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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

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**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**

Lincoln R. Oliver

Thesis submitted
to the Davis College of Agriculture, Natural Resources, and Design
at West Virginia University

in partial fulfillment of the requirements for the degree of

Master of Science in
Wildlife and Fisheries Resources

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ABSTRACT

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

Lincoln R. Oliver

The USDA - Natural Resources Conservation Service (NRCS) supports private lands conservation across the United States to benefit imperiled focal wildlife species using conservation practices to restore habitat. Through the Cerulean Warbler (*Setophaga cerulea*) Forestland Enhancement Project (CWAFEP) and the Working Lands for Wildlife (WLFW) Golden-winged Warbler (*Vermivora chrysoptera*) initiative, the NRCS provides technical and financial assistance to private landowners to implement conservation practices that follow science-based habitat management guidelines. Few research studies have evaluated focal species-specific occupancy on CWAFEP and/or WLFW sites, and research is required to inform each conservation project's effectiveness in an adaptive management framework. This thesis includes 4 chapters which focus on avian occupancy and species richness on CWAFEP and WLFW sites in West Virginia.

In chapter 1, I provide a brief introduction and justification for my research. This chapter summarizes each project's background and the importance of evaluation efforts. Also included in chapter 1 is an overview of Blue-winged Warbler (*Vermivora cyanoptera*) ecology and their relevance to the following thesis chapters.

In chapter 2, I evaluate Cerulean Warbler and forest focal species occupancy and avian guild species richness on CWAFEP sites treated using conservation practices. During May – July 2019 – 2020, I conducted point count surveys at 194 locations on 21 CWAFEP sites in West Virginia. There were no differences in Cerulean Warbler occupancy estimates at untreated and treated locations. Cerulean Warbler occupancy decreased by 91% as elevation increased from 200 to 800 m and increased by 397% as sapling cover increased from 0 to 100%. Occupancy for three forest focal species and species richness in four avian guilds also were not different at untreated and treated locations. My study indicates that Cerulean Warbler and the avian community were not positively correlated with recent conservation practice implementation (1 – 4 years post-treatment) and that CWAFEP must adhere more strictly to the recommended guidelines if it is going to be effective for Cerulean Warbler conservation. I suspect that the lack of differences in occupancy and species richness estimates was due to private lands variability, site selection, small treatment areas, and challenges associated with private lands conservation resulting in insufficient basal area removal. Basal area was above the recommended range of 9.2 – 20.7 m²/ha (40 – 90 ft²/ac) at 40% of post treatment sampling locations. I recommend all CWAFEP sites achieve the recommended basal area range of 9.2 – 20.7 m²/ha (40 – 90 ft²/ac) during contract implementation and refinement of the CWAFEP focal area in West Virginia to improve the project's effectiveness.

In chapter 3, I evaluate *Vermivora* and shrubland focal species occupancy and species richness of avian guilds on WLFW sites treated using conservation practices. During May – July 2019 – 2020, I conducted point count surveys at 147 locations on 22 private properties enrolled in WLFW in West Virginia. There were no differences in *Vermivora* occupancy estimates at

untreated and treated locations. *Vermivora* occupancy increased by 967% as 100-m shrubland increased from 0 to 100% cover and decreased by 87% as 100-m basal area increased from 0 to 30 m²/ha. Occupancy for 1 of the 3 shrubland focal species and species richness in all avian guilds also were not different at untreated and treated locations, suggesting that conservation practices did not meaningfully influence associated shrubland bird occurrence or avian diversity. My study indicates that *Vermivora* and the avian community were not positively correlated with recent conservation practice implementation in the short-term (1 – 8 years post-treatment) and that WLFW must adhere more strictly to the recommended guidelines if it is going to be effective for Golden-winged Warbler conservation. I recommend additional basal area removal to within the recommended range of 1.9 – 3.7 m²/ha (8.3 – 16.1 ft²/ac) during contract implementation and restriction of the WLFW focal area to higher elevations (>600 m) to improve the project's effectiveness.

Finally, chapter 4 focused on identifying key habitat characteristics associated with Blue-winged Warbler occupancy on sites enrolled in CWAFEP and WLFW. Included in analysis were all 341-point count locations from 19 CWAFEP sites, 20 WLFW sites, and 2 sites enrolled in both projects. Treated points had lower occupancy than untreated points by 34 – 44% depending on ecoregion. Occupancy was greatest in the Central Appalachian ecoregion, but I 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 Appalachians. Occupancy increased by 772% as 100-m shrubland increased from 0 to 100% cover and increased by 790% as 100-m young forest/shrubland increased from 0 to 100% cover. Occupancy decreased by 91% as 100-m basal area increased from 0 to 30 m²/ha. NRCS conservation projects for Cerulean Warbler and Golden-winged Warbler generally did not produce conditions to increase occupancy of Blue-winged Warblers. I recommend 50 – 100% shrubland cover at the 100-m radius scale and residual basal area of 0.0 – 4.6 m²/ha (0 – 20 ft²/ac) when managing habitat for Blue-winged Warblers in the Appalachians.

Overall, my findings help to justify, inform, and adapt NRCS conservation efforts for Cerulean and Golden-winged Warblers. The information I have provided in this thesis fills scientific knowledge gaps for Cerulean, Golden-winged, and Blue-winged Warblers and provides useful feedback to NRCS following an adaptive management framework.

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Figure 4.3. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers (*Vermivora cyanoptera*) at 341 point-count surveys on 41 private properties enrolled in the Cerulean Warbler Appalachian Forestland enhancement project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Occupancy models for panels shown included contract treatment status and ecoregion, ecoregion, % 100-m shrubland, % 100-m young forest/shrubland, and 100-m basal area (m²/ha) for occupancy and observer for detection probability. Differences are indicated by alphabetic notation. 120

CHAPTER 1. INTRODUCTION

The Cerulean Warbler (*Setophaga cerulea*; Figure 1.1) and Golden-winged Warbler (*Vermivora chrysoptera*; Figure 1.2) are small, Nearctic-Neotropical migratory songbird species that have experienced precipitous population declines over the last 50 years. Based on North American Breeding Bird Survey (BBS) data, total Cerulean Warbler populations have declined ~75% and Golden-winged Warbler ~68% during 1970 – 2014 (Rosenberg et al. 2016). Golden-winged Warbler populations breeding in the Great Lakes region have declined ~39% and populations breeding in the Appalachians have declined ~98% (Rosenberg et al. 2016). Declines in both species led to petition and status review for Endangered Species Act listing (Hamel 2000, USFWS 2011). While the Golden-winged Warbler petition is still under review, the Cerulean Warbler petition was denied in 2011 because population projections derived from BBS data indicated no chance of extinction within the foreseeable future (USFWS 2006). With an estimated 400,000 breeding pairs remaining (Rosenberg et al. 2016), Golden-winged Warblers have one of the smallest population sizes of any bird not listed under the Endangered Species Act (Confer et al. 2011). While many factors contribute to both species' decline, several primary drivers have been identified. Chief among these for Cerulean Warbler are loss of forested habitats in breeding, wintering, and migration areas (Robbins et al. 1992, Hamel et al. 2004), and changes in forest structural complexity on breeding grounds (Hamel et al. 2004). Primary factors for Golden-winged Warbler include habitat loss on breeding, migration, and wintering grounds (Buehler et al. 2007, Chandler and King 2011, Kramer et al. 2018), hybridization and competition with the closely related Blue-winged Warbler (*Vermivora cyanoptera*; Gill 1980, Confer et al. 2010), and Brown-headed Cowbird (*Molothrus ater*) nest parasitism (Coker and Confer 1990). Breeding populations of Cerulean and Golden-winged Warblers generally are thought to benefit from species-specific habitat management (Roth et al. 2012, Wood et al. 2013). While a key goal for both species is creating breeding habitat, management prescriptions differ.

Structural characteristics beneficial to Cerulean Warblers include canopy gaps, large canopy trees, and well-developed understories typical of old-growth forests (Weakland and Wood 2005, Boves et al. 2013b, Wood et al. 2013, Perkins and Wood 2014). In lieu of ecological succession and natural disturbances, silvicultural techniques including group selection, shelterwood harvests, modified even-aged harvests, and crop-tree release can be used

to create this complex forest structure and composition (Boves et al. 2013a, Wood et al. 2013, Hamel et al. 2016). A series of studies measuring Cerulean Warbler response to 10 ha silvicultural treatments (light, medium, and heavy harvest) applied and evaluated across 7 study areas in the Appalachians formed the basis for the now commonly used *Cerulean Warbler Management Guidelines for Enhancing Breeding Habitat in Appalachian Hardwood Forests* (Wood et al. 2013; hereafter “Cerulean Warbler guidelines”). Results indicate that territory density following forest management generally increased or was maintained from pre-harvest density, ranging from 2.34 – 5.52 territories/10 ha. The highest and most consistent territory density increases occurred with intermediate treatments (average residual basal area = 14 m²/ha [50 ft²/ac]); territory density increased by 6.5 territories/10 ha 3 years post-treatment (Boves et al. 2013a). Residual basal areas of 9.2 – 20.7 m²/ha (40 – 90 ft²/ac) following harvest are recommended to achieve greatest increases in Cerulean Warbler territory density (Sheehan et al. 2014, Wood et al. 2013). Nareff et al. (2019) evaluated Cerulean Warbler response to implementation of the Cerulean Warbler guidelines in the Appalachians, and found 100% territory density increases from pre-harvest to two years post-harvest and increased abundance with increasing percentage of basal area composed of tree species preferred for foraging and nesting (white oak [*Quercus alba*] and chestnut oak [*Q. montanus*], hickory [*Carya* spp.], and sugar maple [*Acer saccharum*]), or of large diameter trees (≥ 40.6 cm diameter at breast height; Nareff et al. 2019).

Forests managed for Cerulean Warbler produce higher relative abundances of disturbance-dependent avian species and contain higher overall avian diversity compared to unmanaged forests (Sheehan et al. 2014). Partial harvest techniques used to benefit Cerulean Warbler, such as preparatory and establishment cuts of shelterwood harvests (Boves et al. 2013a, Sheehan et al. 2014), can support a diverse mix of avian species despite reductions in canopy cover, including both early successional and late successional species (Newell and Rodewald 2012, Sheehan et al. 2014). In southeastern Ohio, densities of canopy-nesting songbirds were 46% greater in establishment cuts of shelterwood harvests than in unharvested reference stands 1 – 3 years following treatment. Species richness increased in establishment cuts of shelterwood harvests (30 ± 1 species) with the overlap of early and late successional avian species when compared to unharvested reference stands (23 ± 1 species; Newell and Rodewald 2012). Additionally, single-species management for Cerulean Warbler can benefit game species

populations, bat habitat, oak regeneration, timber income, and recreation (Lanham et al. 2002, Miller et al. 2004, Lashley et al. 2011, Dodd et al. 2012).

The use of management techniques to create and maintain suitable early successional communities has been identified as a conservation action to sustain current Golden-winged Warbler populations and ultimately reverse declining population trends (Buehler et al. 2007). Management has been prioritized for the Appalachian population (Buehler et al. 2007, Bakermans et al. 2011, Roth et al. 2012), which contains an estimated 5% of the total population (Roth et al. 2012). Various operational management activities including timber harvesting, mechanical clearing, prescribed burning, and herbicide application can be used to benefit Golden-winged Warbler populations by creating or enhancing early successional plant communities used for breeding (Roth et al. 2012, McNeil et al. 2017, Aldinger 2018). In the Appalachians, management for Golden-winged Warblers at high elevations (>600 m) may reduce incidence of hybridization and competition with Blue-winged Warblers because the latter primarily occur at lower elevations (<600 m, Welton 2003, Buehler et al. 2007). Highly forested landscapes with mosaics of forest age-classes (i.e., early, mid, and late successional) are ideal settings for management, as Golden-winged Warblers use multiple stages of succession during their breeding and post-breeding periods (Crawford et al. 2016, Frantz et al. 2016). These management practices emulate natural disturbances (e.g., fire, flooding from beaver (*Castor canadensis*) activity, and windthrow; Lorimer 2001) that are now largely suppressed (Askins 2001) to create habitats required for successful Golden-winged Warbler reproduction.

Recently developed science-based management guidelines (hereafter “Golden-winged Warbler guidelines”) provide a variety of context-specific management practices used to create and maintain breeding habitat to stabilize or reverse population declines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013). A recent study evaluated Appalachian Golden-winged Warbler density, nest success, juvenile movement and survival, adult condition and survival, and habitat selection across 95 sites assigned to one of five U.S. Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) management scenarios using conservation practices suggested by the Golden-winged Warbler guidelines (Larkin et al. 2014, McNeil et al. 2017). Most measures of Golden-winged Warbler demographics (e.g., territory density, adult survival, and nest survival) did not differ among the five management systems evaluated, indicating similar effectiveness to support breeding

populations (Larkin et al. 2014, McNeil et al. 2017). Average adult survival was 0.58 across all management systems (Larkin et al. 2014), which falls near rates found in Tennessee and Ontario (Bulluck et al. 2013). In addition, McNeil et al. (2017) found high nest survival across management scenarios, with productivity ranging between 2.1 – 8.6 fledglings/10 ha, suggesting that management using the Golden-winged Warbler guidelines is effective at creating and maintaining habitats capable of supporting breeding populations (McNeil et al. 2017). However, this research was conducted primarily on public land and offered no comparisons between measures of Golden-winged Warbler demographics before and after treatment.

Management of early successional vegetation communities for Golden-winged Warbler may also benefit declining game species, including Ruffed Grouse (*Bonasa umbellus*) and American Woodcock (*Scolopax minor*; Dessecker and McAuley 2001). Shrubland communities managed for Golden-winged Warblers in Pennsylvania yielded 65% greater American Woodcock density compared to untreated reference sites (Bakermans et al. 2015). Many Neotropical migrant songbirds in eastern North America depend on early successional habitats during breeding (Smith et al. 1993) and post-breeding periods (Vitz and Rodewald 2006). Aldinger et al. (2017) documented high avian diversity (126 species) across sites managed for Golden-winged Warbler in the central Appalachians, likely due to varied vegetation structure of managed sites embedded within a heavily forested landscape.

Blue-winged Warblers are a species of conservation concern in West Virginia that breed in early to middle successional vegetation communities in eastern North America (Gill et al. 2020) and could benefit from management intended for Cerulean and Golden-winged Warblers. While Blue-winged Warbler populations have declined range-wide 22% during 1970 – 2014 (Rosenberg et al. 2016), their breeding distribution has expanded and continues to shift northward and into higher elevations in the Appalachians (Sauer et al. 2020, Bailey and Rucker 2021). Where Blue-winged and Golden-winged Warbler breeding distributions overlap, hybridization, genetic introgression, and competition negatively affect Golden-winged Warbler populations (Vallender and Bull 2016). Blue-winged Warblers are an understudied species outside of research on hybridization and genetic introgression with the closely related Golden-winged Warbler (Buehler et al. 2007, Confer et al. 2003, Vallender et al. 2007). Blue-winged Warblers in areas of sympatry with Golden-winged Warblers have higher breeding success in later successional stages than Golden-winged Warblers and are found in a broader range of

vegetation communities (Confer and Knapp 1981, Confer et al. 2003). While Blue-winged Warbler data have been collected as a coincidence of larger studies, they have rarely been the focal species. Morris et al. (2013) evaluated avian response to silviculture in the Ozark Mountains of Missouri and found that density significantly increased following even- and uneven-aged harvests. At sites managed for Cerulean Warblers (*Setophaga cerulea*) using even-aged harvest with residuals in the Appalachians, Blue-winged Warbler density peaked at low residual basal area ($3 - 5 \text{ m}^2/\text{ha}$ [$13 - 22 \text{ ft}^2/\text{ac}$]; Sheehan et al. 2014). In West Virginia, Aldinger et al. (2017) found 10% naïve occupancy on high elevation (547 – 1,343 m) sites with existing Golden-winged Warbler nesting cover. Additional research on factors associated with Blue-winged Warbler occupancy and response to habitat management is required to address knowledge gaps for this declining species and could have important implications for Golden-winged Warbler conservation in the Appalachians.

Creation and maintenance of breeding habitat on private lands is a priority conservation objective for Cerulean and Golden-winged Warblers (Rosenberg et al. 2016). Private lands conservation is especially important in U.S. states east of the Mississippi River, where an estimated 88% of land area is privately owned (U.S. Geological Survey [USGS] 2019). Intensive habitat management efforts for both species are underway on private lands in West Virginia. Conservation projects were initiated by NRCS in 2012 for Golden-winged Warblers and in 2015 for Cerulean Warblers to stabilize or reverse population declines by creating breeding habitat through species-specific habitat management in focal areas within their respective Appalachian breeding ranges.

Through Working Lands for Wildlife (WLFW), NRCS provides private landowners technical and financial assistance using the Environmental Quality Incentives Program (EQIP) to benefit target wildlife species, while U.S. Fish and Wildlife Service (USFWS) provides regulatory predictability with the Endangered Species Act (ESA). Golden-winged Warblers are one of the WLFW target species, wherein private landowners seek to create and maintain early successional habitats within the Appalachian Mountains breeding range. Cerulean Warblers are the focal species of the Regional Conservation Partnership Program (RCPP) - Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFEP), which uses forest management and reforestation to create or enhance habitat in portions of Kentucky, Maryland, Ohio, Pennsylvania, and West Virginia (Appalachian Mountains Joint Venture [AMJV] 2015). The

RCPP promotes coordination between NRCS and its partners to deliver conservation assistance to private landowners (USDA NRCS 2019). Both conservation projects incorporate science-based management guidelines that recommend various context-specific management practices with the goal of reversing population declines and preventing Endangered Species Act listing (Roth et al. 2012, Wood et al. 2013).

The NRCS conservation planning and financial assistance contract process for each conservation project includes many interconnected steps. The process begins with private landowners contacting NRCS to express their interest. Conservation planners from NRCS and partner organizations develop site-specific plans for eligible applicants after collecting and analyzing resource inventory data for each property. These plans are based on the Cerulean and Golden-winged Warbler guidelines but must account for constraints imposed by property size, landowner objectives, and NRCS policy, namely the National Environmental Policy Act (NEPA). Next, private landowners apply for financial assistance to carry out the conservation plan. Applications are assessed and ranked against each other using a series of evaluation questions that gauge the ecological benefit of implementing the conservation practices in the plan. Selected applicants may sign a contract, requiring NRCS to reimburse the amount of financial assistance specified in the contract after the private landowner has completed the contract items (i.e., conservation practices). Payment is subject to inspection and certification that the landowner completed the contract items according to NRCS standards and specifications (K. Aldinger, personal communication).

The management guidelines for each species were developed from controlled, landscape-level experimental studies on public lands where environmental variability was minimized by testing management strategies in areas that contained preferred Cerulean Warbler and Golden-winged Warbler landscape-level and microhabitat characteristics (Bakermans et al. 2011, Roth et al. 2012, Boves et al. 2013a, Wood et al. 2013). These approaches are not typical of management strategies implemented on private lands in each of the NRCS conservation projects. Private lands enrolled in either conservation project usually contain greater variability and are generally smaller in size than experimental areas used for referenced research (≥ 10 ha [24.7 ac]). Private lands may lack some of the preferred habitat characteristics for each species, such as slope, aspect, elevation, surrounding forest cover, or existing vegetation composition. While a number of studies have assessed wildlife response to NRCS conservation practices (e.g., Berkland and

Rewa 2005, Gray and Teels 2006), including some with implications for Golden-winged Warbler (Aldinger et al. 2015, McNeil et al. 2017, Streby et al. 2018), stronger evidence is needed to determine the effects of conservation practices implemented through either of the respective conservation project on Cerulean Warbler, Golden-winged Warbler, and associated avian species. Therefore, I evaluated Cerulean Warbler and Golden-winged Warbler occupancy, forest and shrubland focal species occupancy, and species richness of avian guilds on CWAFEP and WLFW sites, with the goal of refining and improving implementation of each conservation project in an adaptive management framework. In natural resources management, adaptive management is a structured process of learning by doing and adapting based on what is learned (Walters and Holling, 1990).

My research in the chapters that follow evaluates avian occupancy and species richness on 41 CWAFEP and WLFW study sites throughout West Virginia (Figure 1.3). First, I evaluated Cerulean Warbler occupancy at pre- and post-treatment CWAFEP sites. I also evaluated associated forest focal species occupancy and species richness of avian guilds at pre- and post-treatment CWAFEP sites. Second, I evaluated Golden-winged Warbler and Blue-winged Warbler occupancy at pre- and post-treatment WLFW sites. I also compared associated shrubland focal species occupancy and species richness of avian guilds at pre- and post-treatment WLFW sites. This species-specific evaluation provides critical feedback that will be useful in refining and improving implementation of each conservation project, as well as justifying their continued use. Third, I assess Blue-winged Warbler occupancy to evaluate the effectiveness of each conservation project in creating Blue-winged Warbler habitat, identifying important Blue-winged Warbler habitat relationships, and evaluating Blue-winged Warbler impact on Golden-winged Warbler conservation in West Virginia. Results will inform the effectiveness of each conservation project at creating, improving, or maintaining Cerulean, Golden-winged, and Blue-winged Warbler habitat, and assess both conservation projects' potential to affect avian community composition.

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FIGURES

Figure 1.1. Oil painting of a male Cerulean Warbler by Whitney Oliver.

Figure 1.2. Oil painting of a male Golden-winged Warbler by Whitney Oliver.

Figure 1.3. Study site locations in West Virginia surveyed during 2019 and/or 2020. Study sites were located on private properties enrolled in the Appalachian Forestland Enhancement Project for Cerulean Warblers (CERW) and/or Working Lands for Wildlife for Golden-winged Warblers (GWWA). Study sites locations were randomly offset within a 5-km radius of the actual location to protect personally identifiable information.

CHAPTER 2. Evaluating Avian Occupancy on Sites Treated with NRCS Conservation Practices Implemented to Benefit Cerulean Warblers in West Virginia

ABSTRACT

The USDA Natural Resources Conservation Service (NRCS) supports private lands conservation projects across the United States to benefit imperiled focal wildlife species using conservation practices to restore habitat. The Cerulean Warbler is the focal species of the Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFFEP), which was initiated in 2015 to stabilize or reverse population declines by creating or enhancing breeding habitat in focal areas of the Appalachians. We evaluated Cerulean Warbler occupancy on CWAFFEP sites treated using conservation practices to inform adaptive management for the conservation project. We also assessed associated forest focal species occupancy and species richness of avian guilds to evaluate the effects of conservation practice implementation on the avian community. We conducted point count surveys at 194 locations on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia during May – July 2019 – 2020. Cerulean Warbler occupancy estimates were not different at untreated and treated locations, suggesting that post-treatment study sites surveyed did not achieve their goal of improving Cerulean Warbler occupancy. Cerulean Warbler occupancy decreased by 91% as elevation increased from 200 to 800 m and increased by 397% as sapling cover increased from 0 to 100%. Occupancy for the three forest focal species and species richness in the four avian guilds also were not different at untreated and treated locations. Our study indicates that Cerulean Warbler and the avian community were not positively correlated with recent conservation practice implementation in the short-term (1 – 4 years post-treatment) and that there are opportunities to improve NRCS conservation practice implementation for more effective Cerulean Warbler conservation. We suspect that the lack of differences in occupancy and species richness estimates was due to private lands variability, site selection, small treatment areas, and challenges associated with private lands conservation resulting in insufficient basal area removal. If NRCS conservation practices implemented through CWAFFEP are going to reverse Cerulean Warbler population declines, we recommend all CWAFFEP sites achieve the recommended basal area range of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ ($40 - 90 \text{ ft}^2/\text{ac}$) during contract implementation and refinement of the CWAFFEP focal area in West Virginia.

Keywords: adaptive management, basal area, bird community, conservation project, forest management, occupancy, private lands, silviculture

INTRODUCTION

Private lands conservation efforts are critical for recovery of imperiled species because most land area in the United States is privately owned (U.S. Geological Survey [USGS] 2019). The U.S. Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) supports private lands conservation through programs including the Environmental Quality Incentives Program (EQIP) and Regional Conservation Partnership Program (RCPP; Ciuzio et al. 2013). These conservation programs include several projects which aim to restore habitat on private lands for focal wildlife species using targeted habitat management techniques (Gray and Teels 2006). Administered by the NRCS, conservation projects provide technical and financial assistance to landowners to implement conservation practices to address natural resources concerns for imperiled focal wildlife species such as Greater Sage-Grouse (*Centrocercus urophasianus*), Cerulean Warbler (*Setophaga cerulea*), Golden-winged Warbler (*Vermivora chrysoptera*), Gopher Tortoise (*Gopherus polyphemus*), and Monarch Butterfly (*Danaus plexippus*). No published research has evaluated focal species-specific occupancy on sites treated with conservation practices implemented to benefit Cerulean Warblers, and research is required to inform the conservation project's effectiveness and justify continued funding.

Cerulean Warblers are declining Neotropical migrant songbirds that breed in mature deciduous forests in portions of the eastern U.S. Based on North American Breeding Bird Survey (BBS) data, Cerulean Warbler populations declined 75% during 1970 – 2014 (Rosenberg et al. 2016). Primary factors influencing Cerulean Warbler population declines include forest habitat loss on breeding, wintering, and migration areas and changes in forest structural complexity on breeding grounds (Hamel et al. 2004). Declines led to petition and status review for Endangered Species Act listing, which was denied in 2011 because population projections derived from BBS data indicated no chance of extinction within the foreseeable future (USFWS 2006). Partners in Flight estimates that populations will decrease an additional 50% within 25 years if no proactive conservation measures are taken to address habitat loss and degradation in its forested breeding and non-breeding habitat (Rosenberg et al. 2016). As such, the voluntary creation and maintenance of breeding habitat on private lands through habitat management is a priority conservation action to reverse Cerulean Warbler declines (Rosenberg et al. 2016).

Extensive research conducted on Cerulean Warbler response to forest management in the Appalachians (e.g., Weakland and Wood 2005, Bakermans and Rodewald 2009, Newell and

Rodewald 2012, Boves et al. 2013b) was used to develop the *Cerulean Warbler Management Guidelines for Enhancing Breeding Habitat in Appalachian Hardwood Forests* (Wood et al. 2013; hereafter “guidelines”). The guidelines provide a variety of context-specific management practices used to create and maintain breeding habitat to stabilize or reverse population declines. Nareff et al. (2019) evaluated avian response to implementation of the guidelines on state management areas and found that the management was beneficial for Cerulean Warblers. Extensive habitat management efforts that implement the guidelines are underway on private lands in the Appalachians to address Cerulean Warbler declines but the effectiveness of implementation in this context has not been evaluated.

The RCPP Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFEP) is being implemented by NRCS using conservation practices that follow the guidelines to create or enhance breeding habitat in portions of Kentucky, Maryland, Ohio, Pennsylvania, and West Virginia (Appalachian Mountains Joint Venture [AMJV] 2015). This conservation project was initiated in 2015 with the goal of reversing Cerulean Warbler population declines and preventing Endangered Species Act listing. While several research studies have assessed Cerulean Warbler and associated species response to habitat management (e.g., Boves et al. 2013b, Sheehan et al. 2014, Wood et al. 2013, Hamel et al. 2016, Nareff et al. 2019), research assessing occupancy on CWAFEP sites is needed to evaluate the conservation project’s effectiveness and justify continued funding. Such evaluations are a critical component of the adaptive management process and are required to inform and improve future Cerulean Warbler conservation efforts.

Conservation practices have had variable success in achieving desired outcomes due to numerous social, economic, political, administrative, technical, and environmental issues (Ciuzio et al. 2013). Lituma and Buehler (2020) found mixed responses of priority grassland and shrubland birds to conservation practices and suggested that improved and targeted implementation could increase avian responses. The conservation benefits of conservation practices are largely influenced by the effectiveness with which landowners manage them following contract completion (Briske et al. 2011). The research used in the development of the guidelines applied controlled forest management techniques to isolated treatment areas within heavily forested landscapes (Boves et al. 2013ab, Sheehan et al. 2014, Wood et al. 2013). Treatment areas were located on upper slopes and ridgelines, and on north- to northeast-facing slopes, which are preferred Cerulean Warbler landscape-level characteristics in the Appalachians

(Weakland and Wood 2005). Additionally, treatment areas were 10 ha (24.7 ac) and roughly rectangular, showing little variability in size and shape. These characteristics are not typical of CWAFFEP treatment areas in West Virginia that are often <10 ha and contain highly variable landscape-level and microhabitat characteristics (K. Aldinger, pers. comm.). Private lands variability combined with challenges associated with conservation practice implementation may influence their effectiveness.

Our objective was to evaluate the effects of conservation practice implementation on Cerulean Warbler and the avian community at CWAFFEP sites in West Virginia. We addressed this objective by surveying the avian community on pre-treatment and post-treatment study sites enrolled in CWAFFEP. Additionally, we quantified vegetation and habitat characteristics on all CWAFFEP study sites to identify which most influenced Cerulean Warbler occupancy and to examine how post-treatment vegetation structure and composition compared to the CWAFFEP guidelines. We expected occupancy of Cerulean Warblers and three other forest bird focal species; Blue-gray Gnatcatcher (*Poliophtila caerulea*), Eastern Wood-pewee (*Contopus virens*), and Scarlet Tanager (*Piranga olivacea*); to be greater on post-treatment study sites. We expected species richness to be greater for forest gap, forest generalist, and shrubland bird species and to be lower for forest interior birds on post-treatment study sites. Lastly, we expected vegetation characteristics of post-treatment study sites to be comparable with recommendations in the guidelines.

METHODS

Study Area

We sampled 21 sites 2019 – 2020 on private properties enrolled in CWAFFEP in Braxton, Calhoun, Clay, Doddridge, Hampshire, Jackson, Lewis, Marion, Pendleton, Preston, Tyler, and Upshur counties of West Virginia (Figure 2.1). We surveyed 8 pre-treatment sites where CWAFFEP contract implementation had not begun and 13 post-treatment sites where CWAFFEP contracts were certified by NRCS as completed. We were unable to collect pre- and post-treatment data on the same sites because contract implementation on our sites was planned to occur or occurred over a 1 – 5-year period (mean $\pm$ standard error [SE] = 3.1 ± 0.3 years). We surveyed sites from 1 – 4 years post-treatment to account for multi-year lags in the avian response (Newell and Rodewald 2012, Sheehan et al. 2014, Boves et al. 2013b). Points were placed into 1 of 4 treatment status categories (reference, pre-treatment, 1-year post-treatment, 2 –

4 years post-treatment). Years post-treatment was verified through communication with landowners and NRCS personnel. We obtained ArcGIS shapefiles containing contract treatment areas for each site through communication with NRCS personnel. Total contract treatment area at each site was 4.0 – 36.3 ha (mean $\pm$ SE = 12.2 $\pm$ 3.2 ha). Contract treatment areas were spatially split into separate treatment patches on 4 of 13 post-treatment sites. The 18 treatment patches were 1.0 – 36.3 ha (mean $\pm$ SE = 9.2 $\pm$ 2.5 ha) and 78% were below 10 ha. Contract treatment areas on study sites varied in shape, elevation (210 – 776 m; mean $\pm$ SE = 400 $\pm$ 9 m), slope position, and aspect.

Habitat management in CWAFEP is implemented through conservation practices adapted from recommendations in the guidelines (Wood et al. 2013). Seven types of conservation practices were implemented on post-treatment study sites 2016 – 2020 (Table 2.1). Eleven of 13 post-treatment sites implemented forest management using the conservation practice forest stand improvement, which is used to reduce basal area to between 9.2 – 20.7 m²/ha (40 – 90 ft²/ac). All study sites fell within Cerulean Warbler Focal Areas delineated by the AMJV partnership (Fearer 2011) and are within the core Cerulean Warbler breeding range (Sauer et al. 2020).

All study sites were located within the central Appalachians portion of the Appalachian Mountains Bird Conservation Region (NABCI Committee 2000) and occurred within Central Appalachians, Western Allegheny Plateau, and Ridge and Valley level III ecoregions of West Virginia (Omernik and Griffith 2014). The Central Appalachians ecoregion is a high (elevations ranges 366 – 1,402 m), dissected, 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 (elevation ranges 305 – 610 m) and is dominated by Appalachian oak forests. The Ridge and Valley is characterized by elongated alternating forested ridges and agricultural valleys (elevation ranges 152 – 1,311 m) and is dominated by dry oak-pine forests. These ecoregions contain variable soil conditions, geology, climate, and precipitation (Woods et al. 1999). During May – July, precipitation ranges 762 – 1524 mm and temperature ranges 4 – 35°C (McNab and Avers 1994). Common overstory tree species in the study area 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*; Woods et al. 1999).

Data Collection

Sample point placement. Using ArcGIS, we systematically placed avian sampling points >200 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 placed reference points within each property boundary in adjacent forested areas with similar slope, aspect, elevation, and forest community type as treatment points, whenever possible. We assumed reference points were representative of the pre-treatment condition at treatment points. Reference points were placed into forested areas 52 – 288 m from the edge of treatments or other non-forest habitats.

Point count survey protocol. We surveyed the avian community 11 May – 1 July 2019 – 2020 to coincide with the peak Cerulean Warbler breeding season in the central Appalachians (Newell and Rodewald 2012, Wood and Perkins 2012, Boves et al. 2013a) at 126 points in 2019 and 68 points in 2020 for a total of 194 unique points (Table 2.2). 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 kilometers per hour (i.e., >3 on the Beaufort scale). Cloud cover, wind, and start time were recorded for each survey to incorporate into detection models.

A 2-person field crew consisting of graduate student Lincoln Oliver and a field technician conducted the avian sampling each year (3 total observers). All observers were experienced in bird identification and all were trained in local bird identification, distance estimation with rangefinders, and sampling protocols before surveys began. We recorded all first detections seen or heard within a 10-minute survey into five 2-minute intervals (2, 2, 2, 2, 2 min). All individuals detected were recorded once and monitored throughout the remainder of the survey to avoid double counting. We assigned all detections a distance band, indicating the distance of the bird from the observer (0 – 25 m, >25 – 50 m, >50 – 75 m, >75 – 100 m, and >100 m). We recorded detection type (song, call, drum, visual, fly-over, or wing whistle) and sex for each detection, if possible.

Spatial covariates. We used a 1:24,000 digital elevation model (DEM; USGS 1999) in ArcGIS (version 10.7; ESRI 2011) to calculate 3 topographic metrics (elevation, slope position, and Beers aspect) within a 100-m radius centered on each sampling point. Beers aspect and slope position were calculated using the “Topography Tools for ArcGIS 10.3 and earlier” toolbox

(Dilts 2015). Beers aspect (0 – 2; Beers et al. 1966) transforms aspect azimuths to represent forest productivity with the least productive, southwest aspects near 0 and the most productive, northeast aspects having values near 2. Slope position was originally assigned with 1 of 6 categories: valley, lower slope, flat slope, middle slope, upper slope, and ridge. We reclassified the original 6 categories into 3 (Nareff et al. 2019): lower slope (valley + lower slope), middle slope (flat slope + middle slope), or ridge (upper slope + ridge), as these categories represented most sample points. We calculated elevation, slope position, and Beers aspect within each 100-m radius for 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 (Maxwell et al. 2019) to calculate percent forest cover and edge density (km/km^2) within 1 km of each sampling point location. The 10 forest types included river floodplains, small stream riparian habitats, northern hardwood forests, mixed mesophytic forests, dry-mesic oak forests, dry oak-pine forests, pine-oak rocky woodlands, dry calcareous forests, montane red oak forests, and other forest (Maxwell et al. 2019). We combined all 10 forest land cover classes using the “reclassify” tool to generate a forest cover raster for West Virginia. We generated 1-km buffers around each sampling point using the “buffer” tool to calculate percent forest cover and edge density (km/km^2) within 1 km of each sampling point location. The amount of forested area within each 1-km radius buffer was calculated using the “summarize within” tool. Percent forest cover within 1 km of each sampling point was generated by dividing the forested area within each buffer by the area of each buffer and multiplying by 100. We calculated the length of forest edge within each 1-km radius using the “summarize within” tool and divided by area of the buffer to calculate edge density (km/km^2).

Vegetation covariates. At each sampling point, we measured vegetation to compare differences in habitat characteristics on different pre- and post-treatment study sites for vegetation metrics deemed important for Cerulean Warbler breeding habitat in previous studies (Table 2.3). We conducted vegetation sampling once each year after the second point count survey to ensure full vegetation growth prior to sampling. We measured percent cover of vines, shrubs, saplings (1–8 cm diameter at breast height [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° for a total of 30 samples

per point (adapted from James and Shugart 1970 and McNeil 2019; Figure 2.2). An ocular tube consists of a 2-inch section of plastic pipe to restrict observer field of view and wire crosshairs to identify which cover types intersect. 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 the number of “hits” for that class divided by the thirty sampling points and multiplied by 100.

We measured canopy tree basal area and tree species composition at four prism plots per avian sampling point location placed at the point center and 70 m from point center along the 0°, 120°, and 240° transects (Figure 2.2). Variable radius prism plots were completed using a wedge prism (10-factor English or 2.5-factor metric) to tally live trees and snags ≥ 8 cm dbh at each prism plot. Variable radius prism plots include tree tallies that rely on the relationship between the distance of each tree to the plot center and each tree’s dbh. The observer tallied trees that were “in” the plot by holding the prism at a fixed distance from the eye over the 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. All borderline live trees and snags were counted, but every other borderline live tree was removed for basal area calculations. For each “in” snag ≥ 2 m in height, we recorded dbh.

We calculated basal area of live stems ≥ 8 cm dbh for the center prism plot which reflects basal area within the treatment. We calculated mean basal area for all four prism plots at each sampling point to reflect basal area across the 100-m radius plot (McNeil 2019) and included tree tallies from within and outside the treatment area. For the 100-m radius plot, we calculated mean basal area of live stems and snags ≥ 8 cm dbh, of tree species ≥ 8 cm dbh preferred by Cerulean Warblers, large trees (≥ 40.6 cm dbh), and large trees (≥ 40.6 cm dbh) of species preferred by Cerulean Warblers, as each of these metrics influenced Cerulean Warbler abundance in the Appalachians (Nareff et al. 2019). Preferred tree species included sugar maple, white oaks, and hickories (Wood and Perkins 2012, Wood et al. 2013). For statistical analyses, we calculated the percent basal area of preferred trees, large trees, and large preferred trees by calculating the 100-m basal area for each, dividing by the 100-m basal area, and multiplying by 100 (Nareff et al. 2019).

Forest Focal Species and Habitat Guilds

For the forest focal bird species, we selected common bird species to ensure an adequate number of detections for modeling detection probability and occupancy (Sauer et al. 2020). They included Blue-gray Gnatcatcher, Eastern Wood-pewee, and Scarlet Tanager. Blue-gray Gnatcatchers are a widespread species that can be found in a variety of wooded habitats, but prefer moist areas with deciduous trees, often at or near habitat edges (Kershner and Ellison 2020). In the Appalachians, Blue-gray Gnatcatcher prefer forests containing residual basal areas between 3 – 15 m²/ha (13 – 65 ft²/ac) following forest management (Sheehan et al. 2014). Eastern Wood-pewees are small flycatchers that breed in deciduous forests throughout the eastern United States (Watt et al. 2020). Although Blue-gray Gnatcatcher and Eastern Wood-pewee are common throughout their range, populations have declined in West Virginia at a rate of -2.57% and -2.52% per year respectively, during 1966 – 2019 (Sauer et al. 2020). Scarlet Tanagers breed in mature deciduous forests and mixed deciduous-coniferous forests in eastern North America (Mowbray 2020). Their territory density peaked at residual basal areas of ~20 m²/ha (87 ft²/ac) following moderate harvests but are tolerant of a wide range of residual basal area (Sheehan et al. 2014). While habitat requirements for each species are variable, basal area preference for the three-focal species and Cerulean Warblers (Sheehan et al. 2014) represents the basal area gradient found in CWAFFEP contract treatment areas.

We evaluated species richness of forest interior, forest gap, forest generalist, and shrubland bird species (Appendix A). We classified songbird species *a priori* into these 4 habitat guilds based on breeding biology and previous guild studies from the region (Whitcomb et al. 1981, Duguay et al. 2001, McDermott and Wood 2009; Appendix B). We included all auditory and visual detections except flyovers of adult males or females 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 recorded across the two visits per year.

Statistical Analysis

Cerulean Warbler and Forest Focal Species Occupancy. We estimated Cerulean Warbler and forest focal species occupancy using single-season occupancy models (Fiske and Chandler 2011). 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). We included all detection types except flyovers (i.e., singing, visual, call) within 100 m of each

sampling point in analysis to relate occupancy more closely to vegetation and topographic characteristics measured within 100-m radius of each sampling point. Point count data for each species was converted to detection (1) and nondetection (0) for each visit for estimation of detection probability. We used package unmarked (version 0.11-0; Fiske and Chandler 2011) in program R (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 (AIC_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 all detection covariates (observer, ordinal date, time-since-sunrise, sky, wind, and canopy) in singular detection models for each species to identify which detection covariates were best-supported using AIC_c (Burnham and Anderson 2002; Table 2.4). If a species' detection model set had only one model with $\Delta AIC_c < 2.0$, the detection covariate in that model was used singularly for all subsequent analyses. When multiple detection covariates were supported, they were included in detection models with multiple covariates in all possible combinations and tested against singular detection models to determine the best supported model to be used in all subsequent analyses (Lituma and Buehler 2020).

For our first occupancy model set, we evaluated Cerulean Warbler and forest focal species (Blue-gray Gnatcatcher, Eastern Wood-pewee, and Scarlet Tanager) occupancy across contract treatment status categories. Our first model set had 6 models for each species using contract treatment status as the predictor variable and included ecoregion and elevation as nuisance variables to account for inherent differences in each species' occurrence among study sites.

For Cerulean Warbler occupancy only, we tested 3 additional model sets (Table 2.4). In the second model set, we developed 4 models to examine the influence of spatial variables (Table 2.4 and 2.5) on Cerulean Warbler occupancy. In the third model set, we developed 16 models to examine the influence of vegetation covariates (Tables 2.4 and 2.5). We tested linear and quadratic terms for 100-m basal area, center plot basal area, snag basal area, shrub cover, sapling cover, and canopy cover. In the fourth model set, we included models with $\Delta AIC_c < 2.0$ from the contract treatment status, spatial, and vegetation model sets (model sets 1 – 3) to compare the influence of status against spatial and vegetation covariates. Because our main objective was to evaluate occupancy across contract treatment status categories, we tested

models using all combinations of supported covariates and contract treatment status to evaluate the influence of contract treatment status on best supported models. Occupancy predictions for each species were derived using the ‘predict’ function in program R (R Development Core Team 2019) and differences were assessed based on 95% confidence intervals of beta estimates not overlapping zero.

Guild Richness and Vegetation. We used a one-way analysis of variance (ANOVA) with random effects to compare observed species richness of the four avian guilds and means of covariates across contract treatment status categories using the ‘lme’ and ‘summarySE’ functions in program R (R Development Core Team 2019). We assessed any statistical differences ($p < 0.05$) among contract treatment status categories using a post-hoc Tukey-Kramer test and controlled for site differences by including site name as a random effect.

RESULTS

Cerulean Warbler Occupancy

We detected 71 Cerulean Warblers on 43 points at 10 sites (Appendix B). The top detection model for Cerulean Warbler included observer and time-since-sunrise (Table 2.6). For model sets 1 and 4, model selection results indicated that ecoregion, elevation, and treatment status were the most supported variables for Cerulean Warbler occupancy (Table 2.7). While ecoregion was a strongly supported variable for Cerulean Warbler occupancy, beta confidence intervals overlapped zero because occupancy in the Ridge and Valley was inestimable, as no Cerulean Warblers were detected there. The only variable with a beta coefficient confidence interval that did not overlap zero was elevation (Table 2.8). Cerulean Warbler occupancy decreased by 91% as elevation increased from 200 to 800 m (Table 2.8 and Figure 2.3). We did not detect any significant differences in Cerulean Warbler occupancy between reference, pre-treatment, 1-year post-treatment, and 2 – 4 years post-treatment categories (Table 2.8 and Figure 2.3). For model set 2, model selection results indicated that slope position and Beers aspect were the most supported variables for Cerulean Warbler occupancy; however, beta coefficient confidence intervals overlapped zero (Table 2.8 and Figure 2.3). For model set 3, model selection results indicated that sapling cover was the most supported variable for Cerulean Warbler occupancy (Table 2.7). Cerulean Warbler occupancy increased by 397% as sapling cover increased from 0 to 100% (Table 2.8 and Figure 2.3).

Forest Focal Species Occupancy

We detected 113 Blue-gray Gnatcatchers, 102 Eastern Wood-pewees, and 181 Scarlet Tanagers across 194 point-count surveys conducted during the study (Appendix B). For detection models, wind was the only supported variable for Blue-gray Gnatcatcher, date for Eastern Wood-pewee, and time and wind for Scarlet Tanager (Table 2.6). We did not detect any significant differences in Blue-gray Gnatcatcher, Eastern Wood-pewee, or Scarlet Tanager occupancy estimates among the four contract treatment status categories (Table 2.8).

Guild Richness

We did not detect any significant differences in observed species richness of the four avian guilds across contract treatment status categories (Figure 2.5). The F-statistics and p-values (in parentheses) from the one-way ANOVA comparing observed species richness of the four avian guilds across contract treatment status categories were: 0.95 (0.42) for the forest interior guild, 0.21 (0.89) for the gap specialist guild, 0.10 (0.96) for the forest generalist guild, and 2.34 (0.07) for the shrubland guild. The p-value for shrubland species richness was nearly significant, suggesting some positive influence at 2 – 4 years post-treatment points.

Vegetation

Covariate means across contract treatment status categories were significantly different for elevation, canopy cover, 100-m basal area, center plot basal area, and percent basal area of preferred trees (Table 2.9). Elevation at 1-year post-treatment points was 45% greater than reference, 72% greater than pre-treatment, and 46 % greater than 2 – 4 years post-treatment points (Figure 2.6). Canopy cover at 2 – 4 years post-treatment points was 27% lower than reference and 31% lower than pre-treatment points. Amount of 100-m basal area at reference points was 24% greater than pre-treatment points. Center plot basal area at reference points was 22% greater than pre-treatment points. Percent basal area of preferred trees at 1-year post-treatment points was 28% greater than pre-treatment points. Post-treatment center plot basal area was within the recommended range of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ on 60% of post-treatment points.

DISCUSSION

Cerulean Warbler occupancy estimates were not different at untreated and treated locations, suggesting that post-treatment study sites surveyed did not achieve their goal of benefiting Cerulean Warbler 1 – 4 years post-treatment. Although post-treatment sites surveyed were relatively recently treated, previous studies have consistently found an immediate Cerulean Warbler response that, in most cases, increases for up to 4 years following treatment (Boves et

al. 2013b, Wood et al. 2013, Hamel et al. 2016, Nareff et al. 2019). We suspect that the lack of differences in Cerulean Warbler occupancy was the result of private lands variability, site selection, small treatment areas, and challenges associated with private lands conservation efforts resulting in insufficient reduction in basal area. Post-treatment basal area metrics, except basal area of preferred trees, did not differ among treatments and center plot basal area fell within the recommended range at only 60% of post-treatment points. While mean basal on post-treatment points fell within the recommended range, we documented no measurable differences in basal area between untreated and treated locations. High basal area retained on some post-treatment sites likely resulted from breakdowns during the planning, implementation, and contract certification process that must be rectified if CWAFEP is to provide appropriate habitat conditions. Specified habitat quality targets must be achieved following NRCS conservation practice implementation to result in appropriate vegetation structure to benefit focal species (McCoy et al. 2001, Lituma and Buehler 2020). If NRCS conservation practices are intended to help reverse Cerulean Warbler declines, residual basal area targets of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ ($40 - 90 \text{ ft}^2/\text{ac}$) will have to be attained at all sites during contract implementation in West Virginia.

The recommended basal area range of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ benefits Cerulean Warblers by providing the desired canopy structure and increasing understory vegetation, which, in high densities, provides foraging habitat and protective fledgling cover (Boves et al 2013a, Raybuck et al. 2020). Cerulean Warbler occupancy in our study was positively associated with high sapling cover. Sapling cover in this context refers to forests with dense understories, not young forests dominated by saplings, as high sapling cover with no canopy trees is not Cerulean Warbler breeding habitat. Sapling cover increases following forest management as trees regenerate in response to additional growing space (i.e., sunlight, water, etc.) available from removed trees. Additional basal area removal to within the recommended range of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ during contract implementation is recommended, not only to provide important canopy structure, but also improve other important habitat characteristics such as understory vegetation. Pre-commercial forest management practices implemented on our sites (e.g., forest stand improvement, etc.) are unlikely to meaningfully increase Cerulean Warbler occupancy and benefit other forest birds because of the relatively low volume of removal. Thus, CWAFEP is unlikely to benefit Cerulean Warbler populations, as pre- and non-commercial forestry practices are emphasized in NRCS conservation projects.

Site selection outside of the Cerulean Warbler's core breeding distribution also contributed to the lack of differences in Cerulean Warbler occupancy. Ecoregion was a supported variable for Cerulean Warbler occupancy and strongly influenced where Cerulean Warblers were detected on our study sites. West Virginia supports high Cerulean Warbler breeding populations compared to other areas in their breeding range, but density between ecoregions is variable within the state and generally decreases from west to east (Sauer et al. 2020, Bailey and Rucker 2021). Forty-two percent of our sample size was in the Ridge and Valley Ecoregion, yet no Cerulean Warblers were detected. Ecoregion also affected our occupancy results among contract treatment status categories, as 88% of the 1-year post-treatment points were in the Ridge and Valley ecoregion where no Cerulean Warblers were detected. Cerulean Warbler occupancy in our study was negatively associated with elevation and elevation in the Ridge and Valley is higher than the Western Allegheny Plateau (Woods et al. 1999). Additionally, the dry oak-pine forests that dominate the Ridge and Valley are not the preferred Cerulean Warbler forest type (Weakland and Wood 2005). Habitat management using the guidelines can benefit low density Cerulean Warbler populations if local landscape- and stand-level considerations are met, and Cerulean Warbler populations are present near the site (within ~5 miles; Wood et al. 2013). Our results suggest that conservation practices implemented in the Ridge and Valley are unlikely to benefit Cerulean Warblers because local populations were not close enough for CWAFEP sites to be colonized. Our findings suggest that CWAFEP is most likely to benefit Cerulean Warblers if the eligible focal area in West Virginia excludes counties in the Eastern Panhandle (i.e., Berkeley, Grant, Hampshire, Hardy, Jefferson, Mineral, Morgan, and Pendleton Counties), where occupancy on our study sites was zero.

Slope position and Beers aspect were the most supported spatial variables associated with Cerulean Warbler occupancy. Our model-selection results were consistent with previous research in the central Appalachians and guidelines that found Cerulean Warblers generally occur and are most abundant on upper slopes and ridgetops and on mesic, north- to northeast-facing aspects (Hamel 2000, Weakland and Wood 2005, Newell and Rodewald 2012, Wood et al. 2013). However, confidence intervals for slope position and Beers aspect overlapped 0 and the range of available slope positions and aspects where NRCS conservation practices were applied on our study sites was relatively limited. Nonetheless, we add to a considerable body of evidence suggesting the importance of these topographic conditions.

Forest focal species occupancy estimates and species richness in the four habitat guilds were not different at untreated and treated locations. Our species richness results contrast previous studies that suggests forests managed for Cerulean Warblers contain higher overall avian diversity compared to unmanaged forests (Sheehan et al. 2014). Shrubland species richness was nearly significant and may continue to increase following additional development of understory conditions. The lack of statistical differences was likely influenced by low sample size, as mean richness values for forest gap, forest generalist, and shrubland guilds were higher on 1 – 4 years post-treatment points. Additional suspected reasons for the lack of differences observed from forest focal species occupancy estimates and species richness in the four habitat guilds were the same as those suspected for the lack of Cerulean Warbler occupancy differences: private lands variability, site selection, small treatment areas, and challenges associated with private lands conservation efforts resulting in insufficient reduction in basal area. Most basal area metrics were not different at untreated and treated locations. Residual basal area targets of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ ($40 - 90 \text{ ft}^2/\text{ac}$) will have to be attained at all sites during contract implementation for CWAFFEP to benefit associated forest species and increase avian diversity.

Limitations of this study offer insights into future research priorities to better evaluate Cerulean Warbler response to conservation practices. While surveying the same study sites pre- and post-treatment was not possible in this study, incorporating before-after-control-impact study design in future long-term studies is needed to provide more informative assessments. Longer-term studies are required to assess the longevity of site suitability for Cerulean Warbler following contract completion. Evaluations of survival and reproduction on private lands, which are smaller and more variable than treatment areas used in previous research, are required to provide more informative assessments of habitat quality following CWAFFEP implementation as they more directly relate to population growth (Van Horne 1983). Lastly, an evaluation of Cerulean Warbler response across the CWAFFEP Focal Area (Fearer 2011) is required for a more comprehensive assessment.

With conservation practices being implemented as a primary conservation action for Cerulean Warblers, quantitative evaluations of avian occupancy and species richness are important to inform CWAFFEP to make better use of limited conservation funding. While many research studies have evaluated Cerulean Warbler and the avian community response to habitat management using the guidelines on public lands, this was the first assessment of the “real

world” implementation of the guidelines through conservation practices on private lands. Our results suggest that there are opportunities to improve conservation practice implementation for more effective Cerulean Warbler conservation. We recommend all CWAFFEP sites achieve the recommended basal area range of $\sim 9.2 - 20.7 \text{ m}^2/\text{ha}$ ($40 - 90 \text{ ft}^2/\text{ac}$) during contract implementation and refinement of the CWAFFEP focal area to exclude the Ridge and Valley ecoregion to achieve the desired response. The information we have provided in this study fills a scientific knowledge gap and provides useful feedback to NRCS an adaptive management framework.

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TABLES

Table 2.1. Names, number of sites, and descriptions for Natural Resources Conservation Service conservation practices that were implemented on 13 post-treatment study sites enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia from 2016 – 2020.

Conservation Practice	Sites ^a	Description ^b
Cerulean Warbler Appalachian Forestland Enhancement Program		
Forest stand improvement	11	Manipulation of forest species composition and structure by cutting or killing selected trees and understory vegetation.
Brush management	6	Removal of woody (nonherbaceous or succulent) plants including those that are invasive and noxious.
Structures for wildlife	3	Structures installed to replace or modify a missing or deficient wildlife habitat component. (i.e., partially hinge cut multiple living small diameter trees into a living bush pile)
Early successional habitat development/ management	3	Manipulating a stand of plants to create and maintain early successional attributes that benefit desired wildlife and/or natural communities.
Tree/shrub site preparation	2	Treatment of areas to improve site conditions for establishing trees and/or shrubs.
Forest trails and landings	1	Creation and management of temporary or infrequently used routes, paths, or cleared areas.
Tree/shrub establishment	1	Planting seedlings or cuttings, seeding, or creating conditions that promote natural regeneration.

^a Number of study 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=nrcs143026849>)

Table 2.2. Annual number of point count locations and sites across contract treatment status categories surveyed on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFEP) in West Virginia and naïve occupancy of Cerulean Warbler (*Setophaga cerulean*; CERW), Blue-gray Gnatcatcher (*Poliophtila caerulea*; BGGN), Eastern Wood-pewee (*Contopus virens*; EAWP), and Scarlet Tanager (*Piranga olivacea*; SCTA) across treatment categories on point count locations and sites sampled during 2019 – 2020.

	Reference		Pre-treatment		1-year post-treatment		2 – 4 years post-treatment	
	Points	Sites	Points	Sites	Points	Sites	Points	Sites
Points sampled per year								
2019	50	10	52	8	24	2	0	0
2020	26	9	0	0	3	1	39	10
Total	76	19	52	8	27	3	39	10
Species naïve occupancy								
CERW	0.28	0.42	0.27	0.63	0.00	0.00	0.17	0.40
BGGN	0.43	0.79	0.37	0.75	0.11	0.67	0.59	1.00
EAWP	0.39	0.74	0.36	0.75	0.33	1.00	0.51	0.80
SCTA	0.68	0.95	0.48	1.00	0.44	1.00	0.64	0.90

Table 2.3. Descriptions, notations, and justifications for covariates used to model occupancy of Cerulean Warbler (*Setophaga cerulea*) using 194 point-count surveys across 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020.

Variable	Justification
Contract treatment status	Habitat management implemented based on the guidelines improves habitat quality and provides breeding habitat (Wood et al. 2013)
Elevation	Breed in elevations ranging from <30 m to <1000 m (Hamel 2000)
Slope position	Highest breeding densities found on ridgetops and upper slopes in the Appalachians (Weakland and Wood 2005)
Beers aspect	North and northeast facing slopes are preferred in the Appalachians (Weakland and Wood 2005)
1-km forest cover	Breeding habitat associated with forested landscapes (Weakland and Wood 2005)
1-km edge density	Small forest tract size and the presence of large-scale edge can limit habitat suitability (Wood et al. 2006)
Vine cover	Nest success positively associated with density of grapevines (Bakermans 2008)
Shrub cover	Well-developed understory- and midstory-layers provide increased foraging opportunities and protective fledgling cover (Wood et al. 2005)
Sapling cover	
Canopy cover	Territory densities increase with increasing canopy cover (Weakland and Wood 2005)
100-m basal area	Recommended 9.2 – 20.7 m ² /ha (40 – 90 ft ² /ac; Boves et al. 2013b, Wood et al. 2013) in the Appalachian region
Center plot basal area	
Snag basal area	Territory densities increase with increasing snag density (Weakland and Wood 2005)
Percent basal area of preferred trees	Preferred tree species for nesting and foraging included sugar maple, white oaks, and hickories (Barg et al. 2006)
Percent basal area of large trees	Breeding habitat characterized by large, tall trees within mature deciduous forests (Hamel 2000)
Percent basal area of large preferred trees	Increased abundance associated with increased percentage of basal area of large diameter trees (≥ 40.6 cm dbh) that comprised tree species preferred for foraging and nesting (i.e., white oak species, sugar maple, and hickories) (Nareff et al. 2019)

Table 2.4. Covariates used to model occupancy of Cerulean Warbler (*Setophaga cerulea*) on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020.

Covariate	Code	Covariate type	Description
Canopy cover	canopy	Detection probability	Proportional cover (0 – 1) of trees ≥ 8 cm dbh within 100 m
Observer	observer	Detection probability	Observer conducting survey (L. Oliver or 1 of 2 field technicians)
Ordinal date	date	Detection probability	Day of the year (126 – 178)
Sky	sky	Detection probability	Sky reading (0, 1, 2, 3)
Time-since-sunrise	time	Detection probability	Minutes-since-sunrise (-14 – 240)
Wind	wind	Detection probability	Wind reading on the Beaufort scale (0, 1, 2, 3)
Contract treatment status	status	Status	Treatment status (reference, pre-treatment, 1-year post-treatment, 2 – 4 years post-treatment)
Ecoregion	ecoregion	Nuisance	Level III ecoregion (Central Appalachians, Western Allegheny Plateau, and Ridge and Valley)
Elevation	elev	Nuisance	Majority elevation (m) within 100 m
Slope position	slpos	Spatial	Majority slope position (lower, middle, or ridge) within 100 m
Beers aspect	asp	Spatial	Majority Beers aspect (0–2; 0 is xeric and 2 is mesic) within 100 m
1-km forest cover	forest	Spatial	Forest cover (%) within 1 km
1-km edge density	edge	Spatial	Forest edge density (km/km ²) within 1 km
Vine cover	vine	Vegetation	Percent vine 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
Snag basal area	basnag	Vegetation	Mean basal area (m ² /ha) of snags ≥ 8 cm dbh
Percent basal area of preferred trees	bapref	Vegetation	Percent (0 – 100) of 100 m basal area (m ² /ha) that includes sugar maples, hickories, or white oak group ≥ 8 cm dbh
Percent basal area of large trees	balg	Vegetation	Percent (0 – 100) of 100 m basal area (m ² /ha) that is large diameter trees ≥ 40.6 cm dbh
Percent basal area of preferred large trees	balgpref	Vegetation	Percent (0 – 100) of 100 m basal area (m ² /ha) that is large diameter sugar maples, hickories, or white oak group ≥ 40.6 cm dbh

Table 2.5. Covariates used to model occupancy of Cerulean Warbler (*Setophaga cerulea*) on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. We report the weighted mean and range for continuous variables and the percent of point count surveys that fell in each category for categorical variables. Weighted mean values are also reported where Cerulean Warblers were detected across all point count locations and on post-treatment point count locations.

Covariate	Untreated mean (range) (n=128 points, n=19 sites)	Treated mean (range) (n=66 points, n=13 sites)	Cerulean Warbler absent mean (range) (n=151 points, n=11 sites)	Cerulean Warbler present mean (range) (n=43 points, n=10 sites)	Post-treatment Cerulean Warbler present mean (range) (n=11 points, n=4 sites)
Treatment status					
Reference	59	--	37	46	--
Pre-treatment	41	--	26	28	--
1-year post-treatment	--	41	18	0	0
2 – 4 years post-treatment	--	59	19	26	100
Level III Ecoregion					
Ridge and Valley	41	45	55	0	0
Central Appalachians	16	29	17	30	45
Western Allegheny Plateau	43	26	28	70	55
Elevation	384 (244 – 630)	408 (241 – 679)	414 (241 – 679)	362 (285 – 595)	380 (285 – 508)
Slope position					
Lower	10	0	7	5	0
Middle	87	91	90	81	73
Ridge	3	9	3	14	27
Beers aspect	0.70 (0.06 – 1.74)	0.86 (0.22 – 1.75)	0.69 (0.06 – 1.31)	0.85 (0.22 – 1.75)	1.01 (0.62 – 1.75)
1-km forest cover	88 (61 – 98)	84 (59 – 96)	84 (59 – 98)	89 (61 – 97)	91 (87 – 96)
1-km edge density	8 (3 – 16)	9 (4 – 16)	8 (3 – 16)	8 (4 – 16)	7 (5 – 8)
Vine cover	11 (0 – 61)	8 (0 – 18)	11 (0 – 61)	9 (2 – 23)	9 (3 – 18)
Shrub cover	21 (2 – 61)	11 (0 – 35)	21 (2 – 61)	14 (0 – 41)	8 (0 – 12)
Sapling cover	49 (18 – 95)	40 (30 – 52)	41 (18 – 60)	53 (30 – 95)	34 (30 – 40)
Canopy cover	81 (50 – 100)	64 (45 – 85)	75 (45 – 100)	76 (50 – 94)	62 (50 – 77)
100-m basal area	15 (5 – 24)	16 (10 – 23)	16 (5 – 24)	14 (7 – 20)	15 (10 – 19)
Center plot basal area	18 (4 – 34)	19 (10 – 28)	19 (10 – 28)	16 (4 – 34)	17 (15 – 20)
Snag basal area	1 (0 – 4)	2 (0 – 5)	1 (0 – 5)	1 (0 – 3)	1 (0 – 3)
Percent basal area of preferred trees	42 (18 – 65)	42 (17 – 57)	42 (17 – 65)	41 (18 – 62)	44 (24 – 56)
Percent basal area of large trees	16 (3 – 43)	14 (2 – 42)	13 (2 – 42)	18 (5 – 43)	16 (5 – 25)
Percent basal area of preferred large trees	5 (0 – 12)	5 (1 – 15)	5 (0 – 15)	5 (0 – 12)	4 (2 – 6)

Table 2.6. Detection model selection procedure results for Cerulean Warbler (*Setophaga cerulea*), Blue-gray Gnatcatcher (*Polioptila caerulea*), Eastern Wood-pewee (*Contopus virens*), and Scarlet Tanager (*Piranga olivacea*) occupancy (ψ) and detection probability (p) using 194 point-count surveys across 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Models are ranked in descending order of Akaike's Information Criterion adjusted for small sample sizes (AIC_c) value with the top model first. K is the number of parameters in each model, AIC_c is the Akaike's Information Criterion value for small sample sizes, ΔAIC_c is the difference between each model's AIC_c value and the lowest AIC_c 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 Table 2.4.

Model	K	AIC_c	ΔAIC_c	w_i
Cerulean Warbler				
ψ (1) p (observer + time)	5	300.99	0.00	0.23
ψ (1) p (time + canopy)	4	301.57	0.58	0.17
ψ (1) p (observer)	4	302.21	1.23	0.12
ψ (1) p (observer + time + canopy)	6	302.38	1.39	0.11
ψ (1) p (time)	3	302.60	1.61	0.10
ψ (1) p (canopy)	3	302.96	1.97	0.08
ψ (1) p (date)	3	303.38	2.39	0.07
ψ (1) p (observer + canopy)	5	303.78	2.79	0.06
ψ (1) p (wind)	3	304.30	3.31	0.04
ψ (1) p (sky)	7	306.76	5.77	0.01
Blue-gray Gnatcatcher				
ψ (1) p (wind)	3	424.55	0.00	0.88
ψ (1) p (canopy)	3	429.29	4.74	0.08
ψ (1) p (time)	3	431.37	6.83	0.03
ψ (1) p (observer)	4	434.67	10.12	0.01
ψ (1) p (date)	3	434.69	10.14	0.01
ψ (1) p (sky)	7	439.55	15.00	0.00
Eastern Wood-pewee				
ψ (1) p (date)	3	413.95	0.00	1.00
ψ (1) p (observer)	4	425.19	11.24	0.00
ψ (1) p (wind)	3	427.39	13.44	0.00
ψ (1) p (time)	3	432.68	18.73	0.00
ψ (1) p (sky)	7	433.74	19.79	0.00
ψ (1) p (canopy)	3	433.86	19.91	0.00
Scarlet Tanager				
ψ (1) p (time + wind)	4	513.46	0.00	0.44
ψ (1) p (wind)	3	514.46	1.00	0.27
ψ (1) p (time)	3	515.99	2.53	0.13
ψ (1) p (sky)	7	517.26	3.80	0.07
ψ (1) p (date)	3	517.89	4.43	0.05
ψ (1) p (canopy)	3	518.34	4.88	0.04
ψ (1) p (observer)	4	521.24	7.78	0.01

Table 2.7. Single-season occupancy model selection procedure results for Cerulean Warbler (*Setophaga cerulea*), Blue-gray Gnatcatcher (*Polioptila caerulea*), Eastern Wood-pewee (*Contopus virens*), and Scarlet Tanager (*Piranga olivacea*) occupancy (ψ) and detection probability (p) using 194 point-count surveys across 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Models are ranked in descending order of Akaike's Information Criterion adjusted for small sample sizes (AIC_c) value with the top model first. K is the number of parameters in each model, AIC_c is the Akaike's Information Criterion value for small sample sizes, ΔAIC_c is the difference between each model's AIC_c value and the lowest AIC_c 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 Table 2.4.

Model	K	AIC_c	ΔAIC_c	w_i
Cerulean Warbler model set 1: treatment models				
ψ (status + ecoregion + elev) p (observer + time)	11	247.32	0.00	0.41
ψ (ecoregion + elev) p (observer + time)	8	247.47	0.15	0.38
ψ (ecoregion) p (observer + time)	7	249.31	1.99	0.15
ψ (status + ecoregion) p (observer + time)	10	250.99	3.67	0.06
ψ (status + elev) p (observer + time)	9	291.91	44.59	0.00
ψ (elev) p (observer + time)	6	294.96	47.64	0.00
Cerulean Warbler model set 2: spatial models				
ψ (slppos) p (observer + time)	7	298.51	0.00	0.46
ψ (asp) p (observer + time)	6	299.47	0.96	0.29
ψ (forest) p (observer + time)	6	300.78	2.27	0.15
ψ (edge) p (observer + time)	6	301.43	2.92	0.11
Cerulean Warbler model set 3: vegetation models				
ψ (sapling) p (observer + time)	6	295.46	0.00	0.56
ψ (bacent) p (observer + time)	6	299.02	3.56	0.09
ψ (vine) p (observer + time)	6	299.42	3.97	0.08
ψ (balg) p (observer + time)	6	299.86	4.40	0.06
ψ (bacent ²) p (observer + time)	7	300.53	5.07	0.04
ψ (shrub) p (observer + time)	6	300.88	5.42	0.04
ψ (ba) p (observer + time)	6	301.17	5.72	0.03
ψ (balgpref) p (observer + time)	6	302.25	6.79	0.02
ψ (ba ²) p (observer + time)	7	302.29	6.83	0.02
ψ (basnag) p (observer + time)	6	302.81	7.36	0.01
ψ (bapref) p (observer + time)	6	302.89	7.43	0.01
ψ (canopy) p (observer + time)	6	302.98	7.52	0.01
ψ (basnag ²) p (observer + time)	7	304.26	8.81	0.01
ψ (shrub ²) p (observer + time)	7	305.87	10.42	0.00
ψ (sapling ²) p (observer + time)	7	334.77	39.31	0.00
ψ (canopy ²) p (observer + time)	7	334.77	39.31	0.00
Cerulean Warbler model set 4: top models				
ψ (status + ecoregion + elev) p (observer + time)	11	247.32	0.00	0.44
ψ (ecoregion + elev) p (observer + time)	8	247.47	0.15	0.40
ψ (ecoregion) p (observer + time)	7	249.31	1.99	0.16
ψ (slppos + status) p (observer + time)	10	289.20	41.88	0.00
ψ (asp + status) p (observer + time)	9	289.30	41.98	0.00
ψ (sapling) p (observer + time)	6	295.46	48.14	0.00
ψ (slppos) p (observer + time)	7	298.51	51.19	0.00

ψ (asp) p (observer + time)	6	299.47	52.15	0.00
Blue-gray Gnatcatcher model set: treatment models				
ψ (status + elev) p (wind)	7	410.75	0.00	0.76
ψ (status + ecoregion + elev) p (wind)	9	414.74	3.99	0.10
ψ (elev) p (wind)	4	415.04	4.29	0.09
ψ (ecoregion + elev) p (wind)	6	417.14	6.39	0.03
ψ (status + ecoregion) p (wind)	8	419.09	8.34	0.01
ψ (ecoregion) p (wind)	5	426.38	15.63	0.00
Eastern Wood-pewee model set: treatment models				
ψ (ecoregion) p (date)	5	414.92	0.00	0.34
ψ (elev) p (date)	4	415.18	0.26	0.30
ψ (ecoregion + elev) p (date)	6	416.29	1.37	0.17
ψ (status + ecoregion) p (date)	8	417.02	2.10	0.12
ψ (status + ecoregion + elev) p (date)	9	419.09	4.18	0.04
ψ (status + elev) p (date)	7	420.42	5.50	0.02
Scarlet Tanager model set: treatment models				
ψ (status + ecoregion) p (time + wind)	9	512.56	0.00	0.38
ψ (status + ecoregion + elev) p (time + wind)	10	513.49	0.93	0.24
ψ (status + elev) p (time + wind)	8	513.54	0.98	0.23
ψ (elev) p (time + wind)	5	515.53	2.97	0.09
ψ (ecoregion) p (time + wind)	6	516.32	3.76	0.06
ψ (ecoregion + elev) p (time + wind)	7	519.58	7.02	0.01

Table 2.8. Beta (β) estimates, standard errors (SE), and 95% lower and upper confidence intervals (CI) on the logit-scale from models (see Table 2.7) estimating Cerulean Warbler (*Setophaga cerulea*), Blue-gray Gnatcatcher (*Polioptila caerulea*), Eastern Wood-pewee (*Contopus virens*), and Scarlet Tanager (*Piranga olivacea*) occupancy using 194 point-count surveys across 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020.

Parameter	β estimate	SE	Lower 95% CI	Upper 95% CI
Cerulean Warbler model sets 1 and 4: treatment, supported, and multivariate models				
status + ecoregion + elev				
Reference	8.67	28.33	-46.86	65.00
Pre-treatment	8.56	28.33	-46.97	64.10
1-year post treatment	-5.04	28.37	-60.64	50.55
2 – 4 years post treatment	8.17	28.33	-47.36	63.71
Ridge and Valley	-13.17	66.65	-143.80	117.47
Western Allegheny Plateau	-0.64	0.70	-2.02	0.74
Elevation	-0.01	0.00	-0.02	-0.01
ecoregion + elev				
Central Appalachians	2.49	1.60	-0.64	5.62
Ridge and Valley	-9.72	14.50	-38.15	18.70
Western Allegheny Plateau	-0.43	0.63	-1.67	0.82
Elevation	-0.01	0.00	-0.01	0.01
ecoregion				
Central Appalachians	-0.43	0.39	-1.20	-0.33
Ridge and Valley	-12.08	63.12	-135.79	111.65
Western Allegheny Plateau	0.41	0.48	-0.51	1.32
Cerulean Warbler model set 2: spatial models				
slppos				
Lower	-1.45	0.81	-3.03	0.14
Middle	0.34	0.83	-1.28	1.96
Ridge	2.18	1.14	-0.05	4.41
asp				
Beers aspect	0.59	0.32	-0.03	1.21
Cerulean Warbler model set 3: vegetation models				
sapling				
Sapling	0.02	0.01	0.01	0.04
Blue-gray Gnatcatcher treatment models				
status + elev				
Reference	1.15	1.09	-1.00	3.29
Pre-treatment	0.07	1.37	-2.63	2.76
1-year post treatment	2.44	2.53	-2.51	7.39
2 – 4 years post treatment	2.93	2.11	-1.21	7.06
Elevation	-0.01	0.01	-0.01	0.01

Eastern Wood-pewee treatment models				
ecoregion				
Central Appalachians	-0.10	0.51	-1.09	0.90
Ridge and Valley	1.05	0.55	-0.23	2.34
Western Allegheny Plateau	0.46	0.59	-0.70	1.62
elev				
Elevation	-0.01	0.01	-0.01	0.01
ecoregion + elev				
Central Appalachians	0.35	1.19	-1.98	2.67
Ridge and Valley	0.99	0.64	-0.26	2.24
Western Allegheny Plateau	0.34	0.66	-0.95	1.63
Elevation	-0.01	0.01	-0.01	0.01
Scarlet Tanager treatment models				
status + ecoregion				
Reference	2.62	1.65	-0.61	5.84
Pre-treatment	0.52	0.86	-1.17	2.21
1-year post treatment	-1.04	1.22	-3.43	1.35
2 – 4 years post treatment	2.32	1.34	-0.31	4.95
Ridge and Valley	1.72	1.17	-0.58	4.01
Western Allegheny Plateau	0.82	1.12	-1.38	3.02
status + ecoregion + elev				
Reference	4.49	3.29	-1.96	10.93
Pre-treatment	1.44	1.22	-0.95	3.84
1-year post treatment	-4.37	3.26	-10.76	2.02
2 – 4 years post treatment	3.70	2.07	-0.35	7.75
Ridge and Valley	2.60	1.70	-0.73	5.93
Western Allegheny Plateau	1.96	1.76	-1.48	5.40
Elevation	0.01	0.01	-0.01	0.01
status + elev				
Reference	4.00	3.17	-1.76	9.83
Pre-treatment	0.62	1.05	-1.45	2.68
1-year post treatment	-0.81	1.77	-4.28	2.66
2 – 4 years post treatment	2.02	1.55	-1.01	5.05
Elevation	0.01	0.01	-0.01	0.01

Table 2.9. Covariate weighted mean, standard error (top parentheses), and range (bottom parentheses) between treatment categories across 194 point-count surveys on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Results of analysis of variance comparing differences in the means among treatment categories. Differences in means between treatment categories (p -value <0.05) are indicated by alphabetical notation based on a Tukey-Kramer test. F-statistics (F) and p -values (p) are reported for each covariate.

Covariate	Reference (n=76 points, n=19 sites)		Pre-treatment (n=52 points, n=8 sites)		1-year post-treatment (n=27 points, n=3 sites)		2 – 4 years post-treatment (n=39 points, n=10 sites)		F	p
Elevation	390 ($\pm$ 24) (244 – 630)	B	371 ($\pm$ 41) (244 – 602)	B	491 ($\pm$ 130) (241 – 679)	A	383 ($\pm$ 27) (267 – 508)	B	8.17	0.01
Beers aspect	0.74 ($\pm$ 0.11) (0.06 – 1.74)		0.62 ($\pm$ 0.11) (0.13 – 1.03)		0.94 ($\pm$ 0.14) (0.71 – 1.20)		0.83 ($\pm$ 0.14) (0.22 – 1.75)		0.68	0.57
1-km forest cover	87 ($\pm$ 2) (61 – 98)		89 ($\pm$ 3) (76 – 98)		85 ($\pm$ 4) (79 – 93)		83 ($\pm$ 4) (59 – 96)		1.70	0.17
1-km edge density	8 ($\pm$ 1) (3 – 16)		8 ($\pm$ 1) (3 – 14)		7 ($\pm$ 2) (4 – 11)		10 ($\pm$ 1) (5 – 16)		0.90	0.44
Vine cover	8 ($\pm$ 2) (0 – 32)	A	19 ($\pm$ 7) (0 – 30)	B	8 ($\pm$ 4) (0 – 13)	AB	9 ($\pm$ 2) (2 – 18)	AB	2.41	0.07
Shrub cover	19 ($\pm$ 3) (2 – 61)		25 ($\pm$ 3) (14 – 38)		14 ($\pm$ 10) (2 – 33)		11 ($\pm$ 3) (0 – 35)		2.03	0.11
Sapling cover	48 ($\pm$ 4) (18 – 79)		53 ($\pm$ 7) (34 – 95)		43 ($\pm$ 5) (33 – 51)		39 ($\pm$ 3) (30 – 52)		1.44	0.23
Canopy cover	79 ($\pm$ 3) (50 – 98)	B	86 ($\pm$ 6) (64 – 100)	B	75 ($\pm$ 8) (60 – 85)	AB	61 ($\pm$ 3) (45 – 77)	A	3.80	0.01
100-m basal area	16 ($\pm$ 1) (8 – 24)	A	13 ($\pm$ 2) (5 – 23)	B	15 ($\pm$ 2) (13 – 18)	AB	17 ($\pm$ 1) (10 – 23)	AB	5.62	0.01
Center plot basal area	19 ($\pm$ 2) (8 – 34)	A	15 ($\pm$ 2) (4 – 25)	B	16 ($\pm$ 3) (10 – 19)	AB	19 ($\pm$ 1) (14 – 28)	AB	4.44	0.01
Snag basal area	1 ($\pm$ 1) (0 – 3)		1 ($\pm$ 1) (0 – 2)		1 ($\pm$ 1) (1 – 2)		2 ($\pm$ 1) (0 – 5)		0.96	0.41
Percent basal area of preferred trees	40 ($\pm$ 3) (6 – 65)	AB	40 ($\pm$ 6) (19 – 62)	B	50 ($\pm$ 3) (46 – 57)	A	40 ($\pm$ 4) (17 – 56)	AB	2.86	0.04
Percent basal area of large trees	14 ($\pm$ 1) (4 – 26)		19 ($\pm$ 5) (3 – 43)		9 ($\pm$ 3) (5 – 15)		15 ($\pm$ 4) (2 – 42)		1.66	0.18
Percent basal area of preferred large trees	5 ($\pm$ 1) (0 – 10)		6 ($\pm$ 1) (0 – 12)		4 ($\pm$ 2) (1 – 8)		5 ($\pm$ 1) (1 – 15)		0.76	0.52

FIGURES

Figure 2.1. Study site locations enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Study sites were located on 8 pre-treatment (circles) and 13 post-treatment (squares) private properties. Study sites where Cerulean Warblers (*Setophaga cerulea*) were detected are shown in blue. Study site locations were randomly offset within a 5-km radius of the actual location to protect personally identifiable information.

Figure 2.2. Diagram of plot for sampling vegetation variables at each point count location. Within the 3.14 ha (100-m radius) plot, percent cover of vegetation classes (vines, shrubs, saplings, and canopy trees) was measured at 10 points along three 100-m transects, radiating from point center at 0°, 120°, and 240°. Four prism plots (open circles) were conducted at each sampling plot for basal area calculations. Prism plots were located at point center and 70 m from point center along each transect.

Figure 2.3. Predicted occupancy and 95% confidence intervals of Cerulean Warblers (*Setophaga cerulea*) at 194-point count locations on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Occupancy models for panels shown included contract treatment status, ecoregion, and elevation, elevation, slope position, Beers aspect, and sapling cover as covariates for occupancy and observer and time as covariates for detection probability.

Figure 2.4. Predicted occupancy and 95% confidence intervals of Blue-gray Gnatcatcher (*Poliophtila caerulea*), Eastern Wood-pewee (*Contopus virens*), and Scarlet Tanager (*Piranga olivacea*) at 194-point count locations on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Occupancy models for each species included the following as covariates for occupancy: contract treatment status and elevation for Blue-gray Gnatcatcher, ecoregion for Eastern Wood-pewee, and ecoregion and contract treatment status for Scarlet Tanager. Covariates for detection probability included wind for Blue-gray Gnatcatcher, date for Eastern Wood-pewee, and time and wind for Scarlet Tanager.

Figure 2.5. Observed species richness and 95% confidence intervals of avian habitat guilds on at 194-point count locations on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020.

Figure 2.6. Covariate means and 95% confidence intervals for elevation, vine cover, canopy cover, 100-m basal area, center plot basal area, and percent basal area of preferred trees between treatment categories on at 194-point count locations on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project in West Virginia sampled during 2019 – 2020. Differences in means between contract treatment status categories (p -value < 0.05) are indicated by alphabetical notation based on a Tukey-Kramer test.

CHAPTER 3. EVALUATING AVIAN OCCUPANCY ON SITES TREATED WITH NRCS CONSERVATION PRACTICES IMPLEMENTED TO BENEFIT GOLDEN-WINGED WARBLERS IN WEST VIRGINIA

ABSTRACT

The USDA Natural Resources Conservation Service (NRCS) supports private lands conservation across the United States to benefit imperiled focal wildlife species using conservation practices to restore habitat. The Golden-winged Warbler (*Vermivora chrysoptera*) is a focal species of Working Lands for Wildlife (WLFW), which was initiated in 2012 to stabilize or reverse population declines by creating breeding habitat in focal areas in the Appalachians. Hybridizing and competing Blue-winged Warblers (*V. cyanoptera*) are expanding in the Appalachians, which has important implications for Golden-winged Warbler conservation. We estimated *Vermivora* occupancy on different pre- and post-treatment WLFW sites to evaluate WLFW in an adaptive management framework. We also estimated occupancy of associated shrubland focal species and species richness of avian guilds to evaluate the effects of conservation practice implementation on the avian community. We conducted point count surveys at 147 locations on 22 private properties enrolled in WLFW in West Virginia during 2019 – 2020. There were no differences in *Vermivora* occupancy estimates at untreated and treated locations, suggesting that NRCS conservation planning and conservation practice implementation needs to be adjusted. *Vermivora* occupancy increased by 967% as 100-m shrubland increased from 0 to 100% cover and decreased by 87% as 100-m basal area increased from 0 to 30 m²/ha. Occupancy for 1 of the 3 shrubland focal species and species richness in all avian guilds also were not different at untreated and treated locations, suggesting that conservation practices did not meaningfully influence associated shrubland bird occurrence or avian diversity. We found that *Vermivora* and the overall avian community were not positively correlated with recent conservation practice implementation through WLFW in the short-term (1 – 8 years post-treatment) suggesting that there are opportunities to improve NRCS conservation practice implementation for more effective Golden-winged Warbler conservation. For NRCS conservation practices implemented through WLFW to benefit Golden-winged Warbler populations, we recommend additional basal area removal to within the recommended range of ~1.9 – 3.7 m²/ha (8 – 16 ft²/ac) during contract implementation.

Keywords: adaptive management, bird community, conservation, early succession, habitat management, occupancy, private lands, shrubland

INTRODUCTION

Private lands conservation efforts are critical for recovery of imperiled species because most land area in the United States is privately owned (U.S. Geological Survey [USGS] 2019). The U.S. Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) supports private lands conservation through conservation programs such as the Environmental Quality Incentives Program (Ciuzio et al. 2013). Conservation programs include individual projects, such as those that aim to restore habitat on private lands for focal wildlife species using targeted habitat management techniques (Gray and Teels 2006). NRCS provides technical and financial assistance to landowners to implement conservation practices to address natural resources concerns for imperiled focal wildlife species such as Greater Sage-Grouse (*Centrocercus urophasianus*), Cerulean Warbler (*Setophaga cerulea*), Golden-winged Warbler (*Vermivora chrysoptera*), gopher tortoise (*Gopherus polyphemus*), and monarch butterfly (*Danaus plexippus*). Few research studies have evaluated focal species-specific occupancy on sites treated with conservation practices implemented to benefit Golden-winged Warblers, and more research is required to inform the conservation project's effectiveness and justify continued funding.

Golden-winged Warblers are declining Neotropical migrant songbirds that breed in early successional communities in portions of the upper Great Lakes and Appalachians. Based on North American Breeding Bird Survey data, the Great Lakes subpopulation declined 39% and the Appalachian subpopulation declined 98% since 1970 (Rosenberg et al. 2016). Primary factors influencing Golden-winged Warbler population declines include habitat loss on breeding, migration, and wintering grounds (Buehler et al. 2007, Chandler and King 2011, Kramer et al. 2018), hybridization and competition with the closely related Blue-winged Warbler (*Vermivora cyanoptera*; Gill 1980, Confer et al. 2010), and Brown-headed Cowbird (*Molothrus ater*) nest parasitism (Coker and Confer 1990). With an estimated 400,000 individuals remaining (Rosenberg et al. 2016), Golden-winged Warblers have one of the smallest population sizes of any bird not listed under the Endangered Species Act (Confer et al. 2020). Declines led to a petition for Endangered Species Act listing (USFWS 2011), with a subsequent 90-day finding and status review that remains pending. Habitat management used to create and maintain suitable early successional vegetation communities on breeding grounds is a priority conservation action

to sustain current Golden-winged Warbler populations and ultimately reverse population trends for the Appalachian and Great Lakes subpopulations (Buehler et al. 2007).

The Blue-winged Warbler, the other extant member of the *Vermivora* species complex, breeds in early to mid-successional communities in eastern North America (Gill et al. 2020). The species' range of successional stages used for nesting is broader than, but encompasses that of, the Golden-winged Warbler (Confer and Knapp 1981, Gill 2004). In the central Appalachians during the past ~30 years, elevation has mostly separated Blue-winged Warbler (<600 m) and Golden-winged Warbler (>600 m; Welton 2003, Buehler et al. 2007) populations. However, the Blue-winged Warbler breeding distribution is expanding north and into higher elevations (Sauer et al. 2020). Thus, Blue-winged Warblers may also benefit from Golden-winged Warbler habitat management. Where Blue-winged and Golden-winged Warbler breeding distributions overlap, hybridization, genetic introgression, and competition negatively affect Golden-winged Warbler populations (Vallender and Bull 2016). However, the Blue-winged and Golden-winged Warbler genomes are 99.97% alike (Toews et al. 2016). Blue-winged Warblers are an understudied species outside of research on hybridization and genetic introgression with closely related Golden-winged Warbler (Buehler et al. 2007, Confer et al. 2003, Vallender et al. 2007). Research on Blue-winged Warbler occupancy at sites managed for Golden-winged Warblers is required to address knowledge gaps for declining Blue-winged Warblers and have important implications for Golden-winged Warbler conservation in the Appalachians.

Recently developed science-based management guidelines (hereafter “guidelines”) provide a variety of context-specific management practices used to create and maintain breeding habitat to stabilize or reverse Golden-winged Warbler population declines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013). Recent studies evaluating Golden-winged Warbler response to habitat management recommended by the guidelines in the southern and central Appalachians found habitat management beneficial for Golden-winged Warblers, suggesting that management is effective at creating and maintaining habitats capable of supporting breeding populations (Larkin et al. 2014, Aldinger et al. 2015, McNeil et al. 2017). Habitat management using the guidelines may also benefit other early successional avian species (Aldinger et al. 2017), many of which are experiencing declines partially due to the loss of early successional habitats on the breeding grounds (Dettmers 2003). Extensive habitat management efforts that implement the guidelines are underway on private

lands in the Appalachians to address declines but the effectiveness of implementation in this context has not been adequately evaluated.

Golden-winged Warblers are a focal species of Working Lands for Wildlife (WLFW), which was initiated by NRCS in 2012 to provide private landowners technical and financial assistance to benefit target wildlife species. Through WLFW, private landowners can implement conservation practices that follow the guidelines to create or maintain early successional breeding habitat in portions of Appalachian Golden-winged Warbler breeding range (USDA NRCS 2020). The goal of WLFW is to reverse Golden-winged Warbler population declines and prevent Endangered Species Act listing (Roth et al. 2012). The original Golden-winged Warbler WLFW focal area included high elevation (>600 m) counties in West Virginia (USDA NRCS 2012) and was expanded in 2017 (USDA NRCS 2017) to include some lower elevation counties to increase landowner enrollment. As a result, conservation practice implementation is more likely to also influence declining Blue-winged Warbler populations. McNeil et al. (2020) assessed Golden-winged Warbler response to WLFW on sites 0 – 8 years post-treatment in Maryland, Pennsylvania, and New Jersey and found low occupancy rates (0.22) and many sites uncolonized. However, additional evidence on *Vermivora* occupancy on WLFW sites needed to evaluate the conservation project's effectiveness and justify continued funding. Such evaluations are a critical component of the adaptive management process and are required to inform and improve future Golden-winged Warbler conservation efforts.

NRCS conservation practices have had variable success in achieving desired outcomes due to numerous social, economic, political, administrative, technical, and environmental issues (Ciuzio et al. 2013). Lituma and Buehler (2020) found mixed responses of priority grassland and shrubland birds to conservation practices and suggested that improved implementation could increase avian responses. The conservation benefits of conservation practices are largely influenced by the effectiveness with which landowners manage them following contract completion (Briske et al. 2011). Private land parcels are often small and contain highly variable landscape and microhabitat characteristics compared to treatment areas previously used for research (Roth et al. 2012, Bakermans et al. 2015). Recent research on the Golden-winged Warbler response to habitat management recommended by the guidelines included sites on state and federal lands and were near known Golden-winged Warblers breeding populations but distant from Blue-winged Warbler populations (Aldinger et al. 2015, McNeil et al. 2017).

Together, these challenges and limitations may influence the effectiveness of conservation practice implementation on private lands through WLFW.

Our objective was to evaluate the effects of conservation practice implementation on *Vermivora* and the avian community at WLFW sites in West Virginia. Golden-winged Warbler and Blue-winged Warbler survey data were combined into *Vermivora* because there were not enough detections of each species to analyze them separately. We addressed these objectives by surveying the avian community on pre-treatment sites where WLFW contract implementation had not begun and post-treatment sites where WLFW contracts were certified by NRCS as completed. Additionally, we quantified vegetation and habitat characteristics on all sites to identify which most influenced *Vermivora* occupancy and to examine how post-treatment vegetation structure and composition compared to the guidelines. We expected occupancy of *Vermivora* Warblers and three other shrubland associated focal bird species; Chestnut-sided Warbler (*Setophaga pensylvanica*), Common Yellowthroat (*Geothlypis trichas*), and Field Sparrow (*Spizella pusilla*); to be greater on post-treatment sites. We expected species richness to be greater for forest gap, forest generalist, shrubland, and grassland bird species and to be lower for forest interior birds on post-treatment sites. Lastly, we expected vegetation characteristics of post-treatment sites to be within the recommended ranges in the guidelines.

METHODS

Study Area

We sampled 22 sites during 2019 – 2020 on private properties enrolled in WLFW in Barbour, Greenbrier, Hardy, Monroe, Nicholas, Pocahontas, Randolph, Upshur, and Webster counties of West Virginia (Figure 3.1). We surveyed 6 pre-treatment sites where WLFW contract implementation had not begun and 16 post-treatment sites where WLFW contracts were certified by NRCS as completed. We were unable to collect pre- and post-treatment data on the same sites because contract implementation on our sites occurred over a 2 – 6-year period (mean = 4.4 years). We surveyed sites that were 2 – 8 years post-treatment to account for multi-year lags in the avian response (Bakermans et al. 2015, Aldinger 2018). Points were placed into 1 of 3 contract treatment status categories (reference, pre-treatment, and post-treatment). Years-post treatment was verified through communication with landowners and NRCS personnel. Shapefiles containing contract treatment areas for each site were obtained through communication with NRCS personnel. Total contract treatment area at each site was 1.2 – 20.0

ha (mean $\pm$ standard error [SE] = 7.6 ± 1.2 ha). Contract treatment areas were split into separate treatment patches on 7 of 16 post-treatment sites and were 1.0 – 8.9 ha (mean $\pm$ SE = 3.4 ± 0.3 ha). Contract treatment areas and treatment patches on sites varied in shape, elevation (463 – 1063 m; mean $\pm$ SE = 727 ± 12 m), slope position, and aspect.

Habitat management on sites was implemented using conservation practices adapted from recommendations in the guidelines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013). Eleven unique conservation practices were implemented on post-treatment WLFW sites from 2012 – 2020 (Table 3.1) that can be broadly grouped as forest or shrubland management practices. Forestry-derived management aims to create habitat from existing forest using silviculture treatments such as clearcutting, seed tree harvests, overstory removal with residuals, and shelterwood harvests. Shrubland management aims to create or enhance existing early successional vegetation communities using tree/shrub plantings, mechanical clearing, and invasive species removal. Of the 69 post-treatment points, 46 were forestry-derived and 23 resulted from shrubland management. Of the 23 pre-treatment points, 9 were existing forest planned for forestry-derived management and 14 were planned for shrubland management. All sites met the guidelines' landscape-level criteria and fell within the Appalachian Golden-winged Warbler Conservation Region (Roth et al. 2012).

All sites were located within the central Appalachians portion of the Appalachian Mountains Bird Conservation Region (NABCI Committee 2000) and occurred within Central Appalachians, Western Allegheny Plateau, and Ridge and Valley level III ecoregions of West Virginia (Omernik and Griffith 2014). The Central Appalachians ecoregion is a high (elevation ranges 366 – 1,402 m), dissected, 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 (elevation ranges 305 – 610 m) and is dominated by Appalachian oak forests. The Ridge and Valley is characterized by elongated alternating forested ridges and agricultural valleys (elevations range 152 – 1,311 m) and is dominated by dry oak-pine forests. These ecoregions contain variable soil conditions, geology, climate, and precipitation (Woods et al. 1999). During May – July, precipitation is 762 – 1524 mm and temperature is 4 – 35°C (McNab and Avers 1994). Common overstory tree species in the study area include oaks (northern red [*Quercus rubra*], scarlet [*Q. coccinea*], black [*Q. velutina*], white [*Q. alba*], and chestnut [*Q. montana*]), hickories (*Carya* sp.), red maple

(*Acer rubrum*), sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), and yellow poplar (*Liriodendron tulipifera*) (Woods et al. 1999). Shrublands in the study area primarily result from localized anthropogenic disturbances such as livestock grazing, timber harvesting, mechanical clearing (e.g., mowing or brush-hogging), and surface mining and common shrub species include autumn olive (*Elaeagnus umbellata*), blackberry and raspberry (*Rubus* spp.), hawthorn (*Crataegus* spp.), and multiflora rose (*Rosa multiflora*) (Aldinger 2018). Scattered areas of red spruce (*Picea rubens*) occur at high elevations.

Data Collection

Sample point placement. Using ArcGIS, we systematically placed avian sampling points >200 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 placed reference points within each property boundary in adjacent disturbed vegetation communities where *Vermivora* could potentially be detected (i.e., old fields, shrubland, young forest, forest edges, and recently disturbed mature forests). We placed reference points within each property boundary on similar slope, aspect, and elevation as treatment points, whenever possible. Open habitats (sparse shrubland containing $\leq 30\%$ shrub cover) and shrubland ($\geq 30\%$ shrub cover) resulted from abandoned agricultural activities. Young forests were regenerating forest stands dominated by saplings ≤ 8 cm diameter at breast height (dbh). Forest edges were transitional areas between mature forest and early successional vegetation. Reference points were placed into areas 88 – 1430 m from the edge of treatment areas.

Point count survey protocol. We surveyed the avian community 7 May – 1 July in 2019 and 2020 to coincide with peak songbird breeding season in the central Appalachians. We surveyed 76 points in 2019, 37 points in 2020, and 34 points in both 2019 and 2020 (Table 3.2). All points were surveyed 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 kilometers per hour (i.e., >3 on the Beaufort scale). Cloud cover, wind, and start time were recorded for each survey to incorporate into detection models.

A 2-person field crew consisting of graduate student Lincoln Oliver and a field technician conducted the avian sampling each year (3 total observers). All observers were experienced in

bird identification and all were trained in local bird identification, distance estimation with rangefinders, and sampling protocols before surveys began. We recorded all first detections seen or heard within a 10-minute survey into five 2-minute intervals (2, 2, 2, 2, 2 min). All individuals detected were recorded once and monitored throughout the remainder of the survey to avoid double counting. We assigned all detections a distance band, indicating the distance of the bird from the observer (0 – 25 m, >25 – 50 m, >50 – 75 m, >75 – 100 m, and >100 m). We recorded detection type (song, call, drum, visual, fly-over, or wing whistle) and sex for each detection, if possible.

Spatial covariates. We manually digitized land cover types deemed important for *Vermivora* breeding habitat in previous studies (Table 3.3) using 2018 National Agriculture Imagery Program imagery (1-m cell size collected during the growing season). We chose the 2018 imagery because it is the most recent statewide dataset available for West Virginia. For sites where management occurred after 2018, we used Google Earth imagery georeferenced using ArcGIS (Google Earth 2021). Field visits helped verify habitat conditions present. We digitized land cover within 100 m of each sampling point to align with the maximum distance of point count data that were included in statistical analyses. Our land cover classes included open habitat (dominated by grass and forb species such as goldenrods [*Solidago* spp.], orchard grass [*Dactylis glomerata*], sedges [*Carex* spp.], and tall fescue [*Festuca arundinacea*] with <30% woody cover), shrubland ($\geq 30\%$ shrub cover generally dominated by shrub species such as autumn olive, hawthorn, and multiflora rose with scattered canopy trees and herbaceous understory), and young forest (regenerating forest stands dominated by saplings ≤ 8 cm dbh). We used a 1:24,000 digital elevation model (USGS 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 (Maxwell et al. 2019) to calculate percent forest cover and edge density (km/km^2) within 1 km of each sampling point location. The 10 forest types included river floodplains, small stream riparian habitats, northern hardwood forests, mixed mesophytic forests, dry-mesic oak forests, dry oak-pine forests, pine-oak rocky woodlands, dry calcareous forests, montane red oak forests, and other forest. While habitat characteristics of these forest types are diverse, they are representative of forest cover at the landscape scale, thus, we combined all 10 forest land cover classes using the “reclassify” tool to

generate a forest land cover raster for West Virginia. We used the “buffer” tool to create 1-km buffers around each sampling point. The amount of forested area within each 1-km radius buffer was calculated using the “summarize within” tool. Percent forest within 1 km of each sampling point was generated by dividing the forested area within each buffer by the area of each buffer and multiplying by 100. We calculated the length of forest edge within each 1-km radius using the “summarize within” tool. Edge density (km/km^2) within 1 km of each sampling point location was generated by dividing length of forest edge within each buffer by the area of buffer.

Vegetation covariates. We measured vegetation at the site-level, to quantify habitat characteristics on different pre- and post-treatment sites for vegetation metrics deemed important for *Vermivora* breeding habitat in previous studies (Table 3.3). We conducted vegetation sampling once each year after the second point count survey to ensure full vegetation growth prior to sampling. 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; Figure 3.2). An ocular tube consists of a 2-inch section of plastic pipe to restrict observer field of view and wire crosshairs to identify which cover types intersect. 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 (m) with a handheld rangefinder at each ocular tube sampling point and 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 Golden-winged Warbler nest sites have more variable vegetation height than random locations within the same territory (Aldinger 2018).

We measured canopy tree basal area 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 (Figure 3.2). Variable radius prism plots were completed using a wedge prism (10-factor English or 2.5-factor metric) to tally live trees and snags ≥ 8 cm dbh at each prism plot. The observer tallied trees that were “in” the plot by holding the prism at a fixed distance from the eye over the 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. We calculated basal area at each plot by multiplying the number of “in” live trees by a basal area factor of 2.296. The center prism plot basal area (center plot basal area) reflects basal area within the treatment. Mean basal area across all four prism plots (100-m basal area) reflects basal area across the 100-m radius plot and may include tree tallies from within and outside the treatment area.

Shrubland Focal Species and Habitat Guilds

For the shrubland focal bird species, we selected common bird species associated with shrubland habitats (Sauer et al. 2020) to ensure an adequate number of detections for modeling detection probability and occupancy. Shrubland focal species included Chestnut-sided Warbler, Common Yellowthroat, and Field Sparrow. Chestnut-sided Warblers breed in scrubby second-growth areas and forest edges at high elevations in the Appalachians (Byers et al. 2020). Their populations are stable in West Virginia, during 1966 – 2019 (Sauer et al. 2020). Common Yellowthroats breed in thick, low vegetation (particularly in wet areas) in a wide range of habitats from wetlands to prairie across much of North America (Guzy and Ritchison 2020). Field Sparrows are common songbirds of eastern North America, breeding in brushy pastures and second-growth scrub with scattered woody vegetation for perches (Carey et al. 2008), and are included as a Species of Greatest Conservation Need in the West Virginia State Wildlife Action Plan (West Virginia Department of Natural Resources 2015). Although Common Yellowthroat and Field Sparrow remain abundant throughout their range, populations have declined in West Virginia at a rate of -2.99% and -2.39% per year respectively, during 1966 – 2019 (Sauer et al. 2020). Habitat conditions planned on our sites should be representative of habitat preferences for the focal species and *Vermivora*.

We evaluated species richness of forest interior, forest gap, forest generalist, shrubland, and grassland bird species. We classified songbird species *a priori* into these 5 habitat guilds based on breeding biology and previous guild studies from the region (Whitcomb et al. 1981, Duguay et al. 2001, McDermott and Wood 2009; Appendix A). We included all auditory and visual detections except flyovers of adult males or females 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.

Statistical Analysis

Vermivora and *Shrubland Focal Species Occupancy*. We estimated *Vermivora* and shrubland focal species occupancy using single-season occupancy models (Fiske and Chandler 2011). 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 WLFW points surveyed in 2019 and 2020, we included only the 2020 data in analyses because including data from both years was not compatible with our occupancy analyses and models would not converge using only 2019 data due to low detections. We included all detection types except flyovers (i.e., singing, visual, call) within 100 m of the sampling point in analysis to relate occupancy more closely to vegetation and topographic characteristics measured within 100-m radius of each sampling point. Point count data for each species were converted to detection (1) and nondetection (0) per visit for estimation of detection probability across each survey. We used package unmarked (version 0.11-0; Fiske and Chandler 2011) in program R (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 [min], sky, wind, and canopy) in its own detection model for each species to identify which detection covariates were best-supported using AIC_c (Burnham and Anderson 2002; Table 3.4). If a species' detection model set had only one model with $\Delta AIC_c < 2.0$, the detection covariate in that model was used singularly for all subsequent analyses. When multiple detection covariates were supported, they were included in detection models in all possible combinations and tested against singular detection models to determine the best supported model to be used in all subsequent analyses for each species (Lituma and Buehler 2020).

For our first occupancy model set, we evaluated *Vermivora* and shrubland focal species (Chestnut-sided Warbler, Common Yellowthroat, and Field Sparrow) occupancy across contract treatment status categories to evaluate WLFW conservation practice effectiveness. Our first

model set had 2 models for each species using contract treatment status as the predictor variable and included elevation as a nuisance variable to account for inherent differences in each species' occurrence among sites.

For *Vermivora* occupancy only, we tested 3 additional model sets (Table 3.4). In the second model set, we developed 6 models to examine the influence of spatial variables (Tables 3.4 and 3.5) on *Vermivora* occupancy. In the third model set, we developed 8 models to examine the influence of vegetation covariates (Tables 3.4 and 3.5). We created a fourth model set by including models with $\Delta AIC_c < 2.0$ from the contract treatment status, spatial, and vegetation model sets (model sets 1 – 3) to compare the influence of status against spatial and vegetation covariates. Because our main objective was to evaluate WLFW conservation practice effectiveness, we tested models using all combinations of supported covariates and contract treatment status to evaluate the influence of contract treatment status on best supported models. Occupancy predictions for each species were derived from supported models using the 'predict' function in program R (R Development Core Team 2019) and differences were assessed based on 95% confidence intervals of beta estimates. When making predictions, elevation was held constant at the mean (i.e., 727).

Guild Richness and Vegetation. We used a one-way analysis of variance (ANOVA) including site name as a random effect to compare observed species richness of the five avian guilds and means of vegetation covariates among contract treatment status categories using the 'lme' and 'summarySE' functions in program R (R Development Core Team 2019). For the vegetation analyses, we analyzed forested and forestry-derived post-treatment points separately from shrubland points and shrubland managed post-treatment points. 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

Vermivora Occupancy

We detected 8 Golden-winged Warblers (on 6 points at 3 sites), 30 Blue-winged Warblers (on 18 points at 4 sites), and 1 Brewster's Warbler (hybrid) for a total of 39 *Vermivora* detections across 147 point-count surveys conducted during the study (Appendix B). Both species were detected only on reference and post-treatment points (Table 3.2). The Brewster's Warbler was detected on a post-treatment point.

Observer was the only supported detection covariate and was used singularly as the detection model for all subsequent analyses (Table 3.6). For model set 1, model selection results indicated that a model including contract treatment status and elevation, and a singular model for elevation were the best supported variables for *Vermivora* occupancy (Table 3.7), however, these relationships had little influence because the beta coefficient confidence intervals overlapped zero (Table 3.8). For model set 2, model selection results indicated that 100-m shrubland was the best supported variable for *Vermivora* occupancy (Table 3.7). *Vermivora* occupancy increased by 967% as 100-m shrubland increased from 0 to 100% cover (Table 3.8, Figure 3.3). For model set 3, model selection results indicated that 100-m basal area and center plot basal area were the most supported variables for *Vermivora* occupancy (Table 3.7). *Vermivora* occupancy decreased by 87% as 100-m basal area increased from 0 to 30 m²/ha and center plot basal area had little influence because the beta coefficient confidence intervals overlapped zero (Table 3.8, Figure 3.3). For model set 4, model selection results indicated that a model including contract treatment status and 100-m shrubland was the most supported for *Vermivora* occupancy (Table 3.7), however, contract treatment status had little influence because the beta coefficient confidence intervals overlapped zero (Table 3.8).

Shrubland Focal Species Occupancy

We detected 80 Chestnut-sided Warblers, 58 Common Yellowthroats, and 124 Field Sparrows on all 3 contract treatment status categories (Table 3.2) across 147 point-count surveys conducted during the study (Appendix B). For detection models, canopy was the only supported variable for Chestnut-sided Warbler, date and canopy for Common Yellowthroat, and observer for Field Sparrow (Table 3.6). The model that included contract treatment status and elevation was supported for all 3 shrubland focal species' occupancy (Table 3.7) but it had little influence on Field Sparrow occupancy as beta coefficient confidence intervals overlapped zero (Table 3.8, Figure 3.4). Chestnut-sided Warbler occupancy at post-treatment points was 89% lower than reference points. Common Yellowthroat occupancy at post-treatment points was 27% greater than reference points. Elevation was supported for all three-focal species (Table 3.7). Chestnut-sided Warbler occupancy increased from unoccupied (0) to occupied (1), Common Yellowthroat occupancy increased by 428%, and Field Sparrow occupancy increased by 200% as elevation increased from 500 to 1000 m (Table 3.8, Figure 3.4).

Guild Richness

We did not detect any differences among contract treatment status categories for forest interior ($F = 0.96$, $p = 0.38$), gap specialist ($F = 0.21$, $p = 0.81$), forest generalist ($F = 1.73$, $p = 0.18$), shrubland ($F = 0.16$, $p = 0.85$), or grassland ($F = 0.07$, $p = 0.93$) guild richness (Figure 3.5).

Vegetation

For the forested and forestry-derived analysis, covariate means differed across contract treatment status categories for 100-m young forest cover, 100-m shrubland cover, 100-m young forest/shrubland cover, forb cover, and coefficient of variation (Table 3.9). Amount of 100-m young forest at forestry-derived post-treatment points was 951% greater than forested reference and pre-treatment points (Table 3.9, Figure 3.6). Amount of 100-m shrubland at forestry-derived post-treatment points was 383% greater than forested reference and pre-treatment points. Amount of 100-m young forest/shrubland at forestry-derived post-treatment points was 609% greater than forested reference and pre-treatment points. Forb cover at forestry-derived post-treatment points was 14% greater than forested reference and pre-treatment points. Coefficient of variation for maximum vegetation height at forestry-derived post-treatment points was 56% greater than forested reference and pre-treatment points.

For the shrubland and shrubland managed analysis, covariate means differed across contract treatment status categories for shrub cover (Table 3.10). Shrub cover at shrubland pre-treatment points was 152% greater than shrubland reference and 128% greater than shrubland managed post-treatment points (Table 3.10, Figure 3.6).

Post-treatment center plot basal area was within the recommended range in the guidelines ($\sim 1.9 - 3.7 \text{ m}^2/\text{ha}$ [$8 - 16 \text{ ft}^2/\text{ac}$]; Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013) at 14% of post-treatment points. We found no 100-m young forest/shrubland at 32% of our post-treatment points.

DISCUSSION

Private lands conservation projects are being implemented to benefit many focal species of conservation concern but are seldom monitored to quantify their effectiveness. Evaluating conservation projects is critical to justify their continued use and improve existing conservation efforts. *Vermivora* detections on post-treatment WLFW sites in West Virginia were low, particularly for Golden-winged Warblers, and *Vermivora* occupancy estimates were not different at untreated and treated locations. The low of *Vermivora* occupancy observed and lack of

differences suggests that WLFW implementation on surveyed post-treatment sites did not achieve its goal of increasing *Vermivora* occupancy. Our *Vermivora* results are consistent with recent research that found low Golden-winged Warbler occupancy (0.22) at WLFW sites in Pennsylvania, New Jersey, and Maryland (McNeil et al. 2020). One possible explanation for the lack of Golden-winged Warbler detections is continued declines experienced by the smaller Appalachian subpopulation (Rosenberg et al. 2016). The Appalachian subpopulation of Golden-winged Warblers contains 5% of the total population and has experienced more severe (98%) population declines than the Great Lakes subpopulation (Roth et al. 2012, Rosenberg et al. 2016) due to loss and degradation of early successional breeding habitat and lower survival during the non-breeding season resulting from habitat fragmentation, reduced habitat quality, and habitat loss (Confer et al. 2020). We suspect that the low *Vermivora* occupancy and lack of differences was also influenced by private lands variability, site selection, small treatment areas (treatment patch size ranged 1.0 – 8.9 ha; mean $\pm$ SE = 3.4 ± 0.3 ha), and challenges associated with NRCS conservation practice implementation resulting in insufficient vegetation structure and composition.

If NRCS conservation practices through WLFW are going to be effective at reversing *Vermivora* population declines, conservation practice implementation will have to be improved to result in *Vermivora* habitat at all WLFW sites. Forestry-derived management was effective at creating young forest and shrubland conditions, but we expected greater quantities of these habitats on post-treatment points. One explanation for the low amounts of young forest and shrubland conditions observed on post-treatment points was high basal area retained after management. High basal area on post-treatment points limited regeneration of saplings and shrubs and the creation of preferred young forest and shrubland conditions. Specified habitat quality targets must be achieved following NRCS conservation practice implementation to result in appropriate vegetation structure to benefit focal species (McCoy et al. 2001, Lituma and Buehler 2020). High basal area retained on post-treatment WLFW sites likely resulted from breakdowns during the planning, implementation, and contract certification process that must be rectified if WLFW is to provide appropriate *Vermivora* habitat conditions. Regardless of the area of improvement, additional basal area removal to within the recommended range of $\sim 1.9 - 3.7$ m²/ha (8 – 16 ft²/ac) during contract implementation is needed to achieve desired young forest and shrubland conditions.

For post-treatment sites resulting from shrubland management, very few vegetation metrics in our study were different among contract treatment categories, indicating that WLFW conservation practice implementation did not meaningfully influence vegetation structure and composition. Shrub cover was the only metric that differed and was highest on pre-treatment points. This was likely a spurious result due to low sample size, as our largest pre-treatment site was an abandoned agricultural field dominated by autumn olive. Low shrub cover and 100-m shrubland observed on post-treatment points resulting from shrubland management was likely the result of improper landowner management/maintenance actions (i.e., mowing; personal observation) following contract completion (Briske et al. 2011) and insufficient removal of basal area during contract implementation. Maintenance/management actions such as mowing, haying, and grazing on post-treatment areas prevented or prolong the development of preferred herbaceous, shrub, and sapling vegetation at some WLFW sites. However, another possible explanation for the lack of *Vermivora* response and shrubland conditions following NRCS conservation practice implementation could be lags in vegetation development, as previous research has indicated that Golden-winged Warbler colonization of managed areas in the Appalachians may take 8 – 10 years after management (Golden-winged Warbler Working Group 2013, Aldinger 2018, McNeil et al. 2020) following development of Golden-winged Warbler's preferred shrubland cover (Confer et al. 2020).

Elevation plays an important role in *Vermivora* interactions in the Appalachians and is an important consideration for Appalachian Golden-winged Warbler conservation. In recent history, an elevation threshold mostly separated Golden-winged Warblers (>600 m) from Blue-winged Warblers (<600 m; Welton 2003, Buehler et al. 2007) in the central Appalachians, but Blue-winged Warbler breeding distribution has expanded into higher elevations in recent decades (Sauer et al. 2020). We detected Blue-winged Warblers throughout the range of elevations where Golden-winged Warblers were detected (Table 3.5). Although elevation beta coefficients overlapped 0 for *Vermivora* occupancy, elevation appeared to influence Golden-winged Warbler occurrence as elevation at 5 of the 6 points where Golden-winged Warblers were detected was >900 m. Analyses on only Golden-winged Warblers was not possible due to lack of detections on WLFW sites. The original Golden-winged Warbler WLFW focal area included high elevation (>600 m) counties in West Virginia (USDA NRCS 2012) and was expanded in 2017 (USDA NRCS 2017) to include lower elevation counties to increase landowner enrollment. Our findings

suggest that WLFW is most likely to benefit Golden-winged Warblers if the eligible focal area is limited to counties with elevations >600 m (i.e., Barbour, Fayette, Greenbrier, McDowell, Mercer, Monroe, Nicholas, Pendleton, Pocahontas, Preston, Summers, Raleigh, Randolph, Tucker, Webster, and Wyoming Counties). However, if the goal of WLFW is to benefit *Vermivora*, the current focal area does not need revision.

Elevation was an important factor for the shrubland focal species on our sites, as occupancy estimates for all three species were positively associated with increasing elevation. The relationship with elevation was strongest for Chestnut-sided Warblers, which are most abundant at high elevations in the Appalachians (Hamel 1992). We believe that the Common Yellowthroat and Field Sparrow elevation relationships were spurious and resulted from site selection, as our most productive sites for both species were also among the highest elevation sites surveyed. Both species were relatively common species across the elevation gradient of sites surveyed and are not restricted to higher elevations in the Appalachians.

High Common Yellowthroat occupancy on post-treatment sites suggests that this relatively abundant shrubland species did benefit from NRCS conservation practices implemented through WLFW. This finding is consistent with previous research that identified Common Yellowthroat as a species likely to benefit from habitat management for Golden-winged Warblers (Aldinger et al. 2017). However, like *Vermivora*, we did not observe responses for the other shrubland focal species or species richness in any of the avian guilds, suggesting conservation practice implementation on WLFW sites did not affect habitat conditions sufficiently to influence occurrence of other shrubland associated avian species or overall avian diversity. High Chestnut-sided Warbler occupancy on reference points likely resulted from site selection as the majority of Chestnut-sided Warblers detected were at reference locations on the highest elevation pre- and post-treatment sites. The suspected reasons for the lack of differences observed from the 2 of the 3 forest focal species and species richness in all habitat guilds were the same as those suspected for *Vermivora*: private lands variability, site selection, small treatment areas, and challenges associated with NRCS conservation practice implementation resulting in insufficient vegetation structure and composition. However, the cause of the lack of response is speculation as shrubland focal species occupancy and species richness of avian guilds were only estimated using contract treatment status as the predictor variable.

Limitations of this study offer insights into future research priorities to better evaluate *Vermivora* response to conservation practices implemented through WLFW. While surveying the same sites pre- and post-treatment was not possible in this study, incorporating before-after-control-impact study design in future long-term studies is needed to provide more informative assessments. Longer-term studies are required to assess older sites and more accurately account for lags in the *Vermivora* response associated with vegetation development following contract completion. Evaluations of survival and reproduction on private lands, which are smaller and more variable than treatment areas used in previous research, are required to provide more informative assessments of habitat quality following WLFW implementation as they more directly relate to population growth (Van Horne 1983). Lastly, an evaluation of Golden-winged Warbler response across the WLFW focal area (USDA NRCS 2017) is required for a more comprehensive assessment.

With conservation practices being implemented as a primary conservation action for Golden-winged Warblers, quantitative evaluations are important to inform WLFW effectiveness and better utilize limited conservation funding. While many research studies have evaluated Golden-winged Warbler and the avian community response to habitat management using the guidelines on public lands, this research adds to the growing body of evidence on WLFW conservation practice effectiveness on private lands. This study provides a quantitative assessment of focal species occupancy on WLFW sites where success is typically measured by the area applied. Our results imply that there are opportunities to improve conservation practice implementation for more effective *Vermivora* conservation. We recommend additional basal area removal to within the recommended range of $\sim 1.9 - 3.7 \text{ m}^2/\text{ha}$ ($8 - 16 \text{ ft}^2/\text{ac}$) during contract implementation on all WLFW sites and restriction of the WLFW focal area to higher elevations if Golden-winged Warblers are the primary WLFW focal species. The information we have provided in this study fills a scientific knowledge gap and provides useful feedback to NRCS an adaptive management framework.

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TABLES

Table 3.1. Names, number of sites, and descriptions for Natural Resources Conservation Service conservation practices that were implemented on 16 post-treatment sites enrolled in Working Lands for Wildlife in West Virginia from 2012 – 2020.

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)

Table 3.2. Annual number of point count locations and sites across contract treatment status categories and years since contract completion for post-treatment point counts surveyed on 22 private properties enrolled in Working Lands for Wildlife in West Virginia. We also included naïve occupancy of Blue-winged Warbler (BWWA), Golden-winged Warbler (GWWA), Chestnut-sided Warbler (CSWA), Common Yellowthroat (COYE), and Field Sparrow (FISP) across treatment categories on the 147 point-count surveys sampled during 2019 – 2020. Scientific names are in Appendix B.

	Reference		Pre-treatment		Post-treatment	
	Points	Sites	Points	Sites	Points	Sites
Points sampled per year						
2019	28	9	23	6	25	5
2020	14	5	0	0	23	7
2019 and 2020	13	4	0	0	21	4
Total	55	18	23	6	69	16
Post-treatment points years since contract completion						
1		--	--		0	0
2		--	--		6	1
3		--	--		5	1
4		--	--		12	2
5		--	--		11	2
6		--	--		13	3
7		--	--		18	6
8		--	--		4	1
Total		--	--		69	16
Species naïve occupancy						
BWWA	0.16	0.17	0.00	0.00	0.12	0.13
GWWA	0.02	0.06	0.00	0.00	0.07	0.19
CSWA	0.36	0.50	0.35	0.33	0.19	0.38
COYE	0.22	0.33	0.22	0.33	0.33	0.63
FISP	0.45	0.67	0.26	0.50	0.57	0.88

Table 3.3. Descriptions, notations, and justifications for variables used to model occupancy of *Vermivora* using 147 point-count sampling locations on 22 sites enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. *Vermivora* using 147 point-count sampling locations on 22 sites enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020.

Variable	Justification
Contract treatment status	Habitat management implemented based on the guidelines improves Golden-winged Warbler habitat quality and provides breeding habitat (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013)
Elevation	Elevation threshold historically separated Golden-winged Warblers (>600 m) from Blue-winged Warblers (<600 m, Welton 2003, Buehler et al. 2007) in the Appalachians
1-km forest cover	Golden-winged Warbler breeding habitat associated with forested landscapes (Roth et al. 2012)
1-km edge density	Golden-winged Warbler populations will not persist in highly fragmented, urbanized, or mostly agricultural landscapes. (Roth et al. 2012)
100-m young forest	Golden-winged Warbler abundance positively associated with young-forest cover (Bakermans et al. 2015)
100-m shrubland	Commonly used Golden-winged Warbler nesting cover in West Virginia (Aldinger and Wood 2014) and throughout the breeding range (Confer et al. 2020)
100-m young forest/shrubland	Early successional communities used by Golden-winged Warblers for breeding often include shrubs and saplings (Confer et al. 2020, Roth et al. 2012)
100-m open	Golden-winged Warbler abundance positively associated with herbaceous cover (Bakermans et al. 2015)
Grass cover	Early successional communities used by Golden-winged Warblers for breeding often include herbaceous, shrub, sapling, and canopy tree components (Confer et al. 2020, Roth et al. 2012)
Forb cover	
<i>Solidago</i> cover	
<i>Rubus</i> cover	
Shrub cover	
Sapling cover	
Canopy cover	
100-m basal area	Recommended 1.9 – 3.7 m ² /ha (8 – 16 ft ² /ac) for Golden-winged Warblers the Appalachians (Golden-winged Warbler Working Group 2013)
Center plot basal area	
Coefficient of variation	Golden-winged Warbler nest sites had more variable vegetation height than random locations within the same territory (Aldinger 2018).

Table 3.4. Covariates used to model occupancy of *Vermivora* on 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020.

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 (myself or 1 of 2 field technicians)
Ordinal date	date	Detection probability	Day of the year
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 (reference, pre-treatment, 1 – 3 years post-treatment, 4 – 8 years post-treatment)
Elevation	elev	Status	Majority elevation (m) within 100 m
1-km forest cover	forest	Spatial	Percent forest (of trees ≥ 8 cm) 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 ($\geq 30\%$ shrub cover) within 100 m
100-m young forest/shrubland	woodycover	Spatial	Sum of 100-m young forest (of trees ≤ 8 cm) and 100-m shrubland ($\geq 30\%$ 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
<i>Solidago</i> cover	solidago	Vegetation	Percent <i>Solidago</i> cover (0 – 100) within 100 m
<i>Rubus</i> cover	rubus	Vegetation	Percent <i>Rubus</i> 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

Table 3.5. Covariates used to model occupancy of Blue-winged Warblers and Golden-winged Warblers across 147 point-count surveys on 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. We report the weighted mean and range for continuous variables and the proportion of point count surveys that fell in each category for categorical variables. Weighted mean and range values are also reported where Blue-winged Warblers and Golden-winged Warblers were and were not detected across all point count locations. Scientific names are in Appendix B.

Covariate	Mean (Range) (n=147 points, n=22 sites)	Blue-winged Warbler Not Detected Mean (Range) (n=128 points, n=17 sites)	Blue-winged Warbler Detected Mean (Range) (n=19 points, n=5 sites)	Golden-winged Warbler Not Detected Mean (Range) (n=141 points, n=3 sites)	Golden-winged Warbler Detected Mean (Range) (n=6 points, n=3 sites)
Treatment status					
Reference	0.38	0.34	0.58	0.38	0.17
Pre-treatment	0.16	0.18	0.00	0.16	0.00
Post-treatment	0.46	0.48	0.42	0.46	0.83
Elevation	734 (490 – 1047)	732 (490 – 1047)	748 (648 – 917)	724 (490 – 1047)	826 (573 – 921)
1-km forest cover	80 (40 – 98)	79 (40 – 98)	86 (72 – 92)	80 (40 – 98)	82 (72 – 94)
1-km edge density	9 (3 – 14)	9 (3 – 14)	9 (6 – 12)	9 (3 – 14)	10 (6 – 12)
100-m young forest	5 (0 – 35)	5 (0 – 35)	4 (0 – 19)	4 (0 – 30)	12 (0 – 35)
100-m shrubland	12 (0 – 100)	8 (0 – 58)	35 (0 – 100)	9 (0 – 100)	32 (13 – 51)
100-m young forest/shrubland	16 (0 – 100)	13 (0 – 66)	39 (6 – 100)	13 (0 – 100)	44 (32 – 51)
100-m open	18 (0 – 59)	20 (0 – 59)	4 (0 – 13)	18 (0 – 59)	14 (5 – 26)
Grass cover	35 (4 – 70)	37 (4 – 70)	17 (11 – 26)	35 (4 – 70)	36 (20 – 53)
Forb cover	32 (3 – 63)	32 (3 – 63)	32 (18 – 46)	31 (3 – 63)	35 (18 – 56)
<i>Solidago</i> cover	5 (0 – 45)	5 (0 – 45)	5 (1 – 11)	5 (0 – 45)	5 (0 – 11)
<i>Rubus</i> cover	6 (0 – 25)	6 (0 – 25)	6 (2 – 12)	6 (0 – 25)	4 (0 – 12)
Shrub cover	12 (0 – 38)	12 (0 – 38)	8 (3 – 12)	11 (0 – 38)	12 (7 – 24)
Sapling cover	40 (8 – 71)	40 (8 – 71)	45 (29 – 55)	41 (8 – 71)	35 (20 – 53)
Canopy cover	62 (10 – 93)	61 (10 – 93)	72 (52 – 84)	62 (10 – 93)	62 (52 – 71)
Coefficient of variation	0.80 (0.25 – 1.78)	0.79 (0.25 – 1.78)	0.85 (0.55 – 1.25)	0.77 (0.25 – 1.78)	1.02 (0.63 – 1.43)
100-m basal area	10 (2 – 20)	10 (2 – 19)	11 (2 – 20)	11 (2 – 20)	6 (3 – 11)
Center plot basal area	9 (0 – 26)	9 (0 – 26)	9 (0 – 16)	9 (0 – 26)	4 (2 – 6)

Table 3.6. Detection model selection procedure results for *Vermivora*, Chestnut-sided Warbler, Common Yellowthroat, and Field Sparrow occupancy (ψ) and detection probability (p) using 147 point-count surveys across 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. K is the number of parameters in each model, AIC_c is the Akaike's Information Criterion value for small sample sizes, ΔAIC_c is the difference between each model's AIC_c value and the lowest AIC_c 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 Table 3.4. Scientific names are in Appendix B.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Vermivora</i>				
ψ (1) p (observer)	4	164.27	0.00	0.75
ψ (1) p (date)	3	166.53	2.26	0.24
ψ (1) p (wind)	3	177.16	12.88	0.00
ψ (1) p (canopy)	3	178.56	14.29	0.00
ψ (1) p (time)	3	180.60	16.33	0.00
ψ (1) p (sky)	6	181.17	16.89	0.00
Chestnut-sided Warbler				
ψ (1) p (canopy)	3	264.46	0.00	0.48
ψ (1) p (wind)	3	266.89	2.43	0.14
ψ (1) p (time)	3	267.08	2.62	0.13
ψ (1) p (date)	3	267.11	2.65	0.13
ψ (1) p (sky)	6	268.38	3.92	0.07
ψ (1) p (observer)	4	268.74	4.27	0.06
Common Yellowthroat				
ψ (1) p (date + canopy)	4	245.25	0.00	0.94
ψ (1) p (canopy)	3	251.79	6.54	0.04
ψ (1) p (date)	3	253.22	7.97	0.02
ψ (1) p (wind)	3	257.46	12.22	0.00
ψ (1) p (time)	3	260.47	15.22	0.00
ψ (1) p (observer)	4	262.15	16.91	0.00
ψ (1) p (sky)	6	262.47	17.23	0.00
Field Sparrow				
ψ (1) p (observer)	4	344.30	0.00	0.98
ψ (1) p (sky)	6	352.50	8.19	0.02
ψ (1) p (time)	3	355.67	11.36	0.00
ψ (1) p (wind)	3	359.60	15.30	0.00
ψ (1) p (date)	3	360.82	16.51	0.00
ψ (1) p (canopy)	3	361.25	16.95	0.00

Table 3.7. Single-season occupancy model selection procedure results for *Vermivora*, Chestnut-sided Warbler, Common Yellowthroat, and Field Sparrow occupancy (ψ) and detection probability (p) using 147 point-count surveys across 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. K is the number of parameters in each model, AIC_c is the Akaike's Information Criterion value for small sample sizes, ΔAIC_c is the difference between each model's AIC_c value and the lowest AIC_c 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 Table 3.4. Scientific names are in Appendix B.

Model	K	AIC_c	ΔAIC_c	w_i
<i>Vermivora</i> model set 1: treatment models				
ψ (elev) p (observer)	5	160.77	0.00	0.55
ψ (status + elev) p (observer)	7	161.21	0.44	0.45
<i>Vermivora</i> model set 2: spatial models				
ψ (shrubland) p (observer)	5	139.32	0.00	0.86
ψ (woodycover) p (observer)	5	142.99	3.67	0.14
ψ (open) p (observer)	5	151.37	12.06	0.00
ψ (forest) p (observer)	5	160.82	21.50	0.00
ψ (yngforest) p (observer)	5	166.13	26.81	0.00
ψ (edge) p (observer)	5	166.22	26.91	0.00
<i>Vermivora</i> model set 3: vegetation models				
ψ (ba) p (observer)	5	161.59	0.00	0.33
ψ (bacent) p (observer)	5	163.57	1.98	0.12
ψ (grass) p (observer)	5	163.63	2.04	0.12
ψ (cov) p (observer)	5	163.79	2.20	0.11
ψ (canopy) p (observer)	5	165.07	3.48	0.06
ψ (rubus) p (observer)	5	165.10	3.51	0.06
ψ (forb) p (observer)	5	165.63	4.03	0.04
ψ (solidago) p (observer)	5	165.79	4.20	0.04
ψ (shrub) p (observer)	5	166.19	4.59	0.03
ψ (sapling) p (observer)	5	166.27	4.68	0.03
<i>Vermivora</i> model set 4: supported and multivariate models				
ψ (shrubland + status) p (observer)	7	134.70	0.00	0.91
ψ (shrubland) p (observer)	5	139.32	4.62	0.09
ψ (elev) p (observer)	5	160.77	26.07	0.00
ψ (ba + status) p (observer)	7	161.17	26.46	0.00
ψ (status + elev) p (observer)	7	161.21	26.50	0.00
ψ (ba) p (observer)	5	161.59	26.89	0.00
ψ (bacent + status) p (observer)	7	162.85	28.15	0.00
ψ (bacent) p (observer)	5	163.57	28.87	0.00
Chestnut-sided Warbler treatment models				
ψ (status + elev) p (canopy)	6	199.48	0.00	0.98
ψ (elev) p (canopy)	4	206.98	7.50	0.02
Common Yellowthroat treatment models				
ψ (elev) p (canopy + date)	5	244.12	0.00	0.67
ψ (status + elev) p (canopy + date)	7	245.53	1.42	0.33
Field Sparrow treatment models				
ψ (elev) p (observer)	5	344.34	0.00	0.62
ψ (status + elev) p (observer)	7	345.35	1.01	0.38

Table 3.8. Beta (β) estimates, standard errors (SE), and 95% lower and upper confidence intervals (CI) on the logit-scale from models (see Table 3.6) estimating *Vermivora*, Chestnut-sided Warbler, Common Yellowthroat, and Field Sparrow occupancy using 147 point-count surveys across 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Codes for covariates are defined in Table 3.4. Scientific names are in Appendix B.

Parameter	β estimate	SE	Lower 95% CI	Upper 95% CI
<i>Vermivora</i> model set 1: treatment models				
elev				
Elevation	0.01	0.01	-0.01	0.01
status + elev				
Reference	-0.02	0.52	-1.03	0.99
Pre-treatment	-3.94	4.64	-13.04	5.15
Post-treatment	-3.61	2.07	-7.77	0.44
Elevation	0.01	0.01	-0.01	0.01
<i>Vermivora</i> model set 2: spatial models				
shrubland				
100-m shrubland	0.07	0.02	0.02	0.12
<i>Vermivora</i> model set 3: vegetation models				
ba				
100-m basal area	-0.08	0.04	-0.17	-0.01
bacent				
Center plot basal area	-0.05	0.03	-0.11	0.01
<i>Vermivora</i> model set 4: supported and multivariate models				
status + shrubland				
Reference	-0.91	0.78	-2.43	0.62
Pre-treatment	-16.41	232.78	-472.65	439.83
Post-treatment	-2.03	0.47	-2.96	1.10
100-m shrubland	0.08	0.02	0.03	0.12
Chestnut-sided Warbler treatment model				
status + elev				
Reference	3.16	1.21	0.78	5.54
Pre-treatment	2.37	2.47	-2.47	7.22
Post-treatment	-26.77	5.95	-38.45	-15.12
Elevation	0.03	0.01	0.02	0.05
Common Yellowthroat treatment model				
elev				
Elevation	0.01	0.01	0.01	0.02
status + elev				
Reference	-1.11	0.90	-2.88	0.65
Pre-treatment	-1.46	1.21	-3.84	0.92
Post-treatment	5.34	2.55	0.35	10.34
Elevation	0.01	0.01	0.01	0.02
Field Sparrow treatment model				
elev				
Elevation	0.01	0.01	0.01	0.01
status + elev				
Reference	-0.65	0.49	-1.61	0.31
Pre-treatment	-1.02	0.74	-2.50	0.44
Post-treatment	2.65	1.39	-0.07	5.37
Elevation	0.01	0.01	0.01	0.01

Table 3.9 Covariate weighted mean, standard error (top parentheses), and range (bottom parentheses) between forested reference and pre-treatment points and forestry-derived post-treatment across 83 point-count surveys on 19 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Results of analysis of variance comparing differences in the means among forested and forestry-derived categories. Differences in means between forested and forestry-derived categories (p -value <0.05) are indicated by alphabetical notation based on a Tukey-Kramer test. F-statistics (F) and p-values (p) are reported for each covariate.

Covariate	Forested reference or pre-treatment (n=37 points, n=11 sites)		Forestry-derived post-treatment (n=46 points, n=12 sites)		F	p
Elevation	727 (54) (493 – 1039)		739 (26) (599 – 899)		0.30	0.58
1-km forest cover	85 (4) (58 – 98)		81 (4) (57 – 97)		0.90	0.35
1-km edge density	8 (1) (3 – 14)		9 (1) (5 – 14)		3.11	0.08
100-m young forest	1 (1) (0 – 11)	B	9 (4) (0 – 32)	A	9.75	0.01
100-m shrubland	1 (1) (0 – 6)	B	7 (3) (0 – 28)	A	10.31	0.01
100-m young forest/ shrubland	2 (1) (0 – 11)	B	17 (4) (0 – 40)	A	21.78	0.01
100-m open	11 (5) (0 – 37)		13 (3) (0 – 35)		0.01	0.92
Grass cover	26 (5) (0 – 54)		24 (4) (7 – 49)		0.39	0.53
Forb cover	28 (5) (0 – 61)	B	32 (5) (7 – 63)	A	4.14	0.04
<i>Solidago</i> cover	2 (1) (0 – 15)		1 (1) (0 – 5)		0.55	0.46
<i>Rubus</i> cover	5 (2) (0 – 25)		6 (2) (0 – 21)		0.18	0.67
Shrub cover	12 (4) (0 – 36)		10 (2) (0 – 20)		0.17	0.68
Sapling cover	53 (4) (31 – 68)		43 (5) (13 – 71)		0.51	0.48
Canopy cover	80 (4) (61 – 100)		70 (4) (50 – 88)		1.46	0.23
Coefficient of variation	0.42 (0.07) (0.09 – 0.80)	B	0.71 (0.06) (0.39 – 1.08)	A	9.48	0.01
100-m basal area	13 (1) (6 – 19)		13 (1) (9 – 20)		0.09	0.77
Center plot basal area	14 (1) (7 – 23)		14 (2) (3 – 26)		0.08	0.77

Table 3.10. Covariate weighted mean, standard error (top parentheses), and range (bottom parentheses) between shrubland and shrubland managed categories across 64 point-count surveys on 16 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Results of analysis of variance comparing differences in the means among shrubland and shrubland managed categories. Differences in means between shrubland and shrubland managed categories (p-value <0.05) are indicated by alphabetical notation based on a Tukey-Kramer test. F-statistics (F) and p-values (p) are reported for each covariate.

Covariate	Shrubland reference (n=30 points, n= 11 sites)	Shrubland pre-treatment (n=11 points, n=3 sites)	Shrubland managed post-treatment (n=23 points, n=7 sites)	F	p
Elevation	719 (44) (490 – 918)	649 (109) (503 – 863)	770 (51) (573 – 921)	2.02	0.14
1 km forest cover	75 (4) (49 – 92)	82 (6) (69 – 89)	79 (7) (40 – 94)	1.01	0.37
1 km edge density	10 (1) (5 – 12)	11 (1) (10 – 12)	9 (1) (5 – 12)	0.25	0.78
100 m young forest	1 (1) (0 – 8)	2 (2) (0 – 7)	10 (5) (0 – 35)	1.12	0.34
100 m shrubland	21 (9) (0 – 100)	19 (19) (0 – 58)	18 (6) (0 – 45)	1.10	0.34
100-m young forest/shrubland	22 (9) (0 – 100)	22 (22) (0 – 66)	28 (6) (0 – 48)	1.64	0.21
100-m open	27 (7) (0 – 57)	21 (10) (3 – 35)	27 (8) (5 – 59)	1.36	0.27
Grass cover	48 (6) (11 – 70)	54 (3) (48 – 58)	33 (7) (0 – 53)	0.59	0.56
Forb cover	33 (4) (15 – 50)	17 (11) (5 – 38)	36 (4) (20 – 56)	1.17	0.32
<i>Solidago</i> cover	10 (2) (0 – 28)	5 (1) (4 – 5)	12 (6) (0 – 45)	0.55	0.58
<i>Rubus</i> cover	7 (2) (0 – 14)	7 (1) (5 – 9)	4 (2) (0 – 17)	2.24	0.12
Shrub cover	12 (4) (0 – 38)	21 (5) (13 – 29)	12 (4) (0 – 32)	4.40	0.02
Sapling cover	31 (5) (10 – 55)	20 (6) (8 – 27)	44 (10) (11 – 80)	2.67	0.08
Canopy cover	47 (6) (17 – 81)	45 (13) (21 – 63)	55 (11) (10 – 71)	0.29	0.75
Coefficient of variation	1.13 (0.12) (0.65 – 1.78)	1.03 (0.13) (0.78 – 1.23)	0.94 (0.12) (0.63 – 1.43)	1.98	0.15
100-m basal area	7 (1) (2 – 16)	6 (1) (5 – 8)	7 (2) (2 – 13)	0.07	0.93
Center plot basal area	3 (1) (0 – 9)	4 (2) (2 – 7)	5 (2) (0 – 14)	0.35	0.71

FIGURES

Figure 3.1. Study site locations enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Sites were located on 6 pre-treatment (circles) and 16 post-treatment (squares) private properties. Study sites where we detected Blue-winged Warblers (BWWA) are shown in blue, Golden-winged Warblers (GWWA) are shown in yellow, and both species are shown in green. Study site locations were randomly offset within a 5-km radius of the actual location to protect personally identifiable information. Scientific names are in Appendix B.

Figure 3.2. Diagram of plot for sampling vegetation variables at each point count location. Within the 3.14 ha (100-m radius) plot, percent cover of vegetation classes (grass, forb, *Solidago*, *Rubus*, shrub, sapling, and canopy) was measured at 10 points along three 100-m transects, radiating from point center at 0°, 120°, and 240°. Four prism plots (open circles) were conducted at each sampling plot for basal area calculations. Prism plots were located at point center and 70 m from point center along the 0°, 120°, and 240° transects.

Figure 3.3. Predicted occupancy and 95% confidence intervals of *Vermivora* at 147 point-count surveys on 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Occupancy models for panels shown included contract treatment status and elevation, elevation, 100-m shrubland, 100-m basal area, and center plot basal area as covariates for occupancy and observer for detection probability.

Figure 3.4. Predicted occupancy and 95% confidence intervals of shrubland focal species at 147 point-count surveys on 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Occupancy models for each species included contract treatment status + elevation and elevation covariates for occupancy. Covariates for detection probability included canopy for Chestnut-sided Warbler, canopy and date for Common Yellowthroat, and observer for Field Sparrow. Different letters indicate differences. Scientific names are in Appendix B.

Figure 3.5. Observed species richness and 95% confidence intervals of avian habitat guilds shown relative to contract treatment status on at 147 point-count surveys on 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020.

Figure 3.6. Covariate means and 95% confidence intervals for 100-m young forest, 100-m shrubland, 100-m young forest/shrubland, forb cover, coefficient of variation, and shrub cover between treatment categories across 147 point-count surveys on 22 private properties enrolled in Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Different letters indicate differences in means between contract treatment status categories (p-value <0.05) based on a Tukey-Kramer test.

CHAPTER 4. HABITAT CHARACTERISTICS OF BLUE-WINGED WARBLERS IN WEST VIRGINIA WITH IMPLICATIONS FOR HABITAT MANAGEMENT

ABSTRACT

The Blue-winged Warbler (*Vermivora cyanoptera*), a declining but understudied disturbance-dependent songbird, is expected to benefit from habitat management used as a conservation action to reverse population declines for other imperiled avian species including Cerulean (*Setophaga cerulea*) and Golden-winged Warblers (*Vermivora chrysoptera*). We estimated Blue-winged Warbler occupancy on sites enrolled in USDA - Natural Resources Conservation Service (NRCS) conservation projects implemented to benefit Cerulean and Golden-winged Warblers in West Virginia. We conducted point count surveys at 341 locations on 19 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFFEP), 20 private properties enrolled in Working Lands for Wildlife (WLFW), and 2 properties enrolled in both during 2019 – 2020. Treated points had lower occupancy than untreated points by 34 – 44% depending on ecoregion. Occupancy was greatest in the Central Appalachian ecoregion, but 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 Appalachians. Occupancy increased by 772% as 100-m shrubland increased from 0 to 100% cover and increased by 790% as 100-m young forest/shrubland increased from 0 to 100% cover. Occupancy decreased by 91% as 100-m basal area increased from 0 to 30 m²/ha. These relationships suggest that management used to create high amounts of shrubland and young forest conditions has potential as a conservation action to benefit Blue-winged Warbler occupancy but that the NRCS conservation projects have not produced enough of these habitat conditions. Based on our results, we recommend 50 – 100% shrubland cover at the 100-m radius scale and residual basal area of 0.0 – 4.6 m²/ha (0 – 20 ft²/ac) when managing habitat for Blue-winged Warblers in the Appalachians.

Keywords: Conservation, conservation project, early succession, habitat management, occupancy, private lands, shrubland, silviculture

INTRODUCTION

The Blue-winged Warbler (*Vermivora cyanoptera*) is a declining and understudied eastern North American songbird (Gill et al. 2020). Outside of research on hybridization and competition with the highly imperiled Golden-winged Warbler (*V. chrysoptera*; Buehler et al. 2007, Confer et al. 2003, Vallender et al. 2007), little published research exists on their breeding

habitat characteristics or response to habitat management. Blue-winged Warbler breeding habitat has been described as a dense matrix of herbaceous, shrub, and sapling growth near forest edges where woody vegetation dominates (Askins et al. 2007, Confer and Knapp 1981, Confer et al. 2003, Gill et al. 2020). Prior to European settlement, these vegetation communities in eastern North America were likely uncommon and occurred via natural disturbances such as fires, 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). Blue-winged Warblers benefited from landscape-scale forest clearing in the United States in the late 18th and early 19th century for timber and agriculture (Johnson and Govatski 2013). Today 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, agricultural field abandonment, and recent clearcut harvests (Confer and Knapp 1981, Confer et al. 2003, Gill et al. 2020). Research on habitat characteristics associated with occupancy is required to address knowledge gaps for this declining species.

While their breeding distribution has continued to expand northward and into higher elevations in the Appalachians (Sauer et al. 2020, Bailey and Rucker 2021), populations have declined 22% range-wide during 1970 – 2014 due to habitat loss on breeding, migration, and wintering grounds (Rosenberg et al. 2016, Gill 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 coincidence of larger studies, they have rarely been the focal species. Morris et al. (2013) evaluated avian response to silviculture in the Ozark Mountains of Missouri and found that density significantly increased following even- and uneven-aged harvests. At sites managed for Cerulean Warblers (*Setophaga cerulea*) using even-aged harvest with residuals in the Appalachians, Blue-winged Warbler density peaked at low residual basal area (3 – 5 m²/ha [13 – 22 ft²/ac]; Sheehan et al. 2014). In West Virginia, Aldinger et al. (2017) found 10% naïve occupancy on high elevation (547 – 1,343 m) sites with existing Golden-winged Warbler nesting cover. With populations continuing to decline, evaluating the effects of various sources of targeted disturbance on Blue-winged Warblers to needs to be considered.

Through the Cerulean Warbler Forestland Enhancement Project (CWAFEP) and the Working Lands for Wildlife (WLFW) Golden-winged Warbler initiative, the U.S. Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) provides technical and financial assistance to private landowners to implement conservation practices that follow science-based habitat management guidelines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013, Wood et al. 2013). Our objective was to evaluate Blue-winged Warbler occupancy on CWAFEP and WLFW sites and identify key habitat characteristics associated with Blue-winged Warbler occupancy in West Virginia. Because Blue-winged and Golden-winged Warblers are so closely related (Toews et al. 2016), we reviewed previous studies of Golden-winged Warblers to select spatial and habitat characteristics that we hypothesized would influence Blue-winged Warbler occupancy. We predicted that Blue-winged Warbler occupancy would be greater at locations treated using NRCS conservation practices targeting Cerulean Warbler and Golden-winged Warbler because these latter species similarly depend on considerable disturbance. Results from our study will shed light on whether Blue-winged Warblers can be conserved as an indirect effect of related conservation actions or if targeted efforts may be needed in the future. Additionally, research into Blue-winged Warbler occupancy may help clarify changing Appalachian *Vermivora* dynamics, which could have useful implications for Golden-winged Warbler conservation.

METHODS

Study Area

We sampled 19 sites enrolled in CWAFEP, 20 sites enrolled in WLFW, and 2 sites enrolled in CWAFEP and WLFW on private land in West Virginia during 2019 – 2020 (Figure 4.1). Private landowners implemented conservation practices on their land following recommendations in the Cerulean and Golden-winged Warbler habitat management guidelines (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013, Wood et al. 2013). Twelve unique conservation practices were implemented on post-treatment sites from 2012 – 2020 (Table 4.1). We surveyed 12 pre-treatment sites where contract implementation had not begun and 29 post-treatment sites where contracts were certified by NRCS as completed. We were unable to collect pre- and post-treatment data on the same sites because contract implementation on our sites was planned to occur or occurred over a 1 – 6-year period (mean $\pm$ standard error [SE] = 3.6 ± 0.23 years). 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). Points were placed into 1 of 2 contract treatment status categories (untreated or treated). We treated years post-treatment as a continuous variable, with untreated points having a value of 0 and post-treatment points having values from 1 – 8. Years post-treatment was verified through communication with landowners and NRCS personnel. We obtained ArcGIS shapefiles containing contract treatment areas for each site through communication with NRCS personnel. Total contract treatment area at each post-treatment site was 1.2 – 36.3 ha (mean $\pm$ standard error [SE] = 9.3 ± 1.5 ha). Contract treatment areas were spatially split into separate treatment patches on 11 of 29 post-treatment sites and patches were 1.0 – 36.3 ha (mean $\pm$ SE = 4.9 ± 0.96 ha). Treated areas and patches varied in shape, elevation, slope position, and aspect.

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). The Central Appalachians ecoregion is a high, dissected, 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 forests. The Ridge and Valley is characterized by elongated alternating forested ridges and agricultural valleys and is dominated by dry oak-pine forests. These ecoregions contain variable soil conditions, geology, climate, elevation, and precipitation (Woods et al. 1999). Site means for elevation were 348 – 1047 m (mean $\pm$ SE = 668 ± 28 m) in the Central Appalachians, 241 – 498 m (mean $\pm$ SE = 349 ± 16 m) in the Western Allegheny Plateau, and 244 – 918 m (mean $\pm$ SE = 602 ± 50 m) in the Ridge and Valley. During May – July, precipitation is 762 – 1524 mm and temperature is 4 – 35°C (McNab and Avers 1994). Common overstory tree species in the study area 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 (e.g., mowing or brush-hogging), and surface mining, and include common shrub species such as autumn olive (*Elaeagnus umbellata*),

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 highest elevations.

Data Collection

Sample point placement. Using ArcGIS, we systematically placed sampling points >200 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. Untreated points included pre-treatment and reference points. For CWAFEP sites, we placed reference points in adjacent forested areas on the same property with similar slope, aspect, elevation, and forest community type as treatment points, whenever possible. We assumed reference points were representative of the pre-treatment condition at treatment points. For WLFW sites, we placed reference points in adjacent early to mid-successional vegetation communities on the same property where *Vermivora* could potentially be detected (i.e., shrubland, young forest, and forest edges). Shrubland ($\geq 30\%$ shrub cover) on our study sites resulted from succession on abandoned farms. Young forests were regenerating forest stands dominated by saplings ≤ 8 cm diameter at breast height (dbh). Forest edges were transitional areas between mature forest and early successional vegetation. Reference points were placed 52 – 1430 m from the edge of treatment areas.

Point count survey protocol. We surveyed the avian community from 7 May – 1 July 2019 – 2020 to coincide with peak songbird breeding season in the central Appalachians. We surveyed 202 points in 2019, 105 points in 2020, and 34 points in both 2019 and 2020 (Table 4.2). 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.

A 2-person field crew consisting of graduate student Lincoln Oliver and a field technician conducted the avian sampling each year (3 total observers). All observers were experienced in bird identification and all were trained in local bird identification, distance estimation with rangefinders, and sampling protocols before surveys began. We recorded all first detections seen or heard within a 10-minute period into five 2-minute intervals (2, 2, 2, 2, 2 min). All individuals detected were recorded once and monitored throughout the remainder of the survey to avoid

double counting. We recorded all detections by distance band, indicating the distance of the bird from the observer (0 – 25 m, >25 – 50 m, >50 – 75 m, >75 – 100 m, and >100 m). We recorded detection type (song, call, drum, visual, fly-over, or wing whistle) and sex for each detection, if possible.

Spatial covariates. We manually digitized land cover types deemed important for *Vermivora* breeding habitat in previous studies (Table 4.3) using 2018 National Agriculture Imagery Program imagery (1-m cell size; data collected during the growing season). We chose 2018 imagery because it is the most recent statewide dataset available for West Virginia. For sites where management occurred after 2018, we used Google Earth imagery georeferenced using ArcGIS (Google Earth 2021). Field visits helped verify habitat conditions present. 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 habitat (dominated by grass and forb species such as goldenrods [*Solidago* spp.], orchard grass [*Dactylis glomerata*], sedges [*Carex* spp.], and tall fescue [*Festuca arundinacea*] with <30% woody cover), shrubland ($\geq 30\%$ shrub cover generally dominated by shrub species such as autumn olive [*Elaeagnus umbellata*], hawthorn [*Crataegus* spp.], and multiflora rose [*Rosa multiflora*] with scattered canopy trees and herbaceous understory), and young forest (regenerating stands dominated by saplings ≤ 8 cm dbh). We used a 1:24,000 digital elevation model (DEM; 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 (Maxwell et al. 2019) to calculate percent forest cover and edge density (km/km^2) within 1 km of each sampling point location. The 10 forest types in this dataset included river floodplains, small stream riparian habitats, northern hardwood forests, mixed mesophytic forests, dry-mesic oak forests, dry oak-pine forests, pine-oak rocky woodlands, dry calcareous forests, montane red oak forests, and other forest. While habitat characteristics of these forest types are diverse, they are representative of forest cover at the landscape scale, thus, we combined all 10 forest land cover classes using the “reclassify” tool to generate a forest cover raster for West Virginia. We used the “buffer” tool to create 1-km buffers around each sampling point. The amount of forest area within each 1-km radius buffer was calculated using the “summarize within” tool. Percent forest within 1 km of each sampling point

was generated by dividing the forested area within each buffer by the area of each buffer and multiplying by 100. We calculated the length of forest edge within each 1-km radius using the “summarize within” tool. Edge density (km/km^2) within 1 km of each sampling point location was generated by dividing length of forest edge within each buffer by the area of buffer.

Vegetation covariates. We measured vegetation at the point level to characterize habitat at each site for vegetation metrics deemed important for *Vermivora* breeding habitat in previous studies (Table 4.3). We conducted vegetation sampling once each year after the second point count survey to ensure full vegetation growth prior to sampling. 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; Figure 4.2). An ocular tube consists of a 2-inch section of plastic pipe to restrict observer field of view and wire crosshairs to identify which cover types intersect. 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 (m) with a handheld rangefinder at each ocular tube sampling point and 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 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 (Figure 4.2). Variable radius prism plots were completed using a wedge prism (10-factor English or 2.5-factor metric) to tally live trees and snags ≥ 8 cm dbh at each prism plot. The observer tallied trees that were “in” the plot by holding the prism at a fixed distance from the eye over the 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. We calculated basal area at each plot by multiplying the number of “in” live trees by a basal area factor of 2.296. The center prism plot basal area (center plot basal area) reflects basal area within the treatment. Mean basal area across all four prism plots (100-m basal area) reflects basal area across the 100-m radius plot and may include tree tallies from within and outside the treatment area.

Statistical Analysis

Blue-winged Warbler Occupancy. We estimated Blue-winged Warbler occupancy using single-season occupancy models (Fiske and Chandler 2011). 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 WLFW points surveyed in 2019 and 2020, we included only the 2020 data in analyses because including data from both years was not compatible with our 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, call) within 100 m of sampling point in analysis to relate occupancy more closely to vegetation and topographic characteristics measured within 100-m radius of each sampling point. Point count data was converted to detection (1) and nondetection (0) per visit for estimation of detection probability across each survey. We used package unmarked (version 0.11-0; Fiske and Chandler 2011) in program R (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 4.4) in its own detection model to identify which detection covariates were best-supported using AIC_c (Burnham and Anderson 2002). If the detection model set had only one model with $\Delta AIC_c < 2.0$, the detection covariate in that model was used singularly for all subsequent analysis.

We tested 4 occupancy model sets. In the first occupancy model set, we evaluated Blue-winged Warbler occupancy at untreated and treated locations to evaluate CWAFEP and WLFW conservation practice effectiveness (Tables 4.4 and 4.7). Our first model set had 7 models using

contract treatment status and years-post-treatment as the predictor variables and included ecoregion and elevation to account for inherent differences in occupancy among sites. In the second model set, we developed 6 models to examine the influence of spatial variables (Tables 4.4 and 4.7). In the third model set, we developed 10 models to examine the influence of vegetation covariates (Tables 4.4 and 4.7). We created a fourth model set by including models with $\Delta AIC_c < 2.0$ from the contract treatment status, spatial, and vegetation model sets (model sets 1-3) to compare the influence of status against spatial and vegetation covariates. We tested models using all combinations of supported covariates to evaluate the influence of contract treatment status on best supported models. Occupancy predictions were derived using the ‘predict’ function in program R (R Development Core Team 2019) and differences were assessed based on 95% confidence intervals of beta estimates.

RESULTS

Occupancy

We detected 49 Blue-winged Warblers (on 16 points at 9 CWAFEP sites and 18 points at 4 WLFW sites) across 341 points surveyed during the study (Appendix B). Naïve occupancy was greatest on untreated WLFW points (Table 4.2).

Observer was the only supported detection covariate and was used as the sole detection covariate in models for all subsequent analyses (Table 4.6). For model set 1, model selection results indicated that a model for ecoregion and contract treatment status and a model with only ecoregion were supported (Table 4.7). Occupancy in the Central Appalachians ecoregion was 300% greater than in the Ridge and Valley (Figure 4.3). Treated points had lower occupancy than untreated points by 34 – 44% depending on ecoregion (Table 4.8, Figure 4.3). For model set 2, models containing 100-m shrubland and 100-m young forest/shrubland were best supported (Table 4.7). Occupancy increased by 772% as 100-m shrubland increased from 0 to 100% cover and increased by 790% as 100-m young forest/shrubland increased from 0 to 100% cover (Table 4.8, Figure 4.3). For model set 3, a model containing 100-m basal area was best supported (Table 4.7). Occupancy decreased by 91% as 100-m basal area increased from 0 to 30 m²/ha (Table 4.8, Figure 4.3).

For model set 4, model selection results indicated that 100-m shrubland, contract treatment status and 100-m young forest/shrubland, contract treatment status and 100-m shrubland, and 100-m young forest/shrubland were supported variables but effect sizes were

similar to those in model sets 1 and 2 (Tables 4.7 and 4.8). When comparing site means between untreated and treated points, 100-m shrubland were the same and 100-m young forest was 6% greater on treated points.

DISCUSSION

Habitat management can be a useful tool to reverse avian population declines. We suspected that Blue-winged Warblers may benefit from conservation practices for Cerulean and Golden-winged Warblers. However, occupancy estimates were greater at untreated locations on CWAFFP or WLFW sites. The lower occupancy at treated locations suggests that Blue-winged Warblers did not indirectly benefit from CWAFFP or WLFW implementation. We suspect that the lower occupancy at treated locations was partially due to low amounts of shrubland and high basal area on treated CWAFFP and WLFW sites. While Blue-winged Warblers were not positively correlated with conservation practice implementation, we did identify important habitat characteristics that have implications for habitat management.

Blue-winged Warbler occupancy was positively associated with shrubland and young forest cover. We define shrubland cover as a digitized area with $\geq 30\%$ 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 of shrubland cover has not been identified 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 recommend 50 – 100% shrubland cover at the 100-m radius scale when managing for Blue-winged Warblers in the Appalachians. Shrubland conditions can be achieved by setting back succession through the implementation of disturbance (e.g., timber management, prescribed burning or 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 Cerulean and Golden-winged Warbler guidelines, however we believe that the Golden-winged Warbler guidelines will be more effective 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 on treated CWAFFEP points, and all were detected on points with relatively low basal area and contained shrubland and/or young forest cover. Thus, similar to Sheehan et al. (2014), management for Cerulean Warblers may benefit Blue-winged Warblers only on heavier harvests with residual basal area below 9.2 m²/ha (40 ft²/ac). We recommend residual basal area of 0.0 – 4.6 m²/ha (0 – 20 ft²/ac) when managing for Blue-winged Warblers in the Appalachians, as occupancy was highest at residual basal area of 0.00 m²/ha and decreased by 25% above 4.6 m²/ha (20 ft²/ac; Figure 4.3). This recommendation is consistent with previous research indicating Blue-winged Warblers use early and mid-successional communities (Confer and Knapp 1981, Confer et al. 2003, Gill et al. 2020). The target basal area range can be achieved by implementing silviculture treatments (e.g., clearcutting, seed tree harvests, overstory removal with residuals, and shelterwood harvests) 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. Thirty-six percent of our sample size was in the Ridge and Valley ecoregion, yet only 4 individuals were detected there. 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. Blue-winged Warblers were restricted to lower elevations (<600 m, Buckelew and Hall 1994), but the species' breeding distribution has expanded into higher elevations in recent decades (Bailey and Rucker 2021). We detected Blue-winged Warblers across most of the elevation range surveyed (244 – 917 m; Table 4.5). 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 Warblers outside of their interactions with Golden-winged Warblers. Habitat characteristics important to Blue-winged Warblers are consistent with those previously identified for Golden-winged Warblers, which is unsurprising as both species' genomes are 99.97% alike (Toews et al. 2016). However, our basal area recommendation of 0.0 – 4.6 m²/ha (0 – 20 ft²/ac) encompasses a wider range than those suggested by the Golden-winged Warbler guidelines (~1.9 – 3.7 m²/ha [8 – 16 ft²/ac]; Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013), suggesting that Blue-winged Warblers breed in later successional stages than Golden-winged Warblers and 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 given the species reliance on disturbed habitats. Based on our results, we recommend 50 – 100% shrubland cover at the 100-m radius scale and residual basal area of 0.0 – 4.6 m²/ha (0 – 20 ft²/ac) when managing habitat for Blue-winged Warblers in the Appalachians. Future studies with improved management implementation and larger samples sizes across the species' breeding range will be required to further inform habitat management's potential as a conservation action for Blue-winged Warblers.

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TABLES

Table 4.1. Names, number of sites, and descriptions for Natural Resources Conservation Service conservation practices that were implemented on 13 post-treatment sites enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFEP) and 16 post-treatment sites enrolled in Working Lands for Wildlife (WLFW) in West Virginia from 2012 – 2020.

Conservation practice	CWAFEP sites ^a	WLFW sites ^a	Description ^b
Access control	0	2	The temporary or permanent exclusion of animals, people, vehicles, and equipment from an area.
Brush management	6	16	The management or removal of woody (nonherbaceous or succulent) plants including those that are invasive and noxious.
Critical area planting	0	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.
Early successional habitat development/management	3	9	Manage plant succession to develop and maintain early successional habitat to benefit desired wildlife and/or natural communities.
Fence	0	4	A constructed barrier to animals or people.
Field border	0	2	A strip of permanent vegetation established at the edge or around the perimeter of a field.
Forest stand improvement	11	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.
Forest trails and landings	1	0	A temporary or infrequently used route, path, or cleared area.
Restoration of rare or declining natural communities	0	8	Reestablishment of abiotic (physical and chemical) and biotic (biological) conditions necessary to support rare or declining natural assemblages of native plants and animals.
Structures for wildlife	3	1	A structure installed 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)
Tree/shrub establishment	1	7	Establishing woody plants by planting seedlings or cuttings, by direct seeding, and/or through natural regeneration.
Tree/shrub site preparation	2	2	Treatment of sites to enhance the success of natural or artificial regeneration of desired trees and/or shrubs.

^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)

Table 4.2. Annual number of point count locations and sites across contract treatment status categories surveyed on 21 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project and 22 private properties enrolled in Working Lands for Wildlife in West Virginia and naïve occupancy of Blue-winged Warbler (*Vermivora cyanoptera*; BWWA) across treatment categories on the 341 point-count surveys sampled during 2019 – 2020.

	Untreated		Treated	
	Points	Sites	Points	Sites
Cerulean Warbler Appalachian Forestland Enhancement Project				
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
Working Lands for Wildlife				
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

Table 4.3. Descriptions, notations, and justifications for variables used to model Blue-winged Warbler (*Vermivora cyanoptera*) occupancy at 341 point-count locations on 41 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020.

Variable	Justification
Contract treatment status	While habitat management implemented based on the Cerulean and Golden-winged Warbler guidelines improves habitat quality and provides breeding habitat for each species (Bakermans et al. 2011, Roth et al. 2012, Golden-winged Warbler Working Group 2013, Wood et al. 2013), no studies have evaluated Blue-winged warbler response to management using Cerulean and Golden-winged Warbler guidelines
Years post-treatment	Golden-winged Warbler colonization of managed habitats may take up to 3 years following the development of preferred shrubs and sapling vegetation (Bakermans et al. 2015), suggesting there might also be a lag for Blue-winged Warbler
Elevation	Blue-winged Warblers historically occurred at <600 m elevation in the Appalachians (Welton 2003, Buehler et al. 2007) but are expanding into higher elevations (Canterbury et al. 1996, Sauer et al. 2020)
1-km forest cover	Golden-winged Warbler breeding habitat associated with forested landscapes (Roth et al. 2012)
1-km edge density	Golden-winged Warbler populations will not persist in highly fragmented, urbanized, or mostly agricultural landscapes. (Roth et al. 2012)
100-m young forest	Shrubland and young forest early successional communities are commonly used Blue-winged Warbler breeding habitats throughout the breeding range (Askins et al. 2007, Confer and Knapp 1981, Gill et al. 2020)
100-m shrubland	
100-m young forest/shrubland	
100-m open	Golden-winged Warbler abundance positively associated with herbaceous cover (Bakermans et al. 2015)
Grass cover	Blue-winged Warbler breeding habitat includes a dense matrix of herbaceous, shrub, and sapling growth near forest edges where woody vegetation dominates (Askins et al. 2007, Confer and Knapp 1981, Gill et al. 2020)
Forb cover	
<i>Solidago</i> cover	
<i>Rubus</i> cover	
Shrub cover	
Sapling cover	
Canopy cover	
100-m basal area	Recommended 1.9 – 3.7 m ² /ha (8 – 16 ft ² /ac) for Golden-winged Warblers (Golden-winged Warbler Working Group 2013) and 3.7 – 8.4 m ² /ha (40 – 90 ft ² /ac) for Cerulean Warblers (Wood et al. 2013) in the Appalachians
Center plot basal area	
Coefficient of variation	Golden-winged Warbler nest sites had more variable vegetation height than random locations within the same territory (Aldinger 2018)

Table 4.4. Covariates used to model Blue-winged Warbler (*Vermivora cyanoptera*) occupancy at 341 point-count locations on 41 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020.

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 (L. Oliver or 1 of 2 field technicians)
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	youngforest	Spatial	Percent young forest (of trees ≤ 8 cm) within 100 m
100-m shrubland	shrubland	Spatial	Percent shrubland ($\geq 30\%$ 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 ($\geq 30\%$ 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
<i>Solidago</i> cover	solidago	Vegetation	Percent <i>Solidago</i> cover (0 – 100) within 100 m
<i>Rubus</i> cover	rubus	Vegetation	Percent <i>Rubus</i> 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

Table 4.5. Covariates used to model Blue-winged Warbler (*Vermivora cyanoptera*) occupancy at 341 point-count locations on 41 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFFEP) and/or Working Lands for Wildlife (WLFW) in West Virginia sampled during 2019 – 2020. We report the weighted mean and range across sites for continuous variables and the percent of points that fell in each category for categorical variables. Weighted mean values are also reported where Blue-winged Warblers were and were not detected across all sites. Covariates are defined in Table 4-4.

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)
<i>Solidago</i> cover	4 (0 – 38)	6 (0 – 45)	4 (0 – 45)	9 (0 – 38)
<i>Rubus</i> 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)

Table 4.6. 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 Cerulean Warbler Appalachian Forestland Enhancement Project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. K is the number of parameters in each model, AIC_c is the Akaike's Information Criterion value for small sample sizes, ΔAIC_c is the difference between each model's AIC_c value and the lowest AIC_c 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 Table 4.4.

Model	K	AIC_c	ΔAIC_c	w_i
$\psi(1)p$ (observer)	4	285.64	0.00	0.99
$\psi(1)p$ (date)	3	295.41	9.77	0.01
$\psi(1)p$ (wind)	3	300.23	14.59	0.00
$\psi(1)p$ (canopy)	3	301.88	16.24	0.00
$\psi(1)p$ (time)	3	301.96	16.32	0.00
$\psi(1)p$ (sky)	7	304.85	19.22	0.00

Table 4.7. 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 the Cerulean Warbler Appalachian Forestland Enhancement Project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. K is the number of parameters in each model, AIC_c is the Akaike's Information Criterion value for small sample sizes, ΔAIC_c is the difference between each model's AIC_c value and the lowest AIC_c 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 Table 4.4.

Model	K	AIC_c	ΔAIC_c	w_i
Model set 1: treatment models				
ψ (ecoregion) p (observer)	6	280.79	0.00	0.39
ψ (status + ecoregion) p (observer)	7	281.05	0.26	0.35
ψ (year + ecoregion) p (observer)	7	282.25	2.26	0.19
ψ (status) p (observer)	5	285.58	4.79	0.04
ψ (status + elev) p (observer)	6	287.38	6.59	0.01
ψ (elev) p (observer)	5	287.65	6.86	0.01
ψ (year + elev) p (observer)	6	288.76	7.97	0.01
Model set 2: spatial models				
ψ (shrubland) p (observer)	5	262.03	0.00	0.64
ψ (young forest/shrubland) p (observer)	5	263.16	1.14	0.36
ψ (open) p (observer)	5	280.18	18.15	0.00
ψ (edge) p (observer)	5	283.93	21.90	0.00
ψ (yngforest) p (observer)	5	287.28	25.26	0.00
ψ (forest) p (observer)	5	287.45	25.43	0.00
Model set 3: vegetation models				
ψ (ba) p (observer)	5	275.89	0.00	0.90
ψ (bacent) p (observer)	5	281.65	5.75	0.05
ψ (cov) p (observer)	5	283.17	7.28	0.02
ψ (rubus) p (observer)	5	285.88	9.98	0.01
ψ (sapling) p (observer)	5	286.43	10.54	0.00
ψ (grass) p (observer)	5	286.62	10.73	0.00
ψ (shrub) p (observer)	5	287.13	11.23	0.00
ψ (solidago) p (observer)	5	287.39	11.50	0.00
ψ (canopy) p (observer)	5	287.41	11.52	0.00
ψ (forb) p (observer)	5	287.59	11.70	0.00
Model set 4: supported and combined models				
ψ (shrubland) p (observer)	5	262.03	0.00	0.32
ψ (status + young forest/shrubland) p (observer)	6	262.35	0.32	0.28
ψ (status + shrubland) p (observer)	6	262.86	0.84	0.21
ψ (young forest/shrubland) p (observer)	5	263.16	1.14	0.18
ψ (status + ba) p (observer)	6	275.66	13.64	0.00
ψ (ba) p (observer)	5	275.89	13.87	0.00
ψ (ecoregion) p (observer)	6	280.79	18.77	0.00
ψ (status + ecoregion) p (observer)	7	281.05	19.02	0.00

Table 4.8. Beta (β) estimates, standard errors (SE), and 95% lower and upper confidence intervals (CI) on the logit-scale from models (see Table 4.7) estimating Blue-winged Warbler (*Vermivora cyanoptera*) occupancy using 341 point-count locations on 41 private properties enrolled in the Cerulean Warbler Appalachian Forestland Enhancement Project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Codes for covariates are defined in Table 4.4.

Parameter	β estimate	SE	Lower 95% CI	Upper 95% CI
Model set 1: treatment models				
ecoregion				
Central Appalachians	1.30	0.32	0.68	1.92
Ridge and Valley	-1.32	0.60	-2.48	-0.15
Western Allegheny Plateau	0.35	0.46	-0.54	1.25
status + ecoregion				
Untreated	0.57	0.43	-0.29	1.41
Treated	-1.56	0.38	-2.31	-0.81
Ridge and Valley	-1.38	0.60	-2.56	-0.20
Western Allegheny Plateau	0.23	0.47	-0.69	1.16
Model set 2: spatial models				
shrubland				
100-m shrubland	0.05	0.02	0.02	0.09
young forest/shrubland				
100-m young forest/shrubland	0.04	0.01	0.02	0.06
Model set 3: vegetation models				
ba				
100-m basal area	-0.10	0.03	-0.16	-0.04
Model set 4: supported and combined models				
shrubland				
100-m shrubland	0.05	0.02	0.02	0.09
status + young forest/shrubland				
Untreated	0.77	0.47	-0.15	1.70
Treated	-2.72	0.45	-3.59	-1.85
100-m young forest/shrubland	0.05	0.01	0.02	0.07
status + shrubland				
Untreated	0.49	0.46	-0.41	1.39
Treated	-2.37	0.40	-3.15	-1.59
100-m shrubland	0.06	0.02	0.02	0.09
young forest/shrubland				
100-m young forest/shrubland	0.04	0.01	0.02	0.06

FIGURES

Figure 4.1. Site locations enrolled in Cerulean Warbler Appalachian Forestland Enhancement Project (CWAFAEP) and/or Working Lands for Wildlife (WLFW) in West Virginia sampled during 2019 – 2020. Sites where Blue-winged Warblers (*Vermivora cyanoptera*; BWWA) were detected are shown in blue. Site locations were randomly offset within a 5-km radius of the actual location to protect personally identifiable information.

Figure 4.2. Diagram of plot for sampling vegetation variables at each point count location. Within the 3.14 ha (100-m radius) plot, percent cover of vegetation classes (grass, forb, *Solidago*, vine, *Rubus*, shrub, sapling, and canopy) was measured at 10 points along three 100-m transects, radiating from point center at 0°, 120°, and 240°. Four prism plots (open circles) were conducted at each sampling plot for basal area calculations. Prism plots were located at point center and 70 m from point center along the 0°, 120°, and 240° transects

Figure 4.3. Predicted occupancy and 95% confidence intervals of Blue-winged Warblers (*Vermivora cyanoptera*) at 341 point-count surveys on 41 private properties enrolled in the Cerulean Warbler Appalachian Forestland enhancement project and/or Working Lands for Wildlife in West Virginia sampled during 2019 – 2020. Occupancy models for panels shown included contract treatment status and ecoregion, ecoregion, % 100-m shrubland, % 100-m young forest/shrubland, and 100-m basal area (m^2/ha) for occupancy and observer for detection probability. Differences are indicated by alphabetic notation.

THESIS APPENDICES

Appendix A. Avian guild descriptions.

Guild	Description
Forest Interior	Species that breed mature forests and are sensitive to forest edges (Ries and Sisk 2010).
Forest Generalist	Species that breed in a range of forest successional stages and are insensitive to forest edge habitats (Ries and Sisk 2010)
Forest Gap	Species that breed in mature forest with complex canopy structure (e.g., natural tree-fall gaps) and small canopy openings (Bowen et al. 2007, Perkins and Wood 2014).
Shrubland	Species that breed in early successional habitats (e.g., regenerating forest following recent disturbance, old fields; Rodewald and Vitz 2005).
Grassland	Species that breed in grassland habitats (e.g., hayfields, pastures).

Appendix B. Total avian species detected on point count surveys heard within 100-m of each point count location on 21 private properties enrolled in the Appalachian Forestland Enhancement Project (CWAFFEP) and 22 private properties enrolled in Working Lands for Wildlife (WLFW) in West Virginia sampled during 2019 – 2020. Common and scientific names, American Ornithological Society (AOS) banding codes, and detection counts are listed for each species. Guild assignments are included for species included in guild richness analyses.

AOS code	Common Name	Scientific name	Guild	CWAFFEP Count	WLFW Count
ACFL	Acadian Flycatcher	<i>Empidonax vireescens</i>	Forest Gap	101	22
ALFL	Alder Flycatcher	<i>Empidonax alnorum</i>	Shrubland	0	1
AMCR	American Crow	<i>Corvus brachyrhynchos</i>		26	30
AMGO	American Goldfinch	<i>Spinus tristis</i>	Shrubland	34	52
AMRE	American Redstart	<i>Setophaga ruticilla</i>	Forest Generalist	112	42
AMRO	American Robin	<i>Turdus migratorius</i>	Forest Generalist	63	73
BAOR	Baltimore Oriole	<i>Icterus galbula</i>	Forest Generalist	12	15
BARS	Barn Swallow	<i>Hirundo rustica</i>		0	1
BAWW	Black-and-white Warbler	<i>Mniotilta varia</i>	Forest Interior	77	75
BBCU	Black-billed Cuckoo	<i>Coccyzus erythrophthalmus</i>	Forest Generalist	0	1
BBWA	Bay-breasted Warbler	<i>Setophaga castanea</i>		10	6
BCCH	Black-capped Chickadee	<i>Poecile atricapillus</i>	Forest Generalist	16	43
BEKI	Belted Kingfisher	<i>Megaceryle alcyon</i>		0	1
BGGN	Blue-gray Gnatcatcher	<i>Poliophtila caerulea</i>	Forest Generalist	113	39
BHCO	Brown-headed Cowbird	<i>Molothrus ater</i>	Forest Generalist	79	98
BHVI	Blue-headed Vireo	<i>Vireo solitarius</i>	Forest Interior	38	29
BLBW	Blackburnian Warbler	<i>Setophaga fusca</i>	Forest Interior	2	8
BLGR	Blue Grosbeak	<i>Passerina caerulea</i>	Shrubland	0	4
BLJA	Blue Jay	<i>Cyanocitta cristata</i>	Forest Generalist	71	56
BLPW	Blackpoll Warbler	<i>Setophaga striata</i>		1	0
BOBO	Bobolink	<i>Dolichonyx oryzivorus</i>	Grassland	0	2
BRTH	Brown Thrasher	<i>Toxostoma rufum</i>	Shrubland	8	29
BRWA	Brewster's Warbler	<i>Vermivora leucobronchialis</i>	Shrubland	0	1
BTBW	Black-throated Blue Warbler	<i>Setophaga caerulescens</i>	Forest Gap	6	2
BTNW	Black-throated Green Warbler	<i>Setophaga virens</i>	Forest Gap	30	47
BWHA	Broad-winged Hawk	<i>Buteo platypterus</i>		1	4
BWWA	Blue-winged Warbler	<i>Vermivora cyanoptera</i>	Shrubland	19	30
CACH	Carolina Chickadee	<i>Poecile carolinensis</i>	Forest Generalist	31	7
CANG	Canada Goose	<i>Branta canadensis</i>		0	3
CARW	Carolina Wren	<i>Thryothorus ludovicianus</i>	Forest Generalist	98	95
CAWA	Canada Warbler	<i>Cardellina canadensis</i>	Forest Generalist	2	1
CEDW	Cedar Waxwing	<i>Bombicilla cedrorum</i>	Forest Generalist	36	37
CERW	Cerulean Warbler	<i>Setophaga cerulea</i>	Forest Gap	71	5
CHSP	Chipping Sparrow	<i>Spizella passerina</i>	Shrubland	32	55
CHSW	Chimney Swift	<i>Chaetura pelagica</i>		0	4
CMWA	Cape May Warbler	<i>Setophaga tigrina</i>		1	0
COGR	Common Grackle	<i>Quiscalus quiscula</i>		3	1

CORA	Common Raven	<i>Corvus corax</i>		1	1
COYE	Common Yellowthroat	<i>Geothlypis trichas</i>	Shrubland	7	58
CSWA	Chestnut-sided Warbler	<i>Setophaga pensylvanica</i>	Shrubland	4	80
DEJU	Dark-eyed Junco	<i>Junco hyemalis</i>	Forest Generalist	0	5
DICK	Dickcissel	<i>Spiza americana</i>	Grassland	1	0
DOWO	Downy Woodpecker	<i>Picoides pubescens</i>	Forest Generalist	30	41
EABL	Eastern Bluebird	<i>Sialia sialis</i>	Grassland	16	21
EAKI	Eastern Kingbird	<i>Tyrannus tyrannus</i>	Shrubland	1	7
EAME	Eastern Meadowlark	<i>Sturnella magna</i>	Grassland	4	4
EAPH	Eastern Phoebe	<i>Sayornis phoebe</i>	Forest Generalist	7	14
EATO	Eastern Towhee	<i>Pipilo erythrophthalmus</i>	Shrubland	172	278
EAWP	Eastern Wood-pewee	<i>Contopus virens</i>	Forest Generalist	102	78
EUST	European Starling	<i>Sturnus vulgaris</i>		5	8
FISP	Field Sparrow	<i>Spizella pusilla</i>	Shrubland	30	124
GBHE	Great Blue Heron	<i>Ardea herodias</i>		0	1
GCFL	Great Crested Flycatcher	<i>Myiarchus crinitus</i>	Forest Generalist	58	43
GRCA	Gray Catbird	<i>Dumetella carolinensis</i>	Shrubland	7	54
GRHE	Green Heron	<i>Butorides virescens</i>		1	0
GWWA	Golden-winged Warbler	<i>Vermivora chrysoptera</i>	Shrubland	0	8
HAWO	Hairy Woodpecker	<i>Dryobates villosus</i>	Forest Interior	36	27
HETH	Hermit Thrush	<i>Catharus guttatus</i>	Forest Interior	0	2
HOWA	Hooded Warbler	<i>Setophaga citrina</i>	Forest Gap	82	91
HOWR	House Wren	<i>Troglodytes aedon</i>	Forest Generalist	1	23
INBU	Indigo Bunting	<i>Passerina cyanea</i>	Shrubland	66	244
KEWA	Kentucky Warbler	<i>Geothlypis formosa</i>	Forest Gap	30	1
KILL	Killdeer	<i>Charadrius vociferus</i>		0	4
LEFL	Least Flycatcher	<i>Empidonax minimus</i>	Forest Interior	2	16
LOWA	Louisiana Waterthrush	<i>Parkesia motacilla</i>	Forest Interior	14	4
MAWA	Magnolia Warbler	<i>Setophaga magnolia</i>	Forest Interior	3	0
MODO	Mourning Dove	<i>Zenaida macroura</i>	Shrubland	41	54
NAWA	Nashville Warbler	<i>Leiothlypis ruficapilla</i>		4	0
NOCA	Northern Cardinal	<i>Cardinalis cardinalis</i>	Shrubland	120	108
NOFL	Northern Flicker	<i>Colaptes auratus</i>	Forest Generalist	32	16
NOMO	Northern Mockingbird	<i>Mimus polyglottos</i>	Shrubland	1	1
NOPA	Northern Parula	<i>Setophaga americana</i>	Forest Generalist	17	11
OROR	Orchard Oriole	<i>Icterus spurius</i>	Shrubland	0	6
OVEN	Ovenbird	<i>Seiurus aurocapillus</i>	Forest Interior	200	112
PIWA	Pine Warbler	<i>Setophaga pinus</i>	Forest Interior	37	2
PIWO	Pileated Woodpecker	<i>Dryocopus pileatus</i>	Forest Interior	34	14
PRAW	Prairie Warbler	<i>Setophaga discolor</i>	Shrubland	3	3
RBGR	Rose-breasted Grosbeak	<i>Pheucticus ludovicianus</i>	Forest Generalist	11	36
RBNU	Red-breasted Nuthatch	<i>Sitta canadensis</i>	Forest Interior	0	1
RBWO	Red-bellied Woodpecker	<i>Melanerpes carolinus</i>	Forest Generalist	67	55
REVI	Red-eyed Vireo	<i>Vireo olivaceus</i>	Forest Gap	433	294
RHWO	Red-headed Woodpecker	<i>Melanerpes erythrocephalus</i>		4	0

RTHA	Red-tailed Hawk	<i>Buteo jamaicensis</i>		1	4
RTHU	Ruby-throated Hummingbird	<i>Archilochus colubris</i>	Forest Generalist	8	13
RUGR	Ruffed Grouse	<i>Bonasa umbellus</i>	Shrubland	1	3
RWBL	Red-winged Blackbird	<i>Agelaius phoeniceus</i>	Grassland	9	41
SCTA	Scarlet Tanager	<i>Piranga olivacea</i>	Forest Interior	181	89
SOSP	Song Sparrow	<i>Melospiza melodia</i>	Shrubland	31	59
SUTA	Summer Tanager	<i>Piranga rubra</i>	Forest Generalist	4	0
SWTH	Swainson's Thrush	<i>Catharus ustulatus</i>	Forest Interior	2	0
SWWA	Swainson's Warbler	<i>Limnithlypis swainsonii</i>	Forest Interior	0	1
TEWA	Tennessee Warbler	<i>Leiothlypis peregrina</i>		14	2
TRES	Tree Swallow	<i>Tachycineta bicolor</i>		0	3
TUTI	Tufted Titmouse	<i>Baelophus bicolor</i>	Forest Generalist	132	118
TUVU	Turkey Vulture	<i>Cathartes aura</i>		0	1
VEER	Veery	<i>Catharus fuscescens</i>	Forest Generalist	1	4
WBNU	White-breasted Nuthatch	<i>Sitta carolinensis</i>	Forest Gap	101	70
WEVI	White-eyed Vireo	<i>Vireo griseus</i>	Shrubland	1	2
WEWA	Worm-eating Warbler	<i>Helmitheros vermivorum</i>	Forest Interior	52	5
WIFL	Willow Flycatcher	<i>Empidonax traillii</i>	Shrubland	0	4
WITU	Wild Turkey	<i>Meleagris gallopavo</i>		2	4
WOTH	Wood Thrush	<i>Hylocichla mustelina</i>	Forest Interior	149	76
YBCH	Yellow-breasted Chat	<i>Icteria virens</i>	Shrubland	8	11
YBCU	Yellow-billed Cuckoo	<i>Coccyzus americanus</i>	Forest Generalist	40	24
YEWA	Yellow Warbler	<i>Setophaga petechia</i>	Shrubland	3	10
YRWA	Yellow-rumped Warbler	<i>Setophaga coronata</i>		0	1
YTVI	Yellow-throated Vireo	<i>Vireo flavifrons</i>	Forest Generalist	25	21
YTWA	Yellow-throated Warbler	<i>Setophaga dominica</i>	Forest Interior	7	6