat (young forest embedded in extensively forested landscape) is thought to be the most significant (Buehler et al. 2007).

Figure 1. Revised 2011 Breeding distribution of Golden-winged Warbler. Map created by the Golden-winged Warbler Working Group and is taken from the 2012 Golden-winged Warbler Conservation Plan.



In 2010, the Golden-winged Warbler was petitioned to be listed for protection under the Federal Endangered Species Act. The U.S. Fish and Wildlife Service reviewed the petition and determined that it had substantial merit and initiated a thorough review of the species' status. Thus, the implementation of management prescriptions that create or maintain Golden-winged Warbler breeding habitat 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. While efforts to create and enhance Golden-winged Warbler breeding habitat on public lands in the Appalachian Mountains are underway (i.e., PA, TN, WV, VA, NC), t the fate of this species will likely depend on our ability to manage for high quality habitat on private lands. In 2012, the USDA-Natural Resource Conservation Service (NRCS) and the U.S. Fish and Wildlife Service initiated a collaborative effort entitled Working Lands for Wildlife to create habitat on private lands for 7 imperiled wildlife species including the Golden-winged Warbler.

Herein, we report our results from the first three years of monitoring Golden-winged Warbler response to habitat created or maintained via the NRCS's conservation practices intended to benefit this species in the southern and central Appalachian states. For the purpose of this study, we have grouped these habitats by management systems (e.g., grazing management) which are defined by the primary conservation practice and facilitating practices (see pages 9 – 11 for descriptions of the management systems). Monitoring the response of this species to habitat created via various NRCS management systems will allow for 1) the evaluation of guideline effectiveness, and 2) provide data needed to make necessary modifications to existing practice guidelines via adaptive management to improve program effectiveness.

The Golden-winged Warbler is not the only scrub-shrub dependent bird species considered to be in conservation jeopardy. Other species belonging to this guild that are considered to be at serious risk include Eastern Whip-poor-will, Prairie Warbler, Eastern Towhee, Field Sparrow, Northern Bobwhite, and American Woodcock (North American Bird Conservation Initiative 2009). Moreover, recent analyses of 46 years of Breeding Bird Survey data showed that over half (59%) of shrubland-nesting species in the eastern U.S. are experiencing significant declines (Sauer et al. 2014). Additionally, many mature forest nesting songbirds and their offspring use shrubland and young forest habitat during post-fledging and migration (Marshall et al. 2003, Vitz and Rodewald 2007, Streby et al. 2011). Management of Golden-winged Warbler will thus benefit many other associated avian species (Roth et al. 2012).

Project Goals

The goal of this project is to examine the demographic response of Golden-winged Warblers (GWWA) to habitat management guided by a suite of NRCS conservation practices across portions of the species' Appalachian Mountains breeding range.

This project collects basic demographic and habitat use data on breeding Golden-winged Warblers among sites where various NRCS conservation practices have been implemented to create Golden-winged Warbler breeding habitat. Our monitoring protocol incorporates a 2-phase approach. First, we intensively monitor Golden-winged Warbler demographics at local scales to determine the potential for NRCS conservation practices to produce source habitat (Years 1-3). The second phase will allow for the collection of basic demographic data (GWWA territory density) to gauge population response across the majority of private lands enrolled in the NRCS-WLFW program or similar initiatives (Years 4-6). Ultimately, our monitoring protocol will provide data to reliably evaluate the Initiative's success. Additionally, such information will allow NRCS staff and their partners to modify conservation practice guidelines using a science-based adaptive management framework.

STUDY SITE AND MANAGEMENT SYSTEMS

Study Sites

Summary

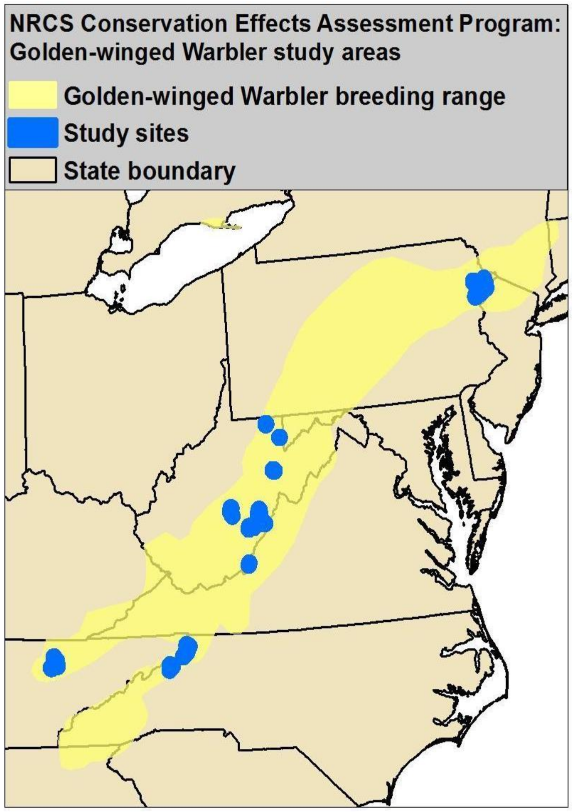
We collected Golden-winged Warbler demographic and habitat use data across 95 study sites distributed among several study areas in North Carolina, Pennsylvania, Tennessee, and West Virginia (Figure 2, Appendix 2). Each study area encompassed known areas of consistently high concentrations of breeding Golden-winged Warblers.

Sites/states

The North Carolina study sites (n = 33) were situated in two globally significant Important Bird Areas of the Blue Ridge Mountains Physiographic region (for more details on these areas see http://ncaudubonblog.org/iba/mountains/?iba=m). The first was the northwest mountains of the state known as the Amphibolite peaks and the second was associated with the Roan Mountain massif south of the Amphibolites. The Amphibolites included sites in Watauga and Ashe Counties, NC and the Roan area included Avery County, NC and Carter County, TN. Elevations ranged from 850 m in Watauga County to 1,645 m on two plots in the Roan area. All sites had a history of grazing although periods of recent exclusion of cattle on some plots varied from 1 to 15 years. Periodic brush management through woods edge management or bush hogging also occurred over a portion of most sites. Ownership varied from state park units, long term NC wildlife gamelands agreements, private lands, and national forest. All sites were embedded in northern hardwood or mid to high elevation mesic forest (85% forested) and varied in size from about 20 to 100 ha. Each site was dominated by hawthorn (*Crataegus* sp.), wild apple (*Malus* sp.), black locust (*Robinia pseudoacacia*), and black cherry (*Prunus serotina*), with goldenrod (*Solidago* spp.), virgin's bower (*Clematis virginiana*) as well as a variety of grasses and sedges (e.g., orchard grass, *Dactylis glomerata*; timothy, *Phleum pratense*) in the understory.

The Pennsylvania study sites (n = 17) were located in and around Delaware State Forest (DESF), which is located in the heart of the Pocono Mountain region (Monroe and Pike Counties) and consists of ~80,000 ha of public lands. Area of the adjoining properties included in surveys was ~7,600 ha for Blooming Grove Hunt and Fish Club. This study area fell within the Appalachian Glaciated Low Plateau physiographic province characterized by rounded hills and valleys with underlying shale, sandstone, and siltstone. Mean elevation for the timber harvests surveyed in this state was 415 m (range = 275 – 563 m). The forested landscape (85% forest; Bakermans et al. in review) was dominated by mature forests (80+ years post-harvest) with wetland, urban, and suburban areas scattered throughout. Forested habitats varied in Delaware State Forest including scrub oak, dry-oak heath, northern hardwood forests and swamps, glacial bogs, and a conifer swamp. Dominant plant species included chestnut (*Quercus montana*), white (*Q. alba),* scrub (*Q. ilicifolia*), and red oak (*Q. rubra*), sweet birch (*Betula lenta*), red maple (*Acer rubrum*), American chestnut stump sprouts (*Castanea dentana*), mountain laurel (*Kalmia latifolia*), blueberry (*Vaccinium pallidum* and *V. angustifolium*), sweet fern (*Comptonia peregrina*), a variety of forbs (e.g., goldenrod), and grasses and sedges (e.g., Pennsylvania sedge, *Carex pensylvanica*). Timber harvests (n = 17) varied in size (9-67 ha), shape, and age (3-11 years post-harvest). We focused our efforts on timber harvesting practices such as shelterwoods, overstory removal, and salvage operations.

Figure 2. Study areas were located throughout the Appalachian Mountains and within the Golden-winged Warbler breeding range.



The Tennessee study sites (n = 21) were located in the North Cumberland Wildlife Management Area (NCWMA), which consists of 60,000 ha of state-owned land spanning four counties (Scott, Anderson, Campbell and Morgan) in the northeastern portion of the state. The predominant land cover of the NCWMA was a combination of mixed-mesophytic and oak-hickory forests (86% forest, Bulluck 2007), but ~15% was in early stages of succession because of timber harvest and surface mining for coal. The NCWMA is managed by the Tennessee Wildlife Resources Agency (TWRA). Mean elevation of our study sites was 780 m (range = 436 – 963 m). Experimental management for Golden-winged Warblers is occurring on 3 timber harvest sites with 6 units each (~160 ha). Each timber harvest site has 3 units that received herbicide in 2012. Prescribed fire was applied to 1 herbicide and 1 non-herbicide unit per site in the fall of 2012. Prescribed fire was also applied to 1 herbicide and 1 non-herbicide unit per site in the spring of 2013. The 2 remaining units per site did not receive any fire management. On two reclaimed coal mine sites, Ash Log and Massengale (~300 ha), coal surface-mine reclamation occurred during 1980–1990. Reclamation involved planting black locust, tall fescue (*Schedonorus phoenix*), sericea lespedeza *(Lespedeza cuneata)*, and autumn-olive (*Elaeagnus umbellata*). Yellow-poplar (*Liriodendron tulipifera*), maples (*Acer* spp.), oaks (*Quercus* spp.), blackberry (*Rubus* spp.), and a variety of forbs (e.g., *Solidago* spp., *Aster* spp.) and grasses (e.g., orchard grass, timothy) have since colonized the sites. On Massengale, three burn units measuring 40 ha, 115 ha, and 145 ha, were on a one- to three-year burning rotation, 2007-2011. All of Massengale Mountain was managed with prescribed fire in the spring of 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 heights generally 1-2 m.

The West Virginia study sites (n = 24) were located on public (Monongahela National Forest and Snake Hill Wildlife Management Area) and private lands in Monongalia, Monroe, Nicholas, Pocahontas, Preston, and Randolph counties, West Virginia. In West Virginia, Golden-winged Warblers are found predominantly on active and abandoned farmlands (Aldinger and Wood 2014), but they occasionally occupy regenerating forest sites after timber harvest. Pastures (n = 11) were annually lightly grazed by livestock (cattle and horses; 0.3-1.3 animal units/ha) and periodically mechanically brush-hogged. We surveyed old fields (n = 10) that were abandoned pastured or fields that currently were managed by mechanical brush-hogging. We also surveyed regenerating forest site (n = 3); each site included a matrix of adjacent harvests (2-9 harvests). Overall, sites contained 1-80 ha of potential Golden-winged Warbler nesting vegetation (mean ± SE = 18 ± 3 ha) and were 613-1,208 m in elevation. Our shrubland-type sites (n = 21) contained a patchy mix of grass-, brush-, shrub-, and forest. Our regenerating forest stands (n = 3) were <10 years post-timber harvest and were characterized by dense sapling regeneration interspersed with residual canopy trees and logging roads and landings. Dominant species were those characteristic of old field habitats in the central Appalachians, including sweet vernal grass (*Anthoxanthum odoratum*), goldenrod (*Solidago* spp.), raspberry/blackberry (*Rubus* spp.), St. John's wort (*Hypericum* spp.), hawthorn (*Crataegus* spp.), wild apple (*Malus* spp.), black locust (*Robinia pseudoacacia*), and black cherry (*Prunus serotina*), nested in a heavily forested landscape (82%, Strager 2012, Aldinger and Wood 2014).

Management Systems

Because there is significant landscape heterogeneity across the Appalachian Mountain portion of the Golden-winged Warbler's range, there are numerous ways in which habitat can be created or maintained for the species. Such management efforts by NRCS are generally the result of a single primary conservation practice with a variable number of facilitating practices. For the purposes of this study, we defined five discrete early-successional communities derived or maintained through NRCS practices for Golden-winged Warbler (hereafter, *management systems*). Note that not all sites were managed via NRCS contracts but were created or maintained through methods analogous to NRCS practices. Throughout the report we test the effects of these management systems on Golden-winged Warbler breeding demographics and habitat use. An example question in analyses might be: Does management system type influence nest survival of Golden-winged Warblers? Descriptions for each of the five management systems are provided below.

Timber Harvest

This management system creates new Golden-winged Warbler habitat via stands of young, regenerating forest with adequate residual trees. Timber Harvest usually consists of the core management practice Early Successional Habitat Development & Management (NRCS practice code 647) combined with one or more facilitating practices to prepare the stand for an overstory removal and/or treat it after harvest (see list of facilitating practices below). Timber Harvest always results in an overstory removal, and the result is a young, regenerating forest with a residual basal area of 2.3-9.2 m^2/ha. Live residual trees are usually the largest and healthiest of the deciduous hardwoods in the stand and there is limited coniferous cover remaining. Snags are also retained.

Facilitating Practices (conservation practice code): Brush Management (314), Fencing (382), Access Control (472), Forest Stand Improvement (666), Herbaceous Weed Control (315), Tree & Shrub Establishment (612), Tree & Shrub Site Preparation (490), and Upland Wildlife Habitat Management (645).

Prescribed Fire – Young Forest

Prescribed Fire – Young Forest utilizes NRCS conservation practices to create new and maintain Golden-winged Warbler habitat using prescribed fire as preparatory treatment for a harvest or as a method of maintaining early successional habitat after a harvest. Maintaining the area in early successional habitat with prescribed fire may mimic natural disturbance events which historically created breeding habitat for Golden-winged Warblers. Prescribed Fire – Young Forest primarily consists of the management practice Prescribed Burning (practice 338) along with one or more of the facilitating practices below. The result of this management system is early successional habitat with prolonged retention of herbaceous cover and restricted or slowed regeneration of the woody understory.

Facilitating Practices (conservation practice code): Brush Management (314), Fencing (382), Access Control (472), Fire Break (394), Forest Stand Improvement (666), Early Successional Habitat Development & Management (647), Herbaceous Weed Control (315), and Upland Wildlife Habitat Management (645).

Prescribed Fire – Old Field

Prescribed Fire – Old Field is a management system that maintains existing shrubland habitat as old fields, including abandoned agriculture and reclaimed surface mines. This strategy for managing Golden-winged Warbler habitat primarily utilizes NRCS management practice

Prescribed Burning (practice 338) along with one or more of the facilitating practices listed below. The result of this management system is an early successional shrubland with herbaceous cover and slowed growth of woody plants such as shrubs and saplings. Prescribed fire on surface mines can be used to set back vegetative growth, although it must be regularly employed to maintain the area in an arrested state of succession.

Facilitating Practices (conservation practice code): Brush Management (314), Fencing (382), Access Control (472), Fire Break (394), Forest Stand Improvement (666), Herbaceous Weed Control (315), Tree & Shrub Establishment (612), and Upland Wildlife Habitat Management (645).

Grazing Management

Grazing Management is a method of maintaining existing Golden-winged Warbler habitat utilizing domestic livestock to limit natural succession. This management system primarily uses NRCS conservation practice Prescribed Grazing (practice 528) along with one or more of the facilitating practices listed below. In areas where Golden-winged Warblers are known to breed, low-intensity grazing (1 animal unit/2-4 ha) may be used during May-October or even year-round if overgrazing is not occurring. High-intensity grazing (up to 1 animal unit/0.4 ha) may be used during non-nesting periods to limit natural succession in overgrown areas (>60% shrub cover). If overgrazing occurs (indicated by <30% shrub cover), excluding livestock for 1-2 years allows natural vegetative succession. At low grazing intensities, overgrazing generally is uncommon; in fact, mechanical brush removal targeting large shrubs that are not susceptible to grazing may be necessary to maintain appropriate vegetative structure for nesting. The result of this management system is a low intensity grazing system that relies on the use of livestock to maintain an area in early successional habitat.

Facilitating Practices (conservation practice code): Brush Management (314), Early Successional Habitat Development & Management (647), Fencing (382), Access Control (472), Herbaceous Weed Control (315), and Upland Wildlife Habitat Management (645).

Old Field Management

Old Field Management is a management system that can be used to maintain Golden-winged Warbler habitat. This management system primarily uses NRCS conservation practice Brush Management (practice 314) along with one or more of the facilitating practices below. This management system sets back succession of shrubs and other woody plants primarily using mechanical methods. The goal of this management strategy is to restrict the growth of woody vegetation and revert late successional shrublands to earlier stages of succession with 30-60% shrub and sapling cover within the targeted area. Keeping the site-level shrub and sapling cover closer to 60% allows for immediate use by nesting Golden-winged Warblers, while management that results in shrub and sapling cover closer to 30% may result in a delayed response as vegetation recovers.

Facilitating Practices (conservation practice code): Early Successional Habitat Development & Management (647), Fencing (382), Access Control (472), Field Border (386), Herbaceous Weed Control (315), Tree & Shrub Establishment (612), and Upland Wildlife Habitat Management (645).

STUDY COMPONENTS

Study Component I: Comparison of study site size and vegetation across management systems

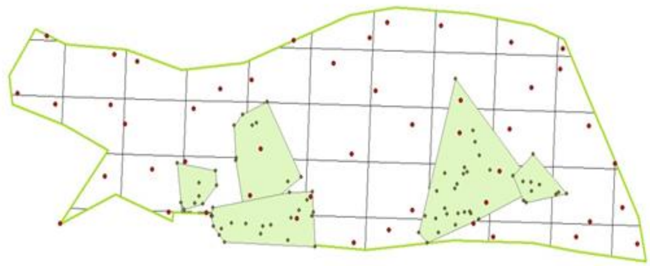
Summary

Over the 3 seasons, we sampled 95 sites across the 4 regions (i.e., NC, TN, WV, and PA) Across 2,347 vegetation plots throughout study sites, we found that vegetation differed by management system. In general, timber harvests had greater amounts of woody vegetation (e.g., woody ground cover and number of saplings) and grazing, old field management, and prescribed fire (old field) had largest amounts of grass and forbs. Furthermore, prescribed fire (young forest) had the greatest amounts of *Rubus* and bare ground cover. All sites provided a mix of the recommended vegetation characteristics from the Golden-winged Warbler Conservation Plan (Roth et al. 2012) but prescribed fire (young forest) and timber harvest sites generally had lower amounts of grass and forb cover and grazing and old field management sites had greater amounts of grass cover than recommended in the plan.

Methods

We sampled vegetation throughout each site that was occupied by Golden-winged Warblers. Using ArcMap we randomly selected 1 point per ha (Figure 3) and the data collected followed the nested plots (1-, 5-, and 11.3-m radius) that were used in the random plots for the nest vegetation sampling (see page 43). We ran a multivariate analysis of variance to test for differences in vegetation metrics that were pooled by management systems across regions and we examined significance of individual vegetation metrics post-hoc. We also used site-level vegetation when evaluating nesting vegetation (see **Component IV: Evaluation of nest-site vegetation and nest survival among management systems**).

Figure 3. Randomly selected points (red dots) at a density of 1 per ha in a site occupied by Golden-winged Warblers (territories and territory points shaded in green).



Results

Over the 3 seasons, we sampled 95 sites across the 4 regions (i.e., NC, TN, WV, and PA; Appendix 2). Mean size of stands for each management system were marginally significantly different ($F_{4,89} = 2.41$, $P = 0.055$) where stands with prescribed fire (old field) were on average the largest while prescribed fire (young forest) were the smallest in area (Table 1).

We collected vegetation data for sites across 2347 plots (n = 493 for NC region; 529 for TN; 621 for WV; 704 for PA). Vegetation differed by management system ($F_{4,59} = 6.49$, $P < 0.001$). All vegetation variables, except number of saplings ($F = 1.65$, $P = 0.174$), differed significantly ($P < 0.05$) in post-hoc univariate tests. Timber harvests had greater litter and woody ground cover (Figures 4 and 5). Prescribed fire (old field) had the greatest forb ground cover and sapling height. Prescribed fire (young forest) had the greatest bare and *Rubus* ground covers, greatest sapling height, and the lowest shrub height. Grazing management had the greatest grass ground cover, number of shrubs (both 1-2 m and >2m), and number of trees but had the fewest number of snags. All sites provided a mix of the recommended vegetation characteristics from the Golden-winged Warbler Conservation Plan (Roth et al. 2012). However, sites with prescribed fire (young forest) and timber harvest management systems had less and grazing management and old field management had greater amounts of grass cover than recommended in the plan (i.e., recommended 5 - 25% grass cover/1-m radius). In addition, sites with timber harvest or prescribed fire (young forest) management systems had less forb cover than recommended by the plan (i.e., recommended 45 - 100% cover/1-m radius). See **Component IV: Evaluation of nest-site selection and nest survival and productivity among management systems** for more analyses comparing vegetation values across sites in this study with those recommended in the Golden-winged Warbler Conservation Plan.

Table 1. Summary of sites used in the study by management system. Primary conservation practice for each management system is in bold followed by the facilitating practices.

Management system	Primary and facilitating NRCS codes	Region	N	Mean size in ha (SE)
Timber harvest	**647**,314, 382, 472, 666, 315, 612, 490, 645	North Carolina	5	
		West Virginia	3	
		Tennessee	7	
		Pennsylvania	16	
		Total	31	18.4 (3.0)
Prescribed fire – young forest	**338**, 314, 382, 472, 394, 666, 647, 315, 645	Tennessee	12	
		Pennsylvania	1	
		Total	13	8.0 (1.3)
Prescribed fire – old field	**338**, 314, 382, 472, 394, 666, 315, 612, 645	Tennessee	2	56.9 (4.4)
Grazing management	**528,** 314, 647, 382, 472, 315, 645	North Carolina	7	
		West Virginia	11	
		Total	18	22.8 (5.6)
Old field management	**314,** 647, 382, 472, 386, 315, 612, 645	North Carolina	21	
		West Virginia	10	
		Total	31	22.4 (5.5)

Figure 4. Mean (± SE) values of stand level ground cover metrics by management system.

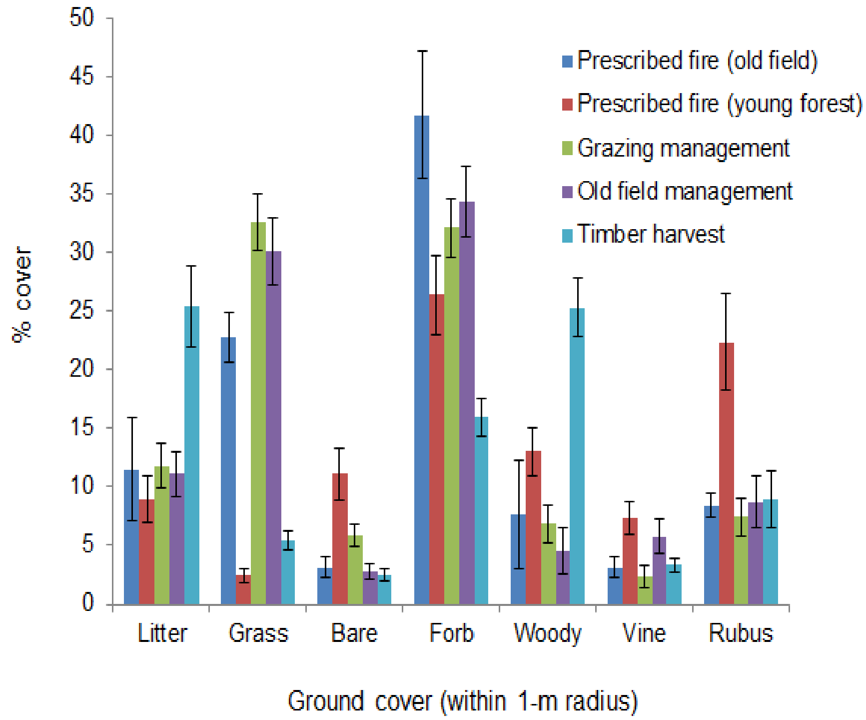
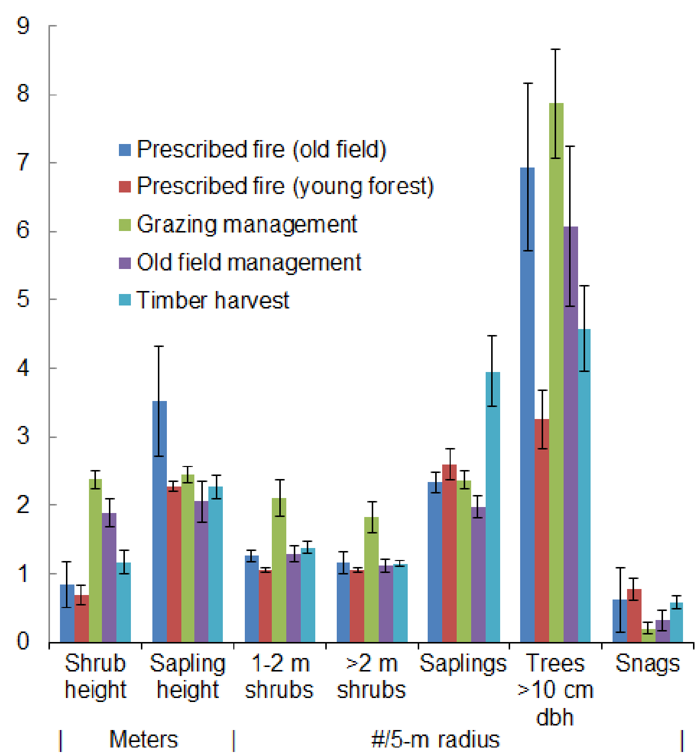


Figure 5. Mean (± SE) values for site level vegetation characteristics by management system.



Study Component II: Annual adult male survival and body condition index among management systems

Summary

Over 3 seasons, we banded 41 female and 290 male adult Golden-winged Warblers and 430 nestlings in which 372 were the result of adult GWWA x GWWA pairing. We calculated a body condition index for adult, male Golden-winged Warblers that accounted for both mass and structural size of birds. There was a significant difference in body condition index among management systems, where adult, male Golden-winged Warblers in grazing management systems had the greatest body condition index and birds in old field management had the lowest body condition index. We also generated estimates of minimum adult annual survival and resighting rate for male Golden-winged Warblers. Resighting rate was 0.76 (0.11 SE). The most supported model for minimum adult male survival rate indicated a management system effect. Model-averaged parameter estimates by management system indicate that prescribed fire (old field) had the highest survival rate (0.81, 0.46 SE) and old field management had the lowest survival rate (0.40, 0.11 SE). We caution that management systems were not evenly distributed across all 4 regions and differences in body condition and survival may have been related to geographic region. Thus, when combining birds from all management systems, the model-averaged survival rate was 0.58 (0.04SE, 95% confidence interval 0.51 - 0.66). On seven occasions, *Vermivora* spp. banded as nestlings (4 Golden-winged and 3 Brewster's Warblers) were re-captured as adults on the breeding grounds the following year.

Methods

We captured and banded male, female, and nestling Golden-winged Warblers and other *Vermivora* spp. at each study site to aid in identification of individuals and estimate annual return rates and estimate minimum survival rates. Banding efforts were greatest in the start of the season while males are actively establishing and defending territories and attracting mates. Males are most responsive when females have recently returned to the breeding grounds and when they are fertile. We used one 6-m mist net, an MP3 recording of Golden-winged Warbler type I and II songs, and a model of a male Golden-winged Warbler to capture targeted males. We fit each captured bird with a standard USGS aluminum leg band and a unique combination of 1-3 additional color leg bands, determined age, and measured wing chord length and body mass.

We generated a body condition index that accounts for both mass and structural size of birds. First, we used a linear regression of mass and wing chord, and the residuals were used as a condition index. The deviation of the predicted values from the expected mass given the body size indicated whether the bird was in good (i.e., residual above the regression line) or in poor (i.e., residual below) body condition (Strong and Sherry 2001, Bakermans et al. 2009). We used original captures of individuals during the study to calculate the body condition index.

We generated estimates of minimum adult survival rate (ϕ) with Cormack-Jolly-Seber methods in program MARK, version 6.1 (White and Burnham 1999). We constructed 8 *a priori* models to examine the influence of management system, year, and body condition on survival rate using a constant resighting probability (p). We expected survival rate would be positively related to body condition (Marra and Holmes 2001, Benson and Bednarz 2010), and could vary by year (Bulluck et al. 2013). Differences in survival may have occurred between management systems if these systems offer different resources (e.g., food, cover from predators) for Golden-winged Warblers. We did not expect resighting probability to vary with the covariates given that consistent and extensive re-sighting efforts occurred in conjunction with activities at each site (e.g., nest searching, territory mapping, point count surveys, etc.).

Because of our limited sample sizes for females and hybrids, we only included adult, male Golden-winged Warblers in condition and survival analyses. However, it should be noted that even with the confirmation of a phenotypic Golden-winged Warbler, there likely exists cryptic hybridization in the Golden-winged Warbler population we studied (Vallender et al. 2009). We used model-averaging to obtain point estimates and standard errors (Burnham and Anderson 2002).

Results

Over 3 seasons, we banded 324 male and 46 female adult *Vermivora* warblers, including 41 female and 290 male Golden-winged Warblers, 5 female and 20 male Brewster Warblers, 13 male Blue-winged Warblers, and 1 male Lawrence's Warbler (Table 2). In addition, we banded 430 nestlings in which 372 were the result of adult GWWA x GWWA pairing, 5 of BWWA x BWWA pairing, and 53 hybrids (resulting from possible pairings of either hybrid adults or different species in a pair).

Adult male Golden-winged Warblers had significantly greater wing chord ($F_{1,306}$ = 115.51, P < 0.001) but less mass ($F_{1,304}$ = 17.49, P < 0.001) than female Golden-winged Warblers. For adult, male Golden-winged Warblers there was a significant difference in body condition index among management systems ($F_{4,261}$ = 5.91, P <0.001; Figure 6).

The most supported model for adult, male survival and resighting rate indicated a management system effect (Table 3). In fact, management system was included in all of the top four models and had an extremely high collective weight of evidence of 0.93 (i.e., summing w_i over all models containing the variable to determine the relative variable importance; Burnham and Anderson 2002). Model-averaged parameter estimates by management system indicate that prescribed fire (old field) had the greatest survival rate and old field management had the least survival rate (Figure 7). When combining birds from all management systems, the model-averaged survival rate was 0.58 (0.04SE, 95% confidence interval 0.51 - 0.66) and falls within the rate (0.62) found in Bulluck et al. (2013) in Tennessee and Ontario. Adult, male survival rate by management system ranged widely, from 0.40 to 0.81. However, caution must be applied for several management systems (e.g., prescribed fire - old field and young forest) because we had relatively low sample sizes. The model-averaged resighting rate was 0.76 (0.11 SE). Resighting rate in our study was less than that reported for Tennessee (0.85) but similar to rates in Ontario (0.75; Bulluck et al. 2013).

Forty-six *Vermivora* spp. were recaptured on additional occasions following their initial banding events. Of these, 39 were Golden-winged Warblers (36 males, 3 females), six were Brewster's Warblers (4 males, 2 females), and one male Blue-winged Warbler was recaptured. Recaptured birds had their features re-measured and, with the exception of banding, were otherwise treated like newly-captured birds. On seven occasions, *Vermivora* spp. banded as nestlings were re-captured as adults on the breeding grounds the following year. These constituted four Golden-winged (one female, three males) and three Brewster's Warblers (two females, one male). Nestling males that were recaptured as adults were given color bands to allow territory mapping.

Table 2. Number of adult Golden-winged (GWWA), Blue-winged (BWWA), and Hybrid Warblers banded within each management system.

Species Sex	Timber harvest	Prescribed fire (young forest)	Prescribed fire (old field)	Grazing management	Old field management
GWWA					
Male	88	13	22	60	107
Female	6	0	2	21	12
Hybrid					
Male	7	0	1	7	6
Female	0	0	1	2	2
BWWA					
Male	4	0	1	6	2
Female	0	0	0	0	0

Figure 6. Mean (diamond) body condition index (± SE) of adult, male Golden-winged Warblers by management system, 2012-2014. (Note: values above Zero line indicate good body condition)

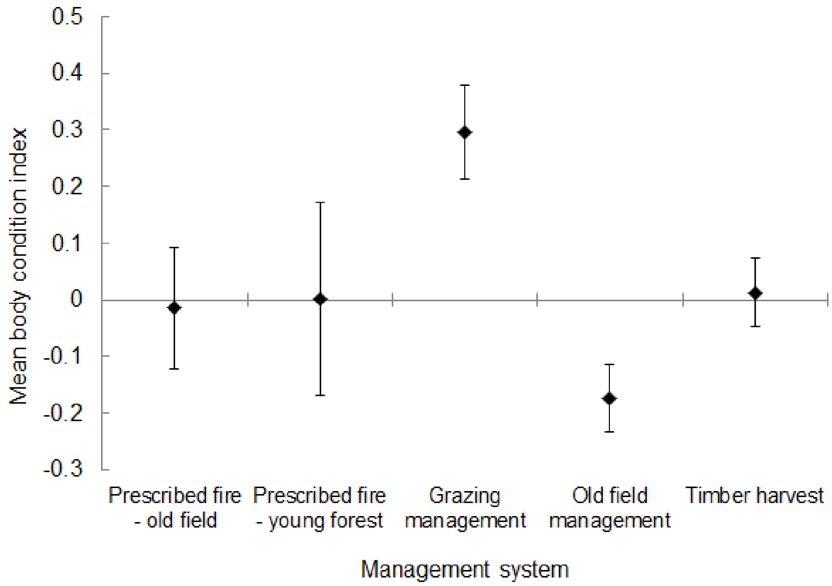
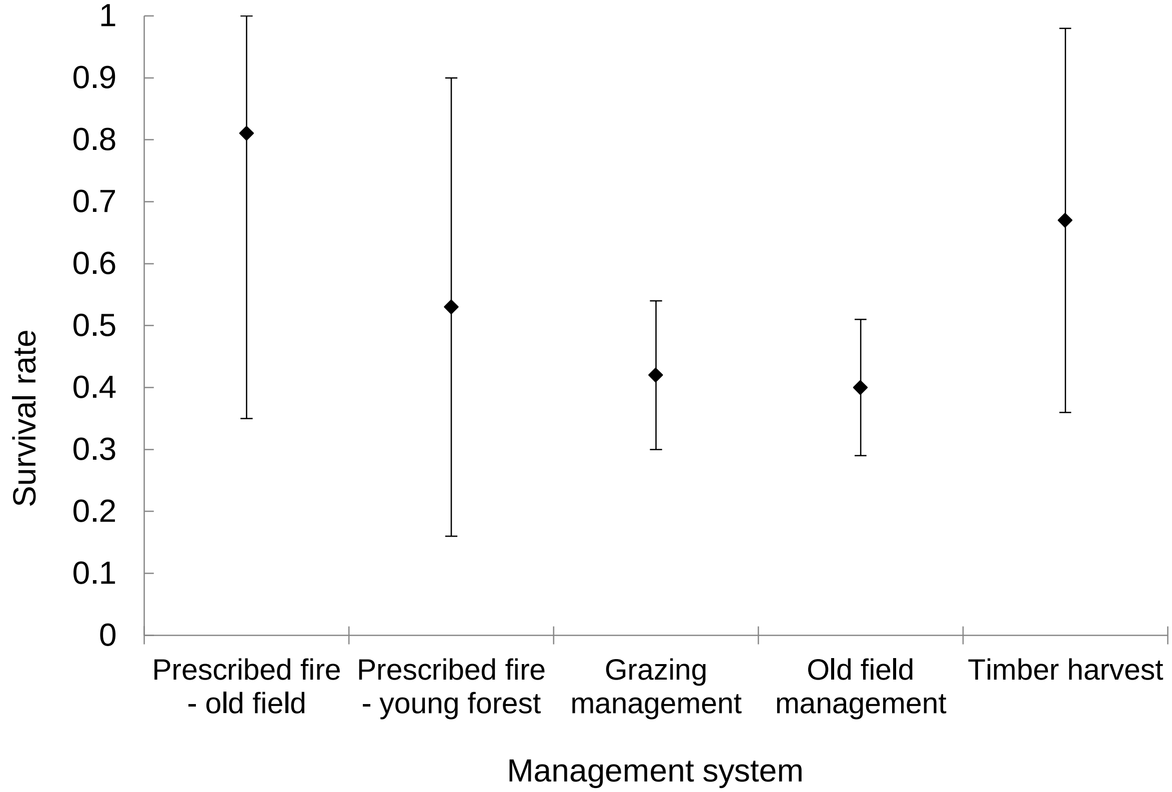


Table 3. Model selection results for adult, male Golden-winged Warbler apparent survival (ϕ) and resighting probability (p) with management system (mgmt), body condition index (body), and time (year) effects included in models, 2012-2014.

Model	K[1]	AIC_c[2]	ΔAIC_c[3]	ω_i[4]
ϕ_{mngmt} p	6	317.32	0.00	0.45
$\phi_{\text{mngmt*year*body}}$ p	17	318.46	1.14	0.26
$\phi_{\text{mngmt*body}}$ p	10	318.99	1.68	0.20
$\phi_{\text{mngmt*year}}$ p	11	322.93	5.61	0.03
ϕ p	2	323.04	5.72	0.03
ϕ_{year} p	3	324.02	6.70	0.02
ϕ_{body} p	3	324.77	7.45	0.01
$\phi_{\text{body*year}}$ p	5	324.82	7.50	0.01

[1]Number of parameters included in the model.
[2] Corrected Akaike's information criterion adjusted for small sample size.
[3] Difference in AIC_c value from that of the best model.
[4] Akaike weight indicating relative support for the model.

Figure 7. Model-averaged annual survival estimates (± SE) for adult, male Golden-winged Warblers.



Study Component III: Estimating avian density using point count surveys

Summary

We conducted 864 point count surveys at 191 point count locations across 70 sites from 2012-2014 to estimate density of Golden-winged Warblers, Wood Thrush, Indigo Buntings, and Field Sparrows. We generated offsets to account for imperfect detection probability using a combination of removal- and distance-sampling models that took into account the influence of covariates on singing rate (e.g., time of day and date) and effective detection radius (e.g., observer, wind speed, and weather). We incorporated these offsets into generalized linear mixed effects models to examine associations between density and covariates (e.g., management system, elevation, latitude, vegetation). Golden-winged Warbler density was similar across management systems. Golden-winged Warbler density increased with elevation at southern sites but decreased with elevation at northern sites. Field Sparrow density was most greatly influenced by management system where densities were greatest in grazing management sites. Indigo Bunting density exhibited a curvilinear latitude trend. Wood Thrush density was greatest at lower elevations and northern latitudes. In addition, Golden-winged Warbler density increased with

sapling count but the other 3 species showed a negative response to sapling count. The accuracy of our Golden-winged Warbler density estimates increased as the temporal and spatial scales increased (i.e., combining all sites within management systems and regions and pooling across years). Because of the scarcity of Golden-winged Warblers throughout the Appalachian Mountain region and the limited number of individuals available for detection among sites, future monitoring efforts should be careful to estimate density at appropriate scales (i.e., larger than a single site). Occupancy models may be better suited for monitoring Golden-winged Warblers, especially since density did not vary among conservation practices.

Methods

We included all sites (n = 70; Appendix 2) that were within the area eligible for enrollment in Working Lands for Wildlife and could be assigned a management system (i.e., grazing management, old field management, prescribed fire (old field), prescribed fire (young forest), or timber harvest), regardless of the presence of Golden-winged Warblers. We assumed that these sites represented the potential outcome of implementing our five management systems across the Working Lands for Wildlife program area.

We conducted 864 10-minute single-observer point counts across 191 point count locations across 70 sites in North Carolina, Pennsylvania, Tennessee, and West Virginia during 2012-2014. To avoid double counting individuals, we randomly placed point count locations in appropriate Golden-winged Warbler breeding habitat ≥250 m apart because the maximum distance at which Golden-winged Warblers can be detected generally is considered to be <200 m (Rosenberg and Blancher 2005, Kubel and Yahner 2007). We conducted point counts during 10 May-25 June when most migrant songbirds had passed through the area and local songbirds were breeding. Point counts occurred between sunrise and 1100 hours EDT in favorable weather conditions (i.e., no heavy rain, high winds, or foggy conditions). We visited each point 1-3 times per season with 3-33 days (mean 17 ± 0.3 days) between first and last visits. Observers approached the point with as little disturbance as possible and began the count after recording point-specific data (date, start time, Beaufort wind index [0-5], sky condition [clear, partly cloudy, cloudy/overcast, fog, drizzle]) and identifying landmarks to help with distance estimation (1-2 minutes). Over a 10-minute time period, we recorded all birds detected and recorded species, distance (0-25 m, 26-50 m, 51-75 m, 76-100 m, >100 m), detection type (call, song, visual, flyover), and sex (male, female, unknown). For all *Vermivora* spp. (i.e., Golden-winged, Blue-winged, and hybrid warblers), we recorded their exact distance from the point count location using a laser rangefinder. After the 10-minute point count, we used a speaker to broadcast 1.5 minutes of Golden-winged Warbler secondary song and then listened for an additional 1.5 minutes. Song broadcast increased visual confirmation of *Vermivora* spp., which is important because Golden-winged Warblers, Blue-winged Warblers, and their hybrids may sing each other’s songs, making identification by song inaccurate.

We collected breeding season-specific vegetation data for 777 point counts across 189 point count locations. All point count locations in North Carolina and Tennessee and one point count location in Pennsylvania in 2012 did not have vegetation data. To sample vegetation, we used a nested plot design (5-m and 11.3-m radius) centered at the point count location. We tallied shrubs (>2 m tall) and saplings (1-10 cm diameter, ≥0.5 m tall) by species within the 5-m radius plot. Within 11.3 m of plot center, we recorded the species and dbh of all live woody trees (>10 cm dbh). We used dbh to calculate basal area (SBA= $\frac{\sum_{i=1}^{n} BA_i}{A}$, where SBA is the stand basal area [m^2/ha], BA_i is the basal area of tree *i* [m^2], and A is area [ha] of the 11.3-m radius plot). We estimated the elevation at each point count location using digital elevation models and a geographic information system program.

To examine the accuracy of our point count density estimates we either intensively mapped territories or visited a site enough times (≥4 visits) to ensure there were no Golden-winged Warblers present at the site (n = 70). See **Study Component V: Estimating territory size and density with territory mapping** section for complete details on territory mapping methods.

Data analysis

We selected four species for analyses, representing our focal species (Golden-winged Warbler), a late-successional nester (Wood Thrush), a mid-successional nester (Indigo Bunting), and an early-successional nester (Field Sparrow; Appendix 1). For all species, we used detections of males and excluded flyovers. Because we measured exact distance for Golden-winged Warblers, we (1) classified detections into 5-m distance bands, (2) grouped all detections ≤20 m to account for movements away from the observer, and (3) excluded 10% of the farthest detections (Buckland et al. 2001), which limited our point count radius to 130 m. For Wood Thrush, Indigo Bunting, and Field Sparrow, we limited our point count radius to ≤100 m.

We used package *maptools* in program R (version 3.1.2, R Development Core Team 2014) to estimate sunrise times for the date and location of each unique point count. Package *maptools* uses the National Oceanic and Atmospheric Administration's sunrise calculator (http://www.ssrb.noaa.gov/highlights/sunrise/sunrise.html, Meeus 1991). We estimated time since sunrise as the difference in hours between the point count start time and local sunrise on the date of the point count. We converted point count date to ordinal date. To aid in model convergence, we standardized time since sunrise and ordinal date by dividing by their maximum potential values (24 and 365, respectively) and elevation, latitude, longitude, distance to forest edge, and shrub, sapling, and tree counts using the *scale* function in program R (Sólymos et al. 2013). Observers (n = 7) that conducted 10 or fewer point counts were pooled under one ID.

We used Akaike's Information Criterion (AIC) to evaluate competing singing rate (i.e., removal-sampling), effective detection radius (i.e., distance-sampling), and density models. We considered the model with the lowest AIC value to be the best-supported model given the data (Burnham and Anderson 2002). We reported beta coefficients, precisions (standard error, SE), and probabilities (p-values) for covariates in the best-supported models. We used the beta coefficients to infer the biological importance of covariates.

We used a combined removal- and distance-sampling approach to account for imperfect detection and model avian density (Sólymos et al. 2013). This combined approach allows for separate estimates, as functions of covariates, of the two components of detection probability (Nichols et al. 2009): availability (p), the probability that a bird present at the time of survey gave a cue and was available for detection, using removal-sampling (Farnsworth et al. 2002) and perceptibility (q), the conditional probability that the available bird was detected, using distance-sampling (Buckland et al. 2001). We used estimates of p and q, along with the area sampled (A), as offsets in our density models to account for imperfect detection. Essentially, we multiplied our predicted counts by A, p, and q to convert counts to density and correct for imperfect detection.

We used conditional multinomial maximum likelihood models to estimate singing rates and effective detection radii using package *detect* (Sólymos et al. 2013) in program R. To estimate singing rates and effective detection radii, we considered each unique point count (n = 864) as an independent sample (Sólymos et al. 2013). Candidate singing rate models included continuous covariates for ordinal date and time since sunrise, as well as the constant model. The constant model, also known as the mean, null, or intercept only model, refers to a model that does not include any independent variables as predictors. Candidate effective detection radius models included categorical covariates for Beaufort wind index, observer, and sky condition, as well as the constant model. We used the best-supported singing rate and effective detection radius models to generate offsets for the density models. We used Poisson lognormal mixed effect models to estimate density using package *lme4* (Bates *et al*. 2014) in program R. All density models included random effects for point nested within site. We organized density models into two model suites. Candidate density models for model suite I included fixed effects for elevation, latitude, and management system, as well as the constant model and used all 864 point counts. Candidate density models for model suite II included fixed effects for distance to forest edge, counts of shrubs, saplings, and trees, and basal area and used the 777 point counts for which we had vegetation data.

We plotted territory mapping (i.e., true) density by point count (i.e., predicted) density estimates and fit linear trend lines with R-squared values to examine the correlation of the two density estimates. We created plots aggregating our estimates across spatial (sites [n = 70], management system [n = 5], and study area [n = 4]) and temporal (years [n = 3]) scales to give insight into the optimal resolution of density estimates from point counts.

Results

Detection probability

For Golden-winged Warbler, the best-supported singing rate model was the constant model (Table 4). Models with linear ordinal date or time since sunrise effects also had substantial support (ΔAIC ≤ 2), although beta estimates were not statistically significant at $\alpha = 0.05$. The best-supported effective detection radius model included a linear Beaufort wind index effect; a similar model with a curvilinear Beaufort wind index effect had substantial support (Table 4). Effective detection radius decreased as wind speed increased.

For Field Sparrow, the best-supported singing rate model (Table 4) suggested that singing rate declined curvilinearly with time since sunrise. The constant singing rate model and a model with linear ordinal date and curvilinear time since sunrise effects also had substantial support (Table 4). The best-supported effective detection radius model included an observer effect. The next best model had ΔAIC of 28.

For Indigo Bunting, the best-supported singing rate model included linear ordinal date and curvilinear time since sunrise effects; no other model had substantial support (Table 4). Similar to Field Sparrow, the best-supported effective detection radius model for Indigo Bunting included an observer effect; no other model had substantial support (Table 4).

Similar to Indigo Bunting, the best-supported singing rate model for Wood Thrush included linear ordinal date and curvilinear time since sunrise effects (Table 4). Four other singing rate models had substantial support (Table 4). The best-supported effective detection radius model was the constant model and a model with a linear Beaufort wind index effect also had substantial support (Table 4).

Density estimates

For Golden-winged Warbler, the best-supported density model in model suite I (elevation, latitude, and management system effects) included linear elevation and latitude effects and an interaction (Table 5). Models with management system had essentially no support (ΔAIC > 10, Burnham and Anderson 2002), suggesting that Golden-winged Warbler density overall was consistent among management systems. At lower (southern) latitudes density increased with elevation, and at higher (northern) latitudes density decreased with elevation (Figure 8, Table 6). The best-supported density model in model suite II (vegetation covariates) included a linear sapling count effect (Figure 9). In fact, for all species the best-supported density model in model suite II included a linear sapling count effect (Table 5, Table 7). For Golden-winged Warbler, density increased with sapling count, whereas for other species density decreased with sapling count. The accuracy of our predicted density estimates increased as the temporal and spatial scales increased (Figure 10). The outlying data points at the management system level were from the prescribed fire (young forest) management system, which had the smallest sample size of our management systems.

For Field Sparrow, the best-supported density model in model suite I included management system and latitude effects (Table 5). Field Sparrow density was greatest in grazing management sites and decreased as latitude increased (Table 6). For Indigo Bunting, the best-supported density model in model suite I included a curvilinear latitude trend (Table 5). Indigo Bunting density decreased as latitude increased (Table 6). For Wood Thrush, the best-supported density model in model suite I included a curvilinear elevation effect and a linear latitude effect (Table 5). Wood Thrush density was greater at lower elevations and northern latitudes (Table 6).

Table 4. Model ranks, based on Akaike's Information Criteria (AIC) values, for conditional multinomial maximum likelihood models of singing rate and effective detection radius for Golden-winged Warbler (GWWA), Field Sparrow (FISP), Indigo Bunting (INBU), and Wood Thrush (WOTH). We used the best-supported (rank=1) models for each species to generate offsets to account for imperfect detection in the density models.

Model	Model rank			
Singing rate (removal-sampling) models	GWWA	FISP	INBU	WOTH
Constant	1†	2†	9	8
Time since sunrise	3†	6	8	9
Time since sunrise + Time since sunrise^2	6	1†	4	7
Ordinal date	2†	4	7	2†
Ordinal date + Ordinal date^2	5	7	6	5†
Ordinal date + Time since sunrise	4	8	3	4†
Ordinal date + Ordinal date^2 + Time since sunrise	8	9	5	6
Ordinal date + Time since sunrise + Time since sunrise^2	7	3†	1†	1†
Ordinal date + Ordinal date^2 + Time since sunrise + Time since sunrise^2	9	5	2	3†
Effective detection radius (distance-sampling) models	GWWA	FISP	INBU	WOTH
Constant	5	2	2	1†
Wind (as factor)	4	3	7	6
Wind (as numeric)	1†	4	3	2†
Wind index + Wind index ^{2} (as numeric)	2†	5	4	3
Sky condition	7	6	5	4
Sky condition + Wind index (as factor)	6	8	8	7
Sky condition + Wind index (as numeric)	3	7	6	5
Observer	8	1†	1†	8

†Model with ΔAIC ≤ 2 of the best-supported model

Table 5. Model ranks, based on Akaike's Information Criteria (AIC) values, for Poisson lognormal mixed-effects density models for Golden-winged Warbler (GWWA), Field Sparrow (FISP), Indigo Bunting (INBU), and Wood Thrush (WOTH). We further investigated the best-supported (rank=1) models for each species by examining beta estimates and/or density plots.

Model	Model rank			
Model suite I – density models	GWWA	FISP	INBU	WOTH
Constant	13	13	13	8
Management system	12	3	11	9
Management system + Elevation	10	2	10	2†
Management system + Latitude	6	1†	4	11
Elevation	11	10	12	12
Elevation + Elevation^2	7	5	9	7
Latitude	9	12	8	10
Latitude + Latitude^2	5	9	1†	4†
Elevation + Latitude	8	7	7	13
Elevation + Elevation^2 + Latitude	4	8	5	1†
Elevation + Latitude + Latitude^2	2	4	2†	5
Elevation + Elevation^2 + Latitude + Latitude^2	3	6	3	3†
Elevation + Latitude + Elevation * Latitude	1†	11	6	6
Model suite II – density models	GWWA	FISP	INBU	WOTH
Constant	8	5	10	3
Edge distance	2†	8	3	7
Edge distance + Edge distance^2	4	11	5	5
Shrub count	7	6	4	10
Shrub count + Shrub count^2	6	9	6	4
Sapling count	1†	1†	1†	1†
Sapling count + Sapling count^2	3†	2†	2†	2†
Tree count	11	7	8	8
Tree count + Tree count^2	5	10	11	9
Basal area	10	4	7	6
Basal area + Basal area^2	9	3	9	11

†Model with ΔAIC $\leq$ 2 of the best-supported model

Table 6. Beta coefficients, precisions, and probabilities for covariates from the best-supported models of density in model suite I (Table 5) for Golden-winged Warbler (GWWA), Field Sparrow (FISP), Indigo Bunting (INBU), and Wood Thrush (WOTH).

Covariate	Beta estimate	SE	z value	P value
Model: GWWA density = Elevation + Latitude + Elevation * Latitude				
Intercept	-2.194	0.177	-12.421	<0.001
Elevation (scaled)	0.192	0.159	1.210	0.226
Latitude (scaled)	0.132	0.191	0.693	0.488
Elevation (scaled) * Latitude (scaled)	-0.575	0.131	-4.379	<0.001
Model: FISP density = Management system + Latitude				
Intercept	-0.280	0.217	-1.292	0.196
Old field management	-0.681	0.324	-2.105	0.035
Prescribed fire - old field	-0.674	0.580	-1.162	0.245
Prescribed fire - young forest	-1.428	0.352	-4.056	<0.001
Timber harvest	-1.587	0.320	-4.963	<0.001
Latitude (scaled)	-0.484	0.149	-3.256	0.001
Model: INBU density = Latitude + Latitude^2				
Intercept	-0.126	0.119	-1.065	0.287
Latitude (scaled)	-0.587	0.094	-6.272	0.000
Latitude^2 (scaled)	-0.445	0.100	-4.427	0.000
Model: WOTH density = Elevation + Elevation^2 + Latitude				
Intercept	-3.088	0.208	-14.851	<0.001
Elevation (scaled)	0.087	0.215	0.403	0.687
Elevation^2 (scaled)	-0.422	0.160	-2.645	0.008
Latitude (scaled)	0.472	0.215	2.199	0.028

Table 7. Beta coefficients, precisions, and probabilities for covariates from the best-supported models of density in model suite II (Table 5) for Golden-winged Warbler (GWWA), Field Sparrow (FISP), Indigo Bunting (INBU), and Wood Thrush (WOTH). In model suite II, the model containing sapling count was the best-supported density model for all species.

Model: Density = Sapling count					
Species	Covariate	Estimate	SE	z value	P value
GWWA	Intercept	-1.753	0.153	-11.433	<0.001
	Sapling count	0.187	0.071	2.657	0.008
FISP	Intercept	-1.298	0.001	-1212.500	<0.001
	Sapling count	-0.309	0.001	-289.200	<0.001
INBU	Intercept	-0.571	0.114	-4.993	<0.001
	Sapling count	-0.260	0.076	-3.414	0.001
WOTH	Intercept	-3.555	0.199	-17.858	<0.001
	Sapling count	-0.456	0.204	-2.234	0.026

Figure 8. The relative (scaled) interactive effect of elevation and latitude on Golden-winged Warbler density. The blue and orange lines represent the lowest and highest latitudes across the range of elevation. At lower (southern) latitudes density increased with elevation, and at higher (northern) latitudes density decreased with elevation.

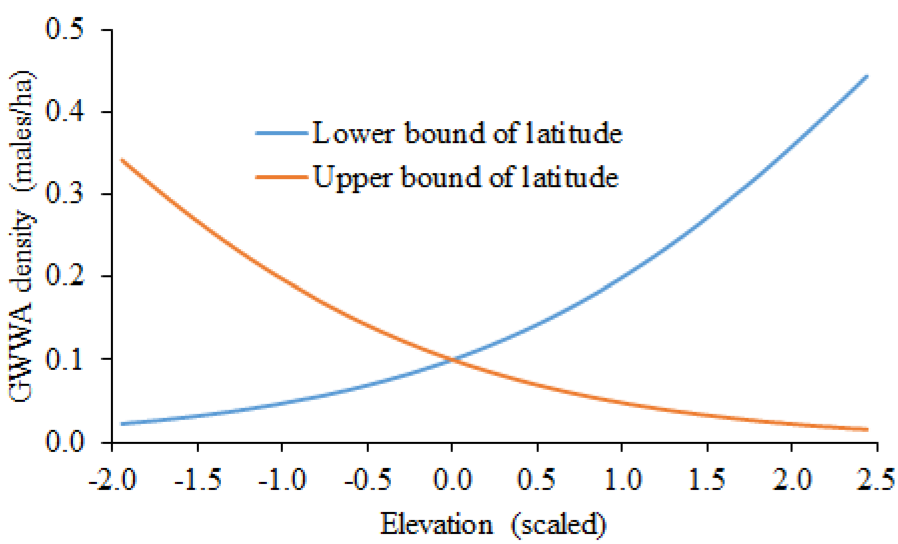


Figure 9. Predicted densities (black lines) for Golden-winged Warbler, Field Sparrow, Indigo Bunting, and Wood Thrush as a function of sapling (1-10 cm diameter, ≥0.5 m tall) counts (#/5-m radius). In model suite II, the model containing sapling count was the best-supported density model for all species. Gray lines represent predicted densities for individual sites (n = 70).

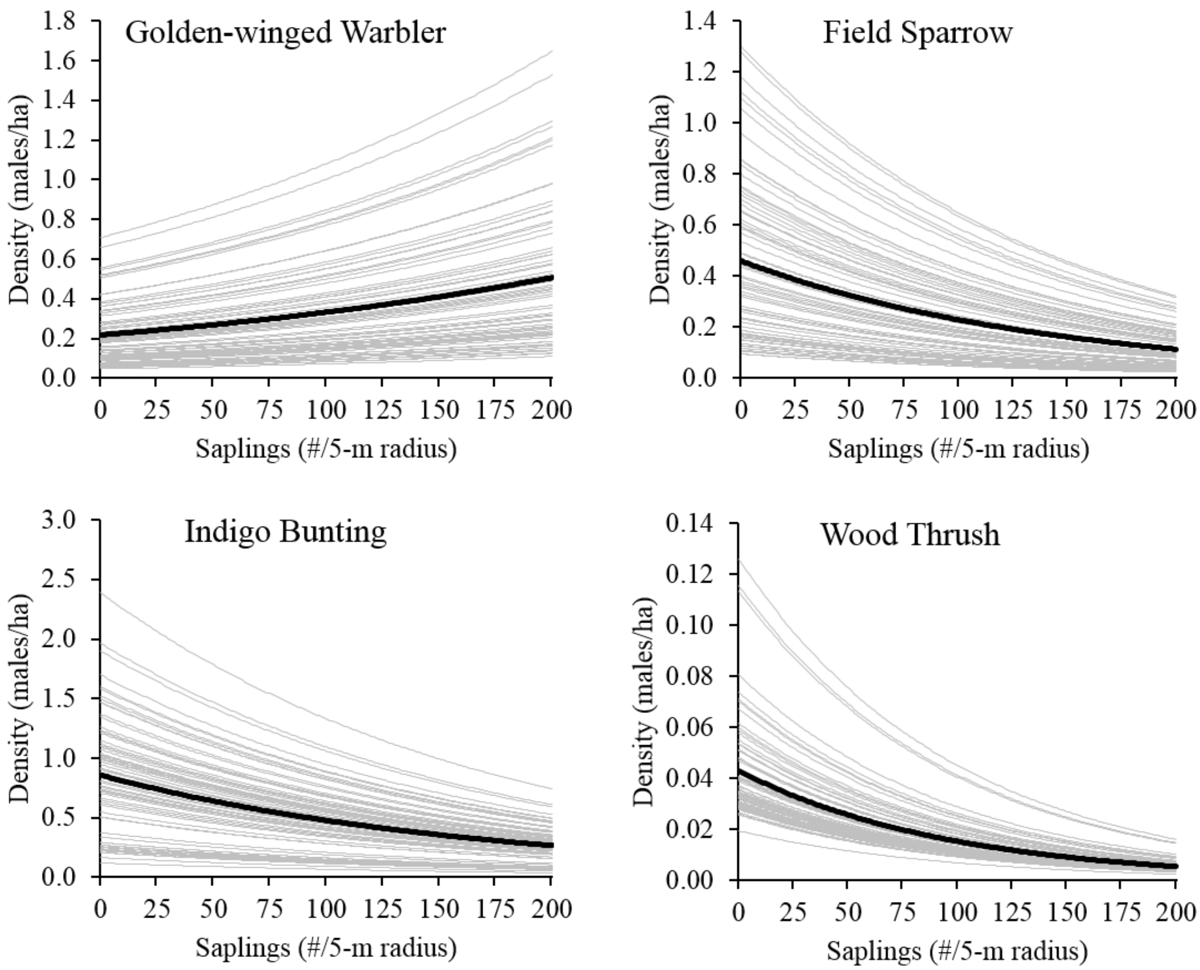
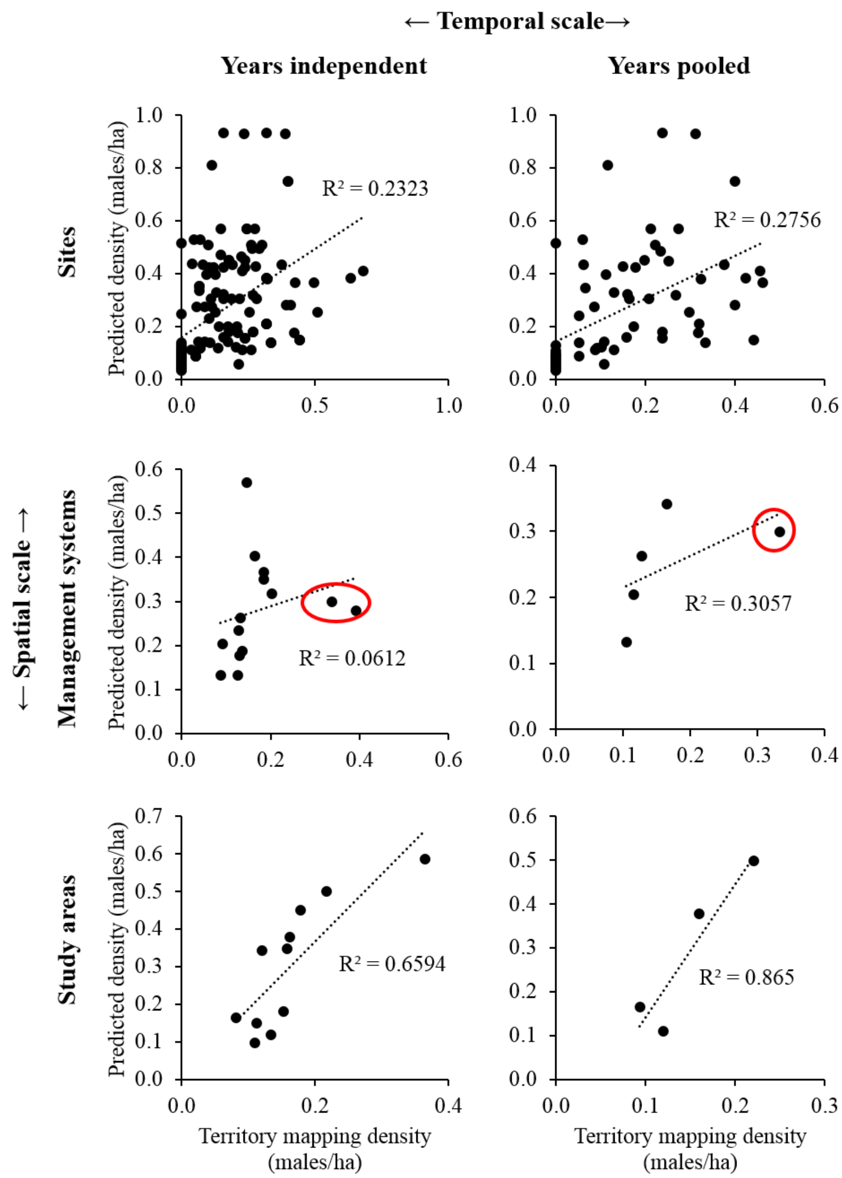


Figure 10. The accuracy of our predicted Golden-winged Warbler density estimates increased as the spatial (site [n = 70], management system [n = 5], and study area [n = 4]) and temporal (year [n = 3]) scales increased. The outlying data points (red circles) at the management system level were from the prescribed fire (old field) management system, which had the smallest sample size (n = 2 sites) of our management systems.



Study Component IV: Characterizing breeding bird communities across management systems

Summary

Across the 70 sites where point count surveys were conducted, 126 bird species were detected. The 10 most common species were similar across all management systems, and according to BBS data (Breeding Bird Surveys, Sauer et al. 2014) about half of these in each management system are experiencing population declines. The most common species represent a mix of guilds including both successional or scrub breeding birds (e.g., Golden-winged Warbler, Eastern Towhee) and woodland breeding birds (e.g., Wood Thrush, American Redstart).

Methods

See **Study Component III: Estimating density with point count surveys** section above for methods relating to point count surveys for all species. Because forest edge is an important component of Golden-winged Warbler habitat use, we quantified avian communities associated with NRCS management systems using unlimited-radius point counts. Although our surveys lacked a fixed radius, the majority of our bird detections occurred within 100 m of the observer.

Results

During 864 point count surveys conducted across 70 sites, we detected 126 bird species. Some species were ubiquitous across regions such as American Goldfinch, American Redstart, Chestnut-sided Warbler, Eastern Towhee, Gray Catbird, Red-eyed Vireo, Cedar Waxwing, Field Sparrow, Indigo Bunting, Scarlet Tanager, Ovenbird, and Mourning Dove. Several other species were detected only within a single region including Purple Finch (PA), Olive-sided Flycatcher (PA), White-throated Sparrow (PA), Bobolink (WV), Clay-colored Sparrow (WV), Orchard Oriole (WV), Summer Tanager (TN), Worm-eating Warbler (TN), and Brown Creeper (NC).

The 10 most common bird species detected on all point count surveys were similar across the five management systems (Tables 8, 9). At least half of the top ten species in each management system are experiencing significant population declines in the U.S. (1966-2012, Sauer et al. 2014). Prescribed fire (old field) was the only management system in which the Golden-winged Warbler was within the top ten most commonly detected species. Other notable species detected include Alder Flycatcher, Black-billed Cuckoo, Brown Thrasher, Canada Warbler, Cerulean Warbler, Eastern Wood-pewee, Least Flycatcher, and Worm-eating Warbler. The Cerulean Warbler is of particular relevance to NRCS as this species is the focus of a NRCS-Regional Conservation Partnership being led by The Appalachian Mountains Joint Venture and its partners in Pennsylvania, Maryland, and West Virginia. Interestingly, Cerulean Warblers were detected on point counts in 3 of 4 states included in this study (PA, WV, and TN). This finding reinforces the notion that Cerulean and Golden-winged Warbler breeding ranges overlap considerably in the heavily forested regions of the Appalachians, and the need to consider both species when developing conservation plans for private forest owners.

Table 8. The ten most common birds detected (by # of detections) at all point count stations (N) in 2012-14. Species in bold are experiencing significant population declines based on Breeding Bird Surveys (BBS; Sauer et al. 2014). See Appendix 1 for all scientific names.

	Grazing management	Old field management	Prescribed fire (old field)	Prescribed fire (young forest)	Timber harvest
N	50	48	28	26	63
No. spp. detected	106	93	52	68	106
			10 most common species		
1.	**Field Sparrow**	Chestnut -sided Warbler	**Indigo Bunting**	**Eastern Towhee**	Chestnut - sided Warbler
2.	Chestnut -sided Warbler	**Indigo Bunting**	**Field Sparrow**	**Indigo Bunting**	**Eastern Towhee**
3.	**Eastern Towhee**	**Eastern Towhee**	**Eastern Towhee**	**Yellow - breasted Chat**	Red-eyed Vireo
4.	**Indigo Bunting**	Red-eyed Vireo	**Yellow - breasted Chat**	**Field Sparrow**	American Redstart
5.	**American Goldfinch**	**Field Sparrow**	Red-eyed Vireo	Carolina Wren	Ovenbird
6.	Red-eyed Vireo	**American Goldfinch**	Hooded Warbler	Chestnut -sided Warbler	Gray Catbird
7.	Gray Catbird	American Robin	**Golden - winged Warbler**	Hooded Warbler	**Common Yellowthroat**
8.	Cedar Waxwing	Gray Catbird	American Redstart	American Redstart	Black-and - white Warbler
9.	American Robin	**Song Sparrow**	Chestnut -sided Warbler	Cedar Waxwing	**Indigo Bunting**
10.	**Common Yellowthroat**	**Common Yellowthroat**	**Common Yellowthroat**	**American Goldfinch**	Veery

Table 9. The ten most common birds detected (by number of detections) at point count stations (N) where Golden-winged Warblers also were detected in 2012-14. Species in bold are experiencing significant population declines based on Breeding Bird Surveys (BBS; Sauer et al. 2014).

	Grazing management	Old field management	Prescribed fire (old field)	Prescribed fire (young forest)	Timber harvest
N	31	27	23	12	37
No. spp. detected	97	84	47	56	80
			10 most common species		
1.	**Field Sparrow**	Chestnut -sided Warbler	**Indigo Bunting**	**Eastern Towhee**	Chestnut-sided Warbler
2.	Chestnut -sided Warbler	**Indigo Bunting**	**Eastern Towhee**	**Indigo Bunting**	**Eastern Towhee**
3.	**Eastern Towhee**	**Eastern Towhee**	**Field Sparrow**	Cedar Waxwing	**Common Yellowthroat**
4.	**Indigo Bunting**	**Field Sparrow**	**Yellow -breasted Chat**	Chestnut -sided Warbler	Gray Catbird
5.	Red-eyed Vireo	Red-eyed Vireo	Red-eyed Vireo	Carolina Wren	American Redstart
6.	**American Goldfinch**	**American Goldfinch**	Chestnut -sided Warbler	American Redstart	Cedar Waxwing
7.	Gray Catbird	Gray Catbird	**American Goldfinch**	Hooded Warbler	Red-eyed Vireo
8.	Cedar Waxwing	American Robin	**Common Yellowthroat**	**Field Sparrow**	Veery
9.	American Redstart	Cedar Waxwing	Hooded Warbler	**Yellow -breasted Chat**	Ovenbird
10.	American Robin	Veery	American Redstart	Red-eyed Vireo	Black-and -white Warbler

Study Component V: Estimating territory size and density across management systems using territory mapping

Summary

We used territory mapping in 70 sites from 2012-2014 across our study area (Appendix 2). We banded most Golden-winged Warbler males at each study site and mapped their territories throughout the breeding season (Figure 11, Appendix 2). Throughout the duration of this study, we collected 15,749 territory points for 739 individual *Vermivora* spp. males across five management systems (Figure 12). Golden-winged Warblers (n = 663; 90%) were the most common *Vermivora* spp., followed by Brewster's (n = 46; 6%), Blue-winged (n = 29; 4%), and Lawrence's (n = 1; <1%) Warblers. Overall territory size was strongly positively skewed so that 90% of all territories were <3 ha in size, averaged 1.52 ± 0.1 ha (Figure 13, Table 10). Although there was variation in the individual density estimates among each site within management systems, the overall mean densities for each management system did not differ (repeated measures ANOVA, $F_{4,69} = 1.86$, $P < 0.13$). Territory density also did not differ by management system for other Non-Golden-winged Warbler *Vermivora* (repeated measures ANOVA, $F_{4,69} = 2.04$, $P = 0.10$).

Methods

To uniquely identify individual Golden-winged Warblers, males were banded with 1-3 colored leg bands in addition to a standard USGS aluminum leg band. An in-depth description of the banding process can be found in the **Study Component II. Annual survival and body condition index among management systems** section. Although it was not necessary for all males to be banded for territory mapping efforts to occur, the majority of males were color banded for the efficiency/accuracy of territory mapping. This allowed for the territories of unbanded males to generally be bordered by banded males such that their lack of bands served effectively as a cue to identity (see Figure 11). Moreover, individual identification of unbanded males was also aided by unique variation in song characteristics (pitch, type, etc.), plumage phenotype, and other characteristics. Still, we attempted to band all males that were included in territory mapping.

Banding efforts (coupled with early spring scouting) gave us an approximate working idea of where each male was beginning to establish his breeding territory. Once males could be individually-differentiated (i.e., most were banded), we visited the area where the bird was believed to be establishing its territory and systematically searched for each male. Attempts to locate individual males occurred generally every 1-3 days and territories were ultimately delineated by visiting individual males' territories to record coordinates. We collected approximately 30 points per male *Vermivora* spp. across at least eight separate days during the breeding season. Because individual sites were usually visited on alternating days, this time period was at least 8-16 days. Locations were marked with flagging for which each male was assigned a different color; this allowed us to avoid marking individual song perches multiple times across consecutive territory visits. The result is a collection of unique locations for each male that span throughout the duration of a single breeding season.

During each visit, each surveyor systematically travelled around the habitat in search of a target male until the bird was located. If a male was undetected within his territory, this was noted after an effort of 30-45 minutes spent searching. Upon the successful detection of a target male, territory locations were recorded during burst-sampling as well as opportunistically. We followed male warblers throughout their territories and each song-post or observed location (e.g., foraging sites) was marked with unique color flagging and the position was recorded using a global positioning system (GPS) receiver. We attempted to allow several minutes (~5) to elapse between recording each coordinate set to ensure that each location was independent. Moreover, we also attempted to record only a few locations (≤5) during each visit to the territory to ensure that the collection of coordinate points for each male were spread across the largest temporal sampling period possible (i.e., to encompass the majority the territorial season for each male). In addition to collecting GPS coordinates for each male's location, we also collected data regarding the observation including behavior (which assisted with nest-searching), time, and substrate species.

To generate indices of *Vermivora* spp. territory size, we incorporated coordinates collected from territory mapping into a Geographic Information System (ArcGIS, version 10.2). Territory points for each male (within a single breeding season) were bounded with minimum convex polygons using the minimum convex hull feature in ArcMap (Figure 12). This approach allowed us to generate a territory density (regardless of territory size) in males/ha for each site and each management system as a whole. Using the calculate geometry function in ArcMap, territory size was estimated for each male during each breeding season from 2012-2014. To examine potential differences between territory densities among different management systems, we used a one-way analysis of variance (ANOVA). As a post-hoc pairwise comparison, we used the Tukey's test to examine differences among groups (i.e., management systems).

Results

During 21 April – 29 June, 2012 - 2014 we located and mapped territories of male Golden-winged Warblers within most study sites (n = 70). We collected 15,749 territory locations for male *Vermivora* spp. during the course of this study. Most of these points (66.3%) were collected as the male perched within trees followed by shrubs (27.0%) and on *Rubus* spp. canes (3.8%). Most territory points were collected while males sang Type 1 songs (typical song; a high-pitched *beee-bzzz-bzzz-bzzz*) but singing Type 2 songs (a more vocally-complex, secondary song composed of irregular trills and buzzes; see Highsmith 1989) and foraging were also common behaviors observed during mapping. Although we did not formally constrain our mapping efforts within specific hours, the majority of territory locations were taken between sunrise and 1100. We also collected fewer territory locations during the second half of the breeding season as males during that time were much less predictable to locate as a consequence of the advancing progression of the breeding season (e.g., feeding nestlings). Males that failed to successfully nest during the first attempt anecdotally appeared to have a bimodal pattern of increased singing behavior before each of their nesting attempts. Other males appeared to nest early (and probably successfully so) and mapping was restricted to the first few visits to the territory after which time these early males fell quiet while they reared their broods.

Minimum territory size

Although there was variation among males in their territorial behavior, we successfully mapped 739 *Vermivora* spp. territories during the study. Golden-winged (n = 663; 90%) were most common, followed by Brewster's (n = 46; 6%), Blue-winged (n = 29; 4%), and Lawrence's (n = 1; <1%) Warblers. Overall territory size was strongly positively skewed so that 90% of all territories were <3 ha in size, averaged 1.52 ± 0.1 ha, and ranged from 0.002 to 22.6 ha (Figure 13, Table 10). Large territories appeared to be the result of 1) unpaired males traveling in search of mates; 2) males that shifted territories during the breeding season; or 3) territories that included non-nesting habitat (i.e., grass fields and closed-canopy forest) within the minimum convex polygon. Excluding seven male Golden-winged Warblers that exhibited these characteristics, the mean and median territory sizes were 1.32 ± 0.07 and 0.88 ha, respectively.

Golden-winged Warbler territory densities across the 70 sites where *Vermivora* spp. were territory-mapped ranged from 0 – 4.61 males/10 ha. Mean Golden-winged Warbler density estimates by management system ranged from 1.04 – 3.74 males/10 ha with a mean density of 1.48 (0.17) males/10 ha (Table 11). Although there was variation in the individual density estimates among each site within management systems, the overall mean densities for each management system were not different (repeated measures ANOVA, $F_{4,69} = 1.86$, $P < 0.13$). Territory density also did not differ by management system for other Non-Golden-winged Warbler *Vermivora* (repeated measures ANOVA, $F_{4,69} = 2.04$, $P = 0.10$). Because many of our sites were studied across multiple consecutive years, we also had the opportunity to observe how Golden-winged Warbler territory density changed throughout time. We observed three general trends among our sites: first, we saw that newly-created sites hosted annually increasing densities of territories (Figure 14a). Second, we observed that sites of intermediate age tended to maintain their territory densities from one year to the next (Figure 14b). Finally, the oldest sites supported annually diminishing numbers of territories until the sites eventually became unoccupied (Figure 14c).

Table 10. Summary statistics of *Vermivora* spp. territories mapped from 2012-2014 in North Carolina, Pennsylvania, Tennessee, and West Virginia. *Mean value with seven outliers removed.

Species	n	Mean size (ha)	SE	Median	Minimum	Maximum
Golden-winged Warbler	521	1.4*	0.1	0.9	0.1	22.6
Brewster's Warbler	39	2.2	0.5	1.5	0.1	14.6
Blue-winged Warbler	18	2.8	0.7	1.6	0.1	9.2
Lawrence's Warbler	1	0.5	-	0.5	0.5	0.5
All *Vermivora*	579	1.5	0.1	0.9	0.1	22.6

Table 11. Mean and median territory density (males/10 ha) across sites occupied by *Vermivora* spp. across each of five management systems.

Management system (n = 70)	Golden-winged Warbler mean density (SE); median	Other *Vermivora* spp. mean density (SE); median
Grazing management (n = 12)	1.26 (0.30); 0.68	0.37 (0.08); 0.27
Old field management (n = 17)	1.39 (0.31); 1.46	0.16 (0.10); 0
Prescribed fire (old field; n = 2)	3.37 (0.82); 4.0	0.45 (0.20); 0.38
Prescribed fire (young forest; n = 13)	1.05 (0.41); 0	0.08 (0.07); 0
Timber harvest (n = 26)	1.69 (0.30); 1.27	0.14 (0.05); 0

Figure 11. An example of a timber harvest (bounded by orange) with the mapped Golden-winged Warbler territories (yellow polygons) from 2014. Most males at this site were color banded (as shown with legs bearing color band combinations) and the few remaining unbanded males were generally bordered by banded males.

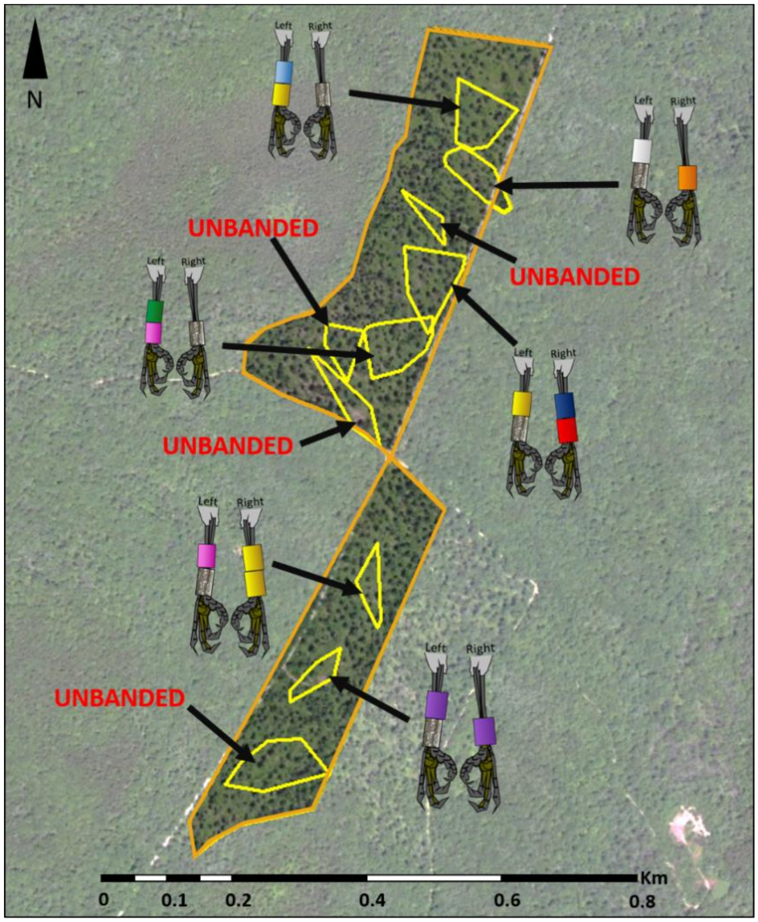


Figure 12. Examples of Golden-winged Warbler territory (polygons) placement across four states and management systems from 2014: WV grazing management (top left), TN prescribed fire (old field) (top right), NC old field management (bottom left), and PA timber harvest (bottom right).

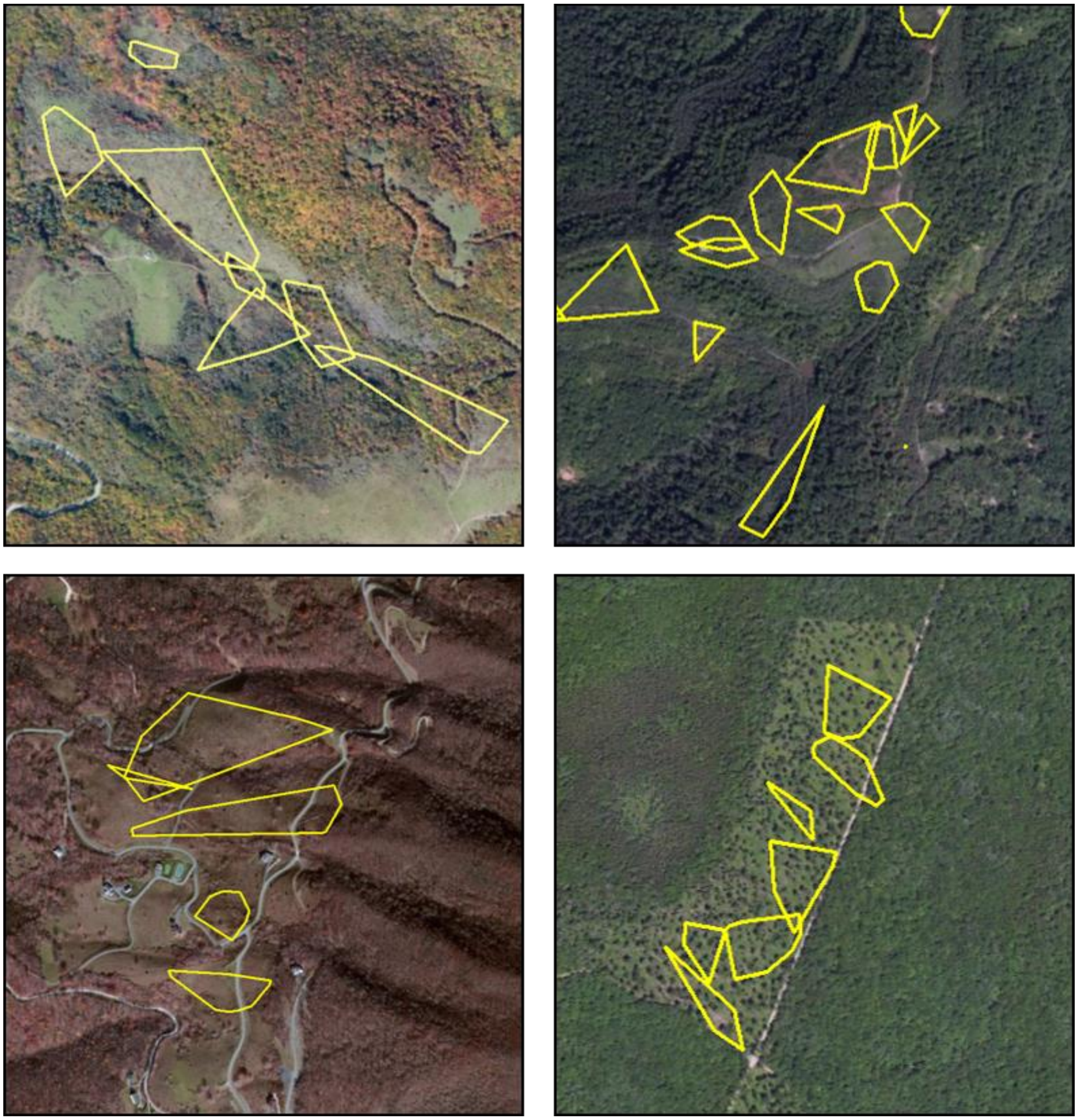


Figure 13. The distribution of Golden-winged Warbler (black) and other *Vermivora* spp. (Blue-winged, Brewster's, and Lawrence's Warblers, gray) territory sizes were positively skewed so that 90% of territories were <3 ha in size.

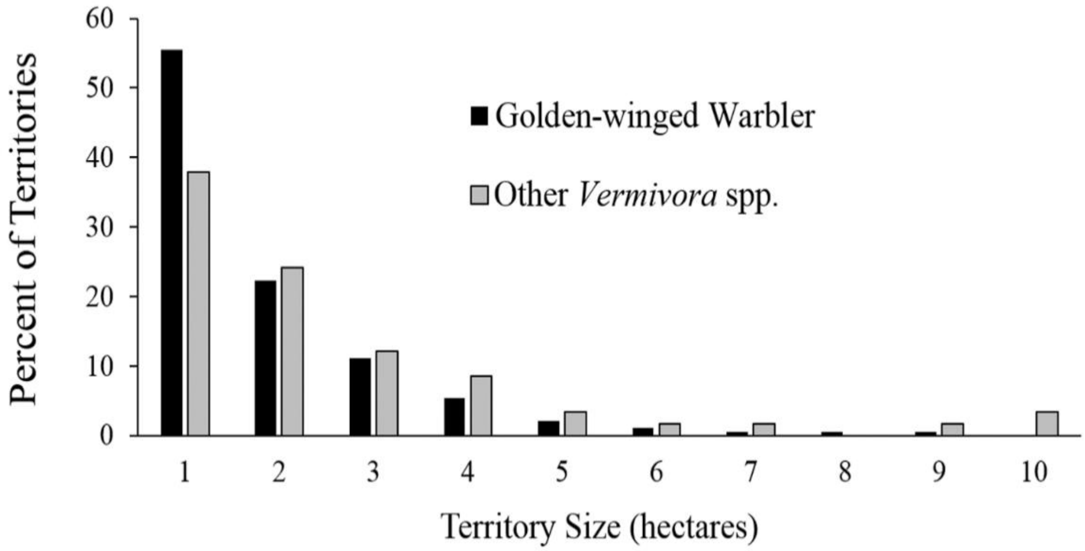
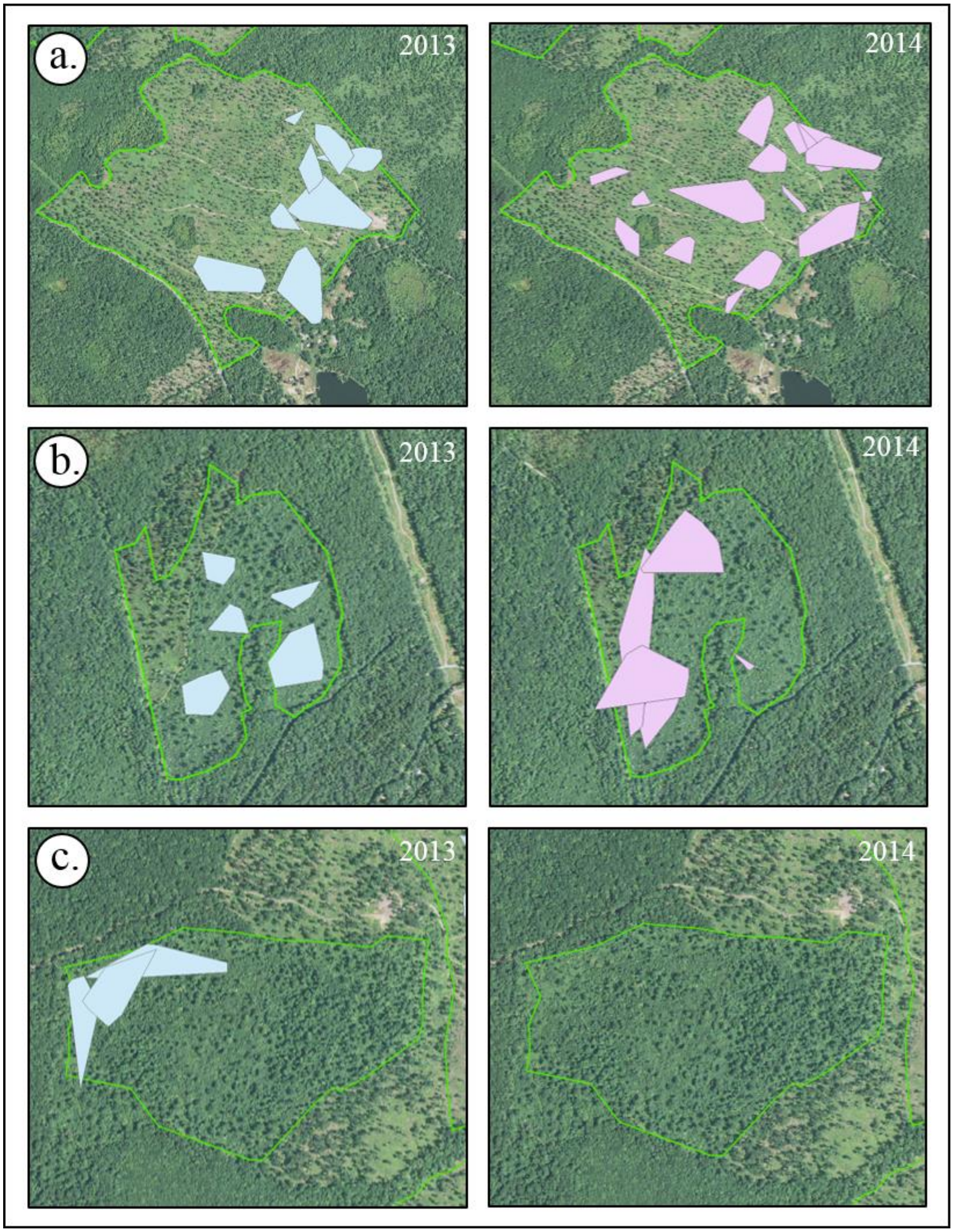


Figure 14. Three general temporal density trends observed for Golden-winged Warbler in Pennsylvania timber harvests where (a) a site exhibited an increase in territory density from 2013-14 during its 2nd and 3rd year post-harvest, (b) a site maintained a constant territory density from 2013-14 during its 7th and 8th years post-harvest, and (c) a site exhibited diminishing densities from 2013-14 during its 11th and 12th years post-harvest.



Study Component VI: Evaluation of nest-site selection and nest survival and productivity among management systems

Summary

Across 46 sites, we found and monitored 337 *Vermivora* spp. nests, 85% of which were Golden-winged x Golden-winged Warbler nests. DSR (daily survival rate) for Golden-winged Warbler nests was 0.963 (± 0.003) with a 0.767 (± 0.035) probability of raising a successful nest over a breeding season. Successful Golden-winged Warblers nests produced 4.0 (± 0.1) fledglings. Nest survival was best explained by the time-within-season, where nests early in the season were more likely to fledge young than nests late in the season. Management system had little to no effect on nest survival rates. A number of vegetation characteristics were related to nest survival rates, including *Rubus* cover (+ association), bare ground cover (- association), and tall shrubs (- association). Mean Golden-winged Warbler nest productivity, the number of fledglings produced per ha, across management systems was 0.51 (± 0.05) fledglings/ha. In addition, we measured vegetation characteristics at 317 nests and 317 random plots to evaluate attainment of ***recommended*** and ***high-quality*** nesting vegetation. We defined ***recommended*** nesting vegetation as the recommended vegetation characteristics provided in the *Golden-winged Warbler Breeding Season Conservation Plan* (Roth et al. 2012) and ***high-quality*** nesting vegetation as vegetative conditions that would result in above-average nest DSR. Our ranges of ***recommended*** levels for bare ground, grass, forb, *Rubus*, and woody vegetation cover/1-m radius overlapped the values recommended in the *Golden-winged Warbler Breeding Season Conservation Plan* (Roth et al. 2012) by 3-53%. In general, increased attention to management of grass cover may provide more potential nest sites because attainment of ***recommended*** levels of this vegetation feature was least (17 ± 3%) across management systems. Attainment of ***high-quality*** nesting vegetation was greatest among timber harvest sites (56 ± 16%) and attainment of ***high-quality*** nesting vegetation was least among grazing management sites (43 ± 12%). In general, increased attention to management of *Rubus* spp. cover may increase nest survival because attainment of ***high-quality*** levels for this vegetation feature was least (17 ± 3%) across management systems.

Methods

Nest searching

During 2012-2014, we located and monitored nests of Golden-winged Warblers, Blue-winged Warblers, and hybrids on 46 sites (Appendix 2) using methods outlined in Martin and Geupel (1993). We considered nests attended to by male and female Golden-winged Warbler phenotypes as Golden-winged Warbler nests, nests attended to by male and female Blue-winged Warbler phenotypes as Blue-winged Warbler nests, and nests attended to by male and female hybrid phenotypes or *Vermivora* spp. phenotypes that did not match as hybrid nests. *Vermivora* spp. raise one brood per season and generally renest up to two times after nest failure, although more than two renests are possible. We minimized the potential bias of discovering a disproportionate number of nests in open vegetation types by following female behavioral cues (such as *tzip* calls (Ficken and Ficken 1968), nest material or food carries, and inconspicuous movements to areas with nesting cover) to locate nests rather than systematic searching. 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 nest fate determination while minimizing potential negative impacts of visiting nests. We defined complete clutch size as the number of Golden-winged Warbler eggs present after the onset of incubation. We defined the number of young fledged as the number of nestlings observed on the last day we monitored the nest prior to fledging. If at least one Golden-winged Warbler nestling fledged, we classified a nest as "successful". To decrease bias associated with misidentification of nest fate (Streby and Andersen 2013), we used a combination of nest condition, the presence and age of fledglings, and the presence and behavior of color-marked adults to determine nest fate.

Vegetation sampling

We measured vegetation characteristics at nests and random plots 19 ± 1 days (range 0-60 days) after determining nest fate. To sample vegetation, we used a nested plot design (1-m, 5-m, and 11.3-m radius) centered at nest sites as well as at a paired random sites located 25-50 m from the nest (Figure 15). At plot center for nest and random plots, we recorded leaf litter depth and percent cover for leaf litter, bare ground, grasses, forbs, vines, blackberry/raspberry (*Rubus* spp.), and woody plant species within a 1-m radius. We tallied 1-2 m tall shrubs ("short shrubs"), >2 m tall shrubs ("tall shrubs"), and saplings (1-10 cm dbh, >0.5 m tall) by species within the 5-m radius plot. Within 11.3 m of plot center, we recorded the species and dbh of all live trees (>10 cm dbh), number of snags (>10 cm dbh), average shrub height, and average sapling height. We used the same vegetation protocol at plots distributed randomly (1 plot/ha) throughout the areas where the conservation practices had been implemented (hereafter, "stand-level plots"). Stand-level plots quantified the vegetative characteristics available across our sites.

We assigned each vegetation plot to a management system (grazing management, old field management, prescribed fire (old field), prescribed fire (young forest), or timber harvest; see management system descriptions, pages 9 – 11) and a vegetation community type (woody- or herbaceous-dominated). Because the Golden-winged Warbler Breeding Season Conservation Plan (Roth et al. 2012) provided different preferred levels of forb cover for woody- and herbaceous-dominated sites, we classified our nests as woody- or herbaceous-dominated when analyzing selection of forb cover. We considered prescribe fire (young forest) and timber harvest as woody-dominated and grazing management, old field management, and prescribe fire (old field) as herbaceous-dominated.

Data analysis

Nest-site selection

All Golden-winged Warbler nests that we located were included in analyses of nest-site selection. We used Simple Saddlepoint Approximation (SSA; Renshaw 1998, Matis et al. 2003) to graphically evaluate the range of vegetative conditions preferred or avoided by Golden-winged Warblers on our sites. SSA uses the mean, variance, and skewness of variables to find a general saddlepoint approximation of a probability distribution, which is akin to an approximation of the probability density function (PDF). We used SSA to obtain the respective PDFs for nest and random plots, which were then used to generate a selection function (nest PDF/random PDF = selection function). A selection function value > 1 indicates positive selection, or use that exceeds realized availability; a value < 1 indicates avoidance, or use less than realized availability; and a selection value of 1 indicates random use, or use in the same proportion to realized availability. The Golden-winged Warbler Breeding Season Conservation Plan (Roth et al. 2012) also used SSA to identify preferred levels of bare ground cover/1-m radius (0-10%), grass cover/1-m radius (5-25%), forb cover/1-m radius at herbaceous-dominated nests (4-45%), forb cover/1-m radius at woody-dominated nests (45-100%), *Rubus* cover/1-m radius (5-40%), and woody vegetation cover/1-m radius (5-50%). We compared our results with those values presented in the Golden-winged Warbler Breeding Season Conservation Plan (Roth et al. 2012) by calculating percent overlap of the two ranges of preferred levels of cover.

Attainment of preferred and quality nesting vegetation

We identified two types of management targets for Golden-winged Warbler nesting vegetation: ***recommended*** nesting vegetation and ***high-quality*** nesting vegetation. We defined ***recommended*** nesting vegetation as the recommended vegetation characteristics for nest sites from the Golden-winged Warbler Breeding Season Conservation Plan (Roth et al. 2012). We defined ***high-quality*** nesting vegetation as vegetative conditions, identified in our most-plausible ($\Delta AIC_c \leq 2$) nest survival models, that would result in above-average DSR. We defined "average DSR" as the overall DSR estimate for all Golden-winged Warbler nests during our study. To evaluate the attainment of ***recommended*** and ***high-quality*** nesting vegetation, we examined vegetation characteristics at stand-level plots. We defined "attainment" as the proportion of stand-level plots having vegetation characteristics that fell within ranges for ***recommended*** and ***high-quality*** nesting vegetation.

Nest survival

We included all nests that reached at least egg-laying in our nest-survival analyses. We developed *a priori* candidate models for *Vermivora* spp. nest daily survival rate (DSR) and grouped the models into three model suites. Model suite 1 included species covariates (male species, female species, and nest species) and was solely intended to evaluate differences in nest survival among Golden-winged Warbler and other *Vermivora* spp. We evaluated species covariates in a separate model suite because our sample size of other *Vermivora* spp. nests was relatively small (n = 49) for modeling other covariates relative to Golden-winged Warbler nests (n = 288). Model suite 2 included only Golden-winged Warbler nests and featured models with management system, study area, time-within-season, vegetation community type, and year covariates. Model suite 3 also included only Golden-winged Warbler nests and included models with vegetation covariates.

We estimated DSR for *Vermivora* spp. nests and evaluated competing DSR models using the nest survival model in program MARK (ver. 7.1, Colorado State University, Ft. Collins, Colorado, USA). We modeled the binomially distributed data with the user-defined, logit-link function while simultaneously considering associations with covariates. We 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, we assumed a 25-day nesting period, with 4 days for egg-laying, 11 days for incubation, and 10 days for brooding (Confer et al. 2011). We did not standardize individual covariates, because the unstandardized covariates did not affect numerical optimization (Dinsmore et al. 2002, Rotella 2007). However, we did standardize MARK nesting dates for each study area. In other words, we independently set the earliest nest date as MARK day 1 for each study area.

We used Akaike's Information Criterion adjusted for small sample bias (AIC_c) for model selection (Burnham and Anderson 2002). We considered the model with the lowest AIC_c value to be the most-supported model given the data and models with $\Delta AIC_c \leq 2$ to be plausible, competing models (Burnham and Anderson 2002). We assessed the relative plausibility of each model in the model suite by comparing model weights (w_i). We presented beta coefficients and their standard errors (SE) and 95% confidence intervals (CI) for covariates in supported models to infer the biological importance of covariates.

Nest productivity

We estimated Golden-winged Warbler nest productivity for each management system, defined as the number of fledglings produced per ha. Nest productivity was the product of four components: 1) probability of nest success given three nesting attempts ($1-[1-DSR^{25}]^3$), 2) number of fledglings produced per successful nest, 3) territory density, and 4) pairing rate. We estimated territory density by mapping territories of all Golden-winged Warblers on our nest-monitoring sites. Territory density for each management system was the mean of the across-year densities for sites within each management system. We used a constant pairing rate (0.8) among management systems based on a compilation of pairing rates from Golden-winged Warbler populations across the Appalachian Mountain region (Confer et al., unpubl. data). We used the *propagate* package in program R (version 3.1.2, R Development Core Team 2014), a general function for the calculation of uncertainty propagation, to incorporate the uncertainty associated with each component into our final estimate of Golden-winged Warbler nest productivity.

Results

The types of and values (mean and SE) for vegetative characteristics measured at nests and used in these analyses is presented in Table 12. We presented all values in text and tables as mean ± standard error of the mean (SE) unless otherwise noted.

Nest-site selection

We measured vegetation characteristics at 317 nests and 317 random plots during 2012-2014. Our ***recommended*** ranges for bare ground, grass, forb, *Rubus*, and woody vegetation cover/1-m radius (Figure 16A-E) overlapped the ***recommended*** ranges provided in the *Golden-winged Warbler Breeding Season Conservation Plan* (Roth et al. 2012) by 3-53% (Figure 16F). We suspect that differences may be due to the greater variety of sites included in the Golden-winged Warbler conservation plan, both in terms of geography and vegetation communities, relative to our CEAP-generated sample from a portion of the Appalachian Mountains population segment.

Attainment of recommended nesting vegetation

Regardless of management system, attainment of ***recommended*** levels of bare ground cover was greatest (85 ± 4%, range 73-92%) and attainment of ***recommended*** levels grass cover was least (32 ± 5%, range 19-44%; Figure 17). When considering all vegetation cover types, attainment of ***recommended*** levels of nesting vegetation was greatest among old field management sites (51 ± 12%, range 17-90%) and least among prescribed fire (young forest) sites (42 ± 10%, range 19-73%). Prescribed fire (young forest) and timber harvest sites, because of their origins in silviculture, had the greatest attainment of ***recommended*** levels of woody cover. Conversely, grazing management, old field management, and prescribed fire (old field), being dominated by herbaceous vegetation, had the greatest attainment of ***recommended*** levels of forb cover. Golden-winged Warbler territories are structurally diverse and must support activities other than nesting (e.g., singing, foraging, and fledgling-rearing). Thus, attainment of ***recommended*** levels of nesting vegetation need not, and perhaps should not, be 100% across an entire site.

Nest survival

We monitored the survival of 288 Golden-winged Warbler x Golden-winged Warbler nests, 3 Blue-winged Warbler x Blue-winged Warbler nests, and 46 mixed species nests during 2012-2014. Overall DSR for all Golden-winged Warbler nests was 0.963 ± 0.003, which equates to a probability of 0.767 ± 0.035 of raising a successful nest, given three attempts. Successful Golden-winged Warbler nests (n = 139) produced 4.0 ± 0.1 fledglings. Overall DSR for other *Vermivora* spp. nests was 0.967 ± 0.007, which equates to a probability of 0.812 ± 0.079 of raising a successful nest given three attempts. Successful other *Vermivora* spp. nests (n = 29) produced 4.0 ± 0.2 fledglings.

Among the models of DSR of all *Vermivora* spp. nests in model suite 1 (species covariates), the most-supported model contained a covariate for male species (Table 13). A model containing male and female species covariates and the null model also were plausible. Based on model selection and the relative importance of covariates from summing model weights (Burnham and Anderson 2002), it appears that male species may be more strongly associated with DSR than female species. Golden-winged Warbler males had nests with lower DSR (0.960 ± 0.003) than other *Vermivora* spp. males (0.977 ± 0.007). If we consider male and female species as surrogates for territory and nest-site characteristics, respectively, then territory selection by males, which differs among *Vermivora* spp. (Patton et al. 2010), may be a more important determinant of nest fate than nest-site selection by females within those territories.

Among the models of DSR of Golden-winged Warbler nests in model suite 2 (management system, study area, time-within-season, vegetation community type, and year covariates), the most-supported model contained a linear time-within-season covariate (Table 14). A model containing linear and quadratic time-within season covariates also was plausible. DSR decreased as the season progressed (Figure 19). Models that included management system had no support (Table 14), suggesting that DSR was similar among management systems. However, the probability of producing a successful nest given three attempts (a common number of attempts among study areas; Aldinger et al., in review) showed more differentiation among management systems on average with the highest DSR among grazing management nests (Figure 20).

Among the models of DSR of Golden-winged Warbler nests in model suite 3 (vegetation covariates), the most-supported model contained a *Rubus* cover/1-m radius covariate (Table 15). Models containing bare ground cover/1-m radius, tall shrubs/5-m radius, or distance to forest edge also were plausible. Among the plausible models, beta estimate 95% confidence intervals all overlapped zero, suggesting relatively weak associations between DSR and vegetation covariates. However, all models had $\Delta AIC_c \leq 4$, suggesting that all were relatively competitive in modeling DSR. Therefore, a variety of vegetation characteristics may be associated with DSR.

Attainment of high-quality nesting vegetation

For ***high-quality*** nesting vegetation, our models suggested 13-90% *Rubus* cover/1-m radius, 0-1% bare ground cover/1-m radius, <5 tall shrubs/5-m radius, and 39-230 m from a forest edge. However, we advise caution regarding the maximum values for *Rubus* cover/1-m radius and distance from a forest edge because 95% of the values for *Rubus* cover/1-m radius and distance from a forest edge were below 48% and 127 m, respectively. As such, we revised our ***high-quality*** levels of *Rubus* cover/1-m radius to be 13-48% and distance from a forest edge to be 39-127 m.

Regardless of management system, attainment of ***high-quality*** numbers of tall shrubs/5-m radius was greatest (80 ± 5%, range 66-96%) and attainment of ***high-quality*** levels of *Rubus* cover/1-m radius was least (17 ± 3%, range 14-41%; Figure 18). When considering all vegetation cover types, attainment of ***high-quality*** levels of nesting vegetation was greatest for timber harvest (56 ± 16%, range 13-82%) and least for grazing management (43 ± 12%, range 18-66%).

Nest productivity

Nest productivity (Figure 21) ranged from 0.25 ± 0.18 fledglings/ha for prescribed fire (young forest) sites to 0.87 ± 0.23 fledglings/ha for prescribed fire (old field) sites (overall = 0.51 ± 0.05 fledglings/ha). However, these two management systems also had the widest error bars due to variation in two of the nest productivity components: 1) probability of nest success given three attempts and 2) number of young fledged per successful nest.

Table 12. An index of the types of and values [mean (SE)] for vegetative characteristics measured at nests and used in these analyses, by management practice.

Variable	Grazing management	Old field management	Prescribed fire (old field)	Prescribed fire (young forest)	Timber harvest
Cover (%/1-m radius)					
Bare ground	0.8 (0.2)	1.0 (0.4)	0.0 (0.0)	0.4 (0.4)	0.7 (0.2)
Litter	3.5 (0.8)	6.6 (0.9)	7.0 (1.7)	14.2 (5.2)	6.5 (1.1)
Grass	24.3 (1.9)	24.8 (1.7)	20.4 (3.1)	10.0 (4.1)	13.9 (2.0)
Forb	40.0 (2.0)	42.0 (2.2)	48.5 (3.9)	48.2 (8.0)	12.6 (1.7)
Rubus	13.1 (1.8)	14.8 (1.7)	17.4 (2.9)	7.7 (5.7)	7.3 (1.9)
Woody	15.2 (2.2)	4.2 (1.1)	2.2 (0.6)	17.9 (5.5)	48.2 (3.1)
Forest edge distance (m)	32.6 (4.3)	23.8 (2.3)	14.8 (2.7)	65.5 (15.7)	63.1 (5.9)
Shrub layer height (m)	2.8 (0.2)	2.7 (0.2)	0.9 (0.2)	1.5 (0.3)	1.7 (0.1)
Sapling layer height (m)	3.1 (0.3)	3.3 (0.2)	3.4 (0.2)	2.5 (0.3)	1.8 (0.1)
Count/5-m radius					
1-2 m tall shrubs	15.6 (2.6)	4.5 (1.0)	4.4 (3.4)	5.5 (2.1)	16.7 (2.3)
>2 m tall shrubs	7.9 (1.4)	4.5 (1.1)	2.9 (1.6)	7.8 (3.6)	4.7 (0.9)
Saplings	5.4 (0.8)	8.9 (1.2)	12.7 (2.1)	44.5 (8.8)	75.4 (6.0)
Count/11.3-m radius					
Snags	0.1 (0.1)	0.1 (0.0)	2.0 (0.6)	1.1 (0.4)	0.5 (0.1)
Woody stems >10 cm dbh	4.3 (0.6)	5.0 (0.6)	7.6 (1.2)	3.5 (0.9)	2.7 (0.3)
Basal area (m^2/ha)	2.9 (0.0)	4.3 (0.0)	8.6 (0.0)	5.0 (0.0)	3.6 (0.0)

Table 13. Model-selection results for daily survival rate (DSR) of nests of Golden-winged Warblers from model suite 1 using program MARK. AIC_c is Akaike's Information Criterion adjusted for small sample size, ΔAIC_c is the difference in AIC_c values between individual models and the top model, w_i is the model weight, and K is the number of parameters in the model. We presented beta estimates for covariates in the plausible ($\Delta AIC_c \leq 2$) models.

DSR model	AIC_c	ΔAIC_c	w_i	K	Beta estimates: Mean (95% CI)
Male species	1034.4	0.00	0.37	2	Non-Golden-winged Warbler male (Intercept): 3.745 (3.118, 4.373) Golden-winged Warbler male: -0.571 (-1.219, 0.077)
Male species + Female species	1035.0	0.56	0.28	3	Intercept: 3.453 (2.691, 4.215) Golden-winged Warbler male: -0.657 (-1.323, 0.009) Golden-winged Warbler female: 0.398 (-0.223, 1.018)
Constant	1035.9	1.50	0.17	1	Intercept: 3.221 (3.064, 3.378)
Nest species	1037.2	2.77	0.09	2	
Female species	1037.4	2.98	0.08	2	

Table 14. Model-selection results for daily survival rate (DSR) of nests of Golden-winged Warblers from model suite 2 using program MARK. AIC_c is Akaike's Information Criterion adjusted for small sample size, ΔAIC_c is the difference in AIC_c values between individual models and the top model, w_i is the model weight, and K is the number of parameters in the model. We presented beta estimates for covariates in the plausible ($\Delta AIC_c \leq 2$) models.

DSR model	AIC_c	ΔAIC_c	w_i	K	Beta estimates: Mean (95% CI)
Time	954.5	0.00	0.71	2	Intercept: 3.857 (3.447, 4.266) T: -0.025 (-0.039, -0.011)
Time + Time2	956.4	1.89	0.28	3	Intercept: 3.973 (3.170, 4.776) T: -0.035 (-0.092, 0.022) TT: 0.000 (-0.001, 0.001)
Constant (intercept only)	964.8	10.28	0.00	1	
Management system	965.9	11.37	0.00	5	
Vegetation community type	966.1	11.62	0.00	2	
Study area	968.4	13.83	0.00	4	
Year	968.7	14.20	0.00	3	
Management system + Year	969.5	15.02	0.00	7	
Vegetation community type + Year	970.1	15.61	0.00	4	
Study area + Year	972.3	17.77	0.00	6	

Table 15. Model-selection results for daily survival rate (DSR) of nests of Golden-winged Warblers from model suite 3 using program MARK. AIC_c is Akaike's Information Criterion adjusted for small sample size, ΔAIC_c is the difference in AIC_c values between individual models and the top model, w_i is the model weight, and K is the number of parameters in the model. We presented beta estimates for covariates in the plausible ($\Delta AIC_c \leq 2$) models.

DSR model	AIC_c	ΔAIC_c	w_i	K	Beta estimates: Mean (95% CI)
Rubus cover/1-m radius	893.0	0.00	0.15	2	Intercept: 3.125 (2.916, 3.334) Rubus cover/1-m radius: 0.010 (-0.001, 0.021)
Bare ground cover/1-m radius	893.5	0.53	0.12	2	Intercept: 3.281 (3.105, 3.457) Bare ground cover/1-m radius: -0.050 (-0.101, 0.002)
Tall shrubs/5-m radius	894.2	1.22	0.08	2	Intercept: 3.312 (3.118, 3.507) Tall shrubs/5-m radius: -0.013 (-0.028, 0.003)
Constant (intercept only)	894.3	1.33	0.08	1	Intercept: 3.245 (3.075, 3.414)
Distance to forest edge	894.5	1.51	0.07	2	Intercept: 3.139 (2.913, 3.365) Distance to forest edge: 0.003 (-0.001, 0.007)
Woody cover/1-m radius	895.2	2.14	0.05	2	
Short shrubs/5-m radius	895.3	2.29	0.05	2	
Grass cover/1-m radius	895.7	2.66	0.04	2	
Snags/11.3-m radius	895.9	2.86	0.04	2	
Herbaceous cover/1-m radius	896.1	3.07	0.03	2	
Sapling height	896.1	3.08	0.03	2	
Non-vegetation cover/1-m radius	896.2	3.18	0.03	2	
Shrub height	896.3	3.26	0.03	2	
All shrubs/5-m radius	896.3	3.29	0.03	2	
Non-herbaceous cover/1-m radius	896.3	3.32	0.03	2	
Saplings/5-m radius	896.3	3.32	0.03	2	
Canopy trees/11.3-m radius	896.3	3.32	0.03	2	
Forb cover/1-m radius	896.3	3.33	0.03	2	
All shrubs and saplings/5-m radius	896.3	3.33	0.03	2	
Litter cover/1-m radius	896.3	3.33	0.03	2	

Figure 15. An example of the placement of nest and random vegetation plots within a Golden-winged Warbler territory (yellow polygon). Vegetation data were collected within 1-m, 5-m, and 11.3-m radius plots (black circles), centered on the nest or random location, and along four 11.3-m transects (black dashed lines), one in each cardinal direction from plot center.

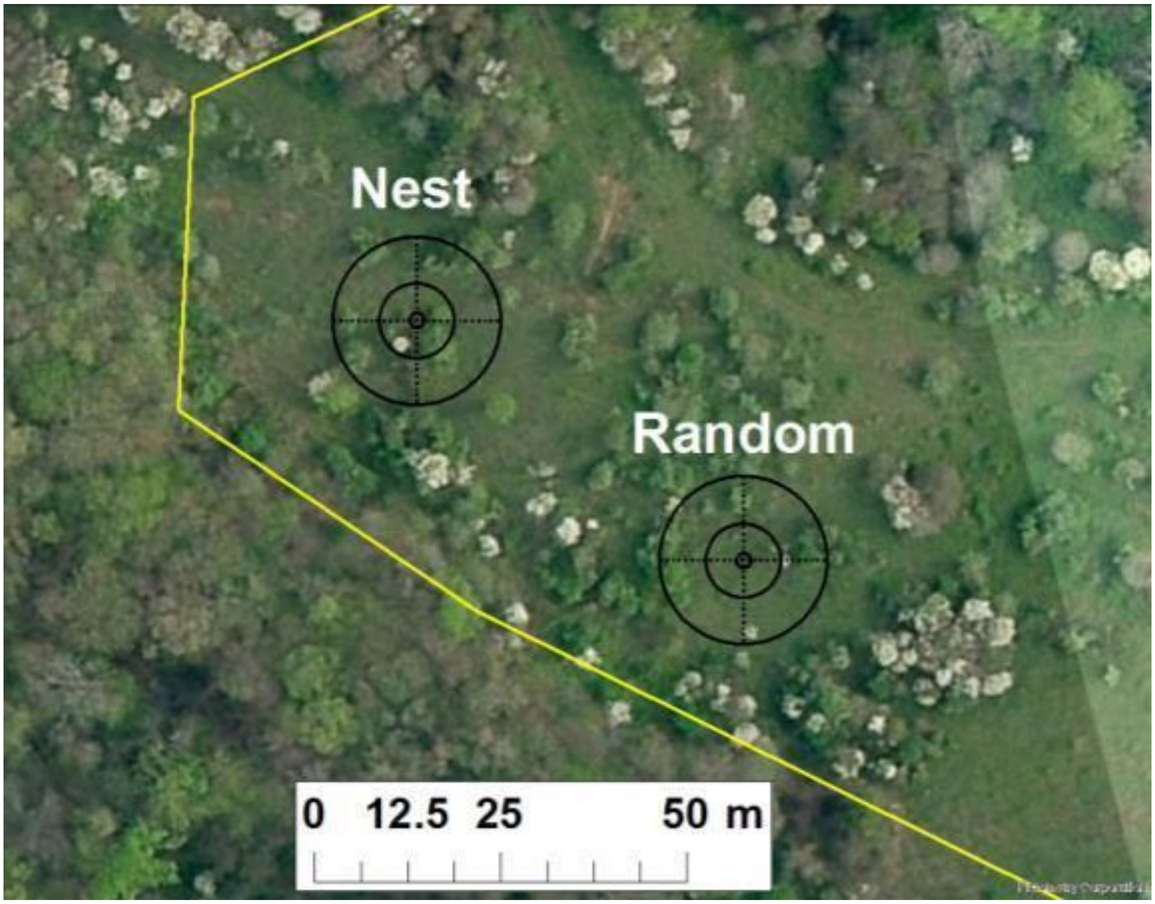


Figure 16. We analyzed selection of (a) bare ground, (b) grass, (d) *Rubus*, and (e) woody cover/1-m radius using all Golden-winged Warbler nests pooled (orange lines). Selection of (c) forb cover/1-m radius was partitioned into woody-dominated nests (green line; prescribed fire (young forest) and timber harvest nests) and herbaceous-dominated nests (blue line; grazing management, old field management, and prescribed fire (old field) nests) to reflect the methods of the *Golden-winged Warbler Breeding Season Conservation Plan* (Roth et al. 2012). A selection ratio (black line) value > 1 indicates selection, or use greater than availability; a value < 1 indicates avoidance, or use less than availability; and a selection value of 1 indicates random use, or no difference in use compared to availability. Our *recommended* levels of cover (a-e) overlapped with values provided in the *Golden-winged Warbler Breeding Season Conservation Plan* by 3-53% (f).

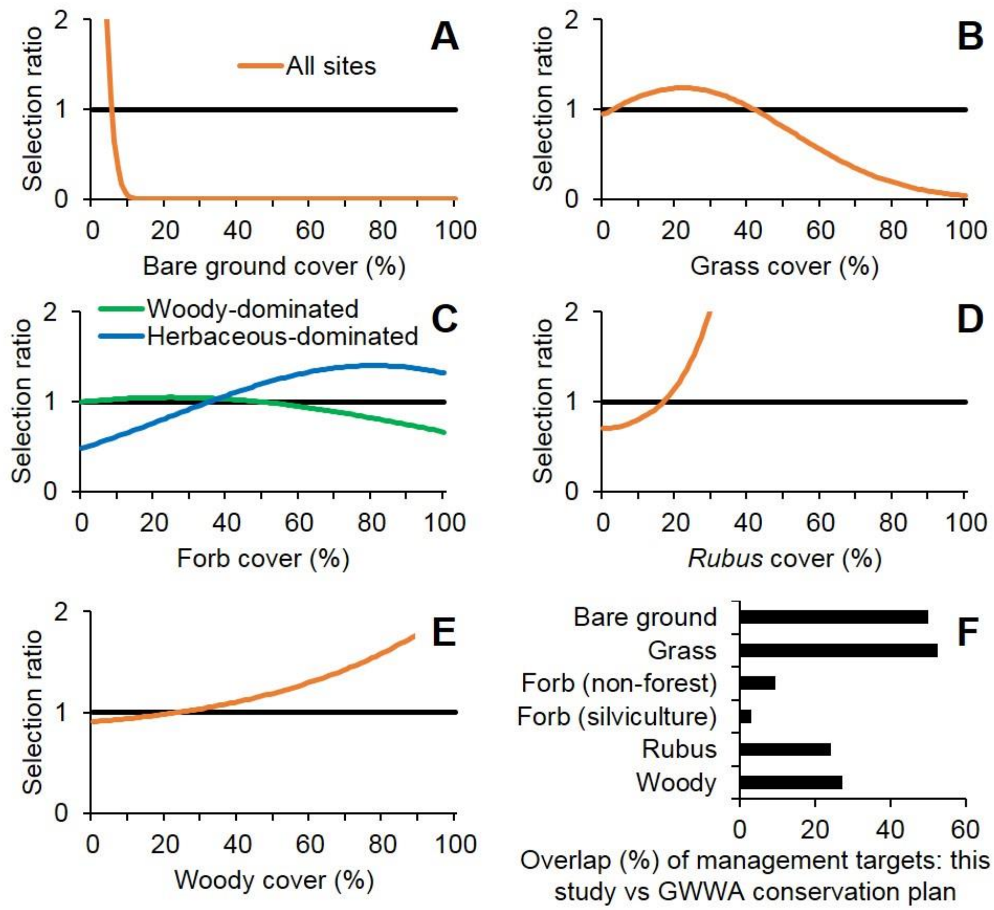


Figure 17. Attainment of *recommended* values of Golden-winged Warbler nesting vegetation based on values provided in the *Golden-winged Warbler conservation Plan* (0-10% bare ground cover/1-m radius, 5-25% grass cover/1-m radius, 4-45% forb cover/1-m radius in herbaceous-dominated sites (grazing management, old field management, and prescribed fire (old field)), 45-100% forb cover/1-m radius in silviculturally-derived sites (prescribed fire (young forest) and timber harvest), 5-40% *Rubus* cover/1-m radius, and 5-50% woody cover/1-m radius; Roth et al. 2012). We defined attainment as the proportion of stand-level vegetation plots having characteristics that fell within the ranges for recommended nesting vegetation.

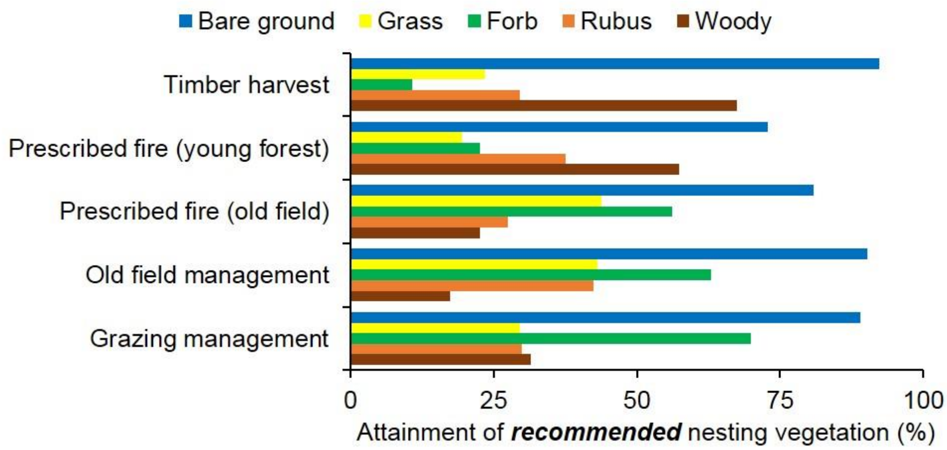


Figure 18. Attainment of *high-quality* values for Golden-winged Warbler nesting vegetation based on our nest survival models (13-47% *Rubus* cover/1-m radius, 0-1% bare ground cover/1-m radius, <5 tall shrubs/5-m radius, and 39-127 m from a forest edge). We defined *high-quality* nesting vegetation as vegetative conditions, identified in our most-plausible ($\Delta AIC_c \leq 2$) nest survival models, that would result in above average DSR (0.962 ± 0.003). We defined attainment as the proportion of stand-level vegetation plots having characteristics that fell within the ranges for *high-quality* nesting vegetation.

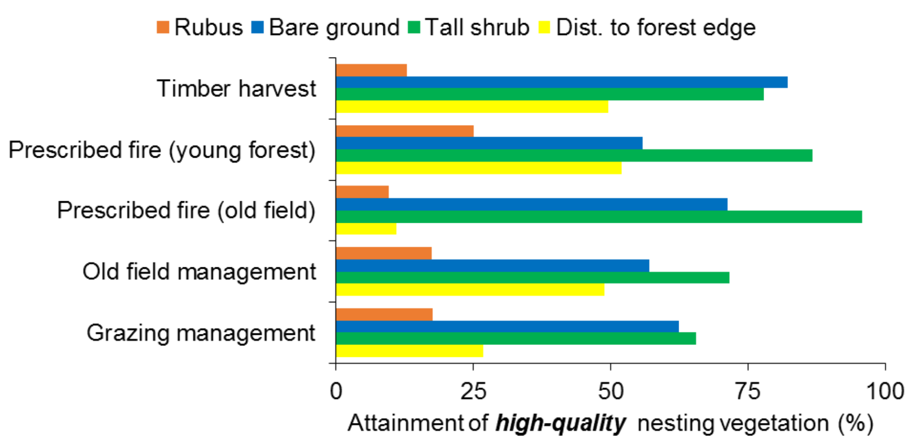


Figure 19. Daily survival rate of Golden-winged Warbler nests decreased as the 69-day nesting season progressed.

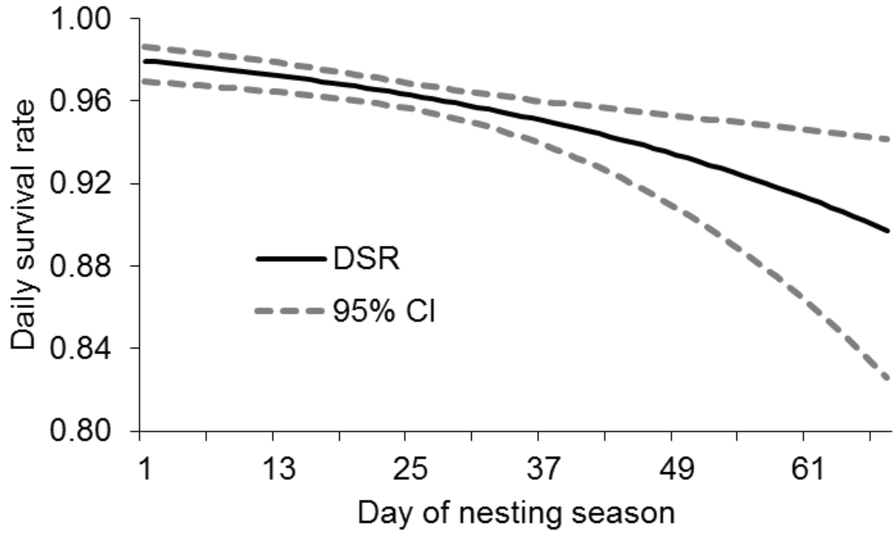


Figure 20. Probability of Golden-winged Warbler nest success (±SE) given three attempts ($1-(1-DSR^{25})^3$) among management systems. Across their range, Golden-winged Warblers commonly have three attempts to successfully fledge one brood (Aldinger et al., in review).

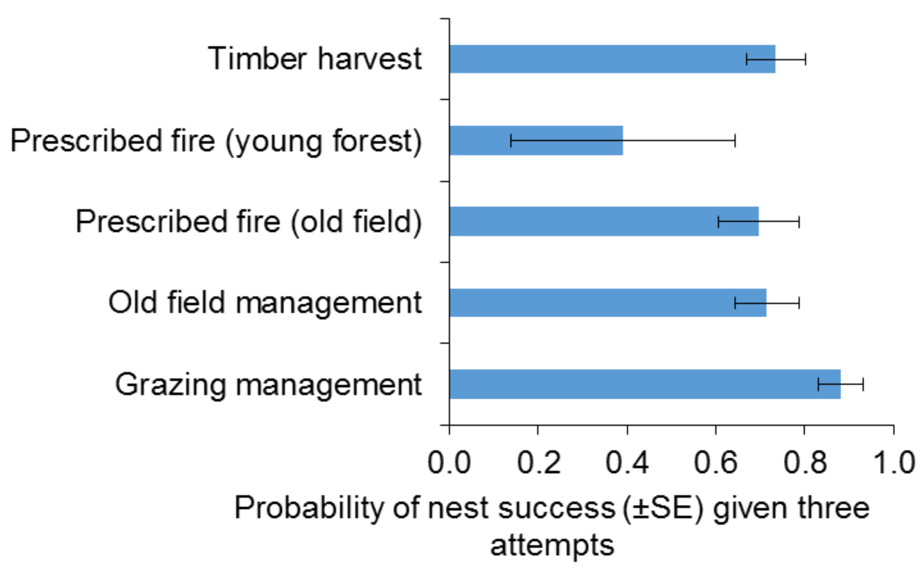
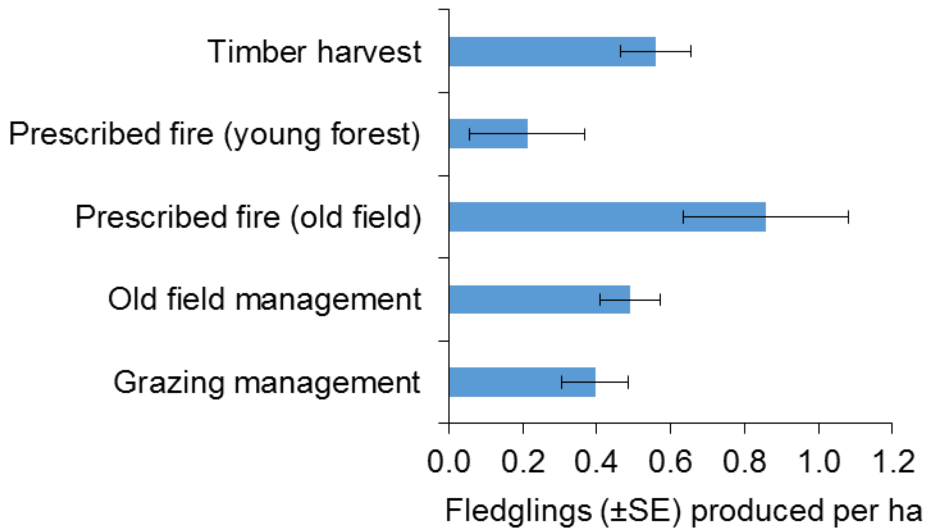


Figure 21. Nest productivity (fledglings [±SE] produced per ha) among management systems. Nest productivity was the product of four components: (1) probability of nest success given three nesting attempts ($1-[1-DSR^{25}]^3$), (2) number of fledglings produced per successful nest, (3) territory density, and (4) pairing rate.



Component VII: Post-fledging survival, movements, and habitat use of juvenile Golden-winged Warblers

Summary

Several studies have looked at the breeding ecology of Golden-winged Warblers in the Appalachian Mountain portion of their range but none have directly studied the post-fledging period. The post-fledging life stage is a major component of annual reproductive success in birds with altricial young (e.g., Golden-winged Warblers). The duration of the post-fledging period for Golden-winged Warblers is ultimately greater than the nesting period, further highlighting the importance of this phase of the species' lifecycle. We radio-tracked 76 fledgling Golden-winged Warblers daily; 35 fledglings were tracked in Pennsylvania during the 2014 breeding season while 10 and 31 fledglings were tracked in Tennessee during the 2013 and 2014 breeding seasons, respectively. Fledglings monitored in Pennsylvania were from nests found in timber harvests. Fledglings monitored in Tennessee were from nests found in timber harvests managed with prescribed fire (n = 7) and old field surface mines managed with prescribed fire (n = 34). Fledgling survival for the entire 25 day post-fledging period was 25.3 ± 8.2% in Tennessee (n = 41) and 45.5 ± 13.3% in Pennsylvania (n = 35). Depredation was greatest in the first four days after fledging, with 81% (34/42) of the mortalities occurred during the first four days. In Tennessee, post-fledging survival differed between management systems whereby survival was 0% (n = 7) in timber harvest managed with prescribed fire and 28.9 ± 5.9% (n = 34) in old fields managed with fire. Average shrub height was the most important habitat covariate associated with daily survival, as fledgling survival was negatively related to average shrub height. Early and mid-successional habitat was used primarily by the fledglings, even as the fledglings got older. Golden-winged Warbler post-fledging brood-splitting has been extensively documented in other portions of the species' range (i.e., the Great Lakes). We confirmed brood-splitting occurred in Tennessee and Pennsylvania, as well, with 87% of fledglings ≥7 days post-fledging being attended exclusively by a single parent. We found no difference in in the daily distanced travelled ($P = 0.794$) or distance from nest ($P = 0.497$) between male- and female-led broods.

Methods

When nestlings were approximately 7-8 days old (1-2 days prior to the anticipated fledge-date), we removed them from the nest, placed them in a cloth sack, and moved them to a stable work-up area at least 10 m from the nest for processing. Each nestling had its weight recorded and we then attached a numbered US Geological Survey band and one color band to each nestling (IACUC UT #561; IUP #14-1314). We randomly selected 1-3 nestlings from each nest and attached a radio transmitter (Figure 22) using the method described below. In Pennsylvania, most transmitters were placed on birds as nestlings, but some individuals were opportunistically captured and equipped with a transmitter 1-14 days after fledging. These post-fledged young were aged (to the nearest day) based on the length of rectrices, projection extent of primary flight feathers, and contour plumage characteristics. These characteristics were judged against the fledglings transmittered in the nest as we observed consistent progression of these traits as fledglings aged (Figure 23). The combined mass of radio transmitter, harness, and leg band was about 0.41g and < 5% of nestling mass. The attachment of leg bands and radio transmitter resulted in 5 minutes of total handling time upon which time the nestlings were returned to their nest.

We attached radio transmitters using a figure-eight harness design (Rappole and Tipton 1991). The harnesses were made from a stretchable 1 mm thread which eventually deteriorates and becomes detached from the transmittered bird (Streby et al. 2013). In 2014, radio transmitters were purchased from Blackburn Transmitters and had a battery life of approximately 30 days. Radio transmitters were used on multiple birds if they were recovered post-deployment and were still in a usable condition (i.e., 10+ days of predicted battery life remaining, antenna not kinked or coiled).

We used the same protocol as Streby et al. (2015) to determine if a bird slipped from the harness, died from depredation in the nest, or died from depredation after fledging. We checked the nest each day after radio-transmitter attachment. If the nest was empty, we would radio-track the transmitter for each bird radio-marked in that nest. If we found a radio-transmitter not attached to a bird we would closely examine the radio-transmitter for signs of depredation (bite marks on harness, antenna, or battery). If we did not observe any signs of depredation, we would conclude that the bird slipped from the harness. If we determined that a bird died from depredation, we would search for parental and sibling activity to determine if it happened before or after fledging. If we observed any sign of a surviving sibling (adults angrily chipping, adults feeding a sibling, begging from sibling) we concluded that the nest fledged. If we did not observe any surviving sibling, we concluded that the entire nest failed and we censored those radio-marked birds from our post-fledging analysis. We tracked each radio-marked fledgling once each day between 0700 and 1300 EDT. We determined approximate location using triangulation and then made visual contact with the target individual using homing to determine if it was alive or dead.

For all fledglings found dead, we attempted to determine the cause of death. One hundred percent of dead fledglings observed within this study were the result of depredation. We used all available evidence to infer the general predator group. Snake predation was easy to identify as the slow metabolic rate of most snakes resulted in fledgling digestion taking several days and direct observation of the predator. Mammalian predator identification, while more complicated, was usually obvious when occurred. Signs of mammalian depredation included variously-sized patches of consumption (often showing clear dentition patterns indicative of rodent predators), missing individual limbs of carcasses, and caching of fledgling remains with other food items. Avian predation events, though somewhat rare, were usually characterized by fledgling remains (including transmitter) being found on high, conspicuous perches with plucked feathers sometimes scattered nearby.

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 made at the location the bird was first observed and a day after tracking, if necessary, to avoid disturbing young birds. At each point we recorded 1) the fledgling's location using a handheld global positioning system, 2) habitat characteristics (described below), 3) which parent(s) was present, 4) fledgling's perch-height from ground, 5) perch substrate, and 6) parent activity. We generalized the overall habitat into four groups: Early Succession (1-10 years post-disturbance), Mid Succession (11-25 years post-disturbance), Late Succession (26+ years post-disturbance) and Edge Habitat (a well-defined edge between two of the succession types, often early and late succession). We estimated canopy cover using a densiometer in all four cardinal directions 5m from plot center (where each fledgling was first observed). We estimated basal area using a 10x wedge prism. We recorded the distance to the mature forest edge, using a negative number for points within a forest, for timber harvest sites in Pennsylvania and Tennessee and any forest edge on the surface mine sites in Tennessee.

We used a density board with twenty squares (20 cm x 20 cm squares) to estimate vegetation density in N-S and W-E alignments. The density board was placed at plot center and the observer stood 5m 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 1m. We used visual estimation and a rangefinder to estimate an 11.3-m radius circle around plot center. In this circle, we estimated the average height of shrubs (m), the average height of saplings (m), and counted the number of snags >11.4 cm diameter breast height.

Fledgling survival was calculated using program MARK's Known Fate model (White and Burnham 1999). We used 2 groups (Tennessee and Pennsylvania) in the modeling process and analyzed Days 1-4 and Days 5-25 separately. We analyzed these two time intervals separately because survival was noticeably lower in the first four days when the birds were still on or near the ground. Fledglings captured at various ages post-fledging were introduced into the model (using pre-capture censoring) appropriately. We also compared three management systems categories from which fledglings originated: old field surface mines managed with prescribed fire (TN), timber harvest managed with prescribed fire (TN), and timber harvest (PA). We evaluated 12 covariates and their relationship with daily fledgling survival. We analyzed 3 general covariates for both analyses: year, fledge date, and number of siblings that fledged. We also analyzed 6 daily vegetation covariates: stand basal area, vegetation density, distance to mature forest edge, number of snags within 11.3 m, average shrub height, and average sapling height. We used the nest vegetation measurements for the first day post-fledging and vegetation at each daily location thereafter. Finally, we analyzed 3 weather covariates for the first four days post-fledging: average precipitation, average high temperatures, and average low temperatures.

We concluded that brood-splitting occurred if we observed only one parent caring for the half-brood after the radio-marked fledgling was ≥7 days old. We calculated daily movements (Euclidean distance to previous day's point) and distance to nest for each fledgling. We then performed a two-tailed Student's t-test on the average daily movements and distance to nest for female-and male-led broods.

Results

We placed transmitters on a total of 89 nestlings during the 2013 and 2014 field season (TN 2013 n = 18; TN 2014 n = 35; and PA 2014 n = 36). Of these 89, 65 survived the nestling stage, had their transmitter stay on during fledging, and were subsequently monitored as fledglings. In Pennsylvania, 11 additional individuals were opportunistically captured and equipped with a transmitter 1-14 days after fledging. As such a total of 76 fledglings were radio-tracked during both years of this post-fledging study (TN 2013 n = 10; TN 2014 n = 31; and PA 2014 n = 35).

The most prevalent fledgling predators differed between the two study areas (Figure 24). Small mammals comprised only 16% of fledgling depredations in Tennessee but 88% of depredations in Pennsylvania (Table 16). The reverse pattern was seen for snake-caused deaths with 0% in Pennsylvania but 72% in Tennessee. Avian-caused deaths were the same in each state with 12% in both Pennsylvania and Tennessee.

Survival was low during the initial first 4 days post-fledging with a daily survival of 74.5 ± 4.3% in Tennessee and 87.3 ± 4.1% in Pennsylvania. Survival for the entire four-day interval was 33.0% in Tennessee (n = 41 fledglings) and 66.1% in Pennsylvania (n = 26 fledglings). Daily survival increased considerably for days 5-25 post-fledging. Daily survival for the 5-25 day interval was 98.7 ± 0.8% in Tennessee (n = 13) and 98.2 ± 0.8% (n = 26) in Pennsylvania. Fledgling survival for the entire 25-day post-fledging period was 25.3 ± 8.2% in Tennessee and 45.5 ± 13.3% in Pennsylvania. In Tennessee, post-fledging survival differed between management systems whereby survival was 0% (n = 7) in timber harvest managed with prescribed fire and 28.9 ± 5.9% (n = 34) in old field habitat managed with fire.

For days 1-4, the best survival model (without incorporating covariates) was one that held age of fledglings constant and used state as a grouping variable (Table 17). Only 2 individual covariates improved this model: number of snags and average shrub height (Figure 25). Delta AIC*c* was 0.53 for number of snags and 2.13 for average shrub height with respect to the base model. Also, β-coefficient overlapped zero for number of snags, suggesting a weak relationship. However, β-coefficient did not overlap zero for average shrub height, suggesting a stronger relationship. Average shrub height had a negative relationship with fledgling survival during the first four days out of the nest. For days 5-25, the best survival model was the null model. No daily vegetation covariates or other general covariates improved the top model.

Fledgling habitat use only changed slightly as the fledglings aged over their first 20 days post-fledging (Figure 26). Late succession and edge habitat were minimal aspects of post-fledging habitat use and only made up a combined total between 13.6% and 20.8% of total use during each of the five time steps (Day 1, 5, 10, 15, and 20 post-fledging). Early and mid-succession habitat comprised 79.2% to 86.4% of the post-fledging habitat use over the five time steps. Fledglings used primarily early succession habitat on the first day post-fledging but gradually used more mid-succession habitat as they aged (Figures 27 and 28).

We tracked 23 fledglings that survived ≥7 days across both years and study areas. Of these, 20 (87%) conclusively had only one parent caring for them and we therefore suggest that brood-spitting occurred in Pennsylvania and Tennessee. Eight fledglings were in male-led broods and 12 fledglings were in female-led broods. There was no difference in daily movements (P = 0.794) or total distance to nest (P = 0.497) between male-led and female-led broods (Table 18). Day-to-day movements and distance to nest increased during each of five time steps examined for all radio-marked birds (Figure 29). Figure 30 shows the daily movements of juvenile Golden-winged Warblers in Tennessee and Pennsylvania.

Table 16. The number and percent of fledglings depredated by 3 different predator groupings (small mammals, snakes, and avian predators) for both Tennessee and Pennsylvania. Of the 18 snake depredations, 11 were by Black Rat Snakes, 6 were by Northern Copperheads, and 1 was by a Corn Snake. Identifying the actual species for the other two predator groupings wasn't possible. However, we believe Eastern Chipmunks and Short-tailed Weasels were the main small mammal predators while Cooper's Hawks and Sharp-shinned Hawks were the main avian predators.

Predator	Tennessee		Pennsylvania	
Small mammal	4	16%	15	88%
Snake	18	72%	0	0%
Avian	3	12%	2	12%
Total	25		17	

Table 17. Select Golden-winged Warbler fledgling survival models from known fate framework in program MARK using days 1-4 post-fledging. We used state (TN vs. PA) as a grouping variable. Number of snags and average shrub height were the only covariates to improve the model. None of the other habitat covariates (average sapling height, distance to forest edge, stand basal area, vegetation density), general covariates (year, fledge date, and number of siblings that fledged), or weather covariates (average precipitation, average high temperatures, and average low temperatures) improved our model.

Model Name	AIC_c	Delta AIC_c	No. Parameters
Group + average shrub height	165.70	0.00	3
Group + number of snags	167.30	1.60	3
Group	167.83	2.13	2
Group x Time since fledging	168.16	2.46	8
Null	169.89	4.19	1
Time since fledging	171.55	5.85	4

Table 18. Daily movement patterns (in meters) of Golden-winged Warbler fledglings over a 20 day interval broken into five different time steps. We measured day-to-day (DTD) movements of all juveniles, distance to nest (DTN) of all juveniles, day-to day movements of both male and female-led broods, and distance to nest of both male and female-led broods.

Day	Total DTD	Total DTN	Male DTD	Female DTD	Male DTN	Female DTN
1	12.9	12.9	21.3	9.5	21.3	9.5
5	59.5	96.7	41.7	91.6	108.7	103.0
10	70.0	168.9	57.4	84.3	192.7	178.8
15	99.8	221.7	88.6	103.7	178.8	252.7
20	235.7	326.7	384.0	153.4	428.4	270.2

Figure 22. A 7 day old nestling Golden-winged Warbler with a numbered USGS band and a 0.4 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 with a 0.4 g radio-transmitter (right photo).

Figure 23. Major developmental stages of a Golden-winged Warbler fledglings: a) after fledglings leave the nest at ~9 days old, they are very limited in their mobility; b) by day 14, fledglings begin to develop more distinct plumage characteristics and become more mobile and able to flutter short distances; c) by 19-24 days old, primary flight feathers and rectrices are more developed, adult plumage characteristics become fairly noticeable (e.g., black face mask/throat patches on males and yellow wing patch) and ability to fly significant distances is apparent; d) by 29-34 days old, fledglings have essentially achieved their full body size and adult plumage characteristics become more clear; and e) by day 39, fledglings molt into their first basic plumage and closely resemble adults.

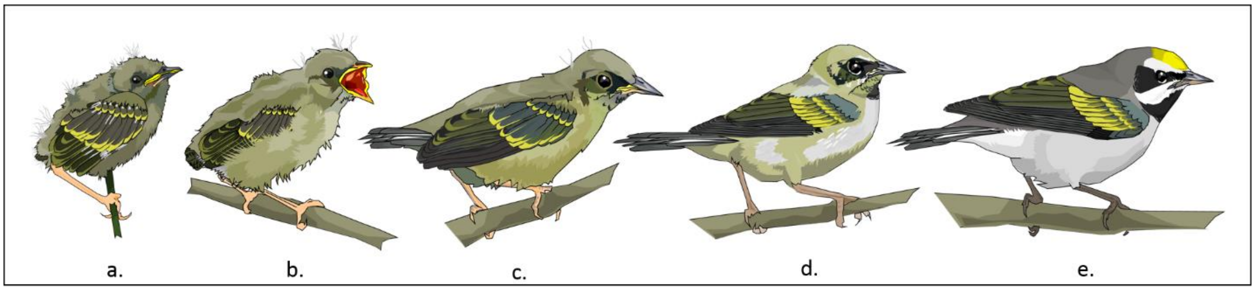
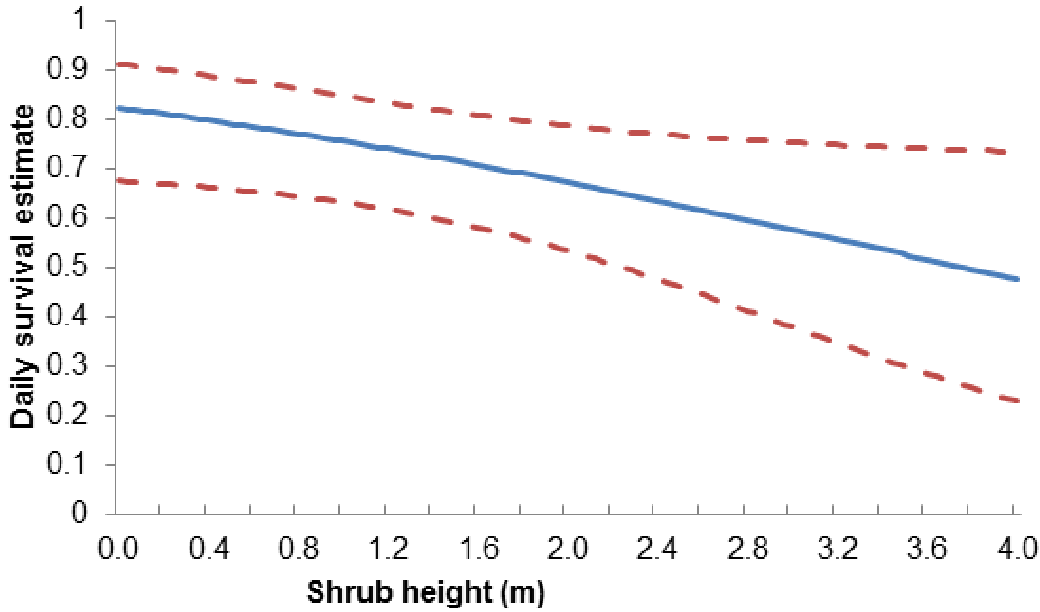


Figure 24. Two common Golden-winged Warbler fledgling predators, the Eastern Chipmunk (left) and the Northern Copperhead (right).

Figure 25. Juvenile Golden-winged Warbler daily survival rate (solid line) and upper and lower 95% confidence intervals (dashed lines) over the first four days post-fledging in relation to the top two daily habitat variables. Average height of shrubs (top graph) and number of snags (bottom graph) have a negative relationship with juvenile survival.



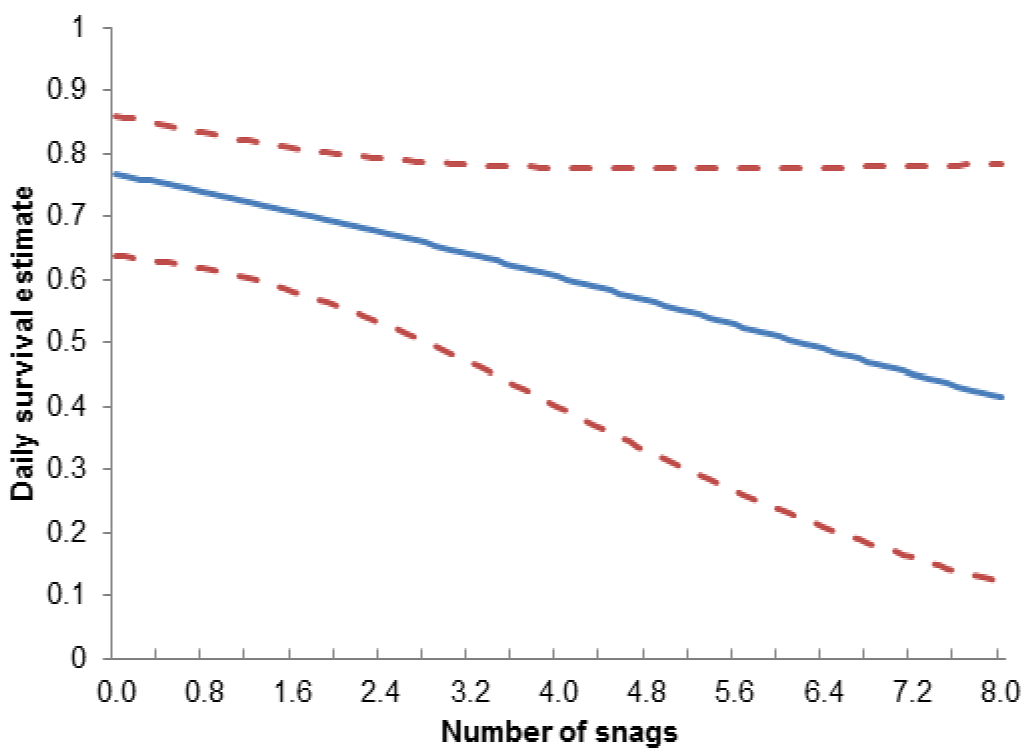


Figure 26. The use of four different cover types (Edge, Late Succession, Mid Succession, and Early Succession) by Golden-winged Warbler fledglings during five time steps across the first 20 days post-fledging.

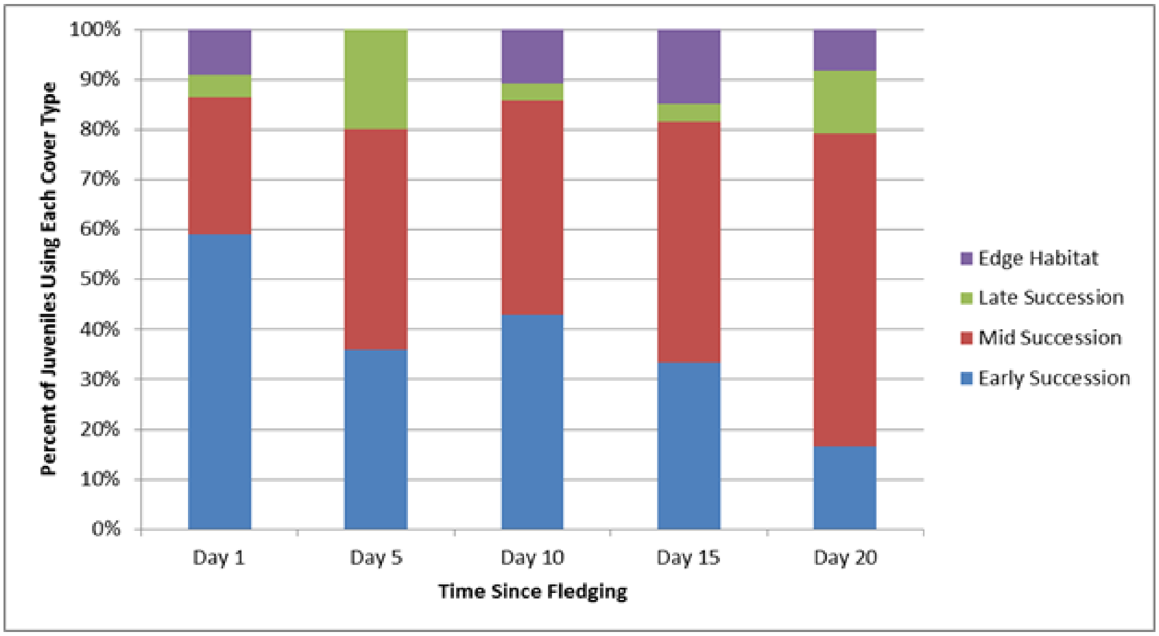


Figure 27. An example of habitat used by young Golden-winged Warbler fledglings in Tennessee and Pennsylvania, oftentimes dense understories of shrubs, saplings, or *Rubus* spp. Photo taken in a regenerating timber harvest in Pennsylvania.

Figure 28. An example of habitat used by older Golden-winged Warbler fledglings, oftentimes a patch of moderately dense regeneration within canopy gaps created by individual tree falls or gypsy moth mortality. Photo taken in a disturbed patch of gypsy moth die-off in the forested matrix surrounding regenerating timber harvests in Pennsylvania.

Figure 29. Daily movement patterns of fledgling Golden-winged Warblers over the first 20 days post-fledging broken into five time steps. Movement is measured as day-to-day movements and distance to nest.

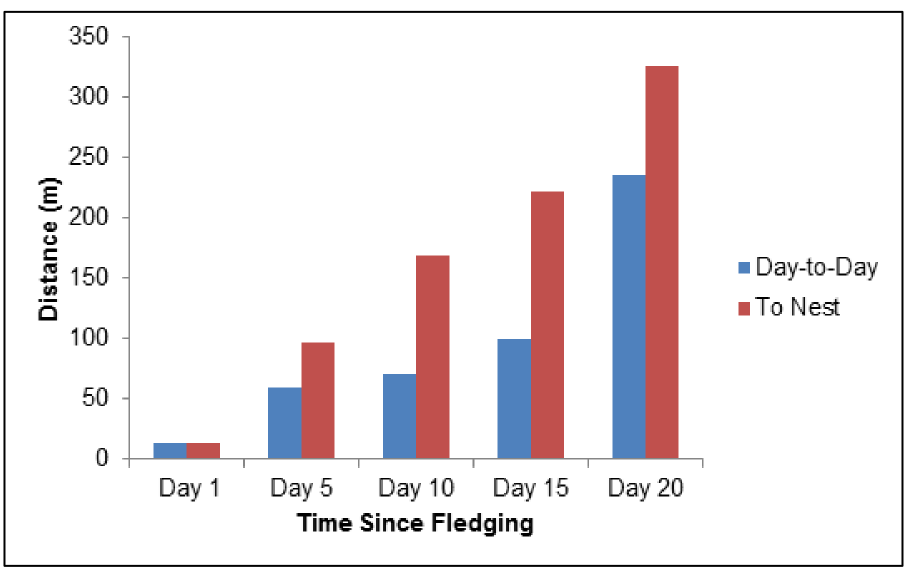
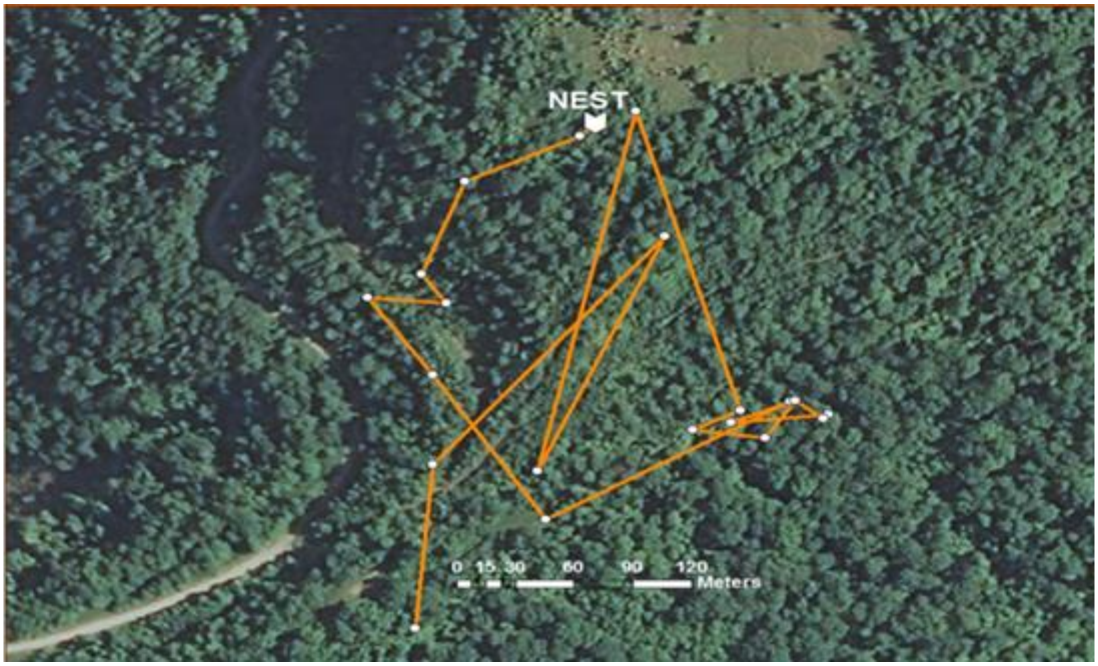
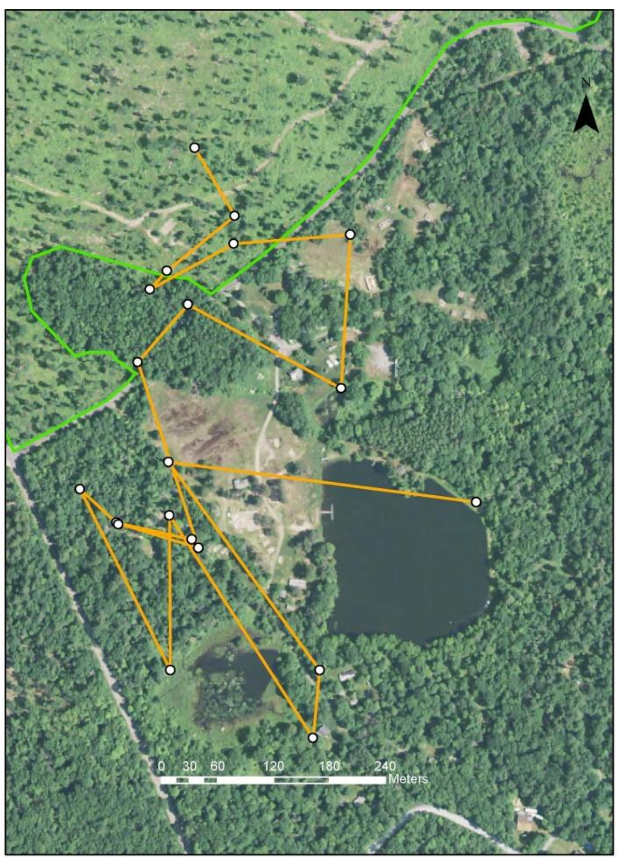


Figure 30. An example of day-to-day movements of a fledgling Golden-winged Warbler on a) an old field surface mine in Tennessee (top image) and b) timber harvest in Pennsylvania (lower image).





Study Component VIII: Investigating space-use of adult male Golden-winged Warblers using radio-telemetry

Summary

In recent radio-telemetry studies in Minnesota (Streby et al. 2012) and Pennsylvania (Frantz 2013, Frantz et al. *in press*), male Golden-winged Warblers occurring at high and low densities, respectively, used resources outside their spot-mapped territories. We compared territories of individual male Golden-winged Warblers obtained using spot-mapping (spot-mapped territories) or radio telemetry (telemetry territories) in cattle pastures in West Virginia. We recorded 616 spot-mapping locations and 488 telemetry locations for 7 males. Forty percent of telemetry locations were outside of spot-mapped territories. Telemetry-territories (100 and 50% minimum convex polygons [MCPs]) were 2–4 times larger than spot-mapped territories. Whereas spot-mapped territories had minimal overlap among individual males, telemetry territories had extensive space use overlap in both the number and amount of MCP overlap. Tree abundance was greater in telemetry-territories (7.3 ± 0.8 trees) than in spot-mapped territories (1.9 ± 0.6 trees). More telemetry locations than spot-mapped locations occurred in forest and telemetry locations were closer to forest edges of pastures than spot-mapped locations. Despite the significant difference, the actual number of telemetry (n=12) and spot-mapped (n=2) locations in forest was small. On several occasions, we observed radio-marked individuals nearly 1 km from their MCP spot-mapped territory boundaries. Our observations suggest foraging, extra-pair copulation, and reconnaissance for post-breeding habitat as possible motives for leaving spot-mapped territories. Spot-mapping alone does not completely reflect Golden-winged Warbler space-use during the breeding season nor does it characterize all cover types used even in areas with relatively low territory densities. Ranking and screening documents for potential Working Lands for Wildlife Golden-winged Warbler projects will need to reflect these findings, especially if this behavior holds true in other portions of the Working Lands for Wildlife target area.

Methods

We monitored male Golden-winged Warblers and measured vegetation characteristics in six pastures in Pocahontas and Randolph counties, West Virginia during May-July 2012 (Appendix #). One pasture had three males and one male traveled between two pastures. Pastures were managed with combinations of ongoing prescribed cattle grazing (0.3–1.3 animal units/ha), recent fences and access control to exclude grazing, and mechanical brush removal.

Between 1 May and 1 July, we captured male Golden-winged Warblers using targeted mist-netting with song playback and a warbler decoy (Anich et al. 2009). We fitted captured individuals with a metal U.S. Geological Survey leg band and a unique combination of 3 color bands for identification purposes. To ensure that the radio transmitter units [BD-2N (0.43 g), Holohil Systems Ltd., Carp, ON] constituted <5% of an individual's mass, we fitted males ≥9 g with a radio transmitter. We glued radio transmitters to the trimmed contour feathers in the interscapular region which required ~5 min of handling time (Frantz 2013) and allowed the transmitter to fall off during the pre-basic molt prior to fall migration (Pyle 1997).

Territory and Home Range Delineation

We refer to areas that we delineated via spot-mapping as spot-mapped territories and areas delineated via radio telemetry as telemetry territories. We considered extra-territorial movements as those that occurred outside the spot-mapped territory, although we recognize that some movements outside the spot-mapped territory might have been within an individuals' true song territory (Streby et al. 2012).

We used spot-mapping to delineate all territories (radio-marked and non-radio-marked males) on our study sites for Golden-winged Warblers, Blue-winged Warblers, and hybrids (referred to collectively as *Vermivora* spp.) by following individual color-banded males every other day through visual observation of feeding, perching, and singing. Monitoring all *Vermivora* spp. allowed us to account for space use overlap with males that neighbored our radio-marked Golden-winged Warblers. Golden-winged Warblers, Blue-winged Warblers, and hybrids appeared to behaviorally treat each other as conspecifics on our study sites. All observations were flagged and we recorded each location using Garmin eTrex and GPSMAP 60CSx global positioning system (GPS) units (typically accurate to <5 m). Like Streby et al. (2012) and Frantz (2013), our methods differed from Barg et al. (2005) in that we recorded each location only once regardless of how long we observed the bird there. We spot-mapped territories for each color-banded male during 30–60-min sampling periods (Barg et al. 2005) between 05:20–14:14 Eastern Daylight Time (EDT).

We collected radio-telemetry data every other day to alternate with spot-mapping days for the life of each transmitter using the homing method (Mech 1983, White and Garrott 1990). We approached each radio-marked Golden-winged Warbler on foot, guided by radio signal strength until we visually or aurally determined the male's location. We tried to avoid approaching within a distance that perceptibly influenced the male's behavior (Vitz and Rodewald 2010). When unable to locate a male without influencing its behavior, we triangulated the location (Anich et al. 2009). To ensure that telemetry locations were biologically independent, we used a sampling interval long enough to allow an individual to move from any point in its territory to any other point (Lair 1987, Holzenbein and Marchinton 1992, McNay et al. 1994, Silva-Opps and Opps 2011). As such, we allowed at least 1 min (although typically 2–10 min) to elapse between successive locations. We conducted telemetry monitoring between 05:40 and 14:05 EDT. For spot-mapping and radio-telemetry, we varied the order and time of visits to individual male Golden-winged Warblers to prevent any time-of-day effects on activity (Shields 1977).

Vegetation Sampling

We sampled vegetation within 1-m and 5-m radius plots at 6 random locations per territory. Each sampling location consisted of central 1-m and 5-m radius plots and four 1-m radius plots 5 m away from the center plot, one in each cardinal direction. We sampled vegetation characteristics using the same method at all telemetry locations ≥12 m outside the spot-mapped territory to allow a buffer between spot-mapped territories and telemetry territories and prevent overlap of measured areas.

Within each 1-m radius plot, we visually estimated % cover of vegetation (grass, forbs, ferns, goldenrod, woody, vines, bare ground, and litter), shrubs <1 m tall, shrubs >1 m tall, saplings (<10 cm dbh), and % canopy cover. Our visual estimates should be considered indices comparing spot-mapped locations and telemetry locations. Observers trained together using a standard collection protocol to limit individual bias with visual estimates. We measured distance to a microedge (i.e., change in vegetation height or composition) from plot center. We also measured the number of snags within 11.3 m and live trees (>10 cm dbh) using a 2.5 m^2/ha prism from each plot center. On the 5-m radius plots, we counted shrubs ≥1 m tall and saplings (≥0.5 m tall and dbh 1-10 cm). We measured distance from plot center to the nearest forest edge. We defined forest edge as the edge of the forest canopy forming an interface between nearly 100% closed canopy contiguous forest and non-forest (shrubland) cover types. We assigned negative distances to spot-mapped and telemetry locations of radio-marked Golden-winged Warblers within forest, a distance of 0 m to locations on a forest edge, and positive distances to locations in non-forest cover types.

To examine macro-habitat characteristics, we assigned each spot-mapped and telemetry location to a cover type (shrubland or forest) based on the composition of a 0.25-ha circular buffer around each location. We defined shrubland as non-forested, shrub-scrub cover with sparse canopy trees and with an herbaceous understory of forbs and grasses. We classified contiguous, closed-canopy areas with ≥0.25 ha of trees (>10 cm dbh) as forest. If the 0.25-ha circular buffer around a location was not completely forested (i.e., contained shrubland cover), then that location was not classified as forest. For each forest location, we measured canopy cover within a 90 x 90 m window around each location using Focal Statistics in GIS based on the National Land Cover Dataset 2001 Percent Tree Canopy Version 1.0 (Homer et al. 2004), ground-truthing, and review of aerial 1-m resolution photographs in ArcMap.

Data Analysis

We delineated spot-mapped territories and home ranges using 100% and 50% minimum convex polygons (MCPs; see Chandler 2011) in ArcMap. Although MCPs tend to overestimate home-range size (White and Garrot 1990), we used this method to ensure maximum quantification of area needed to support male Golden-winged Warblers, to be consistent with other Golden-winged Warbler studies that used spot-mapping and MCPs (e.g., Patton et al. 2010, Terhune et al. 2015), and to be consistent with recent radio-telemetry studies conducted on

Golden-winged Warblers elsewhere (Chandler 2011, Streby et al. 2012). Our spot-mapped territories may have excluded parts of the "real" territory (Streby et al. 2012), but can be considered an approximate estimate (Anich et al. 2009) of principal defended areas of the breeding territory used by Golden-winged Warblers.

We used Selected Cores Analysis in Ranges 7 (Anatrack, Wareham, UK) with the re-calculated Ac (RAc) peel centre method to determine which points were removed for 50% MCPs (South et al. 2008). We tested data for normality and applied a log transformation to non-normal data prior to analysis (Zar 2010). We used a paired-*t* test for normal data or an analogous non-parametric Wilcoxon Signed Rank test when the log transformation did not normalize the data to determine if there were size differences between home ranges and spot-mapped territories.

For each male, radio-marked Golden-winged Warbler's spot-mapped territory and home range, we used the intersect tool in GIS to measure the amount of area overlap with all neighboring spot-mapped *Vermivora* territories (similar to Patton et al. 2010). In addition, we counted the number of spot-mapped *Vermivora* territories that overlapped each individual's spot-mapped territory and home range. We used a non-parametric Wilcoxon Signed Rank test to compare the amount of area overlap (in ha) and number of territories that overlapped each individual's spot-mapped territory and home range.

For each radio-marked male, we averaged habitat variables across all vegetation plots within the spot-mapped territory and across all vegetation plots at home range telemetry locations that were outside the spot-mapped territory. We tested habitat variables for normality and used an appropriate transformation prior to analysis if needed. We used a paired *t*-test or non-parametric Wilcoxon Signed Rank test to compare averaged habitat variable measurements between spot-mapped territories and home ranges. We used Holm's (1979) correction to control experiment-wise error rate when conducting multiple comparisons [α / (n - 1); $P < 0.003$]. We compared distance to forest edge between Golden-winged Warbler use locations in spot-mapped territories and home ranges using a paired *t*-test or non-parametric Wilcoxon Signed Rank test.

We examined macro-habitat characteristics of areas used by Golden-winged Warblers by comparing the number of locations within each cover type (shrubland or forest) at all spot-mapped and telemetry locations using a χ^2-test of independence. We compared only use of each cover type between the two monitoring methods and not use relative to availability. Unless otherwise noted, values were presented as mean ± standard error of the mean (SE).

Results

We recorded 488 telemetry and 616 spot-mapping locations for 7 males. We recorded 1–29 locations (7.6 ± 0.6 locations) per visit, made 6–16 visits (11.7 ± 1.5 visits) per territory, and totaled 33–178 locations (89.7 ± 19.6 locations) per territory using spot-mapping. We recorded 1–23 locations (11.9 ± 1.0 locations) per visit, made 3–8 visits (6.0 ± 0.7 visits) per territory, and totaled 44–155 locations (73.9 ± 14.2 locations) per territory using telemetry. Forty percent of all telemetry locations fell outside their respective male's spot-mapped territory. We observed radio-marked individuals up to 909 m from their spot-mapped territory boundary.

Spot-mapped Territory vs. Home-range Size

Among radio-marked males, home ranges (100% MCPs) were larger than spot-mapped territories (Wilcoxon Signed Rank test: $Z_7 = -2.37$, $P = 0.018$; Table 19). Core telemetry-territories (50% MCP) also were larger than core spot-mapped territories (50% MCP) ($t_6 = -2.75$, $P = 0.033$). Although core areas (50% MCPs) were on average two times larger when delineated by telemetry than spot-mapping (Table 19), four out of seven telemetry and spot-mapped core areas overlapped (Figure 31).

Spot-mapped Territory vs. Home-range Overlap

Spot-mapped territories of individual males rarely overlapped territories of neighboring males (0–2 overlapping territories, Table 19), but telemetry territories of individual males overlapped up to 9 spot-mapped territories (Figure 32). Spot-mapped territories were overlapped twice as often by other telemetry territories than they were by other spot-mapped territories, though this trend was not statistically significant ($Z = -1.63$, $P = 0.102$). In terms of overlap with neighboring spot-mapped territories, telemetry territories of radio-marked males overlapped over six times more area than spot-mapped territories of radio-marked males (Table 19). Most of the overlapping territories were Golden-winged Warblers, but one Blue-winged Warbler and two hybrids were included as overlapping the radio-marked individuals.

Habitat Characteristics of Spot-mapped Territories and Home Ranges

We sampled vegetation at 126 telemetry locations that occurred outside spot-mapped territories. Telemetry territories had three times as many trees as spot-mapped territories ($t_6 = -5.31$, $P = 0.002$) and distance to forest edge was shorter for telemetry locations (14.3 m ± 8.0) than for spot-mapped locations (44.8 m ± 6.7; $t_6 = 2.92$, $P = 0.012$; Table 20), suggesting that extra-territorial telemetry locations were in older forests but along their edges. Our other vegetation characteristics were not statistically significantly different (Table 20).

Locations in Forest vs. Shrubland Cover Types

A greater proportion of telemetry locations than spot-mapped locations occurred in forest ($\chi^2 = 9.91$, df = 1, $P = 0.002$). Two out of 616 spot-mapped locations representing 2 of 7 individuals were located in forest, whereas 12 out of 488 telemetry locations representing 4 of 7 individuals were in forest. Despite the significant difference, the actual number of telemetry (n=12) and spot-mapped (n=2) locations in forest was small. Moderate amounts of canopy cover (68.5 ± 4.2%) in the 90 x 90 m window around forest locations resulted in presence of shrub, sapling, and herbaceous ground cover at 1-m and 5-m plot scales (Table 21). Distance to forest edge was low (41.3 m ± 3.8; Table 21).

Table 19. Size of radio-marked Golden-winged Warbler spot-mapped territories and home ranges using 50% and 100% minimum convex polygons (MCPs). Number and area overlap of neighboring Vermivora spot-mapped territories that overlapped with the 100% MCP spot-mapped territories and 100% MCP home ranges of radio-marked Golden-winged Warblers in West Virginia (n = 7). Individual home ranges of radio-marked males overlapped more area (in ha) of neighboring spot-mapped territories than their spot-mapped territories did (Z = -2.20, P = 0.028).

	Radio-marked Spot-mapped Territory			Radio-marked Telemetry Territory		
Metric	Mean	SE	Range	Mean	SE	Range
Territory Size (ha):						
100% MCP	2.4	0.5	0.79–4.77	11.8	6.2	2.27–47.99
50% MCP	0.3	0.1	0.13–0.63	0.6	0.1	0.20–1.28
Number of neighboring spot-mapped territories overlapped	1.0	0.2	0–2	2.4	1.1	0–9
Area of neighboring spot-mapped territories overlapped (ha)	0.4	0.2	0.00–1.18	2.6	1.7	0.00–12.48

Table 20. Vegetation sampled within male Golden-winged Warbler spot-mapped territories and outside territories but within home ranges in West Virginia. After Holm's correction, we considered P<0.003 to be significant. Values in bold were statistically significantly different from each other.

	Spot-mapped Territory (n = 7)		Telemetry territory (*n* = 7)	
Habitat Variable	Mean	SE	Mean	(± SE)
Grass (%)	28.8	3.2	21.3	2.7
Forbs (%)	27.3	2.3	25.6	2.7
Ferns (%)	0.2	0.2	0.7	0.2
Rubus spp. (%)	7.3	2.5	7.1	1.0
Goldenrod (*Solidago* spp.) (%)	16.5	2.7	8.8	2.3
Woody Cover (%)	3.7	0.8	7.3	1.6
Litter (%)	9.5	2.4	20.1	2.2
Vine (%)	1.9	1.7	0.5	0.3
Bare Ground (%)	4.6	1.4	8.7	2.0
Shrub <1 m (%)	4.1	0.4	7.1	1.7
Shrub >1 m (%)	6.6	1.2	9.9	1.8
Sapling (%)	1.5	0.6	2.8	0.9
Canopy cover (1-m scale) (%)	5.8	3.6	31.4	7.1
Distance to microedge(m)	2.2	0.3	2.6	0.6
No. trees	**1.9**	**0.6**	**7.3**	**0.9**
No. Snags	0.0	0.0	0.3	0.1
No. of shrubs	11.0	1.7	15.5	1.6
No. of saplings	7.3	3.2	6.5	1.6
Distance to forest edge (m)	**44.8**	**6.7**	**14.3**	**8.0**

Table 21. Vegetation characteristics at forested locations where Golden-winged Warblers were observed during spot-mapping or via radio-telemetry in West Virginia. We did not collect micro-habitat vegetation data at the three forested spot-mapped locations or at the one forested telemetry location within a spot-mapped territory.

	Forested Locations (n = 11)	
Habitat Variable	Mean	(± SE)
Grass (%)	9.2	1.6
Forbs (%)	33.8	2.9
Ferns (%)	2.0	0.5
Rubus spp. (%)	2.3	0.9
Goldenrod (*Solidago* spp.) (%)	0.04	0.04
Woody Cover (%)	10.9	2.6
Litter (%)	27.0	3.2
Vine (%)	0.5	0.3
Bare Ground (%)	14.2	2.7
Shrub <1 m (%)	7.4	2.1
Shrub >1 m (%)	2.7	0.7
Sapling (%)	5.0	1.4
Canopy cover (1-m scale) (%)	76.4	3.3
Distance to microedge (m)	5.4	0.9
No. trees	12.6	1.2
No. Snags	0.8	0.3
No. of shrubs	31.1	8.3
No. of saplings	7.6	3.1
Distance to forest edge (m)	41.3	3.8

Figure 31. An example of overlapping spot-mapped (light grey) and telemetry-based (dashed polygon) core areas (50% MCPs), with spot-mapped locations (circles) and telemetry locations (stars) indicated. Core areas were on average two times larger when delineated by telemetry than spot-mapping, and four out of seven telemetry and spot-mapped core areas overlapped.

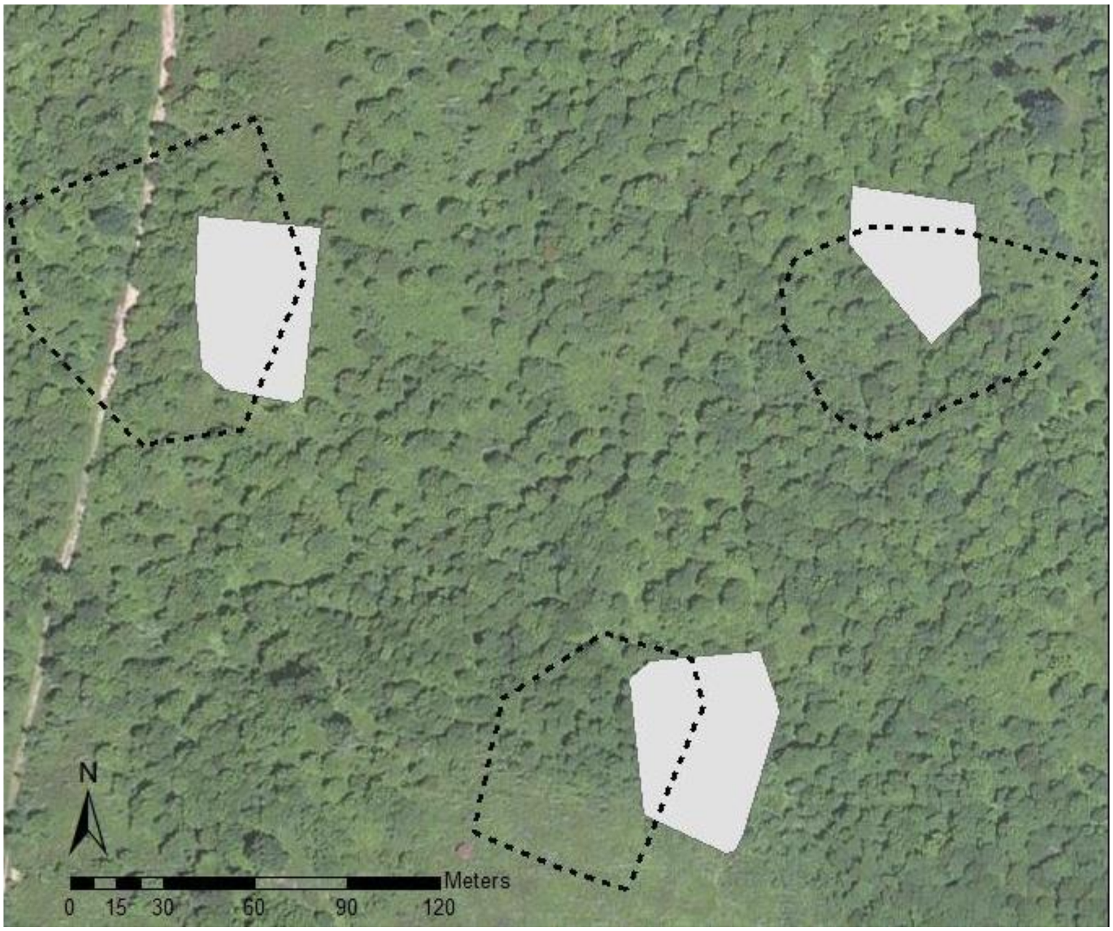
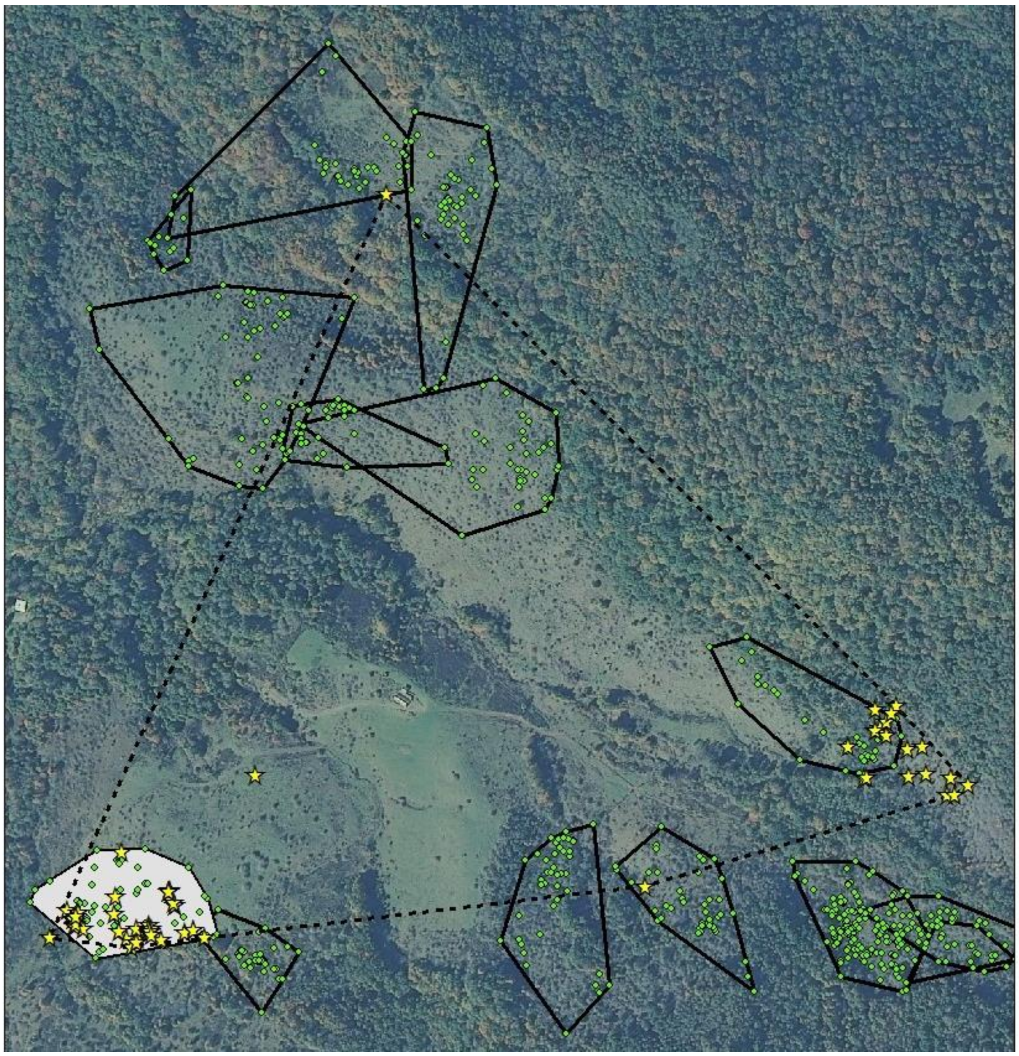


Figure 32. A spot-mapped territory (grey) and telemetry territory (dashed polygon) for an individual male Golden-winged Warbler. The individual's spot-mapped territory overlapped with one other *Vermivora* spp. spot-mapped territory (hollow polygons), but his telemetry territory overlapped with portions of spot-mapped territories of nine other individuals. Spot-mapped territory locations are represented as circles and telemetry locations as stars.



Study Component IX: Relationships between male plumage ornamentation, region, and management systems

Summary

Little research has examined variation and signaling function of plumage coloration in Golden-winged Warblers. Because ornamental plumage coloration in birds is often a reliable indicator of individual quality, a better understanding of Golden-winged Warbler plumage and how it relates to habitat quality could help guide land management decisions. Our objectives were to investigate potential relations between Golden-winged Warbler plumage ornamentation, body condition, reproductive success, geographic region, and land management systems in the Appalachians. We sampled 134 Golden-winged Warbler territorial males across 24 sites in North Carolina, Pennsylvania, and West Virginia. These individuals had established territories in areas subjected to various land management systems: grazing management (n = 17), old field management (n = 77), timber harvest (n = 31), and natural wetlands (n = 9). We found that plumage coloration differed significantly with both geographic region and management system, with the least-ornamented males occurring in the old field habitat of North Carolina. However, it is difficult to disentangle the importance of geographic range from management system because there was no management system that occurred in all three regions—only grazing management and old field management were replicated in North Carolina and West Virginia. But taken together, these data demonstrate that North Carolina birds are less ornamented and of lighter mass compared to the other regions. Our results suggest that a large amount of variation in the coloration of Golden-winged Warblers is due to geographical mechanisms and independent of management system.

Methods

We collected Golden-winged Warbler feather samples across 10 sites in North Carolina, 8 sites in West Virginia, and 6 sites in Pennsylvania from April 27th to June 23, 2014 (Table 22). Reproductive measures included the size of first clutch and the number of offspring that we assumed fledged successfully from each nest. We excluded data on replacement nests.

Upon mist-net capture we measured body mass and wing length and collected 6 crown and throat feathers and the outermost right tail feather. We classified birds by age (second year (SY) or after-second year (ASY)). Feather collection is a minimally invasive and commonly-utilized procedure to collect data on plumage coloration and DNA (Taberlet and Bouvet 1991, Katzner et al. 2012).

Reflectance Measures

We stored feathers in envelopes in a climate-controlled environment and then taped them by the rachis to black non-reflectance paper in a way that mimics the way that feathers lie flat naturally on the bird (Figure 33). We measured spectral data with an Ocean Optics S2000 spectrometer (range 250-880 nm; Dunedin, FL) using a micron fiber-optic probe placed at a 90° angle to the feather surface. Each measurement was an average of 20 readings and each feather patch was measured 3 times to create a mean reflectance measure.

Reflectance curves of yellow crown feathers of Golden-winged Warblers reflect light that is typical of carotenoid-based pigmentation (Jones and Siefferman 2014). Because we assumed this yellow plumage is carotenoid based, we quantified the yellow crown color using the carotenoid chroma descriptor of reflectance spectra: carotenoid chroma = $(R_{\lambda 450} - R_{\lambda 700}) / R_{\lambda 700}$, where $R_{\lambda i}$ is the percent reflectance at the i^{th} wavelength (λ_i) (Montgomerie 2006). An animal with more-ornamented plumage should have higher carotenoid chroma; representing a more saturated yellow color.

Reflectance curves of black throat feathers of Golden-winged Warblers reflect light that is typical of eumelanin-based pigmentation (Siefferman, personal observation) while the tail white is indicative of reflection of non-organized feather microstructure. We assessed ornamentation of black and white plumage using the mean brightness of each region. Mean brightness = $\int(R_{\lambda 300}$ to $R_{\lambda 700}) / 401$. An animal with more ornamented black throat plumage should have lower brightness (darker plumage) representing lower reflectance of light. An animal with more ornamented tail white should have brighter plumage representing greater reflectance of light.

Statistical Analyses

We performed statistical analyses in SPSS v22. We first tested for year effects on plumage coloration and body condition in North Carolina with Students t-tests. Also, we used Student's t-tests to determine whether age (SY versus ASY) influenced plumage coloration or body condition. Next, we tested for effects of geographic region and management system on plumage coloration and body condition using 1-way ANOVAs. Finally, we investigated correlations between multiple measures of coloration, body condition, and reproductive output with Pearson correlations (after controlling for effects of geographic region).

Results

We sampled 134 Golden-winged Warbler territorial males across 24 sites in North Carolina, West Virginia, and Pennsylvania (Table 22). These individuals had established territories in areas subjected to various land management systems: grazing management (n = 17), old field management (n = 77), timber harvest (n = 31), and unmanaged natural wetlands (n = 9). The North Carolina samples were collected in 2013 and 2014. Measures of coloration and body condition did not differ between 2013 and 2014 for the North Carolina samples (t-tests; P = 0.079, P = 0.486, respectively). As such, we combined the 2013 and 2014 North Carolina samples for all subsequent analyses. Capture date had a significant negative effect on crown chroma in 2014, most likely due to natural feather wear during the breeding season ($R^2 = 0.062$, F = 6.684, P = 0.011, n = 103). Thus, the standardized residuals of crown chroma were used for all analyses. Crown ornamentation, throat brightness, tail brightness, mass, and body condition did not vary with age and we combined age classes. Linear regression models revealed that body mass was positively related to wing length ($R^2 = 0.049$, $F = 6.627$, $P = 0.011$, $n = 131$; Figure 34). As a measure of body condition, we used the standardized residuals of the regression of mass on wing and body mass

We found significant effects of geographic region on yellow crown ornamentation, throat ornamentation, and body condition (Tables 23, 24, Figures 33 and 34). Males from North Carolina had less-saturated yellow crowns (lower carotenoid chroma) and lower body condition compared to males from Pennsylvania and West Virginia. Males from North Carolina also had less-ornamented throats (i.e., higher throat brightness, duller black) compared to those from Pennsylvania. We found significant effects of management system on yellow crown ornamentation (Table 25, Figures 35 and 36). Post hoc analyses (LSD) revealed that crown chroma for males sampled from old field management sites was lower than that of males sampled from timber harvest sites ($P = 0.007$, Figure 37). We attempted to disentangle the effects of geographic region from management system by testing for effects on plumage coloration and body condition within each region. However, only 3 birds were sampled from grazing management sites in North Carolina and due to this low sample size we were not confident in analyzing management system effects in this region. Thus, were able to make the following comparisons: Pennsylvania (timber harvest vs. natural wetland); and West Virginia (old field vs. grazing). We found no significant effects of management system on plumage or morphology within regions (all $F < 2$ and $P > 0.05$; Figure 36).

To correct for the significant regional differences when testing for co-variance between morphological measures and correlations between morphology and reproductive success, we used morphological data that was standardized to region (z score; crown chroma, throat brightness, and body condition). Birds with more elaborate yellow crown chroma also exhibited darker black throat coloration (Table 26). All other relationships between ornamental traits and measures of body condition were non-significant (Table 26). We found no significant relationships between measures of plumage ornamentation or body condition on clutch size and number of fledglings (Table 26). As expected, birds with larger clutch sizes fledged more offspring (Table 26).

Table 22. Sites where Golden-winged Warbler feather samples were collected with sample size ranges (some birds did not have all feather regions collected).

North Carolina (n)	West Virginia (n)	Pennsylvania (n)
Amphibolite Gamelands (1)	Edray Farm (8)	Cheecho (9)
Beck and Burleson (2-3)	Hannah (2)	Dancing Ridge 2 (6)
Cove Creek (1-2)	Hoover (3)	Elbow Swamp East (4)
Grassy Ridge (1-3)	GaJa (2)	Flat Ridge (5)
Hampton Creek Cove (5-14)	BoJe (3)	Laurel Run (7)
Little Hump (1)	Lake Reed (6-7)	William Penn (9)
Roan Gamelands (1-2)	RoPh (2)	
Shady Grove (2)	Shearer South (1)	
State Park (8-16)		
Sunalei (13-21)		

Table 23. Results of 1-way ANOVA; effect of geographic region on plumage ornamentation and body condition of Golden-winged Warblers.

Trait		n	Mean	SD	F	P
Crown Chroma	NC	65	-0.269	1.107	5.181	0.007
	WV	28	0.173	0.876		
	PA	40	0.316	0.723		
	Total	133	0.000	0.989		
Throat Brightness	NC	36	0.041	0.009	3.822	0.025
	WV	27	0.039	0.010		
	PA	40	0.035	0.008		
	Total	103	0.038	0.009		
Tail Brightness	NC	34	0.314	0.018	0.143	0.867
	WV	28	0.315	0.025		
	PA	40	0.312	0.024		
	Total	102	0.313	0.022		
Body Condition	NC	63	-0.317	0.890	7.315	0.001
	WV	28	0.441	0.807		
	PA	40	0.190	1.121		
	Total	131	0.000	0.996		

Table 24. Post hoc analyses (Fisher's Least Significant Difference; LSD) from 1-way ANOVA comparing ornamentation and body condition of Golden-winged Warblers from different geographic regions.

Trait	(I)	(J)	Mean Difference (I-J)	SE	P
Crown Chroma	NC	WV	-0.441*	0.217	0.044
		PA	-0.585*	0.193	0.003
	WV	NC	0.441*	0.217	0.044
		PA	-0.143	0.236	0.545
	PA	NC	0.585*	0.193	0.003
		WV	0.143	0.236	0.545
Throat Brightness	NC	WV	0.002	0.002	0.283
		PA	0.005*	0.002	0.007
	WV	NC	-0.002	0.002	0.283
		PA	0.003	0.002	0.154
	PA	NC	-0.005*	0.002	0.007
		WV	-0.003	0.002	0.154
Tail Brightness	NC	WV	-0.001	0.006	0.893
		PA	0.002	0.005	0.702
	WV	NC	0.001	0.006	0.893
		PA	0.003	0.006	0.617
	PA	NC	-0.002	0.005	0.702
		WV	-0.003	0.006	0.617
Body Condition	NC	WV	-0.758*	0.216	0.001
		PA	-0.507*	0.192	0.009
	WV	NC	0.758*	0.216	0.001
		PA	0.251	0.234	0.287
	PA	NC	0.507*	0.192	0.009
		WV	-0.251	0.234	0.287

Table 25. Results of 1-way ANOVA of management system on morphology of Golden-winged Warblers (1 = Grazing management, 2 = Old field management, 3 = Timber harvest, 4 = Natural wetland).

Trait		n	Mean	SD	df	F	P
Crown Chroma	1	17	0.224	0.700	3, 129	3.038	0.032
	2	76	-0.216	1.110			
	3	31	0.344	0.752			
	4	9	0.221	0.642			
	Total	133	0.000	0.989			
Throat Brightness	1	16	0.039	0.010	3, 99	2.196	0.093
	2	47	0.040	0.009			
	3	31	0.036	0.008			
	4	9	0.034	0.005			
	Total	103	0.038	0.009			
Tail Brightness	1	16	0.314	0.022	3, 98	0.264	0.851
	2	46	0.314	0.021			
	3	31	0.310	0.024			
	4	9	0.317	0.025			
	Total	102	0.313	0.022			
Body Condition	1	17	0.347	0.838	3, 127	2.062	0.109
	2	74	-0.183	0.927			
	3	31	0.177	1.187			
	4	9	0.238	0.919			
	Total	131	0.000	0.996			

Table 26. Pearson correlations between morphology and reproductive measures of Golden-winged Warblers.

Trait		Throat Brightness (z)	Tail Brightness	Body Condition (z)	1st Clutch Size	Number Fledged
Crown Chroma (z)	R	-0.255**	0.056	0.089	-0.043	0.091
	P	0.009	0.575	0.313	0.729	0.464
	N	103	102	130	67	67
Throat Brightness (z)	R		0.158	0.050	0.067	-0.122
	P		0.114	0.624	0.638	0.389
	N		101	100	52	52
Tail Brightness	R			0.162	0.059	-0.012
	P			0.109	0.677	0.930
	N			99	53	53
Body Condition (z)	R				-0.119	-0.036
	P				0.351	0.776
	N				64	64
1st Clutch Size	R					0.486**
	P					0.000
	n					67

Figure 33. Examples of Golden-winged Warblers feather samples prepared for spectral measurements.

Figure 34. Relationship between wing length and mass of Golden-winged Warblers, all regions and age classes combined.

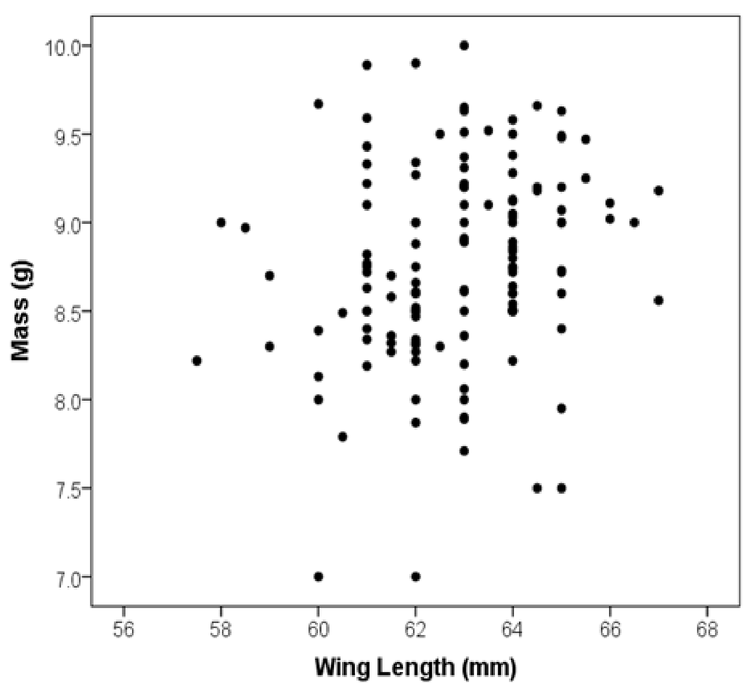


Figure 35. Regional differences in crown coloration of Golden-winged Warblers.

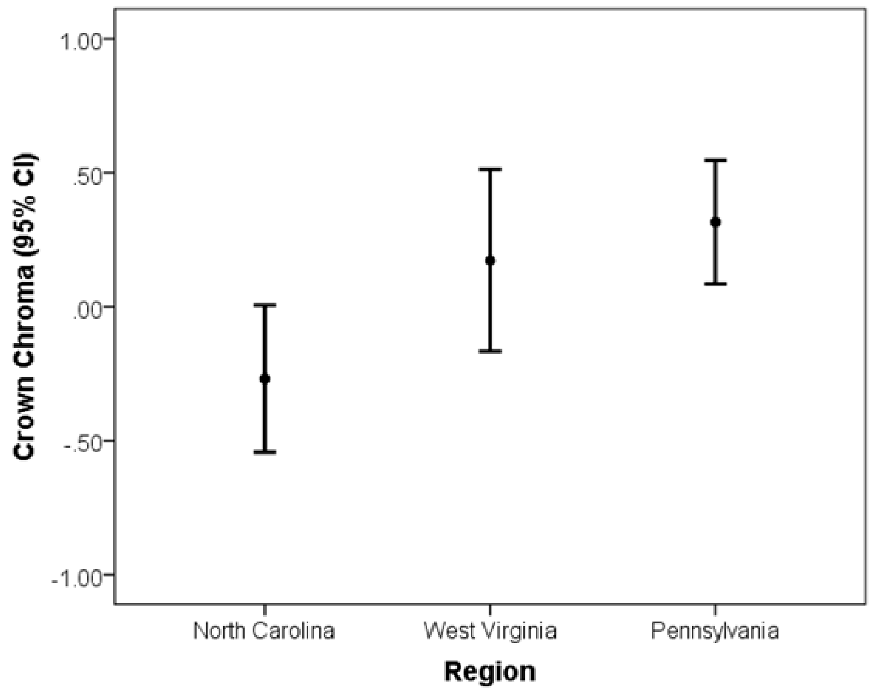


Figure 36. Crown coloration of Golden-winged Warblers grouped by region and management system.

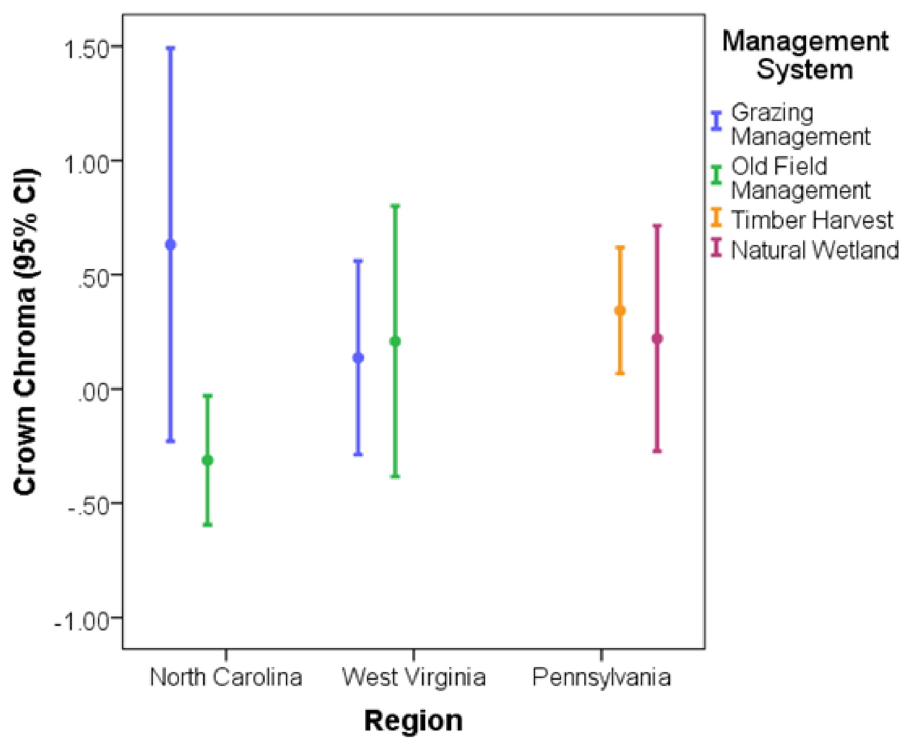
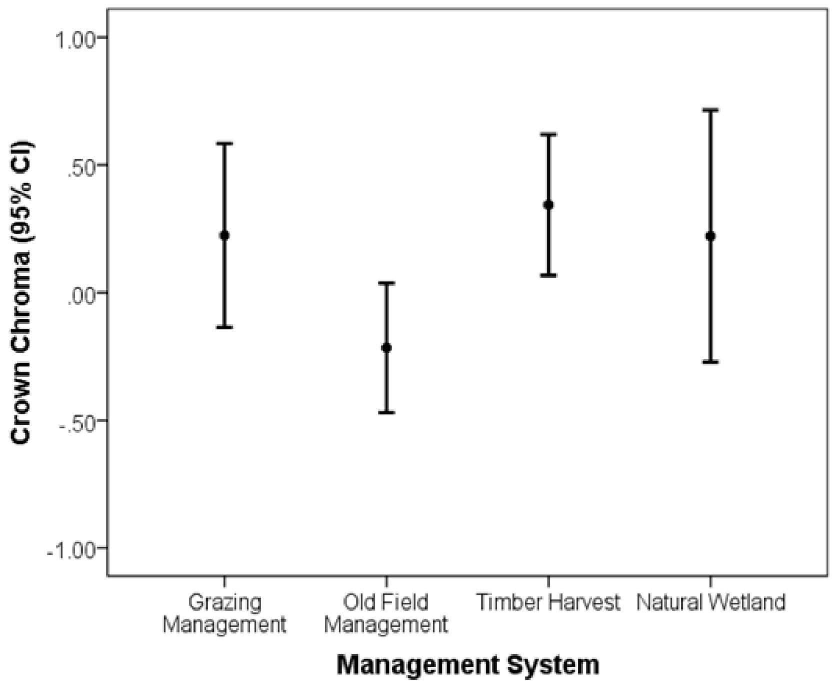


Figure 37. Golden-winged warbler crown ornamentation across management systems.



DISCUSSION

Golden-winged Warbler, a species that nests in early successional habitat, is in decline throughout its Appalachian Mountains breeding range. This decline is largely due to the loss of heavily forested landscapes that contain adequate amounts of early successional nesting habitat. Large-scale implementation of science-based habitat guidelines, such as NRCS's *Working Lands For Wildlife* program, are necessary to stabilize and reverse Golden-winged Warbler population declines. The purpose of this study was to monitor demographic characteristics of Golden-winged Warblers in early successional communities created or maintained via several NRCS conservation practices in the southern and central Appalachian states and to provide recommendations for monitoring private lands created through the *Working Lands For Wildlife* program. From 2012-2014, we collected Golden-winged Warbler demographic data across 95 sites in Pennsylvania, West Virginia, Tennessee, and North Carolina and grouped these sites according to five management system (timber harvest; prescribed fire (young forest); prescribed fire (old field); grazing management; and old field management) which are defined by the primary NRCS conservation practice and facilitating practices. Although our results describe variation in demographic parameters among the five management systems (Table 27), not all of these differences were statistically significant or may not represent ecologically meaningful differences. Collectively, our study reinforces that a highly forested landscape with multiple age-classes of forests is critical for breeding and post-breeding Golden-winged Warblers.

As expected, vegetation structure and composition differed among the five management systems we studied. In particular, timber harvests had greater amounts of woody ground cover, prescribed fire (old field) had the greatest forb cover, prescribed fire (young forest) had the greatest *Rubus* cover, tallest sapling height, and the lowest shrub height. Furthermore, grazing management had the greatest grass cover, number of shrubs (both 1-2 m and >2 m), and number of trees but had the fewest number of snags. Although our study sites differed in vegetation structure and composition, they all generally provided a sufficient mix of the recommended levels of the vegetation components outlined in the *Golden-winged Warbler Conservation Plan* (Roth et al. 2012) to support Golden-winged Warbler nesting. Nonetheless, there are a few aspects of vegetation for which managers need to pay close attention in order to improve attainment of recommended levels. Specifically, woody-dominated sites (i.e., prescribed fire [young forest] and timber harvest) generally needed more grass cover (recommended 5 – 25%, our sites 2 – 6%) and herbaceous-dominated sites (e.g., grazing and old field management) needed to reduce grass cover (recommended 5-25%, our sites 30-35%). The recommended values for these particular vegetation components can be achieved by incorporating the appropriate facilitating practices into NRCS conservation plans.

As NRCS led efforts such as *Working Lands For Wildlife* and *Regional Conservation Partnership Program* continue to create Golden-winged Warbler breeding habitat on private lands, there is a need to efficiently and reliably monitor the species response to management. The quantification of male territory density is a logical cost-effective metric to evaluate the response of Golden-winged Warbler to NRCS programs. The density estimates for Golden-winged Warblers we generated from our point count surveys and territory mapping indicated that densities were similar across management systems. Thus, each of the five management systems appears to have a similar capacity to support Golden-winged Warbler breeding populations. Our analyses revealed that Golden-winged Warbler density increased with sapling count and increased with elevation at southern sites but decreased with elevation at northern sites. Point count density estimates most closely correlated with true density estimates (determined through territory mapping) when increasing the temporal (i.e., pooling across multiple years) and spatial (i.e., combining all sites within management systems and regions) scales. These latter findings have important implications for future monitoring. Specifically, if point count methods are used to estimate density of Golden-winged Warblers, future monitoring ***must*** be careful not to estimate density at too small of a scale (i.e., single sites). In fact, because Golden-winged Warblers tend to be rare, occupancy modeling may be best suited for monitoring and evaluating habitat management success.

Territory mapping efforts undertaken during our study also provided an index of territory size (particularly the area actively-defended by a male). Similar to other studies that have described the primary defended area of Golden-winged Warbler territories, our work has shown that Golden-winged Warbler territories are relatively small with most (>90%; n = 463) defended territories being <3 ha in size with an overall average of 1.36 ha. We found that among Golden-winged, Brewster's, and Blue-winged Warblers, Golden-winged Warblers had the smallest territories, Blue-winged Warblers had the largest territories, and phenotypic hybrids defended intermediate-sized territories.

This study represents one of the single largest efforts to relate Golden-winged Warbler nesting success to a suite of specific land management practices. We found and monitored a total of 286 Golden-winged x Golden-winged Warbler nests across all study areas. Management system itself was not associated with DSR of Golden-winged Warbler nests, but specific vegetation characteristics created by each management system may be related to DSR. Regardless of management system, nest sites with greater than average nest DSR were 39-127 m from a forest edge and composed of 13-48% *Rubus* cover, <1% bare ground cover, and <640 shrubs >2 m tall per ha. Of these four vegetation components, values for grass cover were least consistent with the recommended values provided in the Golden-winged Warbler Conservation Plan (Roth et al. 2012). Regardless of management system, 77% of stand-level vegetation plots were outside of the desired range for *Rubus* cover. Overall, because a number of vegetation covariates showed some relationship with DSR, we suggest managing for these targets within a patchy matrix that include all of the known components of Golden-winged Warbler nesting vegetation (grasses, forbs, *Rubus*, shrubs, saplings, trees, forest edge). Furthermore, because male species (Golden-winged Warbler vs. other *Vermivora* spp.) was more important than female species in predicting nest fate, we suspect that territory-scale (or larger), rather than nest-site scale, habitat characteristics are critical correlates of nest survival.

Over the past decade, considerable effort has been spent to identify and quantify factors that influence Golden-winged Warbler territory placement, density, and nesting success. The majority of these studies have been based solely on visual observations of color banded individuals. However, recent advances in technologies have resulted in radio-telemetry transmitters that are small enough to use on small songbirds like the Golden-winged Warbler. Our study was the first in the species' Appalachian Mountains breeding range to use radio-telemetry to gain additional insight to 1) breeding season movements and habitat use of adult males; and 2) habitat use, movements, and survival of fledglings. Until this study, the post-fledgling period was an understudied (yet critical) part of the species annual life cycle. Data from both our adult and fledgling telemetry demonstrate that Golden-winged Warblers use forest habitat (i.e., mid- and late-successional stages) beyond the young forest / edge habitat where nesting occurs. Indeed, 40% of telemetry locations for adult males we monitored in West Virginia were outside their spot-mapped territories and in areas with nearly 4x greater tree abundance compared to their spot-mapped territories. At times, adult males were found nearly 1km from their spot-mapped territory. These frequent, and sometimes long-distance, movements outside defended spot-mapped territories into areas with different vegetation structure than found in typical nesting habitat stresses the importance of managing for a diversity of forest age classes at the local landscape scale.

The concept of providing young forest nesting habitat within a mosaic of other forest age classes also appears to be important for the post-fledging period. The fledglings we monitored used a combination of early, mid, and late successional communities within the first 25 days post-fledging. Use of early successional habitat by fledglings declined over the time period from 60% of fledglings using early successional forest cover on day 1 to 17% on day 20. Conversely, about 61% of fledglings where in areas we categorized as mid-successional forest on day 20. In the first 4 days post-fledging, there was a difference in survival between Pennsylvania (66.1%; n=26 fledglings) and Tennessee (33%; 41 fledglings) study sites, primarily because of snake depredation in Tennessee. Fledgling survival for the entire 25-day post-fledging period was 25.3 ± 8.2% in Tennessee and 45.5 ± 13.3% in Pennsylvania. The Pennsylvania survival rate was similar to that recently reported for a population in the Great Lakes portion of the species' breeding range (Streby et al. *in press*). Of all the vegetation characteristics we measured, only average shrub height was significant to fledgling survival during the first 4-days post-fledging. Average shrub height may be related to available cover with lower-growing shrubs offering more cover from predators. For days 5- 25 post-fledging, survival did not differ between states or with vegetation, likely because of increased mobility of fledglings over time. For example, once juvenile birds were >15 days post-fledging day-to-day movements were large (e.g., ranged >200 m) allowing birds to select forest cover at greater distances from their nestling location. Our research reveals that the post-fledging period, particularly the first 4-days out of the nest, results in significant fledgling mortality and could be a focal point for habitat management to increase fecundity.

While we only examined fledgling survival in two management systems (old field-prescribed fire and timber harvest), we found that fledgling survival can vary significantly between management systems. Such differences in post-fledgling survival are critical for comparing and evaluating each conservation practice's potential for successfully contributing to Golden-winged Warbler population recovery. For example, based on demographic parameters that we collected, we estimated that timber harvest and old field- prescribed fire management systems produced about 5.6 and 8.6 fledglings/10ha, respectively. However, when post-fledgling survival for these two practices (0.45;timber harvest and 0.25; old field-prescribed fire) is also factored in, 2.5 and 2.15 fledglings/10ha are produced for timber harvest and old field-prescribed fire, respectively. Future research should attempt to quantify post-fledging survival in habitats created by other management systems that we were unable to investigate. Ultimately, it is critical that both the nesting and post-fledgling habitat needs of the Golden-winged Warbler are considered when developing conservation plans for private landowners.

For all adult males we banded across the entire study (n = 290), both body condition index and apparent annual survival were related to management system whereby old field management had the lowest values and grazing management had the highest body condition index and prescribed fire (old field) had the greatest apparent survival. Management systems may differ in annual survival rates if these systems offer different resources (e.g., food, cover from predators, etc.) for Golden-winged Warblers. However, we caution that management systems were not evenly distributed across all regions and, thus, differences in body condition and survival may be a result of geographic influences, especially those on the wintering grounds and migratory routes. Across all management systems, adult male apparent annual survival was 0.58 (0.04SE, 95% confidence interval 0.51 - 0.66) and the resighting rate was estimated at 0.76 (0.11 SE). These annual survival and resighting rates were similar to those found in Tennessee and Ontario populations (Bulluck et al. 2013). Annual apparent adult survival will be an important input to future full life cycle population models.

It is well documented that many plumage aspects directly communicate physical quality and behavior of an individual as well as indirectly communicate habitat quality and reproductive strategy. Understanding plumage signaling can be beneficial for monitoring sensitive populations and managing for their habitat. We found no significant relationships between measures of plumage ornamentation or body condition on clutch size and number of fledglings for 134 males Golden-winged Warblers from which we collected feathers. Our results suggest that variation in Golden-winged Warbler coloration is due to geographical mechanisms and not the habitat management system in which they breed. These data demonstrate that North Carolina birds are less ornamented and of lighter mass compared to the other regions. There are multiple potential explanations for regional differences in morphology. It may be that there are genetic differences between birds breeding in each region and color and body mass may be genetically influenced. It is also likely that coloration and body mass might reflect over-winter habitat quality. Wintering and migration conditions play a large role in condition of migratory species, and Golden-winged Warblers undergo prealternate molt on the wintering grounds (Confer et al. 2011). Because we know there are connections between breeding ranges and wintering ranges for populations of Golden-winged Warblers, it is possible that many of the North Carolina birds are over-wintering in lower quality habitat. Thus, both plumage and body condition could be affected by wintering ground variables, especially if regional populations follow consistent migration paths and settlement patterns (as seen in American Redstarts; Reudink et al. 2009). Indeed, one known contribution to Golden-winged Warbler declines is habitat loss in the wintering grounds (Buehler et al. 2007). Our results regarding regional variation in body condition and plumage coloration warrant the need to better understand migratory connectivity between Golden-winged Warbler breeding and wintering ranges. Research on migratory connectivity would help ensure that conservation efforts on the breeding grounds were aligned with conservation efforts on winter grounds.

Our study also reveals that several other avian species, many of which are also experiencing population declines, may benefit from the implementation of Golden-winged Warbler breeding habitat guidelines. Specifically, we documented 126 bird species of a wide range of guilds across all sites. The presence of this diverse group of bird species was likely due to the varied habitat structure of managed sites (i.e., a mix of grasses and forbs, shrubs, trees, etc.) embedded within heavily forested landscapes. For example, several of the canopy-nesting species that were detected, like Cerulean Warblers, incorporated portions of site with higher canopy cover and used such areas for foraging, singing, and other territorial activities. Cerulean Warbler and 43 other species (34%) detected at our sites are experiencing significant negative population declines according to BBS (Breeding Bird Surveys) data and similar monitoring programs (Sauer et al. 2014, Cooper and Rau 2014). In particular, approximately half of the 10 most common birds detected in each management system are experiencing population declines. It is clear that the habitat structure and composition created specifically for Golden-winged Warblers via NRCS practices also supported a large suite of other species.

Table 27. Summary of the major demographic measures collected for Golden-winged Warblers across management systems, 2012-2104. Numbers in parentheses represent standard errors.

Demographic metric	Timber harvest (n=26)	Prescribed fire (young forest) (n=13)	Prescribed fire (old field) (n=2)	Grazing management (n=12)	Old field management (n=17)
Territory mapping density (#/10 ha)	1.69 (0.30)	1.05 (0.41)	3.37 (0.82)	1.26 (0.30)	1.39 (0.31)
Point count density (#males/10 ha)	3.26 (0.48)	0.98 (0.24)	3.23 (0.47)	1.94 (0.41)	3.21 (0.46)
Nest daily survival rate	0.960 (0.006)	0.927 (0.029)	0.956 (0.008)	0.973 (0.005)	0.958 (0.006)
Nest success (given three attempts)*	0.735 (0.066)	0.391 (0.253)	0.697 (0.092)	0.882 (0.050)	0.715 (0.072)
Fledglings/nest	4.05 (0.19)	3.50 (0.56)	4.11 (0.16)	4.09 (0.21)	3.80 (0.14)
Nest productivity (fledglings/ha)	0.56 (0.10)	0.21 (0.16)	0.86 (0.22)	0.40 (0.09)	0.49 (0.08)
Adult male annual survival	0.67 (0.31)	0.53 (0.37)	0.81 (0.46)	0.42 (0.12)	0.40 (0.11)
Juvenile survival	45.5 (13.3)	NA	25.3 (8.2)	NA	NA

***=** $1-(1-DSR^{25})^3$

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Appendices

Appendix 1. Bird species and region in which the species was detected during point count surveys, 2012-2014. Species in bold are experiencing significant negative population declines ($P < 0.05$) throughout the Appalachian Mountains (1966 - 2012; Sauer et al. 2014, Cooper and Rau 2014).

Common Name	Scientific name	PA	WV	TN	NC
Northern Bobwhite	*Colinus virginianus*		X		
Sharp-shinned Hawk	*Accipiter striatus*		X	X	
Cooper's Hawk	*Accipiter cooperii*		X		X
Red-shouldered Hawk	*Buteo lineatus*	X	X	X	
Broad-winged Hawk	*Buteo platypterus*	X	X	X	X
Red-tailed Hawk	*Buteo jamaicensis*		X	X	X
Wild Turkey	*Meleagris gallopavo*	X	X	X	X
Ruffed Grouse	*Bonasa umbellus*	X	X		X
Killdeer	*Charadrius vociferus*		X		
American Woodcock	*Scolopax minor*		X		
Mourning Dove	*Zenaida macroura*	X	X	X	X
Barred Owl	*Strix varia*	X	X	X	X
Chimney Swift	*Chaetura pelagica*	X	X	X	X
Yellow-billed Cuckoo	*Coccyzus americanus*	X	X	X	X
Black-billed Cuckoo	*Coccyzus erythropthalmus*	X	X		
Ruby-throated Hummingbird	*Archilochus colubris*	X	X	X	X
Red-bellied Woodpecker	*Melanerpes carolinus*	X	X	X	X
Northern Flicker	*Colaptes auratus*	X	X	X	X
Yellow-bellied Sapsucker	*Sphyrapicus varius*	X			

Common Name	Scientific name	PA	WV	TN	NC
Downy Woodpecker	*Picoides pubescens*	X	X	X	X
Hairy Woodpecker	*Picoides villosus*	X	X	X	X
Pileated Woodpecker	*Dryocopus pileatus*	X	X	X	X
Olive-sided Flycatcher	*Contopus cooperi*	X			
Eastern Wood-pewee	*Contopus virens*	X	X	X	X
Acadian Flycatcher	*Empidonax virescens*		X	X	X
Alder Flycatcher	*Empidonax alnorum*	X	X		X
Willow Flycatcher	*Empidonax traillii*		X		X
Least Flycatcher	*Empidonax minimus*	X	X	X	X
Eastern Phoebe	*Sayornis phoebe*	X	X	X	X
Great Crested Flycatcher	*Myiarchus crinitus*	X	X	X	X
Eastern Kingbird	*Tyrannus tyrannus*		X		X
White-eyed Vireo	*Vireo griseus*	X	X	X	X
Yellow-throated Vireo	*Vireo flavifrons*	X	X	X	X
Blue-headed Vireo	*Vireo solitaries*		X	X	X
Warbling Vireo	*Vireo gilvus*		X		
Red-eyed Vireo	*Vireo olivaceus*	X	X	X	X
Blue Jay	*Cyanocitta cristata*	X	X	X	X
American Crow	*Corvus brachyrhynchos*	X	X	X	X
Fish Crow	*Corvus ossifragus*	X			
Common Raven	*Corvus corax*		X	X	X
Tufted Titmouse	*Baeolophus bicolor*	X	X	X	X
Tree Swallow	*Tachycineta bicolor*	X	X	X	X

Common Name	Scientific name	PA	WV	TN	NC
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	X	X	X	X
Barn Swallow	*Hirundo rustica*		X	X	X
Carolina Chickadee	*Poecile carolinensis*		X	X	X
Black-capped Chickadee	*Poecile atricapillus*	X	X		
Red-breasted Nuthatch	*Sitta canadensis*		X		
White-breasted Nuthatch	*Sitta carolinensis*	X	X	X	X
Brown Creeper	*Certhia americana*				X
Blue-gray Gnatcatcher	*Polioptila caerulea*	X	X	X	X
Golden-crowned Kinglet	*Regulus satrapa*		X		
House Wren	*Troglodytes aedon*	X	X		X
Winter Wren	*Troglodytes hiemalis*		X		
Carolina Wren	*Thryothorus ludovicianus*		X	X	X
Eastern Bluebird	*Sialia sialis*	X	X	X	X
Wood Thrush	*Hylocichla mustelina*	X	X	X	X
Veery	*Catharus fuscescens*	X	X	X	X
Swainson’s Thrush	*Catharus ustulatus*	X	X		
Hermit Thrush	*Catharus guttatus*	X	X		
American Robin	*Turdus migratorius*	X	X	X	X
Gray Catbird	*Dumetella carolinensis*	X	X	X	X
Northern Mockingbird	*Mimus polyglottos*		X		X
Brown Thrasher	*Toxostoma rufum*		X	X	X
European Starling	*Sturnus vulgaris*		X	X	X
Cedar Waxwing	*Bombycilla cedrorum*	X	X	X	X

Common Name	Scientific name	PA	WV	TN	NC
Ovenbird	*Seiurus aurocapillus*	X	X	X	X
Worm-eating Warbler	*Helmitheros vermivorus*			X	
Northern Waterthrush	*Parkesia noveboracensis*	X			
Louisiana Waterthrush	*Parkesia motacilla*		X		X
Golden-winged Warbler	*Vermivora chyrsoptera*	X	X	X	X
Blue-winged Warbler	*Vermivora cyanoptera*	X	X	X	
Brewster's Warbler		X	X	X	X
Lawrence’s Warbler			X		
Black-and-white Warbler	*Mniotilta varia*	X	X	X	X
Tennessee Warbler	*Oreothlypis peregrina*	X	X		
Nashville Warbler	*Oreothlypis ruficapilla*	X			
Mourning Warbler	*Geothlypis philadelphia*		X		
Kentucky Warbler	*Geothlypis Formosa*		X	X	
Common Yellowthroat	*Geothlypis trichas*	X	X	X	X
Hooded Warbler	*Setophaga citrina*		X	X	X
American Redstart	*Setophaga ruticilla*	X	X	X	X
Cerulean Warbler	*Setophaga cerulea*	X	X	X	
Northern Parula	*Setophaga americana*	X	X		X
Magnolia Warbler	*Setophaga magnolia*	X	X		
Bay-breasted Warbler	*Setophaga castanea*	X			
Blackburnian Warbler	*Setophaga fusca*	X	X		
Yellow Warbler	*Setophaga petechia*	X	X	X	X
Chestnut-sided Warbler	*Setophaga pensylvanica*	X	X	X	X

Common Name	Scientific name	PA	WV	TN	NC
Blackpoll Warbler	*Setophaga striata*	X	X		
Black-throated Blue Warbler	*Setophaga caerulescens*	X	X		X
Pine Warbler	*Setophaga pinus*	X			X
Yellow-rumped Warbler	*Setophaga coronata*	X			
Yellow-throated Warbler	*Setophaga dominica*		X	X	
Prairie Warbler	*Setophaga discolor*	X	X	X	
Black-throated Green Warbler	*Setophaga virens*	X	X	X	X
Canada Warbler	*Cardellina canadensis*	X	X		X
Yellow-breasted Chat	*Icteria virens*		X	X	X
Summer Tanager	*Piranga rubra*			X	
Scarlet Tanager	*Piranga olivacea*	X	X	X	X
Eastern Towhee	*Pipilo erythrophthalmus*	X	X	X	X
Clay-colored Sparrow	*Spizella pallida*		X		
Chipping Sparrow	*Spizella passerine*	X	X	X	X
Field Sparrow	*Spizella pusilla*	X	X	X	X
Vesper Sparrow	*Pooecetes gramineus*		X		X
White-throated Sparrow	*Zonotrichia albicollis*	X			
Song Sparrow	*Melospiza melodia*	X	X	X	X
Swamp Sparrow	*Melospiza georgiana*	X	X		
Dark-eyed Junco	*Junco hyemalis*		X		X
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	X	X	X	X
Northern Cardinal	*Cardinalis cardinalis*	X	X	X	X
Indigo Bunting	*Passerina cyanea*	X	X	X	X

Common Name	Scientific name	PA	WV	TN	NC
Eastern Meadowlark	*Sturnella magna*		X		X
Bobolink	*Dolichonyx oryzivorus*		X		
Red-winged Blackbird	*Agelaius phoeniceus*	X	X	X	X
Common Grackle	*Quiscalus quiscula*	X	X		X
Brown-headed Cowbird	*Molothrus ater*	X	X	X	X
Baltimore Oriole	*Icterus galbula*	X	X		X
Orchard Oriole	*Icterus spurius*		X		
Purple Finch	*Haemorhous purpureus*	X			
House Finch	*Haemorhous mexicanus*		X		
Red Crossbill	*Loxia curvirostra*		X		
American Goldfinch	*Carduelis tristis*	X	X	X	X

Appendix 2. Name, ownership, size (amount of treated area), management system, and research aspect of study sites by region for the CEAP 2012-2014 project. B = bird banding; N = nest monitoring; T = true density (via territory mapping or ≥4 visits); P = point transects; A = adult telemetry; J = juvenile telemetry. Ownership abbreviations are as follows: WRC = Wildlife Resources Commission, SAHC = Southern Appalachians Highlands Conservancy, USFS = U.S. Forest Service, DESF = Delaware State Forest, MNF = Monongahela National Forest, and WVDNR = West Virginia Division of Natural Resources.

Region	Site/Stand	Ownership	Size (ha)	Management system	Research aspect
NC	Ager	Private	5.6	Old field management	P
NC	Amphibolite Gamelands	Private/state-leased	75.4	Grazing management	B,N,T,P
NC	Bango	Private	1.9	Grazing management	P
NC	Beck and Burleson	Private and WRC	15.4	Old field management	B,N,T,P
NC	Brewer	Private	0.9	Old field management	P
NC	Buck	Private	.	Timber harvest	P
NC	Cove Creek	Private	35	Grazing management	B,N,T,P
NC	Giradina	Private	26.1	Timber harvest	P
NC	Grassy Ridge	SAHC	26.1	Old field management	B,N,T,P
NC	Hampton Creek Cove	SAHC	95.2	Old field management	B,N,T,P
NC	Hump Mountain	USFS	80	Old field management	B,N,T
NC	Isaacs	Private	4.2	Grazing management	P
NC	Larson	Private	1.9	Old field management	P
NC	Mash	Private	6.9	Grazing management	P
NC	McKinny	Private	0.7	Old field management	P
NC	Merten	Private	8.2	Timber harvest	P
NC	Morris	Private	0.9	Timber harvest	P
NC	Niziol	Private	10.3	Old field management	P
NC	Ritchhart	Private	11.1	Old field management	P
NC	Roan Gamelands	Private/USFS	12.4	Old field management	B,N,T,P

Region	Site/Stand	Ownership	Size (ha)	Management system	Research aspect
NC	Roan-High Balds	USFS	125	Old field management	T,P
NC	Shady Grove	Private	28.7	Old field management	B,N,T,P
NC	Shipe	Private	35.6	Grazing management	P
NC	Sieberling	Private	17.1	Old field management	P
NC	Simandle	Private	1.2	Timber harvest	P
NC	Smith	Private	4.8	Old field management	P
NC	State Park	State Parks	57.8	Old field management	B,N,T,P
NC	Sunalei	Private	75.4	Old field management	B,N,T,P
NC	Thomas	Private	6.6	Grazing management	P
NC	Whitesides	Private	14.6	Old field management	P
NC	Wiehs	Private	0.9	Old field management	P
NC	Wilson, G	Private	0.3	Old field management	P
NC	Wilson, R	Private	3.2	Old field management	P
PA	Big Wide Open	DESF	42.4	Timber harvest	B,T,P
PA	Blooming Grove	Private	19.1	Timber harvest	B,N,T,P
PA	Brewster Rd	DESF	31.6	Timber harvest	B,N,T,P
PA	Burnt Mills	DESF	9.2	Timber harvest	B,T,P
PA	Dancing Ridge 1	DESF	18.9	Timber harvest	B,N,T,P
PA	Dancing Ridge 2	DESF	37.9	Timber harvest	B,N,T,P,J
PA	Elbow Swamp East	DESF	14.1	Timber harvest	B,N,T,P,J
PA	Elbow Swamp West	DESF	8.8	Timber harvest	B,N,T,P
PA	Flat Ridge	DESF	25.7	Timber harvest	B,N,T,P,J
PA	Laurel Run	DESF	49.5	Timber harvest	B,N,T,P,J
PA	Minisink	DESF	10	Timber harvest	B,N,T,P
PA	Painter Swamp	DESF	17.9	Timber harvest	B,N,T,P
PA	Rattle	DESF	20.5	Prescribed fire - young forest	B,N,T,P,J
PA	Thunderbird	DESF	27.7	Timber harvest	P

Region	Site/Stand	Ownership	Size (ha)	Management system	Research aspect
PA	White Birch Swamp	DESF	12.6	Timber harvest	B,N,T,P,J
PA	Whittaker Lane	DESF	24.6	Timber harvest	B,N,T,P
PA	William Penn	DESF	67.2	Timber harvest	B,N,T,P,J
TN	Anderson 1	TN Wildlife Resources Agency	8.8	Timber harvest	P,T
TN	Anderson 2	TN Wildlife Resources Agency	10.2	Timber harvest	P,T
TN	Anderson 3	TN Wildlife Resources Agency	12.7	Prescribed fire - young forest	P,T
TN	Anderson 4	TN Wildlife Resources Agency	5.9	Prescribed fire - young forest	P,T
TN	Anderson 5	TN Wildlife Resources Agency	8	Prescribed fire - young forest	P,T
TN	Anderson 6	TN Wildlife Resources Agency	11.5	Prescribed fire - young forest	P,T
TN	Ashlog	TN Wildlife Resources Agency	61.3	Prescribed fire - old field	B,N,T,P,J
TN	Burge 1	TN Wildlife Resources Agency	4.7	Prescribed fire - young forest	B,N,T,P
TN	Burge 2	TN Wildlife Resources Agency	4.5	Prescribed fire - young forest	B,N,T,P
TN	Burge 3	TN Wildlife Resources Agency	3.5	Prescribed fire - young forest	T,P
TN	Burge 4	TN Wildlife Resources Agency	4.2	Prescribed fire - young forest	N,T,P
TN	Burge 5	TN Wildlife Resources Agency	3	Timber harvest	T,P
TN	Burge 6	TN Wildlife Resources Agency	3.8	Timber harvest	T,P
TN	Burge Control	TN Wildlife Resources Agency	7.5	Timber harvest	B,N,T
TN	Massengale	TN Wildlife Resources Agency	52.5	Prescribed fire - old field	B,N,T,P,J
TN	Red Oak 1	TN Wildlife Resources Agency	4.7	Timber harvest	T,P
TN	Red Oak 2	TN Wildlife Resources Agency	5	Timber harvest	T,P
TN	Red Oak 3	TN Wildlife Resources Agency	9.5	Prescribed fire - young forest	B,N,T,P,J
TN	Red Oak 4	TN Wildlife Resources Agency	8.1	Prescribed fire - young forest	T,P
TN	Red Oak 5	TN Wildlife Resources Agency	4.9	Prescribed fire - young forest	B,N,T,P.J
TN	Red Oak 6	TN Wildlife Resources Agency	5.8	Prescribed fire - young forest	T,P
WV	Coberly Sods North	USFS-MNF	22.6	Grazing management	B,N,T,P,A
WV	Coberly Sods South	USFS-MNF	19.3	Grazing management	B,N,T,P,A
WV	Edray Farm	Private	25.6	Grazing management	B,N,T,P

Region	Site/Stand	Ownership	Size (ha)	Management system	Research aspect
WV	Forinash	USFS-MNF	14.7	Grazing management	B,N,T,P,A
WV	ClGa	Private	25	Timber harvest	T,P
WV	Gay Sharp	USFS-MNF	26.4	Grazing management	B,N,T,P,A
WV	RoGe	Private	26.2	Old field management	P
WV	Hannah	USFS-MNF	32	Grazing management	B,N,T,P,A
WV	Hoover	USFS-MNF	79.8	Grazing management	B,N,T,P,A
WV	Hoover clearcut	USFS-MNF	18.4	Timber harvest	T,P
WV	GaJa	Private	11.3	Grazing management	B,N,T,P
WV	BoJe	Private	16.9	Old field management	B,N,T,P
WV	FeJi	Private	4.1	Old field management	T,P
WV	HoKi	Private	1.9	Old field management	T,P
WV	Lake Reed	Private	26.6	Old field management	B,N,T,P
WV	BeLa	Private	6	Old field management	P
WV	DiLl	Private	4.9	Old field management	T,P
WV	PoPh	Private	6.3	Old field management	B,N,T,P
WV	ToRa	Private	6.9	Grazing management	T,P
WV	KeSe	Private	5.1	Old field management	T,P
WV	Shearer South	USFS-MNF	7.9	Grazing management	B,N,T,P
WV	Snake Hill WMA	WVDNR	47	Timber harvest	T,P
WV	DrSt	Private	8.3	Grazing management	P
WV	McTr	Private	0.1	Old field management	T,P