AVIAN CONSERVATION & ECOLOGY

VOLUME 18, ISSUE 1, ARTICLE 21

Oliver, L. R., R. S. Bailey, K. R. Aldinger, P. B. Wood, and C. M. Lituma. 2023. Evaluating the effects of Natural Resources Conservation Service project implementation on the disturbance-dependent avian community with implications for Blue-winged Warblers. Avian Conservation and Ecology 18(1):21. https://doi.org/10.5751/ACE-02464-180121

Research Paper

Evaluating the effects of Natural Resources Conservation Service project implementation on the disturbance-dependent avian community with implications for Blue-winged Warblers

Lincoln R. Oliver [1,2,3], *Richard S. Bailey* [4], *Kyle R. Aldinger* [5], *Petra B. Wood* [3] and *Christopher M. Lituma* [2]

[1]U.S. Fish and Wildlife Service, Illinois-Iowa Ecological Services Field Office, Moline, IL, [2]Division of Forestry and Natural Resources, West Virginia University, Morgantown, WV, [3]West Virginia Cooperative Fish and Wildlife Research Unit, West Virginia University, Morgantown, WV, [4]West Virginia Division of Natural Resources, Wildlife Resources Section, Elkins, WV, [5]U.S. Department of Agriculture, Natural Resources Conservation Service, Morgantown, WV

ABSTRACT. The Blue-winged Warbler (*Vermivora cyanoptera*) is a songbird that breeds in eastern deciduous forests of North America. The species is declining, partially due to declines in forest disturbances. According to the umbrella species concept, management actions implemented to benefit other critically declining disturbance-dependent species like the Cerulean (*Setophaga cerulea*) and Golden-winged (*Vermivora chrysoptera*) warblers should positively affect Blue-winged Warbler site occupancy and species richness of shrubland and grassland birds. Similarly, determining if the umbrella concept is supported by relating species richness of disturbance-dependent avian guilds would support continued funding for species-specific conservation and management. Our goal was to evaluate if Natural Resources Conservation Service (NRCS) projects in West Virginia implemented for Cerulean and Golden-winged warblers also positively affected Blue-winged Warbler site occupancy and the disturbance-dependent avian community. We hypothesized that Blue-winged Warbler single-season occupancy and species richness for shrubland and grassland bird species would be greater on treated sites than on untreated sites. We also included other vegetation variables (i.e., percent cover of grasses, forbs, etc.) and spatial variables (i.e., elevation (m), ecoregion, etc.) that could affect Blue-winged Warbler site occupancy. We conducted point count surveys at 341 total locations distributed among 20 private properties managed for Golden-winged Warblers (n = 147); 19 private properties managed for Cerulean Warblers (n = 197); and two properties managed for both species during 2019–2020. Treatments included a variety of management practices (i.e., brush management) following specific guidelines to improve Cerulean and Golden-winged warbler habitat. We identified and defined untreated sites as either pre-treatment sites with planned management that had not yet occurred, or as reference sites, which were outside of treatment areas and representative of pre-treatment vegetation structure conditions. Contrary to our hypotheses, treated points had lower Blue-winged Warbler site occupancy than untreated points by 34–44% depending on ecoregion (Central Appalachians, Ridge and Valley, Western Allegheny Plateau), and shrubland and grassland avian guild richness were not different at untreated and treated locations. Thus, NRCS conservation project implementation for Cerulean and Golden-winged warblers did not meaningfully affect Blue-winged Warbler site occupancy or associated shrubland and grassland bird avian richness. We detected Blue-winged Warblers across the range of elevations surveyed (244–917 m), suggesting that their breeding distribution is continuing to expand into higher elevations in the Central Appalachians. Additionally, Blue-winged Warbler site occupancy was positively correlated with shrubland conditions within 100 m of survey points and decreased with increasing basal area within 100 m of survey points. Thus, management that increases the amount of shrubland in the Central Appalachians has potential as a conservation action to benefit Blue-winged Warbler site occupancy.

Évaluation des effets de la mise en œuvre de projets du Natural Resources Conservation Service sur la communauté aviaire dépendante de perturbations et répercussions sur la Paruline à ailes bleues

RÉSUMÉ. La Paruline à ailes bleues (*Vermivora cyanoptera*) est un passereau qui niche dans les forêts de feuillus de l'Est de l'Amérique du Nord. L'espèce est en diminution, en partie à cause de la raréfaction de perturbations forestières. Selon le concept des espèces généralistes, les mesures de gestion mises en œuvre en faveur d'autres espèces dépendantes de perturbations et en baisse draconienne, telles que la Paruline azurée (*Setophaga cerulea*) et la Paruline à ailes dorées (*Vermivora chrysoptera*), devraient avoir un effet positif sur la fréquentation des sites par la Paruline à ailes bleues et la richesse d'espèces d'oiseaux d'arbustaies et de prairies. De même, la détermination à savoir si le concept d'espèces généralistes est corroboré par la richesse en espèces de la guilde d'espèces dépendantes de perturbations justifierait le financement continu de la conservation et de la gestion spécifiques aux espèces. Notre étude cherchait à déterminer si les projets du Natural Resources Conservation Service (NRCS) en Virginie-Occidentale mis en œuvre pour la Paruline azurée et la Paruline à ailes dorées avaient également un effet positif sur la fréquentation des sites par la Paruline à ailes bleues et la communauté d'espèces dépendantes de perturbations. Nous avons émis l'hypothèse voulant que le taux de fréquentation de la Paruline à ailes bleues au cours d'une saison et la richesse en espèces d'oiseaux d'arbustaies et de prairies seraient plus élevées sur les sites traités

Corresponding author: Christopher M Lituma, cml0017@mail.wvu.edu

que sur les sites non traités. Nous avons également inclus d'autres variables de végétation (c.-à-d. le pourcentage de couverture de graminées, d'herbacées, etc.) et des variables spatiales (c.-à-d. l'altitude (m), l'écorégion, etc.) qui pourraient influer sur la fréquentation des sites par la Paruline à ailes bleues. Nous avons effectué des dénombrements par points d'écoute à 341 sites répartis sur 20 propriétés privées gérées pour la Paruline à ailes dorées (n = 147); 19 propriétés privées gérées pour la Paruline azurée (n = 197); et 2 propriétés gérées pour ces deux espèces au cours de 2019–2020. Les traitements comprenaient une variété de pratiques de gestion (c.-à-d. gestion des broussailles) suivant des lignes directrices spécifiques destinées à améliorer l'habitat de la Paruline azurée et de la Paruline à ailes dorées. Nous avons identifié et défini les sites non traités comme étant soit des sites de prétraitement avec une gestion planifiée qui n'avait pas encore eu lieu, soit des sites de référence, qui étaient en dehors des zones de traitement et représentatifs des conditions de la structure végétale avant le traitement. Contrairement à nos hypothèses, la fréquentation des sites par la Paruline à ailes bleues était plus faible aux sites traités qu'aux sites non traités, de 34 à 44 % selon l'écorégion (Appalaches Centrales, Crête et vallée, Ouest du plateau d'Alleghenys), et la richesse de la guilde d'oiseaux d'arbustaies et de prairies n'était pas différente aux endroits traités et non traités. Ainsi, la mise en œuvre des projets de conservation du NRCS pour les Parulines azurée et à ailes dorées n'a pas eu d'effet significatif sur la fréquentation des sites par la Paruline à ailes bleues ou sur la richesse d'espèces d'arbustaies et de prairies qui y est associée. Nous avons détecté des Parulines à ailes bleues à toutes les altitudes examinées (244–917 m), ce qui indique que leur aire de reproduction continue de s'étendre à des altitudes plus élevées dans les Appalaches Centrales. De plus, la fréquentation des sites par la Paruline à ailes bleues était positivement corrélée à l'état des arbustes dans un rayon de 100 m autour des points d'écoute, et diminuait avec l'augmentation de la surface basale dans un rayon de 100 m autour des points d'écoute. Par conséquent, une mesure de gestion visant la hausse des arbustaies dans les Appalaches Centrales a le potentiel d'être une activité de conservation bénéfique pour la fréquentation des sites par la Paruline à ailes bleues.

Key Words: *avian community; conservation project; early successional; habitat management; NRCS; occupancy; private lands; shrubland; young forest*

INTRODUCTION

Through the umbrella species concept, habitat management for focal species has been proposed as a mechanism to indirectly benefit co-occurring species and make better use of limited conservation funding (Roberge and Angelstam 2004). Habitat management efforts are underway in priority areas of the Appalachian Mountains region to benefit Golden-winged (*Vermivora chrysoptera*) and Cerulean (*Setophaga cerulea*) warblers through Natural Resources Conservation Service (NRCS) projects (Appendix 1). Management actions implemented in these projects follow science-based Golden-winged and Cerulean warbler habitat management guidelines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013, Wood et al. 2013), which may benefit co-occurring species. Many disturbance-dependent wildlife species in eastern North America have experienced population declines resulting from land use change and suppression of disturbance regimes (Hunter et al. 2001, King and Schlossberg 2014). Prior to European settlement, unique vegetation conditions in eastern North America were created via disturbances such as natural fire, intentional fire by Native Americans, windthrow, flooding, and activities by other wildlife species (e.g., North American beaver [*Castor canadensis*], elk [*Cervus canadensis*], and American bison [*Bison bison*]; Lorimer 2001). While the utility of the umbrella species concept as a conservation tool has been criticized, an opportunity exists to determine if Golden-winged and Cerulean warbler-specific habitat management on private lands is positively affecting other declining disturbance-dependent species, such as the Blue-winged Warbler (*Vermivora cyanoptera*).

The Blue-winged Warbler, a disturbance-dependent generalist (Confer and Knapp 1981), is a declining and understudied North American songbird (Gill et al. 2020). Besides studies on hybridization and competition with the imperiled Golden-winged Warbler (Buehler et al. 2007, Confer et al. 2003, Shapiro et al. 2004, Vallender et al. 2007), little published research exists on Blue-winged Warbler breeding habitat characteristics or response to habitat management. Their breeding habitat has been described as a dense matrix of herbaceous, shrub, and sapling growth near forest edges where woody vegetation dominates (Confer and Knapp 1981, Askins et al. 2007, Confer et al. 2003, Gill et al. 2020). Landscape-scale forest clearing in the United States during the late 18th and early 19th century for timber and agriculture, likely benefited Blue-winged Warblers (Johnson and Govatski 2013). Now they breed in a broad range of early to mid-successional vegetation communities predominantly resulting from anthropogenic disturbances such as utility corridors, reclaimed surface mines, abandoned agricultural fields, and clearcut harvests in early stages of succession (Confer and Knapp 1981, Confer et al. 2003, Gill et al. 2020).

While Blue-winged Warbler breeding distribution has continued to expand northward and into higher elevations in the Appalachians (Canterbury et al. 1993, Patton et al. 2010, Bailey and Rucker 2021), populations declined at a rate of -0.76%/year in West Virginia during 1966–2019 due to habitat loss on breeding, migration, and wintering grounds (Rosenberg et al. 2016, Gill et al. 2020, Sauer et al. 2020). They undoubtedly benefit from habitat management techniques used to create or maintain shrubland and young forest communities (e.g., heavy timber harvest, grazing, prescribed fire, and old field management), however, their response to these techniques has not been well quantified. While Blue-winged Warbler data have been collected as a component of larger studies, the species has rarely been the primary focus because other avian species, such as the Golden-winged Warbler, have experienced more precipitous population declines. Morris et al. (2013) evaluated avian response to silviculture in the Ozark Mountains of Missouri and found that Blue-winged Warbler density significantly increased following even- and uneven-aged harvests. At sites managed for Cerulean Warblers using even-aged harvest with varying levels of residual basal area in the Central Appalachians, Blue-winged Warbler density peaked at low residual basal area (3–5 m^2/ha; Sheehan et al. 2014). With Blue-winged Warbler populations continuing to decline, evaluating the effects of various sources of targeted disturbance on the species needs to be considered.

Our objective was to evaluate the response of Blue-winged Warblers and other early successional avian species to NRCS conservation projects in West Virginia. Additionally, we aimed to identify key habitat characteristics associated with Blue-winged Warbler site occupancy. We addressed these objectives by surveying the avian community, vegetation, and habitat characteristics on pre-treatment and post-treatment sites. Because Blue-winged and Golden-winged warblers are often documented nesting in the same areas (Confer et al. 2020), we reviewed previous studies of Golden-winged Warblers to select spatial and habitat characteristics that we hypothesized would influence Blue-winged Warbler site occupancy. We predicted that Blue-winged Warbler site occupancy would be higher at sites managed for Golden-winged and Cerulean warblers. Additionally, we predicted that species richness for shrubland and grassland guilds would be greater at post-treatment sites enrolled in the Golden-winged Warbler Project, as these species are similarly disturbance-dependent. Results from our study may inform whether habitat management for Golden-winged Warblers benefits Blue-winged Warblers and the early successional species guilds or if targeted efforts may be needed in the future. Additionally, research into Blue-winged Warbler site occupancy may help inform their expanding Appalachian distribution, which could have useful implications for Golden-winged Warbler conservation.

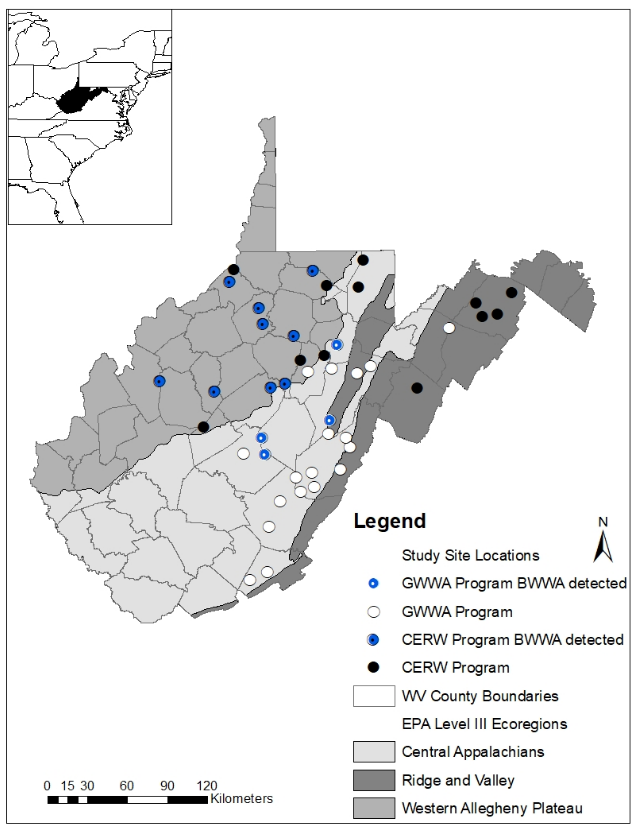
METHODS

Study Area

We sampled 20 sites enrolled in the Golden-winged Warbler Project, 19 sites enrolled in the Cerulean Warbler project, and 2 sites enrolled in both projects on private lands in West Virginia during 2019–2020 (Fig. 1). Among the sites (n = 41) surveyed in these two projects, we surveyed post-treatment sites (n = 29) that had been certified by NRCS as completed and pre-treatment sites (n = 12) where habitat management had been planned by NRCS but not yet initiated. We considered treatment the species-specific conservation practices administered by NRCS (Appendix 1). Treatments followed recommendations in the habitat management guidelines for Golden-winged and Cerulean warblers (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013, Wood et al. 2013). There were 12 conservation treatments which included a range of manipulations designed to improve habitat for the target species. Treatments were not mutually exclusive (sites could have received more than one treatment) but treatments were designed specifically for the Appalachians. Although the treatments were different and variable, we hypothesized that they would positively affect site occupancy of Blue-winged Warblers and other disturbance-dependent species because they all disturb the forest vegetation structure in a way that should elicit a positive site occupancy response. We did not collect pre- and post-treatment data on the same sites because contract implementation occurred over a 1- to 6-year period. We surveyed sites that were 1–8 years post-treatment to account for multi-year lags in avian response (Sheehan et al. 2014, Bakermans et al. 2015, Aldinger 2018).

We placed sample points in three defined site categories: 1) pre-treatment, which refers to sites with planned NRCS management but have not been initiated, 2) post-treatment sites that were certified by NRCS and treatments that had been completed 1–8 years prior to this research, 3) reference sites, which are areas outside of treated sites but within the property boundary and should be representative of pre-treatment conditions. For data analyses, we created a categorical variable by combining points on pre-treatment and reference sites into a single "reference" category and compared those to treatment site points. We also evaluated years post-treatment as a continuous variable, with values ranging from 0 (untreated) to 8 years. We verified the number of years since treatment through communication with landowners and NRCS personnel. Total area of treated areas was 1.2–36.3 ha (mean ± standard error [SE] = 9.3 ± 1.5 ha). Treatment areas on 11 of 29 post-treatment sites included multiple non-contiguous patches within the property boundary. These non-contiguous patches were 1.0–36.3 ha (mean ± SE = 4.9 ± 0.96 ha) and varied in shape, elevation, slope position, and aspect.

Fig. 1. Site locations enrolled in Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged (*Vermivora chrysoptera*) Warblers in West Virginia sampled during 2019–2020. Site locations were randomly offset within a 5-km radius of the actual location to protect personally identifiable information. CERW = Cerulean Warbler and GWWA = Golden-winged Warbler.



All sites were located within the Central Appalachians portion of the Appalachian Mountains Bird Conservation Region (NABCI Committee 2000) and occurred within the Central Appalachians, Western Allegheny Plateau, and Ridge and Valley level III ecoregions of West Virginia (Omernik and Griffith 2014; Fig. 1). The Central Appalachians ecoregion is a high elevation and rugged plateau with extensive forest cover dominated by northern hardwood and mixed-mesophytic forests (Woods et al. 1999). The Western Allegheny Plateau is characterized by sharp ridge tops and narrow valleys and is dominated by Appalachian oak (*Quercus* spp.) forests. The Ridge and Valley is characterized by elongated alternating forested ridges and agricultural valleys and is dominated by dry oak-pine (*Pinus* spp.) forests. These ecoregions contain variable soil conditions, geology, climate, elevation, and precipitation (Woods et al. 1999). Site means for elevation were 348–1047 m in the Central Appalachians, 241–498 m in the Western Allegheny Plateau, and 244–918 m in the Ridge and Valley. May–July precipitation is 762–1524 mm and temperature is 4–35°C (McNab and Avers 1994). Common overstory tree species include oaks (northern red [*Quercus rubra*], scarlet [*Q. coccinea*], black [*Q. velutina*], white [*Q. alba*], and chestnut [*Q. montana*]), hickories (*Carya* spp.), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), and yellow poplar (*Liriodendron tulipifera*). Shrublands in the study area primarily result from localized anthropogenic disturbances such as livestock grazing, timber harvesting, mechanical cutting for oil and gas wells (e.g., mowing or brush-hogging), and surface mine reclamation. Shrublands on our study sites were primarily the result of active/abandoned livestock grazing or timber harvesting, which commonly occur throughout the study area. Common shrub species in the study area include autumn olive (*Elaeagnus umbellate*), blackberry and raspberry (*Rubus* spp.), hawthorn (*Crataegus* spp.), and multiflora rose (*Rosa multiflora*) (Aldinger 2018). Scattered areas of red spruce forest (*Picea rubens*) occur at the highest elevations.

Data Collection

Sample point placement

Using ArcGIS, we systematically placed sampling points 200–943 m apart within treatment and reference areas to avoid double counting individual birds (Ralph et al. 1995). For small and/or irregular shaped treatment areas, we placed points in the approximate center of the treatment area for maximum coverage. We did not use random point placement; rather post-treatment points were placed >4 m from the edge of treated boundaries in treatment areas. Though this is an unconventional way to place points, we wanted our sample inference frame (100 m) to include treatment effects which could extend beyond the physical treatments (Paton 1994), and we were limited by the size of treatments. All point centers were >200 m apart, thus reference points were >100 m from treatment areas. This was to ensure no opportunity for overlap of treatment effects on reference points. For sites enrolled in the Golden-winged Warbler Project, we placed reference points in existing early to mid-successional vegetation communities on the same property that contained elements of *Vermivora* habitat (i.e., shrubland, young forest, and forest edges). For sites enrolled in the Cerulean Warbler project, we placed reference points in adjacent forested areas on the same property with similar slope, aspect, elevation, and forest community type as treated points, whenever possible. Consequently, pre-treatment and reference points had similar habitat conditions and we assumed conditions at reference points were representative of the pre-treatment condition at treated points.

Point count survey protocol

We surveyed the avian community from 7 May to 1 July in 2019 and 2020 to coincide with peak songbird breeding season in the Central Appalachians (Canterbury et al. 1993, Bakermans et al. 2015, Aldinger 2018). We surveyed 202 points in 2019, 105 points in 2020, and 34 points in both 2019 and 2020 (Table 1). We surveyed all points twice per year, with at least one week between surveys. We began surveys 15 minutes before official sunrise and ended 4 hours after official sunrise on days without consistent rain or sustained winds >19 km/hour (i.e., >3 on the Beaufort scale). Cloud cover, wind, and start time were recorded for each survey to incorporate into detection models.

Table 1. Annual number of point count locations and sites across contract treatment status categories surveyed on 21 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean Warblers (*Setophaga cerulea*) and 22 private properties enrolled in Natural Resources Conservation Service practices for Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia and naïve occupancy of Blue-winged Warblers (*Vermivora cyanoptera*) (BWWA) across treatment categories on the 341 point-count surveys sampled during 2019–2020.

	Untreated		Treated	
	Points	Sites	Points	Sites
Cerulean Warbler sites				
2019	102	10	24	2
2020	26	9	42	11
Total	128	19	66	13
BWWA naïve occupancy	0.09	0.37	0.06	0.31
Golden-winged Warbler sites				
2019	51	9	25	5
2020	14	5	23	7
2019 and 2020	13	4	21	4
Total	78	18	69	16
BWWA naïve occupancy	0.13	0.17	0.12	0.13

A two-person field crew conducted the avian sampling each year (three total observers). All observers were experienced in bird identification, and all were trained in local bird identification, distance estimation with range finders and sampling protocols before surveys began. We recorded all first detections seen or heard within a 10-minute period. All individuals detected were recorded once and monitored throughout the remainder of the survey to avoid double counting. We recorded detections by distance band of the bird from the observer (0–25 m, 25–50 m, 50–75 m, 75–100 m); we did not record or include any detections from beyond 100 m. We recorded detection type (song, call, visual, or fly-over) and sex for each detection, if possible.

GIS-derived covariates

We first used 2018 National Agriculture Imagery Program (NAIP) imagery (1-m cell size; data collected during the growing season) to manually digitize and identify land cover types deemed important for *Vermivora* breeding habitat in previous studies (Oliver 2021; Appendix 2). Additionally, we did ground truthing during field work to verify cover type accuracy from GIS imagery. One person (Lincoln Oliver) digitized all imagery to minimize classification inconsistencies. We chose 2018 imagery because it was the most recent statewide dataset available for West Virginia. For three of 29 (10%) post-treatment sites where management occurred after 2018, we used Google Earth imagery georeferenced using ArcGIS (Google Earth 2021). We digitized land cover within 100 m of each sampling point to align with the maximum distance band of point count data that were included in statistical analyses. Our land cover classes included open vegetation communities (<30% woody cover and dominated by grass and forb species such as goldenrods [*Solidago* spp.], orchard grass [*Dactylis glomerata*], sedges [*Carex* spp.], and tall fescue [*Festuca arundinacea*]; Bakermans et al. 2015), shrubland (≥30% shrub cover generally dominated by shrub species such as autumn olive, hawthorn, and multiflora rose with scattered canopy trees and herbaceous understory; Confer and Knapp 1981, Askins et al. 2007, Gill et al. 2020), and young forest (regenerating stands dominated by saplings ≤8 cm dbh; Askins et al. 2007, Confer and Knapp 1981, Gill et al. 2020). When delineating shrubland and young forest, the amount of woody cover was determined visually using 2018 NAIP imagery (Bakermans et al. 2015, Aldinger et al. 2018). We also included the sum of young forest (of trees ≤8 cm dbh) and shrubland (≥30% shrub cover) within 100-m of each point in analysis. We used a 1:24,000 digital elevation model (US Geological Survey 1999) in ArcGIS version 10.7 (ESRI 2011) to calculate elevation within a 100-m radius centered on each sampling point by obtaining the majority from the raster layer in ArcGIS, using the "zonal statistic as table" tool.

We used 5-m resolution land cover data generated from 2016 NAIP imagery (Maxwell et al. 2019) to calculate percent forest cover (deciduous, mixed, and conifer combined) and edge density (km/km²; Roth et al. 2012) within 1 km of each sampling point location (Oliver 2021). We included percent forest cover and edge density because *Vermivora* breeding habitat is associated with forested landscapes, and *Vermivora* populations will not persist in highly fragmented landscapes (Roth et al. 2012). We created 1-km buffers around each sampling point and evaluated percent forest by dividing the total forested area (ha) within each buffer by the area (ha) of each buffer and multiplying by 100. We chose a 1-km buffer following the guidelines recommended for landscape management for *Vermivora*, and because others have documented significant landscape-level effects (Bakermans et al. 2015, Aldinger 2018). Within each 1-km buffer, we also estimated edge density (km/km²) by dividing the length of forest edge within each buffer by the area of buffer.

Vegetation covariates

We measured vegetation at the point level to characterize vegetation communities at each site for structural metrics deemed important for *Vermivora* breeding (Confer and Knapp 1981, Askins et al. 2007, Gill et al. 2020). We conducted vegetation sampling once each year after the second point count survey to ensure vegetation growth was maximized within the survey period. We measured percent cover of grass, forbs, *Solidago*, *Rubus*, shrubs, saplings (1-8 cm dbh and ≥1 m tall), and canopy trees (>8 cm dbh) within each plot based on ocular tube "hits" at 10 points spaced 10 m apart along each of three 100-m transects, radiating from plot center at 0°, 120°, and 240° (adapted from James and Shugart 1970 and McNeil 2019; Oliver 2021). We recorded the occurrence of each vegetation class when looking straight up and down through the vertical ocular tube. Percent cover of each vegetation class was calculated as the number of "hits" for a class divided by the total number of ocular tube sampling points (n = 30) and multiplied by 100. We recorded maximum vegetation height to the nearest meter by taking a reading with a handheld range finder, looking straight up to the approximate tallest tree or shrub. We calculated the coefficient of variation as the standard deviation divided by the mean for the 30 maximum vegetation height values. We estimated coefficient of variation for maximum vegetation height for each sampling point because *Vermivora* nest sites have more variable vegetation height than random locations within the same territory (Aldinger 2018).

We measured canopy tree basal area (Golden-winged Warbler Working Group 2013, Wood et al. 2013) at four prism plots per sampling point location placed at the point center and 70 m from point center along the 0°, 120°, and 240° transects. Variable radius prism plots were completed using a wedge prism (equivalent to a 2.2296-BAF metric prism) to tally live trees and snags ≥8 cm dbh at each prism plot (Nareff et al. 2019). The observer tallied trees that were "in" the plot by sighting through the prism held over plot center and rotating around the point. For each "in" live tree, we recorded tree species or group (e.g., hickory group, red oak group) and dbh measured to the nearest centimeter (cm) using a dbh tape. For each "in" snag ≥2 m in height, we recorded dbh. All borderline (i.e., trees that were unclear whether they were "in" or "out" of the prism plot) live trees and snags were counted, but every other borderline live tree was removed for basal area calculations (Bell and Alexander 1957). We calculated basal area at each plot by multiplying the number of "in" live trees by a basal area factor of 2.296. Mean basal area across all four prism plots (100-m basal area) reflects basal area across the 100-m radius plot and, therefore, may include tree tallies from within and outside the treatment area.

Species richness and Habitat guilds

We evaluated species richness of shrubland and grassland bird species on sites managed for Golden-winged and Cerulean warblers. We classified songbird species a priori into these habitat guilds based on breeding biology and previous guild studies from the region (McDermott and Wood 2009; Appendix 3). The shrubland guild consisted of 26 species that breed in early successional vegetation communities (e.g., regenerating forest following recent disturbance, old fields). The grassland guild consisted of 4 species that breed in grasslands (e.g., hayfields, pastures). We included all auditory and visual detections, except flyovers of adult males within a 100-m radius of each point count in species richness analysis. We defined species richness at each point as the total number of bird species within each habitat guild detected across the two visits per year. We chose these guilds because they include disturbance-dependent species, which continue to experience population declines (Rosenberg et al. 2016) and are groups of birds most likely to be positively affected by the management on sites.

Statistical Analysis

We estimated Blue-winged Warbler site occupancy using single-season occupancy models. Single-season occupancy models use spatially and temporally repeated surveys to estimate the proportion of sites occupied by a species of interest as a product of ecological processes and imperfect detection by linking two sub-models (MacKenzie et al. 2002). For the 34 points on sites surveyed in 2019 and 2020, we included only the 2020 data in analyses because including data from both years was not compatible with our site occupancy analyses and models would not converge using only 2019 data due to low detections. We included all detection types except flyovers (e.g., singing, visual, and call) of adult males within 100 m of sampling point in analysis to relate site occupancy more closely to vegetation and topographic characteristics measured within 100-m radius of each sampling point. Point count data were formatted as detection (1) and non-detection (0) per visit for estimation of detection probability across each survey. We used the *occu* function in package *unmarked* version 0.11-0 (Fiske and Chandler 2011) in program R version 3.5.2 (R Development Core Team 2019) for all hierarchical modeling. We considered models with the lowest Akaike's Information Criterion score adjusted for small sample sizes (ΔAIC_c; Burnham and Anderson 2002) to be the best supported model given the data and any models with $\Delta AIC_c < 2.0$ were considered plausible (Burnham and Anderson 2002).

We first included each detection covariate (observer, ordinal date, time-since-sunrise, sky, wind, and canopy; Table 2 and Appendix 2) in its own detection model to identify which detection covariates were best supported using AIC_c (Burnham and Anderson 2002). We then checked confidence intervals of beta estimates, and if confidence intervals did not overlap zero, we created an additive model with those covariates (Arnold 2010).

Table 2. Detection model selection procedure results for Blue-winged Warbler (*Vermivora cyanoptera*) occupancy (ψ) and detection probability (p) using 341 point-count locations on 41 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020. K is the number of parameters in each model, AICc is the Akaike's Information Criterion value for small sample sizes, ΔAICc is the difference between each model's AICc value and the lowest AICc value in the candidate set, and w_i is the Akaike weight of each model in relation to each model set. Codes for covariates are defined in Appendix 2.

Model	K	ΔAIC_c	w_i
ψ (1) p (observer + date)[a]	5	0.00	0.97
ψ (1) p (observer)	4	6.73	0.03
ψ (1) p (date)	3	16.50	0.00
ψ (1) p (1)	2	21.05	0.00
ψ (1) p (wind)	3	21.32	0.00
ψ (1) p (canopy)	3	22.97	0.00
ψ (1) p (time)	3	23.05	0.00
ψ (1) p (sky)	7	25.94	0.00

[a] Lowest AIC_c: 278.91.

We tested three occupancy model sets. We chose to use a step-wise modeling approach because we did not want treatment effects to be confounded by landscape or vegetation variables, but we wanted to account for those other potential relationships.

Table 3. Single-season occupancy model selection procedure results for Blue-winged Warbler (*Vermivora cyanoptera*) occupancy (ψ) and detection probability (p) using 341 point-count locations on 41 private properties enrolled in Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020. K is the number of parameters in each model, AICc is the Akaike's Information Criterion value for small sample sizes, ΔAICc is the difference between each model's AICc value and the lowest AICc value in the candidate set, and wi is the Akaike weight of each model in relation to each model set. Codes for covariates are defined in Appendix 2.

Model	K	ΔAIC_c	w_i
Model set 1: treatment models			
ψ (ecoregion) p (observer + date)	7	0.00	0.40
ψ (status + ecoregion) p (observer + date)	8	0.39	0.33
ψ (year + ecoregion) p (observer + date)	8	1.60	0.18
ψ (status) p (observer + date)	6	4.76	0.04
ψ (status + elev) p (observer + date)	7	6.11	0.02
ψ (elev) p (observer + date)	6	6.25	0.02
ψ (year + elev) p (observer + date)	7	7.56	0.01
ψ (1) p (1)	2	25.56	0.00
Model set 2: GIS-derived models			
ψ (shrubland) p (observer + date)	6	0.00	0.65
ψ (young forest/shrubland) p (observer + date)	6	1.27	0.35
ψ (open) p (observer + date)	6	21.47	0.00
ψ (edge) p (observer + date)	6	24.99	0.00
ψ (yngforest) p (observer + date)	6	27.81	0.00
ψ (forest) p (observer + date)	6	28.18	0.00
ψ (1) p (1)	2	47.33	0.00
Model set 3: vegetation models			
ψ (ba) p (observer + date)	6	0.00	0.91
ψ (bacent) p (observer + date)	6	6.05	0.04
ψ (cov) p (observer + date)	6	6.84	0.03
ψ (rubus) p (observer + date)	6	11.30	0.00
ψ (sapling) p (observer + date)	6	11.96	0.00
ψ (shrub) p (observer + date)	6	12.17	0.00
ψ (grass) p (observer + date)	6	12.32	0.00
ψ (solidago) p (observer + date)	6	12.63	0.00
ψ (forb) p (observer + date)	6	12.79	0.00
ψ (canopy) p (observer + date)	6	12.91	0.00
ψ (1) p (1)	2	32.06	0.00

[a] Lowest AIC_c: 274.40 for model set 1; 252.63 for model set 2; 267.90 for model set 3.
[b] ba = mean basal area; bacent = center plot basal area; cov = vegetation height (m) coefficient of variation; elev = elevation (m); open = percent open within 100 m; shrubland = percent shrubland within 100 m; status = contract treatment status; yngforest = percent young forest within 100 m.

Proportions of cover types or vegetation structure can affect early successional bird site occupancy differently and be scale dependent (Thogmartin 2010, West et al. 2016). In the first occupancy model set, we evaluated Blue-winged Warbler site occupancy at reference and treated locations to evaluate the conservation project's effectiveness (Table 3 and Appendix 2). Our first model set had seven models using contract treatment status (treated vs. reference) and years-post-treatment as the predictor variables and included ecoregion and elevation to account for inherent differences in site occupancy among regions. According to data present in the inclusive thesis (Oliver 2021), we did not include interactive effects between contract treatment status and vegetation covariates because very few vegetation metrics in our

Table 4. Beta (β) estimates, standard errors (SE), and 95% lower and upper confidence intervals (CI) on the logit-scale from models (Table 3) estimating Blue-winged Warbler (*Vermivora cyanoptera*) occupancy using 341 point-count locations on 41 private properties from 2019–2020. Properties were enrolled in Natural Resources Conservation Service programs for either Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*). Codes for covariates are defined in Appendix 2.

Parameter	β estimate	SE	Lower 95% CI	Upper 95% CI
Model set 1: treatment models				
Ecoregion				
Central Appalachians	1.33	0.31	0.72	1.93
Ridge and Valley	-1.34	0.59	-2.50	-0.18
Western Allegheny Plateau	0.24	0.45	-0.63	1.19
Status + ecoregion				
Untreated	2.03	0.39	0.27	1.79
Treated	-0.54	0.43	-1.38	0.30
Ridge and Valley	-1.41	0.60	-2.58	-0.23
Western Allegheny Plateau	0.12	0.46	-0.79	1.02
Model set 2: GIS-derived models				
Shrubland				
100-m shrubland	0.06	0.02	0.02	0.10
Young forest/shrubland				
100-m young forest/shrubland	0.05	0.01	0.02	0.07
Model set 3: vegetation models				
ba				
100-m basal area	-0.11	0.03	-0.17	-0.04

study differed among contract treatment categories, indicating that management implementation did not meaningfully influence vegetation structure and composition on treated sites. In the second model set, we developed six models to examine the influence of GIS-derived variables (Table 3 and Appendix 2). In the third model set, we developed 10 models to examine the influence of vegetation covariates (Table 3 and Appendix 2). We evaluated Goodness of Fit for top models using the MacKenzie and Bailey (2004) fit statistics for site occupancy. If models did not fit well ($p < 0.05$), we considered alternative distributions and analyses. Site occupancy predictions were derived using the "predict" function in program R and differences were assessed based on 95% confidence intervals of beta estimates.

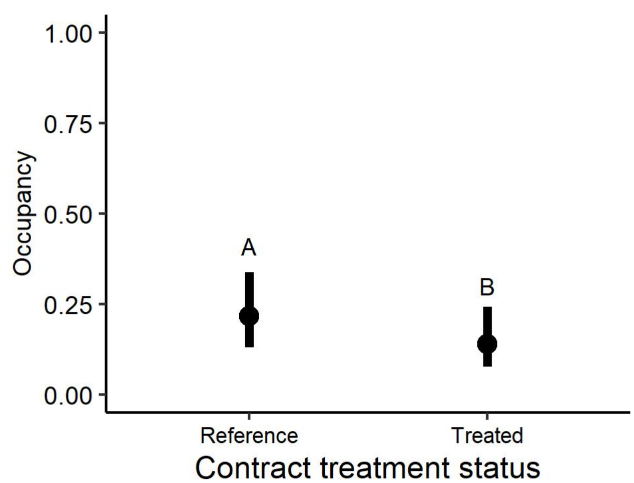
We used a one-way analysis of variance (ANOVA) including site name as a random effect to compare observed species richness of shrubland and grassland avian guilds reference and treated locations categories using the "lme" and "summarySE" functions in program R. For the 34 points on sites surveyed in 2019 and 2020, we included only the 2020 data in analyses. For significant ANOVAs, we then identified which contract treatment status categories differed using a post hoc Tukey-Kramer test. We set statistical significance at $p < 0.05$.

RESULTS

We detected 49 Blue-winged Warblers (on 18 points at four Golden-winged Warbler sites and 16 points at nine Cerulean Warbler sites) across 341 points surveyed during the study. Naïve occupancy, which is unadjusted using detection probability, was highest on reference points at sites enrolled in the Golden-winged Warbler Project (Table 1).

Observer (Obs1 β = 3.59 ± 2.57; Obs2 β = 4.10 ± 1.00; Obs3 β = 2.95 ± 0.87) and date (β = -0.044 ± 0.17) were the only supported detection covariates and were used as the detection covariates in models for all subsequent analyses (Table 2). All models passed goodness-of-fit tests ($p > 0.05$; c-hat ≤ 1.40). For model set one, model selection results indicated that a model for ecoregion and contract treatment status and a model with only ecoregion were supported (Table 3). Treated points had lower site occupancy than reference points by 34–44% depending on ecoregion (Table 4 and Fig. 2). Site occupancy in the Central Appalachians ecoregion was 300% greater (0.25 +/- 0.07) than in the Ridge and Valley (0.06 +/- 0.03; Fig. 3). From model set 2, models examining GIS variables containing 100-m shrubland and 100-m young forest/shrubland in the immediate landscape were best supported (Table 3). Site occupancy increased by 880% as 100-m shrubland increased to 100% and by 922% as 100-m young forest/shrubland increased to 100% (Table 4 and Figs. 4 and 5). For model set 3, a model containing 100-m basal area was best supported (Table 3). Site occupancy decreased by 93% as 100-m basal area increased from 0 to 30 m^2/ha (Table 4 and Fig. 6). When comparing site means of covariates between reference and treated points, 100-m shrubland were the same and 100-m young forest was 6% greater on treated points (Appendix 4).

Fig. 2. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers at 341 point-count surveys on 41 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora cyanoptera*) in West Virginia sampled during 2019–2020. Presented is occupancy related to treatment status and observer + date for detection probability from top models in Model Set 1. Differences are indicated by alphabetic notation at α = 0.05.



We detected four species in the grassland guild and 26 in the shrubland guild (Appendix 3), across 147 point-count surveys on sites managed or planned to be managed for Golden-winged and Cerulean warblers. There were no differences among the status categories for shrubland ($F = 1.56$, $p = 0.19$) or grassland ($F = 1.39$, $p = 0.24$) richness (Figs. 7 and 8).

Fig. 3. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers (*Vermivora cyanoptera*) at 341 point-count surveys on 41 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020. Presented is occupancy related to ecoregion and observer + date for detection probability from top models in Model Set 1. Differences are indicated by alphabetic notation at α = 0.05.

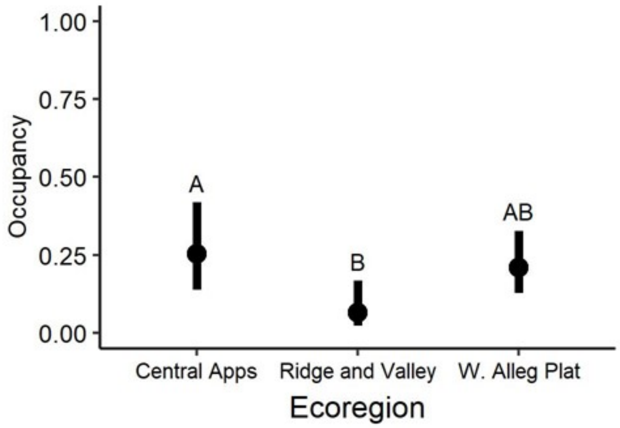


Fig. 4. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers (*Vermivora cyanoptera*) at 341 point-count surveys on 41 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020. Presented is occupancy related to percentage of 100-m shrubland and observer + date for detection probability from top models in Model Set 2.

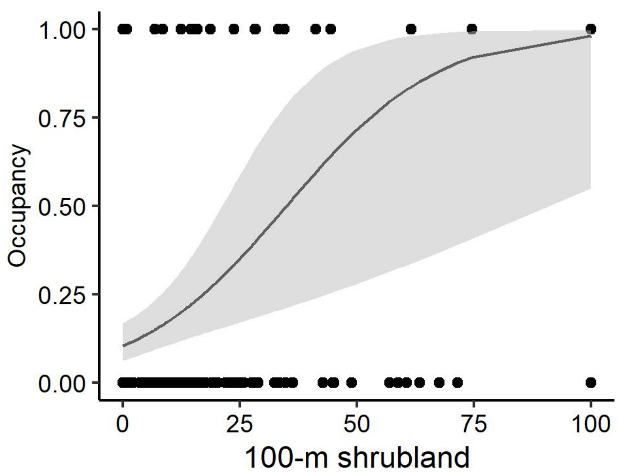


Fig. 5. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers (*Vermivora cyanoptera*) at 341 point-count surveys on 41 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020. Presented is occupancy related to percentage of 100-m young forest/shrubland and observer + date for detection probability from top models in Model Set 2.

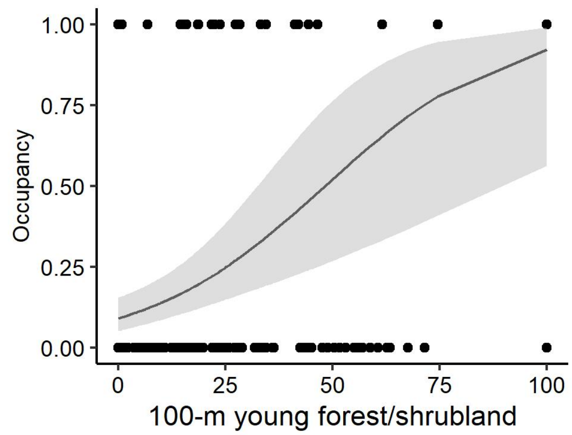
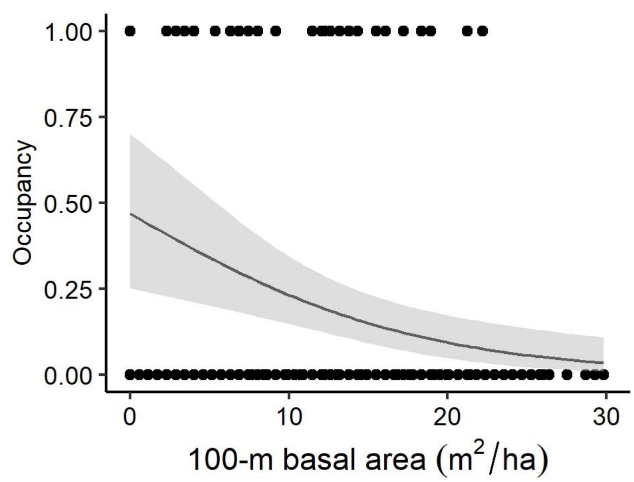


Fig. 6. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers (*Vermivora cyanoptera*) at 341 point-count surveys on 41 private properties enrolled in the Natural Resources Conservation Service practices for Cerulean (*Setophaga cerulea*) or Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020. Presented is occupancy related to percentage of 100-m basal area and observer + date for detection probability from top model in Model Set 3.



DISCUSSION

Private lands conservation projects are being implemented to benefit many imperiled species of conservation concern, but the effects of implementation on these co-occurring species are seldom evaluated. Evaluating the response of co-occurring species is critical to assess the potential of these conservation projects to provide "umbrella" benefits to other wildlife species. We did not observe positive responses for Blue-winged Warbler site occupancy to Golden-winged and Cerulean warbler management, nor species richness in the grassland or shrubland avian guilds to Golden-winged Warbler management, suggesting the disturbance-dependent avian community did not indirectly benefit from habitat management. We suspect that the lack of avian response was influenced by private lands variability, site selection, small treatment areas, and challenges associated with conservation project implementation resulting in insufficient vegetation structure and composition. For disturbance-dependent species specifically, there was low shrubland cover on treated sites enrolled in the Golden-winged Warbler Project, likely resulting from high basal area retained during implementation.

While Blue-winged Warblers were not positively correlated with implementation of habitat management for Golden-winged and Cerulean warblers, we did identify important habitat characteristics that have implications for habitat management. Blue-winged Warbler site occupancy was positively associated with shrubland. We defined shrubland cover as a digitized area with ≥30% shrub cover generally dominated by shrub species with scattered canopy trees and herbaceous understory. The importance of shrubland cover for the closely related Golden-winged Warbler has been repeatedly demonstrated (Hanowski 2002, Bulluck and Buehler 2008, Roth et al. 2012, Aldinger and Wood 2014, Aldinger 2018). Shrubs are important to *Vermivora* because nest sites are often located at ecotones between forest edges, shrubs, and herbaceous vegetation, and foraging usually occurs on arthropods from the peripheral branches of trees and shrubs (Gill et al. 2020). While shrubs are a preferred Blue-winged Warbler habitat component (Confer and Knapp 1981, Confer et al. 2003, Gill et al. 2020), the importance and amount of shrubland cover had not been quantified for Blue-winged Warblers. Although habitat management on our sites was not targeted for Blue-winged Warblers and our study was limited by sample size, spatial extent, and treatment implementation, we found that 50–100% shrubland cover at the 100-m radius scale produced highest site occupancy for Blue-winged Warblers. Shrubland conditions can be achieved by setting back succession through the implementation of disturbance (e.g., timber management, prescribed burning, grazing, and mechanical clearing) or advancing succession by reducing disturbance to allow for shrub establishment in existing early successional communities.

We predicted that Blue-winged Warblers would benefit from the guidelines for Golden-winged and Cerulean warblers, however, we believe that the Golden-winged Warbler guidelines will be more effective than Cerulean Warbler guidelines when managing for Blue-winged Warblers. Blue-winged Warbler occupancy on our sites was negatively associated with basal area. We detected only 4 Blue-winged Warblers at 4 sites treated for Cerulean Warblers, and all were detected on points with basal area from 2.3–18.4 m²/ha and contained shrubland and/or young forest cover. Thus, similar to Sheehan et al. (2014), management for Cerulean Warblers (recommended residual basal area of 9.2–20.7 m²/ha) is unlikely to benefit Blue-winged Warblers. The minimum 100-m basal area for points where Blue-winged Warblers were detected was 2.0 m²/ha (Oliver 2021), which is near the minimum basal area recommendation for Golden-winged Warblers of 1.9 m²/ha. Site occupancy decreased by 25% above 4.6 m²/ha (Fig. 2E). Therefore, we recommend residual basal area of 1.9–4.6 m²/

Fig. 7. Observed species richness and 95% confidence intervals of the shrubland bird guild relative to contract treatment status on at 147 point-count surveys on 22 private properties managed for Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020.

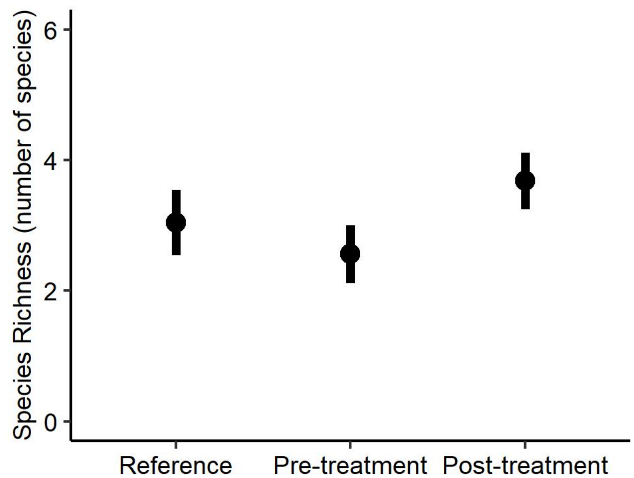
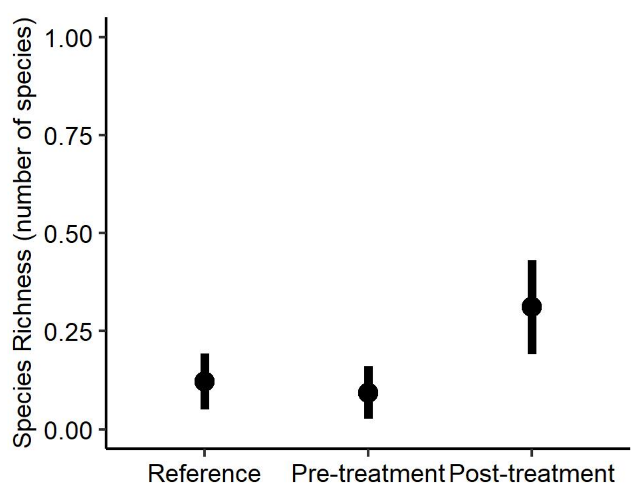


Fig. 8. Observed species richness and 95% confidence intervals of the grassland bird guild relative to contract treatment status on at 147 point-count surveys on 22 private properties managed for Golden-winged Warblers (*Vermivora chrysoptera*) in West Virginia sampled during 2019–2020.



ha when managing for Blue-winged Warblers in West Virginia. This recommendation is consistent with previous research indicating that Blue-winged Warblers use early and mid-successional communities (Confer and Knapp 1981, Confer et al. 2003, Gill et al. 2020). Our basal area finding suggests that residual canopy trees are not necessary to incorporate in habitat management for Blue-winged Warblers, unlike recommendations in the Golden-winged Warbler habitat management guidelines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013). However, managers should use caution when drastically reducing basal area in large areas for Blue-winged Warblers, as territories normally include a forest edge (Patton et al. 2010). The target basal area range can be achieved by implementing silviculture treatments (e.g., clearcutting, seed tree harvests, and overstory removal with residuals) in existing forest or shrubland management practices (e.g., mechanical clearing) to create or enhance existing early successional vegetation communities.

Ecoregion strongly influenced occupancy on our sites, as occupancy predictions were highest in the Central Appalachians and lowest in the Ridge and Valley. Although 36% of the 341-point count locations were in the Ridge and Valley ecoregion, Blue-winged Warblers ($n = 4$) were only detected on one site. Blue-winged Warbler density is low in West Virginia's Eastern Panhandle (Bailey and Rucker 2021), as this area is near the eastern edge of the species' breeding distribution (Gill et al. 2020). The highest elevations in West Virginia occur in the Central Appalachians ecoregion. Historically, Blue-winged Warblers were restricted to lower elevations (<600 m, Buckelew and Hall 1994), but the species' breeding distribution has expanded into higher elevations (maximum elevation detected = 856 m; Bailey and Rucker 2021). We detected Blue-winged Warblers across most of the elevation range surveyed (244–917 m; Appendix 4). Our findings add to the growing body of research indicating that their breeding distribution is continuing to expand to higher elevations. Populations will require future monitoring to document continued upslope expansion to possibly identify priority areas for habitat management should population declines accelerate.

Our study is one of only a handful focusing on Blue-winged Warbler breeding habitat characteristics especially investigating response to habitat management for Golden-winged and Cerulean warblers. Habitat characteristics important to Blue-winged Warblers are consistent with those previously identified for Golden-winged Warblers, which is unsurprising as both species regularly nest in the same areas (Confer et al. 2020). However, our basal area recommendation of 1.9–4.6 m²/ha encompasses a wider range than suggested for Golden-winged Warblers (~1.9–3.7 m²/ha; Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013), suggesting that Blue-winged Warblers are found in a broader range of vegetation communities (Confer and Knapp 1981, Confer et al. 2003). Based on important breeding habitat characteristics that we identified, we believe that habitat management has potential as a conservation action to benefit populations in the Central Appalachians, Western Allegheny Plateau, and Ridge and Valley of West Virginia, given the species' reliance on disturbance. Based on our results, we recommend 50–100% shrubland cover at the 100-m radius scale and residual basal area of 1.9–4.6 m²/ha when managing habitat for Blue-winged Warblers in West Virginia. Though these results are limited by the scope of our study area and sample design, we are confident in their applicability as a guide and baseline for Blue-winged Warbler management to improve site occupancy in the region. Future studies with improved management implementation and larger sample sizes across the species' breeding range will be required to further inform the potential of habitat management as a range-wide conservation action for Blue-winged Warblers.

Author Contributions:

L.R.O., C.M.L., and P.B.W. formulated the questions; L.R.O collected data; R.S.B., K.R.A., C.M.L., and P.B.W. supervised research; L.R.O. analyzed the data; and L.R.O., R.S.B., K.R.A., C.M.L., and P.B.W. wrote the paper and revisions.

Acknowledgments:

We thank field technicians Caden Haines and Joseph Girgente for their hard work collecting data. We owe a special thanks to Natural Resources Conservation Service and West Virginia Division of Natural Resources staff for providing project assistance: Matt Aberle, Tiffany Beachy, Liz Brewer, Katie Loucks, and Jessie Reese. Finally, we thank numerous private landowners for allowing access to study sites. This project was funded by the National Institute of Food and Agriculture, McIntire-Stennis through West Virginia University Accession #1011563 and West Virginia Division of Natural Resources Project #10024251.

LITERATURE CITED

Aldinger, K. R., and P. B. Wood. 2014. Reproductive success and habitat characteristics of Golden-winged Warblers in high-elevation pasturelands. Wilson Journal of Ornithology 126:279-287. https://doi.org/10.1676/13-114.1

Aldinger, K. R. 2018. Ecology and management of Golden-winged Warblers (Vermivora chrysoptera) and associated avian species in the Allegheny Mountains of West Virginia. Ph.D. dissertation, West Virginia University, Morgantown, West Virginia, USA. https://doi.org/10.33915/etd.7152

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's information criterion. Journal of Wildlife Management 74:1175-1178. https://doi.org/10.1111/j.1937-2817.2010.tb01236.x

Askins, R. A., B. Zuckerberg, and L. Novak. 2007. Do the size and landscape context of forest openings influence the abundance and breeding success of shrubland songbirds in southern New England? Forest Ecology and Management 250:137-147. https://doi.org/10.1016/j.foreco.2007.05.009

Bailey, R. S. and C. B. Rucker. 2021. The Second Atlas of Breeding Birds in West Virginia. The Pennsylvania State University Press, University Park, Pennsylvania, USA.

Bakermans, M. H., J. L. Larkin, B. W. Smith, T. M. Fearer, and B. C. Jones. 2011. Golden-winged Warbler habitat best management practices in forestlands in Maryland and Pennsylvania. American Bird Conservancy, The Plains, Virginia, USA.

Bakermans, M. H., B. W. Smith, B. C. Jones, and J. L. Larkin. 2015. Stand and within-stand factors influencing Golden-winged Warbler use of regenerating stands in the central Appalachian Mountains. Avian Conservation and Ecology 10(1):10. https://doi.org/10.5751/ACE-00747-100110

Bell, J. F., and L. B. Alexander. 1957. Application of the variable plot method of sampling forest stands. Research Note No. 30. Oregon State Board of Forestry, Salem, OR, USA.

Buckelew, A. R., Jr., and G. A. Hall. 1994. The West Virginia Breeding Bird Atlas. University of Pittsburgh Press, Pittsburgh, Pennsylvania, USA.

Buehler, D. A., A. M. Roth, R. Vallender, T. C. Will, J. L. Confer, R. A. Canterbury, S. B. Swarthout, K. V. Rosenberg, and L. P. Bulluck. 2007. Status and conservation priorities of Golden-winged Warbler (Vermivora chrysoptera) in North America. The Auk 124:1439-1445. https://doi.org/10.1093/auk/124.4.1439

Bulluck, L. P., and D. A. Buehler. 2008. Factors influencing Golden-winged Warbler (Vermivora chrysoptera) nest-site selection and nest survival in the Cumberland Mountains of Tennessee. The Auk 125:551-559. https://doi.org/10.1525/auk.2008.07075

Burnham, K. P, and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York, NY, USA.

Canterbury, R. A., D. M. Stover, and T. C. Nelson. 1993. Golden-winged Warblers in southern West Virginia: status and population ecology. Redstart 60(4):97-106.

Confer, J. L., and K. Knapp. 1981. Golden-winged Warblers and Blue-winged Warblers: The relative success of a habitat specialist and a generalist. The Auk 98:108-114.

Confer, J. L., J. L. Larkin, and P. E. Allen. 2003. Effects of vegetation, interspecific competition, and brood parasitism on Golden-winged Warbler (Vermivora chrysoptera) nesting success. The Auk 120:138-144. https://www.researchgate.net/publication/335654327_Effects_of_Vegetation_Interspecific_Competition_and_Brood_Parasitism_on_Golden-Winged_Warbler_Vermivora_Chrysoptera_Nesting_Success

Confer, J. L., C. Porter, K. R. Aldinger, R. A. Canterbury, J. L. Larkin, and D. J. McNeil Jr. 2020. Implications for evolutionary trends from the pairing frequencies among Golden-winged and Blue-winged warblers and their hybrids. Ecology and Evolution 10:10633-10644. https://doi.org/10.1002/ece3.6717

ESRI. 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, California, USA.

Fiske I., and R. Chandler. 2011. Unmarked: an r package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software. 43:1-23. https://doi.org/10.18637/jss.v043.i10

Gill, F. B., R. A. Canterbury, and J. L. Confer. 2020. Blue-winged Warbler (Vermivora cyanoptera), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the World. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.buwwar.01

Google Earth. 2021. Version 7.3. December 2020 West Virginia imagery. Mountain View, CA, USA.

Golden-winged Warbler Working Group. 2013. Best management practices for Golden-winged Warbler habitats in the Appalachian Region. https://gwwa.org/for-resource-professionals/

Hanowski, J. M. 2002. Habitats and landscapes used by breeding Golden-winged Warblers in western Great Lakes forests. The Loon 74:127-133.

Hunter, W. C., D. A. Buehler, R. A. Canterbury, J. L. Confer, and P. B. Hamel. 2001. Conservation of disturbance-dependent birds in eastern North America. Wildlife Society Bulletin 29 (2):440-455.

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

Johnson, C., and D. Govatski. 2013. Forests for the people the story of America's eastern National Forests. Island Press, Washington, D.C., USA. https://doi.org/10.5822/978-1-61091-215-0

King, D. I., and S. Schlossberg. 2014. Synthesis of the conservation value of the early-succession stage in forests of eastern North America. Forest Ecology and Management 324:186-195. https://doi.org/10.1016/j.foreco.2013.12.001

Lorimer, C. G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9000 years of change. Wildlife Society Bulletin 29:425-439.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255. https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

MacKenzie, D. I., and L. L. Bailey. 2004. Assessing the fit of site-occupancy models. Journal of Agricultural, Biological, and Environmental Statistics 9:300-318. https://doi.org/10.1198/108571104X3361

Maxwell, A. E., M. P. Strager, T. A. Warner, C. A. Ramezan, A. N. Morgan, and C. E. Pauley. 2019. Large-Area, high spatial resolution land cover mapping using random forests, GEOBIA and NAIP orthophotography: Findings and recommendations. Remote Sensing 12:486. https://doi.org/10.3390/rs11121409

McDermott, M. E., and P. B. Wood. 2009. Short- and long-term implications of clearcut and two-age silviculture for conservation of breeding forest birds in the central Appalachians, USA. Biological Conservation 142:212-220. https://doi.org/10.1016/j.biocon.2008.10.016

McNab, W. H. and P. E. Avers. 1994. Ecological subregions of the United States: section descriptions. Administrative publication WO-WSA-5. United States Department of Agriculture, Forest Service, Washington, D.C., USA.

McNeil, D. J. 2019. Population dynamics of species recovery: multiscale demography in restored habitats. Doctoral Dissertation. Cornell University, Ithaca, New York, USA.

Morris, D. L., P. A. Porneluzi, J. Haslerig, R. L. Clawson, and J. Faaborg. 2013. Results of 20 years of experimental forest management on breeding birds in Ozark forests of Missouri, USA. Forest Ecology and Management 310:747-760. https://doi.org/10.1016/j.foreco.2013.09.020

NABCI Committee. 2000. The North American bird conservation initiative in the United States: a vision of American bird conservation. U.S. Fish and Wildlife Service, Division of North American Waterfowl and Wetlands, Arlington, VA, USA.

Nareff, G. E., P. W. Wood, D. J. Brown, T. Fearer, J. L. Larkin, and W. M. Ford. 2019. Cerulean Warbler (Setophaga cerulea) response to operational silviculture in the central Appalachian region. Forest Ecology and Management 448:409-423. https://doi.org/10.1016/j.foreco.2019.05.062

Oliver, L. R. 2021. Evaluating avian occupancy on sites treated with NRCS conservation practices implemented to benefit Cerulean (Setophaga cerulea) and Golden-winged Warblers (Vermivora chrysoptera) in West Virginia. M.S. thesis, West Virginia University, Morgantown, WV, USA. https://doi.org/10.33915/etd.8001

Omernik, J. M., and G. E. Griffith. 2014. Ecoregions of the conterminous United States: evolution of a hierarchical spatial framework. Environmental Management 54:1249-1266. https://doi.org/10.1007/s00267-014-0364-1

Paton, P. W. 1994. The effect of edge on avian nest success: How strong is the evidence? Conservation Biology 8:17-26. https://doi.org/10.1046/j.1523-1739.1994.08010017.x

Patton, L. L., D. S. Maehr, J. E. Duchamp, S. Fei, J. W. Gassett, and J. L. Larkin. 2010. Do the Golden-winged Warbler and Blue-winged Warbler exhibit species-specific differences in their breeding habitat use? Avian Conservation and Ecology 5(2):2. https://doi.org/10.5751/ACE-00392-050202

Ralph, C. J., J. R. Sauer, and S. Droege. 1995. Monitoring bird populations by point counts. U.S. Department of Agriculture Forest Service General Technical Report PSW-GTR-149. https://doi.org/10.2737/PSW-GTR-149

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J. D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, D. W. Demarest, W. E. Easton, J. J. Giocomo, R. H. Keller, A. E. Mini, A. O. Panjabi, D. N. Pashley, T. D. Rich, J. M. Ruth, H. Stabins, J. Stanton, and T. Will. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee, USA.

Roberge, J. M., and P. Angelstam. 2004. Usefulness of the umbrella species concept as a conservation tool. Conservation Biology 18:76-85. https://doi.org/10.1111/j.1523-1739.2004.00450.x

Roth, A. M., R. W. Rohrbaugh, K. R. Aldinger, M. H. Bakermans, S. Barker Swarthout, D. A. Buehler, J. L. Confer, D. Crawford, C. Friis, R. M. Fowlds, J. L. Larkin, J. Loegering, J. D. Lowe, M. Piorkowski, K. V. Rosenberg, C. Smalling, T. M. Terhune, R. Vallender, T. Will, and P. B. Wood. 2012. Golden-winged Warbler breeding season conservation plan. In A. M. Roth, R. W. Rohrbaugh, T. Will, and D. A. Buehler, editors. Golden-winged Warbler Status Review and Conservation Plan. https://gwwa.org/wp-content/uploads/2022/08/GWWA_Conservation-Plan_191007_low-res.pdf

R Development Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Sauer, J. R., W. A., Link, and J. E. Hines. 2020. The North American breeding bird survey, results and analysis 1966-2019. Version 11.03.2020. USGS Patuxent Wildlife Research Center, Laurel, MD, USA.

Shapiro, L. H., R. A. Canterbury, D. M. Stover, and R. C. Fleischer. 2004. Reciprocal introgression between the Golden-winged and Blue-winged warblers (Vermivora chrysoptera and V. pinus) in eastern North America. Auk 121(4):1019-1030. https://www.jstor.org/stable/4090471

Sheehan, J., P. B. Wood, D. A. Buehler, P. D. Keyser, J. L. Larkin, A. D. Rodewald, T. B. Wigley, T. J. Boves, G. A. George, M. H. Bakermans, T. A. Beachy, A. Evans, M. E. McDermott, F. L. Newell, K. A. Perkins, and M. White. 2014. Avian response to timber harvesting applied experimentally to manage Cerulean Warbler breeding populations. Forest Ecology and Management 321:5-18. https://doi.org/10.1016/j.foreco.2013.07.037

Thogmartin, W. E. 2010. Modeling and mapping Golden-winged Warbler abundance to improve regional conservation strategies. Avian conservation and Ecology 5(2):2. https://doi.org/10.5751/ACE-00426-050212

U.S. Department of Agriculture Natural Resources Conservation Service. 2022. Conservation Practices. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849#G

U.S. Geological Survey. 1999. National elevation dataset (West Virginia subset). U.S. Geological Survey, EROS Data Center, Sioux Falls, SD, USA. https://www.wvgis.wvu.edu/data/dataset.php?ID=29

Vallender, R., R. J. Robertson, V. L. Friesen, and I. J. Lovette. 2007. Complex hybridization dynamics between Golden-winged and Blue-winged Warblers (Vermivora chrysoptera and Vermivora pinus) revealed by AFLP, microsatellite, intron and mtDNA markers. Molecular Ecology 16:2017-2029. https://doi.org/10.1111/j.1365-294X.2007.03282.x

West, A. S., P. D. Keyser, C. M. Lituma, D. A. Buehler, R. D. Applegate, and J. Morgan. 2016. Grassland bird occupancy of native warm-season grass. Journal of wildlife Management 86:1081-1090. https://doi.org/10.1002/jwmg.21103

Wood, P. B., J. Sheehan, P. Keyser, D. Buehler, J. Larkin, A. Rodewald, S. Stoleson, T. B. Wigley, J. Mizel, T. Boves, G. George, M. Bakermans, T. Beachy, A. Evans, M. McDermott, F. Newell, K. Perkins, and M. White. 2013. Management guidelines for enhancing cerulean warbler breeding habitat in Appalachian hardwood forests. American Bird Conservancy, The Plains, VA, USA.

Woods, A. J., J. M. Omernik, and D. D. Brown. 1999. Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR, USA.

Editor-in-Chief: Judit K Szabo
Subject Editor: Andrew J. Campomizzi

Sponsored by the Society of Canadian Ornithologists and Birds Canada

Parrainée par la Société des ornithologistes du Canada et Oiseaux Canada

Appendix 1.

Conservation Practice	Sites[a]	Description[b]
Brush Management	16	Removal of woody (non-herbaceous or succulent) plants including those that are invasive and noxious.
Early Successional Habitat Development/ Management	9	Manage plant succession to develop and maintain early successional habitat to benefit desired wildlife and/or natural communities.
Forest Stand Improvement	9	The manipulation of species composition, stand structure, or stand density by cutting or killing selected trees or understory vegetation to achieve desired forest conditions or obtain ecosystem services.
Restoration of Rare or Declining Natural Communities	8	Reestablishment of abiotic (physical and chemical) and biotic (biological) conditions necessary to support rare or declining natural assemblages of native plants and animals.
Tree/Shrub Establishment	7	Establishing woody plants by planting seedlings or cuttings, by direct seeding, and/or through natural regeneration.
Critical Area Planting	4	Establishing permanent vegetation on sites that have, or are expected to have, high erosion rates, and on sites that have physical, chemical, or biological conditions that prevent the establishment of vegetation with normal seeding/planting methods.
Fence	4	A constructed barrier to animals or people.
Access Control	2	The temporary or permanent exclusion of animals, people, vehicles, and equipment from an area
Field Border	2	A strip of permanent vegetation established at the edge or around the perimeter of a field.
Tree/Shrub Site Preparation	2	Treatment of sites to enhance the success of natural or artificial regeneration of desired trees and/or shrubs.
Structures for Wildlife	1	A structure to replace or modify a missing or deficient wildlife habitat component. (i.e., partially hinge cut multiple living small diameter trees into a single living bush pile)

[a] Number of sites where each practice was implemented
[b] Conservation practice descriptions from NRCS website (https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849)

Appendix 2.

Covariate	Code	Covariate type	Description
Canopy cover	canopy	Detection probability	Percent cover (0 – 100) of trees ≥8 cm dbh within 100 m
Observer	observer	Detection probability	Observer conducting survey
Ordinal date	date	Detection probability	Day of the year (126 – 183)
Sky	sky	Detection probability	Sky reading (0, 1, 2, 3)
Time-since-sunrise	time	Detection probability	Minutes-since-sunrise
Wind	wind	Detection probability	Wind reading on the Beaufort scale (0, 1, 2, 3)
Contract treatment status	status	Status	Treatment status (untreated or treated)
Years post-treatment	year	Status	Years since contract completion (0 – 8)
Ecoregion	ecoregion	Spatial	Level III ecoregion (Central Appalachians, Western Allegheny Plateau, and Ridge and Valley)
Elevation	elev	Spatial	Majority elevation (m) within 100 m
1-km forest cover	forest	Spatial	Percent forest within 1 km
1-km edge density	edge	Spatial	Forest edge density (km/km^2) within 1 km
100-m young forest	yngforest	Spatial	Percent young forest (of trees ≤8 cm) within 100 m
100-m shrubland	shrubland	Spatial	Percent shrubland (≥30% shrub cover) within 100 m
100-m young forest/shrubland	young forest/shrubland	Spatial	Sum of 100-m young forest (of trees ≤8 cm) and 100-m shrubland (≥30% shrub cover)
100-m open	open	Spatial	Percent open (dominated by grasses and forbs with <30% woody cover) within 100-m
Grass cover	grass	Vegetation	Percent grass cover (0 – 100) within 100-m
Forb cover	forb	Vegetation	Percent forb cover (0 – 100) within 100-m
Solidago cover	solidago	Vegetation	Percent *Solidago* cover (0 – 100) within 100 m
Rubus cover	rubus	Vegetation	Percent *Rubus* cover (0 – 100) within 100 m
Shrub cover	shrub	Vegetation	Percent shrub cover (0 – 100) within 100 m
Sapling cover	sapling	Vegetation	Percent cover (0 – 100) of trees ≤8 cm dbh within 100 m
Canopy cover	canopy	Vegetation	Percent cover (0 – 100) of trees ≥8 cm dbh within 100 m
100-m basal area	ba	Vegetation	Mean basal area (m^2/ha) of all live tree stems ≥8 cm dbh within 100 m

Center plot basal area	bacent	Vegetation	Basal area (m^2/ha) of all live tree stems ≥8 cm dbh at center prism plot
Coefficient of variation	cov	Vegetation	Ratio of the maximum vegetation height standard deviation to its mean within 100 m

Appendix 3.

AOS code	Common Name	Scientific name	Guild	Count
ACFL	Acadian Flycatcher	*Empidonax virescens*		22
ALFL	Alder Flycatcher	*Empidonax alnorum*	Shrubland	1
AMCR	American Crow	*Corvus brachyrhynchos*		30
AMGO	American Goldfinch	*Spinus tristis*	Shrubland	52
AMRE	American Redstart	*Setophaga ruticilla*		42
AMRO	American Robin	*Turdus migratorius*		73
BAOR	Baltimore Oriole	*Icterus galbula*		15
BARS	Barn Swallow	*Hirundo rustica*		1
BAWW	Black-and-white Warbler	*Mniotilta varia*		75
BBCU	Black-billed Cuckcoo	*Coccyzus erythropthalmus*		1
BBWA	Bay-breasted Warbler	*Setophaga castanea*		6
BCCH	Black-capped Chickadee	*Poecile atricapillus*		43
BEKI	Belted Kingfisher	*Megaceryle alcyon*		1
BGGN	Blue-gray Gnatcatcher	*Polioptila caerulea*		39
BHCO	Brown-headed Cowbird	*Molothrus ater*		98
BHVI	Blue-headed Vireo	*Vireo solitarius*		29
BLBW	Blackburnian Warbler	*Setophaga fusca*		8
BLGR	Blue Grosbeak	*Passerina caerulea*	Shrubland	4
BLJA	Blue Jay	*Cyanocitta cristata*		56
BOBO	Bobolink	*Dolichonyx oryzivorus*	Grassland	2
BRTH	Brown Thrasher	*Toxostoma rufum*	Shrubland	29
BRWA	Brewster's Warbler	*Vermivora leucobronchialis*	Shrubland	1
BTBW	Black-throated Blue Warbler	*Setophaga caerulescens*		2
BTNW	Black-throated Green Warbler	*Setophaga virens*		47
BWHA	Broad-winged Hawk	*Buteo platypterus*		4
BWWA	Blue-winged Warbler	*Vermivora cyanoptera*	Shrubland	30
CACH	Carolina Chickadee	*Poecile carolinensis*		7
CANG	Canada Goose	*Branta canadensis*		3
CARW	Carolina Wren	*Thryothorus ludovicianus*		95
CAWA	Canada Warbler	*Cardellina canadensis*		1
CEDW	Cedar Waxwing	*Bombycilla cedrorum*		37
CERW	Cerulean Warbler	*Setophaga cerulea*		5
CHSP	Chipping Sparrow	*Spizella passerina*	Shrubland	55
CHSW	Chimney Swift	*Chaetura pelagica*		4
COGR	Common Grackle	*Quisicalus quiscula*		1
CORA	Common Raven	*Corvus corax*		1
COYE	Common Yellowthroat	*Geothlypis trichas*	Shrubland	58
CSWA	Chestnut-sided Warbler	*Setophaga pensylvanica*	Shrubland	80
DEJU	Dark-eyed Junco	*Junco hyemalis*		5
DOWO	Downy Woodpecker	*Picoides pubescens*		41
EABL	Eastern Bluebird	*Sialia sialis*	Grassland	21
EAKI	Eastern Kingbird	*Tyrannus tyrannus*	Shrubland	7
EAME	Eastern Meadowlark	*Sturnella magna*	Grassland	4

EAPH	Eastern Phoebe	*Sayornis phoebe*		14
EATO	Eastern Towhee	*Pipilo erythrophthalmus*	Shrubland	278
EAWP	Eastern Wood-pewee	*Contopus virens*		78
EUST	European Starling	*Sturnus vulgaris*		8
FISP	Field Sparrow	*Spizella pusilla*	Shrubland	124
GBHE	Great Blue Heron	*Ardea herodias*		1
GCFL	Great Crested Flycatcher	*Myiarchus crinitus*		43
GRCA	Gray Catbird	*Dumetella carolinensis*	Shrubland	54
GWWA	Golden-winged Warbler	*Vermivora chrysoptera*	Shrubland	8
HAWO	Hairy Woodpecker	*Dryobates villosus*		27
HETH	Hermit Thrush	*Catharus guttatus*		2
HOWA	Hooded Warbler	*Setophaga citrina*		91
HOWR	House Wren	*Troglodytes aedon*		23
INBU	Indigo Bunting	*Passerina cyanea*	Shrubland	244
KEWA	Kentucky Warbler	*Geothlypis formosa*		1
KILL	Killdeer	*Charadrius vociferus*		4
LEFL	Least Flycatcher	*Empidonax minimus*		16
LOWA	Louisiana Waterthrush	*Parkesia motacilla*		4
MODO	Mourning Dove	*Zenaida macroura*	Shrubland	54
NOCA	Northern Cardinal	*Cardinalis cardinalis*	Shrubland	108
NOFL	Northern Flicker	*Colaptes auratus*		16
NOMO	Northern Mockingbird	*Mimus polyglottos*	Shrubland	1
NOPA	Northern Parula	*Setophaga americana*		11
OROR	Orchard Oriole	*Icterus spurius*	Shrubland	6
OVEN	Ovenbird	*Seiurus aurocapillus*		112
PIWA	Pine Warbler	*Setophaga pinus*		2
PIWO	Pileated Woodpecker	*Dryocopus pileatus*		14
PRAW	Prairie Warbler	*Setophaga discolor*	Shrubland	3
RBGR	Rose-breasted Grosbeak	*Pheucticus ludovicianus*		36
RBNU	Red-breasted Nuthatch	*Sitta canadensis*		1
RBWO	Red-bellied Woodpecker	*Melanerpes carolinus*		55
REVI	Red-eyed Vireo	*Vireo olivaceus*		294
RTHA	Red-tailed Hawk	*Buteo jamaicensis*		4
RTHU	Ruby-throated Hummingbird	*Archilochus colubris*		13
RUGR	Ruffed Grouse	*Bonasa umbellus*	Shrubland	3
RWBL	Red-winged Blackbird	*Agelaius phoeniceus*	Grassland	41
SCTA	Scarlet Tanager	*Piranga olivacea*		89
SOSP	Song Sparrow	*Melospiza melodia*	Shrubland	59
SWWA	Swainson's Warbler	*Limnothlypis swainsonii*		1
TEWA	Tennessee Warbler	*Leiothlypis peregrina*		2
TRES	Tree Swallow	*Tachycineta bicolor*		3
TUTI	Tufted Titmouse	*Baelophus bicolor*		118
TUVU	Turkey Vulture	*Cathartes aura*		1
VEER	Veery	*Catharus fuscescens*		4
WBNU	White-breasted Nuthatch	*Sitta carolinensis*		70

WEVI	White-eyed Vireo	*Vireo griseus*	Shrubland	2
WEWA	Worm-eating Warbler	*Helmitheros vermivorum*		5
WIFL	Willow Flycatcher	*Empidonax traillii*	Shrubland	4
WITU	Wild Turkey	*Meleagris gallopavo*		4
WOTH	Wood Thrush	*Hylocichla mustelina*		76
YBCH	Yellow-breasted Chat	*Icteria virens*	Shrubland	11
YBCU	Yellow-billed Cuckoo	*Coccyzus americanus*		24
YEWA	Yellow Warbler	*Setophaga petechia*	Shrubland	10
YRWA	Yellow-rumped Warbler	*Setophaga coronata*		1
YTVI	Yellow-throated Vireo	*Vireo flavifrons*		21
YTWA	Yellow-throated Warbler	*Setophaga dominica*		6

Appendix 4.

Covariate	Untreated mean (range) (n=206 points, n=35 sites)	Treated mean (range) (n=135 points, n=29 sites)	Not detected mean (range) (n=307 points, n=28 sites)	Detected mean (range) (n=34 points, n=13 sites)
Treatment status				
Untreated	--	--	60	65
Treated	--	--	40	35
Years post-treatment (0–8)	0.00	4.71	1.74	1.58
Ecoregion				
Ridge and Valley	36	36	38	12
Central Appalachians	33	52	39	53
Western Allegheny Plateau	31	12	23	35
Elevation	545 (244 – 1047)	595 (241 – 921)	586 (241 – 1047)	471 (244 – 917)
1-km forest cover	84 (49 – 98)	81 (40 – 97)	82 (40 – 98)	86 (61 – 96)
1-km edge density	8 (3 – 16)	9 (4 – 16)	8 (3 – 16)	9 (5 – 16)
100-m young forest	1 (0 – 16)	6 (0 – 35)	3 (0 – 35)	3 (0 – 19)
100-m shrubland	7 (0 – 100)	7 (0 – 45)	5 (0 – 58)	13 (0 – 100)
100-m young forest/shrubland	8 (0 – 100)	14 (0 – 48)	9 (0 – 66)	16 (0 – 100)
100-m open	11 (0 – 57)	11 (0 – 59)	13 (0 – 59)	5 (0 – 25)
Grass cover	27 (0 – 70)	25 (5 – 53)	28 (0 – 70)	21 (8 – 38)
Forb cover	27 (0 – 62)	34 (5 – 63)	28 (0 – 63)	34 (15 – 52)
Solidago cover	4 (0 – 38)	6 (0 – 45)	4 (0 – 45)	9 (0 – 38)
Rubus cover	6 (0 – 30)	7 (0 – 23)	5 (0 – 25)	8 (0 – 30)
Shrub cover	17 (0 – 61)	11 (0 – 35)	15 (0 – 41)	13 (0 – 61)
Sapling cover	45 (8 – 95)	41 (11 – 71)	43 (8 – 95)	44 (29 – 73)
Canopy cover	71 (17 – 100)	64 (10 – 91)	68 (10 – 100)	71 (50 – 93)
100-m basal area	12 (2 – 24)	14 (2 – 23)	13 (2 – 24)	13 (2 – 20)
Center plot basal area	13 (0 – 34)	14 (0 – 28)	13 (0 – 34)	14 (0 – 26)
Coefficient of variation	0.55 (0.09 – 1.78)	0.66 (0.33 – 1.43)	0.60 (0.09 – 1.78)	0.56 (0.20 – 1.25)