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Evaluating Golden-winged Warbler use of alder and aspen communities managed with shearing in the western Great Lakes

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Abstract

Best management practices are often written by researchers to guide land managers and landowners in the creation of habitat for wildlife species of interest. These documents are based on research evaluating the habitat needs of a species, but they also describe tools and strategies managers can implement to create or restore desired conditions. Shrub and sapling shearing is a management practice often used to improve habitat for early-successional species, yet little monitoring or research has focused on wildlife response to shearing. The goal of this research was to formally evaluate the effect of shrub and sapling shearing as a best management strategy for Golden-winged Warbler (*Vermivora chrysoptera*) conservation at a regional scale. Specifically, we surveyed for male Golden-winged Warblers during the breeding season in sheared sites and untreated reference sites across portions of the western Great Lakes to assess the effects of (1) management status (i.e., sheared aspen or alder vs. untreated sites) and (2) patch-level vegetation characteristics on male abundance. We found that male Golden-winged Warbler abundance was twice as high in sheared sites than in mature reference sites and peaked when sapling cover was ~40%. Male abundance was also negatively associated with percent cover of forbs and nonvegetated ground. These findings highlight the importance of patch-level heterogeneity when implementing shearing treatments for Golden-winged Warblers and demonstrate the potential need for pretreatment site assessments to help focus conservation efforts for this species. Ultimately, our results support the use of a site-specific, nuanced approach to shearing implementation to maximize cost efficiency and desired species outcomes.

KEYWORDS

alder, *Alnus*, aspen, best management practices, breeding habitat, forest management, Golden-winged Warbler, mowing, *Populus*, shearing, shrubland management, *Vermivora chrysoptera*

INTRODUCTION

Best management practices (BMPs) are published documents intended to guide the management or restoration of habitats for wildlife species of conservation concern (Youngberg et al., 2016). Effective BMPs are science-based and rooted in an understanding of the habitat needs of target species. Through summarization and synthesis of published literature on a species' habitat needs, BMPs provide managers with conservation practices that can be implemented with the intent of creating or enhancing habitat for target species (Bakermans, Smith, et al., 2015; Wood et al., 2013). BMPs often include detailed descriptions of desired habitat outcomes, including pictures and quantitative vegetation targets against which management success can be gauged (Bakermans, Smith, et al., 2015; Westwood et al., 2017; Wood et al., 2013). Ideally, BMPs are part of an adaptive management framework where habitat and target species outcomes are evaluated to inform the iterative refinement of BMPs (Reever et al., 2006).

Monitoring is a critical step in the adaptive management cycle, but it is often underfunded, poorly executed, or forgotten altogether (Aceves-Bueno et al., 2015; Reever et al., 2006). Because BMPs focus on the various tools and strategies that can be used to create or improve habitat, it is often easy to conduct research and monitoring that evaluates target species response based on the management tool or treatment used (e.g., single tree vs. group selection silvicultural systems) rather than specific vegetation metrics (i.e., basal area and understory density). Yet, wildlife monitoring that evaluates target species response based on habitat-treatment category alone may run the risk of oversimplifying the range of habitat variation that can occur across sites treated in the same manner (Akresh et al., 2021; Hanle et al., 2020). Successful adaptive management for biological conservation requires thoughtful planning and implementation of actions and scientifically meaningful monitoring of outcomes (Martin, Kitchens, & Hines, 2007; Nichols & Williams, 2006). Well-designed monitoring of BMPs is rare (McNeil, Rodewald, Robinson, et al., 2020; Nareff et al., 2019) and is most effective when monitoring is based on management-oriented hypotheses (Nichols & Williams, 2006; Reiley et al., 2019) and provides an assessment of target species response to multiple vegetation characteristics (Martin, Kitchens, & Hines, 2007).

One species that has been the focus of increasingly widespread conservation is the Golden-winged Warbler (*Vermivora chrysoptera*), a migratory songbird species that breeds across eastern North America, primarily across the Appalachian Mountains and Upper Great Lakes region (Confer et al., 2020). Golden-winged Warblers require early-successional habitats (like young forests and shrublands) within predominantly deciduous forested landscapes for nesting and brood rearing (Confer et al., 2020). Historically, these vegetation communities were maintained through disturbances such as wind events, flooding from beavers (*Castor canadensis*), wildfire, and agricultural practices and burning by Native American peoples (Askins, 1998; DeGraaf & Miller, 1996; Litvaitis et al., 1999). More recently, the suppression of flooding and fires and habitat loss from land use change have reduced the amount of early-successional forest and shrubland habitat across the Eastern United States (King & Schlossberg, 2014; Trani et al., 2001), and many bird species have experienced population declines in correlation with this loss of habitat (Askins, 1998; Sauer et al., 2020). Like other early-successional specialists, the Golden-winged Warbler is experiencing long-term population declines (Sauer et al., 2020), making it a species of conservation concern in the United States (USFWS, 2008) and listed as threatened in Canada (Environment Canada, 2014). North American Breeding Bird Survey data suggest a range-wide −1.85% (95% CI: −2.57% to −1.13%) population change per year between 1966 and 2019 (Sauer et al., 2020). It is widely accepted that successful conservation of early-successional forest birds, including the Golden-winged Warbler, relies, in part, on restoring or mimicking natural disturbances to create breeding habitat on both public and private land (King & Schlossberg, 2014; Litvaitis et al., 2021; McNeil, Rodewald, Robinson, et al., 2020; Roth et al., 2019; Smetzer et al., 2014).

To address the need for habitat management efforts to stem population losses in this species, the Golden-winged Warbler Working Group created BMPs (published in 2012, revised in 2019) to aid land managers with the creation and enhancement of Golden-winged Warbler breeding habitat (Golden-winged Warbler Working Group, 2019). The BMPs and the corresponding conservation plan explain landscape- and patch-scale factors affecting habitat use by Golden-winged Warblers, such as landscape-scale forest cover and composition and patch-level canopy, mid-story, and understory vegetation characteristics (Roth et al., 2019). The BMPs highlight a variety of practices for different plant communities that can be used to achieve target habitat metrics to create and enhance Golden-winged Warbler breeding habitat (Golden-winged Warbler Working Group, 2019).

One management practice suggested in the Golden-winged Warbler BMPs is mowing or shearing shrubs and saplings (hereafter "shearing"; Golden-winged Warbler Working Group, 2019). Shearing is used to mimic natural disturbances in shrub and sapling communities (e.g., beaver activity, etc.; Hanowski et al., 1999; Sargent & Carter, 1999; Zuckerberg & Vickery, 2006) by targeting mature and senescent shrubs and dense, homogenous stands of aging saplings (2–10 cm in diameter and in a stem exclusion stage of forest stand development). Shearing helps to reestablish interspersed woody and herbaceous vegetation structure and is hypothesized to increase the longevity of the site for early-successional wildlife, including breeding Golden-winged Warblers (Hanowski et al., 1999; Roth et al., 2019; Sargent & Carter, 1999; Zuckerberg & Vickery, 2006). Shearing can reestablish a more structurally diverse vegetation community by opening the canopy and allowing for the release of herbaceous growth such as ferns, forbs, grasses or sedges, and brambles. Shearing encourages stump and root sprouting of species, like alder (*Alnus* spp.), willow (*Salix* spp.), aspen (*Populus* spp.), and maple (*Acer* spp.), creating patches of dense woody stems that can be used to increase structural complexity of vegetation known to be important for many wildlife species (Leuenberger et al., 2017; Tews et al., 2004). Although shearing is a common management practice recommended for early-successional forest wildlife conservation (Gilbart, 2012; Kelley et al., 2008; Litvaitis et al., 2021; Roth et al., 2019), surprisingly little research has focused on evaluating wildlife responses to shearing (Bakermans, Ziegler, & Larkin, 2015; Hanowski et al., 1999; Masse et al., 2015; McNeil et al., 2017).

To assess the merit of shearing for creating or enhancing habitat for the Golden-winged Warbler, we developed a large-scale regional study whereby we monitored biological responses to sites treated with this conservation practice. Specifically, we surveyed for male Golden-winged Warblers during the breeding season in sheared sites and untreated reference sites across portions of the western Great Lakes to assess the effects of (1) management status and interaction with two plant communities, sapling-dominated aspen forest and alder-dominated shrubland, and (2) the patch-level vegetation characteristics on male Golden-winged Warbler abundance.

METHODS

Study area

We estimated Golden-winged Warbler abundance and measured associated vegetation at 243 sites in Minnesota and Wisconsin, USA (between 45.1° and 48.6° latitude and −89.2° and −95.6° longitude; Figure 1). Sites were even-aged alder-dominated shrublands or sapling-dominated aspen forests and located within landscapes dominated by deciduous forests. From 2013 to 2018, the

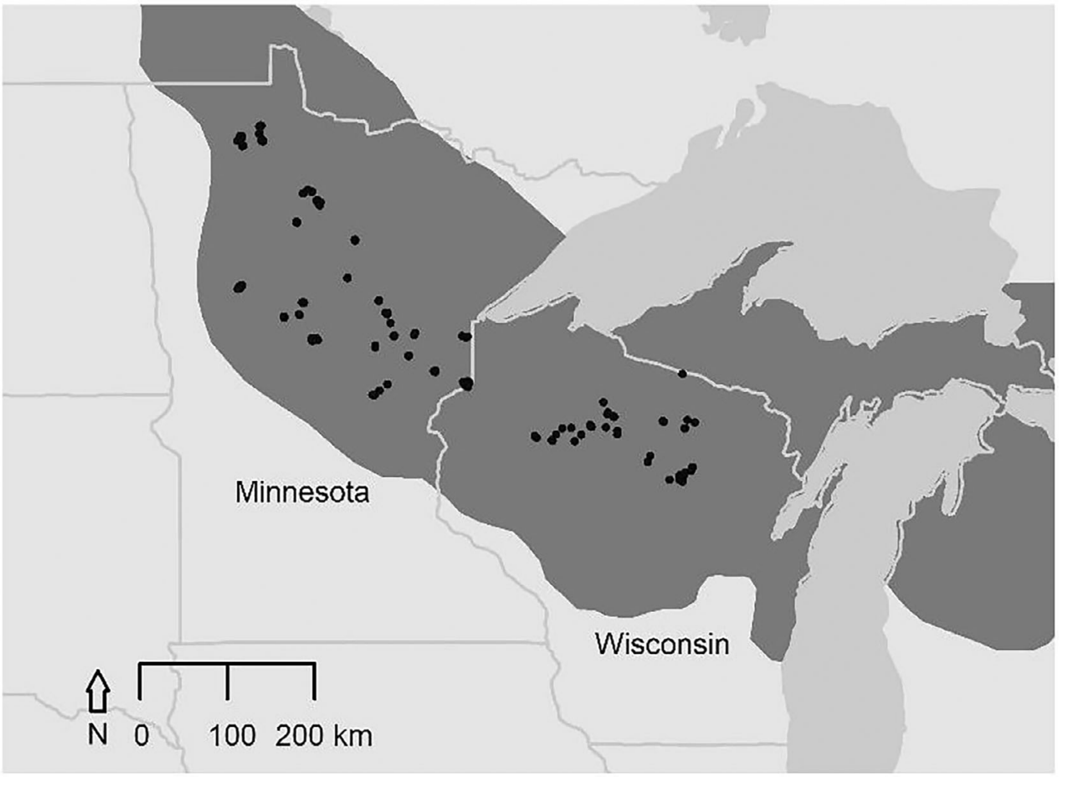

FIGURE 1 Black dots indicate the 243 sites where Golden-winged Warbler point count surveys were conducted during the 2012–2013 and 2015–2018 breeding seasons. The dark gray polygon represents the 2011 Golden-winged Warbler breeding range as delineated by the Golden-winged Warbler Working Group.

American Bird Conservancy, Wisconsin Young Forest Partnership, and several state, federal, and county partners helped identify private and public sites in Wisconsin and Minnesota where implementation of the Golden-winged Warbler BMPs via shearing was either planned or previously implemented. Alder sites were sheared following Golden-winged Warbler BMPs using small, tracked machines with mower attachments (e.g., brush hog and Fecon) during winter when the ground was frozen. The intent was to regenerate woody vegetation through coppicing (stump sprouting) while also opening growing space for herbaceous components such as grasses, sedges, ferns, and forbs. When present, scattered trees were retained across sites, and patches of dense shrubs and saplings were left uncut to promote the heterogeneous conditions preferred by Golden-winged Warblers. We considered sites that were 0–3 growing seasons postshear as "managed" sites ($n = 235$) and alder shrubland sites >20 years since management ($n = 44$) as unmanaged "reference" sites (Figure 2). Managed sites were dominated either by sheared alder shrubland (0–3 growing seasons) or sheared aspen stand (0–2 growing seasons). Managed alder and aspen sites averaged 3.82 ha (ranging from 0.12 to 29.87 ha). Reference alder sites had future shearing plans that averaged 5.03 ha (ranging from 0.28 to 29.87 ha), but on most sites, alder communities expanded beyond proposed treatment areas. Reference sites were unmanaged for at least 20 years prior to monitoring and dominated by tall alder (>3 m tall) with decadent, horizontal stems that shaded much of the ground. Scattered herbaceous vegetation used by Golden-winged Warblers for nesting was present, but very limited, at most reference sites. The exact age of reference alder sites was unknown, so we grouped all reference sites into a single "mature" growing season category. We did not survey stands of aspen in the stem exclusion stage because it is well documented that nesting Golden-winged Warblers are very uncommon during this successional stage due to uniform coverage of high sapling density that eliminates ground vegetation the species requires for nesting (Bakermans, Smith, et al., 2015; Martin, Lutz, & Worland, 2007; Roth & Lutz, 2004). Soil conditions ranged from dry upland to saturated lowland, with patches of standing water on some sites at the time of survey. We used ArcGIS (ESRI, 2010) to place a single survey point in the geometric center of each managed or reference site to maximize survey coverage. We ensured that all survey points were at least 250 m apart to maintain independence of observations and minimize the potential for double counting individuals (Ralph et al., 1995).

Field methods

We counted male Golden-winged Warblers at each site using a passive 10-min point count between May 25 and July 2 each year (2012–2013, 2015–2018; $n = 1222$ point counts conducted). Points were visited once annually in 2012–2013 ($n = 13$ points per year) and twice annually in 2015–2018 ($n = 68$–217 points per year), and surveys were conducted in favorable weather conditions (no heavy precipitation, wind, or fog) and between 30 min before sunrise and 5 h after sunrise. Prior to the start of each point count, we recorded survey metadata including weather conditions (precipitation type, Beaufort wind index, percent cloud cover [0%–100%] rounded to the nearest 25%), point location, date, survey start time, and observer identity. Beaufort wind categories 0–2 were combined into a low wind index category, and Beaufort categories 3–5 were combined to make a high wind index category for modeling. All visually and aurally detected Golden-winged Warblers were recorded, as well as detection type (visual, audio, or both), sex, and distance (estimated to the nearest 5 m). At sheared sites, we noted whether each

FIGURE 2 (A, B) The distinctive changes in postshearing vegetation structure at an alder-dominated shrubland stand in Lincoln County, WI, from early July during the first growing season (A) to late June during the second growing season (B). For comparison, (C) shows the dense structure of a mature alder stand that has not experienced disturbance in over 20 years. Photos by A. Buckardt Thomas.

Golden-winged Warbler detected was inside or outside the treatment footprint.

We collected vegetation data at each location where Golden-winged Warblers were surveyed during 2015–2018 to examine relationships between male Golden-winged Warbler abundance and patch-level habitat characteristics. We determined vegetation variables to sample based on existing literature on Golden-winged Warbler breeding habitat use and selection (Aldinger et al., 2015; Bakermans, Smith, et al., 2015; Bulluck & Harding, 2010; Leuenberger et al., 2017; Martin, Kitchens, & Hines, 2007; McNeil et al., 2017; McNeil, Rodewald, Ruiz-Gutierrez, et al., 2020; Peterson et al., 2016; Rossell et al., 2003; Terhune II et al., 2016) and the Golden-winged Warbler Conservation Plan (Roth et al., 2019). We sampled vegetation annually each field season from early July to August, except at reference sites, which we only surveyed once under the assumption that the vegetation structure at these sites remained consistent throughout the duration of our sampling. We quantified vegetation characteristics along three 100-m-long transects radiating from each point count location at 0-, 120-, and 240-degree azimuths. Every 10 m along each transect ($n = 30$ locations/transect), we used an ocular tube (James & Shugart, 1970) to record the presence or absence of vegetation strata: bare ground, leaf litter, graminoids (grass and sedge), forbs, ferns, *Rubus*, shrubs, saplings, and canopy trees. Leaf litter and bare ground strata were combined into nonvegetated strata for modeling. At the same 30 locations, we recorded the presence or absence of woody regeneration (shrubs and saplings) in four categories (none, small [0–1 m tall], medium [>1–2 m tall], and large [>2 m tall]) within a 1-m-radius area, for a site-level percent occurrence value of each category. Although we aimed for 30 locations of sampling at each site, we truncated transect lengths when they extended beyond the boundary of a treatment footprint, thus resulting in fewer than 30 subplots for some sites with irregular boundaries or a small footprint. We estimated patch-level cover and occurrence values for each vegetation component by dividing the number of subplots where a component was present by the total number of subplots sampled. Percent occurrence (measured at 1-m-radius woody regeneration plots) differs from the commonly used percent cover metric (which was used for other metrics in this study) because it does not take the density of each habitat element into account, only its presence or absence throughout the site.

Statistical methods

We plotted the average and 95% confidence interval of the percent cover or percent occurrence of each vegetation component to quantify and visualize changes in patch-level vegetation during our study. Average vegetation values were calculated for each unique plant community (alder or aspen) and growing season (0, 1, 2, 3, and mature) combination.

We used N-mixture models (Royle, 2004) to compare the relative abundance of male Golden-winged Warblers across sites. There is some concern regarding the reliability and robustness of density estimates produced by N-mixture models (Barker et al., 2017; Link et al., 2018). However, we felt comfortable drawing inferences from N-mixture estimates because we were making relative assessments and not absolute density estimates (Kéry, 2018). Models were run in program R (R Core Team, 2021) using package unmarked (Fiske & Chandler, 2011), and model rank was assessed using corrected Akaike information criterion (AIC_c) adjusted for small sample sizes (Akaike, 1974; Burnham & Anderson, 2002).

We created two model sets to investigate the relationship between Golden-winged Warbler abundance: (1) treatment effects and (2) patch-level vegetation characteristics. The first model set (hereafter referred to as management models) examined the influence of time-since-management and management category on Golden-winged Warbler abundance and included data from all sites surveyed from 2012 to 2018 ($n = 243$ sites). Though data from 2012 to 2013 were limited ($n = 13$ sites), they bolstered the sample size of sheared alder sites in later growing seasons and increased the temporal and geographic scope of the dataset to more confidently quantify treatment effects. The second model set (hereafter referred to as vegetation models) tested the impact of specific patch-level vegetation components on Golden-winged Warbler abundance and incorporated avian and vegetation data collected from 2015 to 2018 ($n = 230$ sites). We did not combine the two model sets primarily because of the inherent overlap in habitat category and the vegetation characteristics produced by management and, secondarily, because vegetation assessment protocols in 2012 and 2013 differed from those in 2015–2018. The sampling units for modeling were each unique site-year combination ($n = 637$), and count data from multiple visits to a site in a single year were stacked (Kéry & Royle, 2016). For each model set, we first identified the best detection model (limited to three variables or fewer) and then modeled abundance by comparing all model combinations of up to three variables. Detection and abundance components of the models were limited to three variables each to avoid overparameterizing models (MacKenzie et al., 2018).

Golden-winged Warbler count data were truncated to include only males detected within 100 m, which eliminated ~3% of detections. Pearson's correlation coefficient (r) matrix was calculated between all pairwise combinations of vegetation variables. The majority of variable combinations had $|r|$ values <0.7 and were not considered correlated (Sokal & Rohlf, 1969). However, small woody regeneration was correlated with no woody regeneration ($r = -0.72$); thus, these two variables were never included in the same model. Either the linear or quadratic form of each vegetation variable was selected for inclusion in the final vegetation model set based on AIC_c rank of single variable models. A list of final variables included in the two model sets can be found in Table 1.

Model selection and abundance estimation

We used AIC_c model ranking (Akaike, 1974; Burnham & Anderson, 2002) to evaluate models and 85% confidence intervals of variable β estimates to evaluate model variables (Arnold, 2010). Models within 2 ΔAIC_c and with nonzero β coefficients were considered to be top-supported models. For both model sets, we first identified the best detection model (limited to three detection variables or fewer; Table 1) and kept that top detection component when building the abundance component of the rest of the models (Burnham & Anderson, 2002). For the abundance component of the management model set, we started by testing the influence of treatment on abundance. Because the treatment model performed better than the null, we kept treatment as our base abundance model and added all possible combinations of up to two more management variables ($n = 17$ models; variables in Table 1) to build our final management model set. To model the abundance component of the vegetation model set, we created all possible model combinations of up to three vegetation variables (Table 1), which resulted in $n = 368$ models. Relative abundance of male Golden-winged Warblers was estimated using the best-supported models and is presented as males/100-m-radius survey (3.14 ha). When making direct comparisons between abundance estimates for a particular variable, all but the variable of interest were held constant.

RESULTS

We visited 242 sites to conduct 1223 point count surveys resulting in 1243 male Golden-winged Warblers detected during 741 point count surveys (60.6% of surveys). Twenty-four Golden-winged Warbler point counts were conducted across 13 sheared alder sites in north-central Wisconsin over the 2012 and 2013 breeding seasons, and between 2015 and 2018, an additional 1199 point counts were conducted at 229 sites throughout the Golden-winged Warbler's breeding range in Wisconsin and Minnesota (Figure 1). This resulted in sampling at 36 sites that were surveyed as mature alder reference and again in future years as sheared alder: 9 mature alder reference sites, 138 sheared alder sites, and 59 sheared aspen sites. Each unique site-year combination (with multiple point count visits stacked) was treated as an independent sampling unit, resulting in 56 mature alder shrubland, 460 sheared alder shrubland (162 with zero growing seasons elapsed, 132 with one growing season elapsed, 101 with two growing seasons elapsed, and 65 with three growing seasons elapsed), and 122 sheared aspen sapling (33 with zero growing seasons elapsed, 49 with one growing season elapsed, and 40 with two growing seasons elapsed) samples.

Patch-level vegetation structure varied by plant community (aspen or alder) and growing season (Figure 3). The percent occurrence of small woody regeneration did not differ by plant community, but it was greater in the first four growing seasons after shearing (e.g., alder GS2: 73.6; 95% CI: 67.9–79.3) than at mature alder reference sites (41.7; 95% CI: 36.3–47.1; Figure 3D). The percent occurrence of large woody regeneration and the percent cover of saplings were greater for aspen sites than alder sites during the first three growing seasons (Figure 3B,F) and relatively high at mature alder reference sites (large woody regeneration: 58.1, 95% CI: 52.0–64.3; sapling: 54.1, 95% CI: 48.8–59.3). There was more *Rubus* cover at aspen sites (GS0: 34.3, 95% CI: 26.4–42.2, GS1: 25.0, 95% CI: 19.0–31.0, and GS2: 53.3, 95% CI: 44.5–62.1), than alder sites (GS0: 13.3, 95% CI: 10.5–16.1; GS1: 14.8, 95% CI: 11.3–18.3; and GS2: 19.7, 95% CI: 14.4–25.0) over the first three growing seasons after shearing (Figure 3J) and was lowest at mature alder reference sites (8.8, 95% CI: 7.2–10.4).

Management model results

Detection probability in the management model set (Appendix S1: Table S1) was best modeled by a zero-inflated Poisson distribution with variables for percent cloud cover ($\beta = -0.005 \pm 0.002$ 85% CI), ordinal date ($\beta = -0.22 \pm 0.08$ 85% CI), and Beaufort wind index ($\beta = -0.28 \pm 0.14$ 85% CI). After accounting for detection probability and confirming a treatment effect, our management model set indicated only one competing abundance model ($\Delta AIC_c < 2.0$; Table 2), which included a positive effect of treatment ($\beta_{sheared} = 0.69 \pm 0.22$ 85% CI) as well as effects of year ($\beta_{2013} = 1.42 \pm 1.58$ 85% CI; $\beta_{2015} = 2.70 \pm 1.45$ 85% CI; $\beta_{2016} = 2.73 \pm 1.45$ 85% CI; $\beta_{2017} = 2.74 \pm 1.45$ 85% CI; $\beta_{2018} = 2.48 \pm 1.45$ 85% CI) and latitude ($\beta = -0.13 \pm 0.06$ 85% CI; Table 2). Growing season was not included in the top model, indicating it was not an important contributor to the variation in male Golden-winged Warbler abundance. The top model in our

TABLE 1 Variables included in N-mixture models of male Golden-winged Warbler abundance based on point count surveys conducted in Minnesota and Wisconsin from 2012 to 2018.

Variable	Description	Model set	Model component
Day	Ordinal date of survey	Both	Detection
TSS	Time since sunrise, calculated as the difference in survey start time and sunrise time	Both	Detection
Wind	Binomial category for low (Beaufort wind force scale category 0–2) and high wind (Beaufort wind force scale category 3–5)	Both	Detection
Cloud	Percent of cloud cover at the start of the survey to the nearest 25%	Both	Detection
Year	The year in which the survey was conducted	Both	Abundance
Community	Plant community; alder-dominated or aspen-dominated	Both	Abundance
Lat	Latitude of survey point	Man	Abundance
Lon	Longitude of survey point	Man	Abundance
Area	Hectares sheared at each site; with unsheared, reference sites having 0 ha sheared	Man	Abundance
GS	No. growing seasons since treatment in five categories: 0, 1, 2, 3, and mature	Man	Abundance
Treatment	Treatment status of the survey site; either sheared or unsheared reference	Man	Abundance
Canopy	Site-level percent cover of canopy trees at ocular tube sample points	Veg	Abundance
Shrub[a]	Site-level percent cover of shrubs at ocular tube sample points; shrubs had multiple main stems with branching at/below the soil	Veg	Abundance
Sapling[a]	Site-level percent cover of saplings at ocular tube sample points; saplings were 10 cm or taller, <10-cm dbh, and had one main stem with branching occurring above the soil	Veg	Abundance
Forb	Site-level percent cover of forbs at ocular tube sample points	Veg	Abundance
Fern[a]	Site-level percent cover of ferns at ocular tube sample points	Veg	Abundance
Graminoid[a]	Site-level percent cover of grass and sedge at ocular tube sample points	Veg	Abundance
Rubus	Site-level percent cover of *Rubus* spp. at ocular tube sample points	Veg	Abundance
Nonveg	Site-level percent cover of nonvegetated ground (bare ground or leaf litter) at ocular tube sample points	Veg	Abundance
S.Regen	Site-level percent occurrence of small woody regeneration (woody stems 0–1 m tall) based on presence/absence in 1-m-radius subplots	Veg	Abundance
M.Regen[a]	Site-level percent occurrence of medium woody regeneration (woody stems 1–2 m tall) based on presence/absence in 1-m-radius subplots	Veg	Abundance
L.Regen[a]	Site-level percent occurrence of medium woody regeneration (woody stems >2 m tall and <10 cm in diameter) based on presence/absence in 1-m-radius subplots	Veg	Abundance
N.Regen	Site-level percent occurrence of no woody regeneration based on presence/absence in 1-m-radius subplots	Veg	Abundance

Note: Variables are categorized by their inclusion in the detection or abundance component of the model and whether they were included in the management (Man) or vegetation (Veg) model set, or both.

[a]Variables that were modeled as quadratic terms.

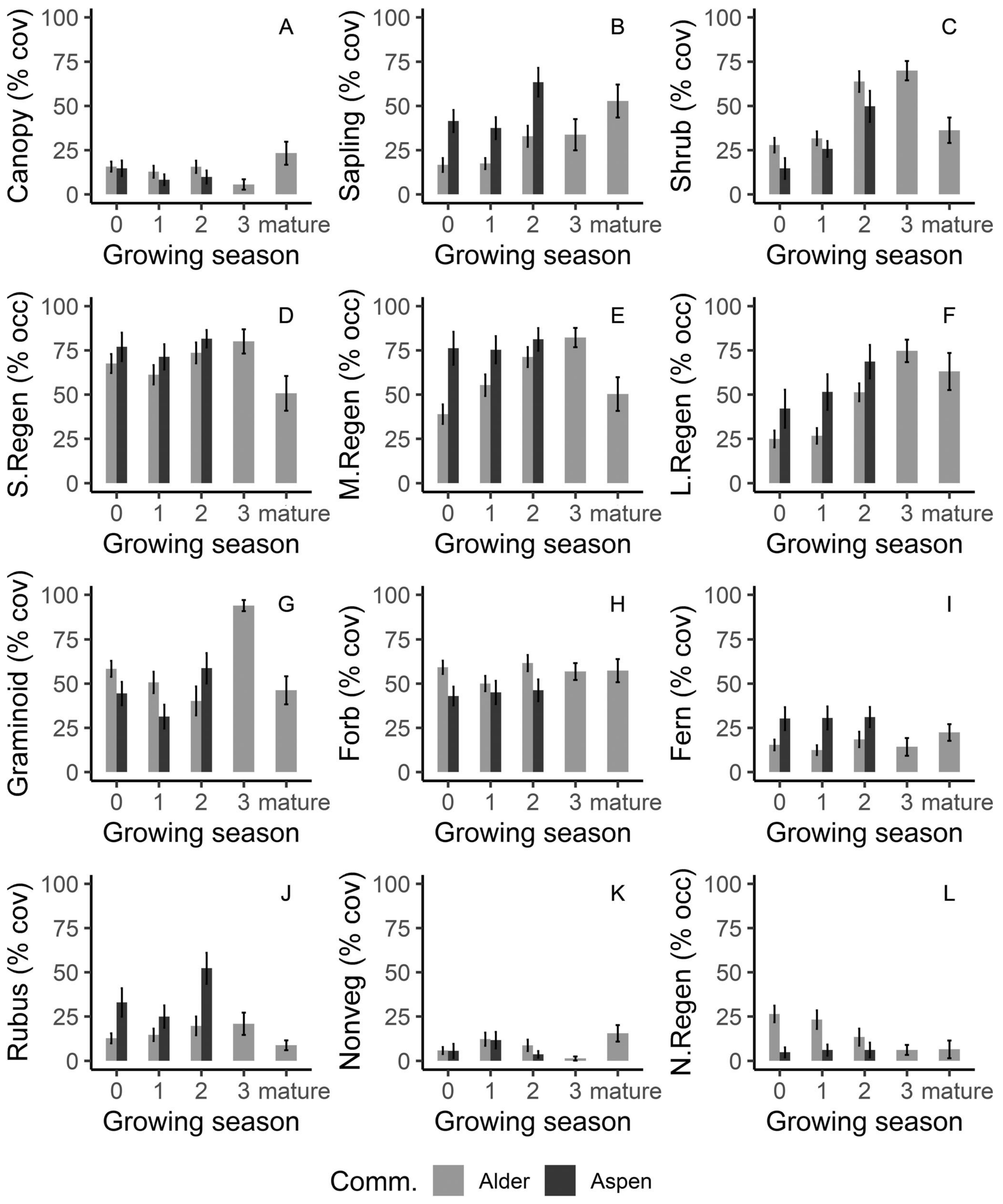

FIGURE 3 The average percent cover (% cov; A, canopy; B, sapling; C, shrub; G, graminoid; H, forb; I, fern; J, rubus; and K, nonvegetated) and occurrence (% occ; D, small woody regeneration; E, medium woody regeneration; F, large woody regeneration; and L, no woody regeneration) of patch-level vegetation values measured at Wisconsin and Minnesota Golden-winged Warbler point count locations during the 2015–2018 breeding seasons stratified by growing season category and plant community type (Comm.). Error bars represent 95% confidence intervals. All averages and confidence intervals were derived from a minimum of 32 samples per growing season/cover category ($n = 32$ for aspen cover, growing season 0).

TABLE 2 The top five male Golden-winged Warbler abundance models in the management model set with the null and base models for comparison.

Abundance models with βs and 85% CI	*K*	ΔAIC_c	Likelihood	*W*
treatment(**sheared[0.73 ± 0.22]**) + year(2013[1.42 ± 1.58]; **2015[2.70 ± 1.45]**; **2016[2.73 ± 1.45]**; **2017[2.74 ± 1.45]**; **2018[2.48 ± 1.45]**) + latitude(**−0.13 ± −0.06**)	13	0.00	1.00	0.73
treatment(**sheared[0.59 ± 0.22]**) + latitude(**−0.36 ± 0.09**) + longitude(**−0.33 ± 0.09**)	9	2.27	0.32	0.24
treatment(**sheared[0.69 ± 0.23]**) + year(2013[1.39 ± 1.55]; **2015[2.37 ± 1.42]**; **2016[2.49 ± 1.42]**; **2017[2.52 ± 1.42]**; **2018[2.19 ± 1.42]**) + area(**0.006 ± 0.005**)	13	8.18	0.02	0.01
treatment(**sheared[0.69 ± 0.23]**) + year(2013[1.42 ± 1.58]; **2015[2.43 ± 1.45]**; **2016[2.48 ± 1.45]**; **2017[2.52 ± 1.45]**; **2018[2.22 ± 1.45]**) + community(**aspen[0.14 ± 0.12]**)	13	8.495	0.01	0.01
treatment(**sheared[0.74 ± 0.22]**) + year(2013[1.43 ± 1.58]; **2015[2.43 ± 1.45]**; **2016[2.53 ± 1.45]**; **2017[2.56 ± 1.45]**; **2018[2.25 ± 1.45]**)	12	9.08	0.01	0.01
treatment(**sheared[0.64 ± 0.22]**)	7	31.60	0.00	0.00
intercept(**1.03 ± 0.16**)	6	49.57	0.00	0.00

Note: βs for each model variable are shown and bolded when 85% confidence intervals do not include zero (significant). Models were derived from data collected in Minnesota and Wisconsin from 2012 to 2013 and 2015–2018. The number of model variables (*K*), delta corrected Akaike information criterion (ΔAIC_c) adjusted for small sample size, model likelihood, and model weight (*W*) are shown.

management set suggested that sheared sites had a mean Golden-winged Warbler abundance of 2.89 males/survey (95% CI: 2.27–3.66), whereas untreated sites had half this abundance: 1.39 males/survey (95% CI: 0.96–2.02).

Patch-level vegetation model results

Detection in the vegetation model set (Appendix S1: Table S2) was best predicted by a zero-inflated Poisson distribution with variables for ordinal date ($\beta = -0.24 \pm 0.08$ 85% CI), Beaufort wind index ($\beta = -0.23 \pm 0.14$ 85% CI), and time since sunrise ($\beta = -0.10 \pm 0.07$ 85% CI). There was one abundance model <2 ΔAIC_c in the patch-level vegetation model set. The top abundance model (Table 3) included sapling^2 ($\beta = -0.15 \pm 0.06$ 85% CI), forb ($\beta = -0.10 \pm 0.05$ 85% CI), and nonvegetated ground ($\beta = -0.15 \pm 0.05$ 85% CI) and had a c-hat value of 0.87. In particular, the top model suggested Golden-winged Warbler abundance was greatest (abundance = 3.46 males/survey [95% CI: 2.54–4.71]; Figure 4) at intermediate sapling cover (~40%) and low levels of nonvegetated (abundance = 4.07 males/survey [95% CI: 2.93–5.66] at 0% nonvegetated; Figure 4) and forb cover (abundance = 4.32 males/survey [95% CI: 3.05–6.10] at 0% forb cover; Figure 4).

DISCUSSION

Our study demonstrated how an imperiled wildlife species, the Golden-winged Warbler, responded to habitat BMPs implemented in two important plant communities (Roth et al., 2019) in temperate deciduous forest landscapes of the western Great Lakes region. Shearing sapling stands and shrublands as outlined by species BMPs resulted in significant increases in Golden-winged Warbler abundance as soon as the first growing season posttreatment. Hanowski et al. (1999) found higher densities of Golden-winged Warblers at unmanaged shrub wetlands than sheared and/or burned shrub wetlands in Minnesota. However, in that study, sites were treated to encourage open emergent wetland conditions and not selected or treated to enhance or create habitat conditions specific to any species, such as was done in our study. Work by McNeil et al. (2018) quantified Golden-winged Warbler abundance in a similar habitat type in Pennsylvania, unmanaged shrub wetlands, and reported abundance (1.32 males/survey) to be similar to our observations for unmanaged alder stands (1.39 males/survey). Prior to our study, it was well recognized that closed-canopy stands dominated by sapling-diameter trees (i.e., stem exclusion; ~9–15 years) host very few nesting Golden-winged Warbler pairs (Bakermans, Smith, et al., 2015; Martin, Lutz, & Worland, 2007; Otto & Roloff, 2012; Roth & Lutz, 2004). Our work provides justification for the use of shrub or sapling shearing (as outlined by the species' BMPs; Roth et al., 2019) to prolong or restore the productive life of Golden-winged Warbler nesting habitat patches. In the Great Lakes region, the typical rotation length for aspen stands is 35–70 years (Perala, 1977; WI DNR, 2020), extending well beyond the early-successional stage when nesting Golden-winged Warblers are present. Regenerating aspen forests in the context of a full rotation would likely result

TABLE 3 The top ranked N-mixture Golden-winged Warbler abundance models in the vegetation model set within five delta corrected Akaike information criterion (ΔAIC_c) and the null model for comparison.

Abundance models with βs and 85% CI	K	ΔAIC_c	Likelihood	W
sapling**(0.09 ± 0.07)** + sapling^2**(−0.15 ± 0.06)** + forb**(−0.10 ± 0.05)** + nonveg**(−0.15 ± 0.05)**	10	0.00	1.00	0.39
sapling**(0.07 ± 0.07)** + sapling^2**(−0.15 ± 0.06)** + nonveg**(−0.17 ± 0.06)** + shrub(−0.05 ± 0.06) + shrub^2**(−0.08 ± 0.06)**	11	2.17	0.34	0.13
sapling(0.03 ± 0.08) + sapling^2**(−0.14 ± 0.06)** + nonveg**(−0.15 ± 0.05)** + fern**(0.14 ± 0.08)** + fern^2**(−0.09 ± 0.05)**	11	2.28	0.32	0.13
sapling**(0.09 ± 0.07)** + sapling^2**(−0.16 ± 0.06)** + nonveg**(−0.15 ± 0.05)** + canopy**(−0.07 ± 0.06)**	10	4.65	0.10	0.04
sapling(0.06 ± 0.07) + sapling^2**(−0.14 ± −0.06)** + nonveg**(−0.19 ± 0.07)** + graminoid**(−0.10 ± −0.08)** + graminoid^2**(−0.71 ± 0.06)**	11	4.75	0.09	0.04
sapling(0.06 ± 0.07) + sapling^2**(−0.17 ± −0.06)** + nonveg**(−0.14 ± 0.06)** + m.regen**(0.08 ± −0.07)** + m.regen^2**(0.10 ± 0.07)**	11	4.76	0.09	0.04
intercept**(1.07 ± 0.18)**	6	29.51	0.00	0.00

Note: βs for each model variable are shown and bolded when 85% confidence intervals do not include zero. The number of model variables (*K*), ΔAIC_c adjusted for small sample size, the model likelihood, and the model weight (*W*) are shown.

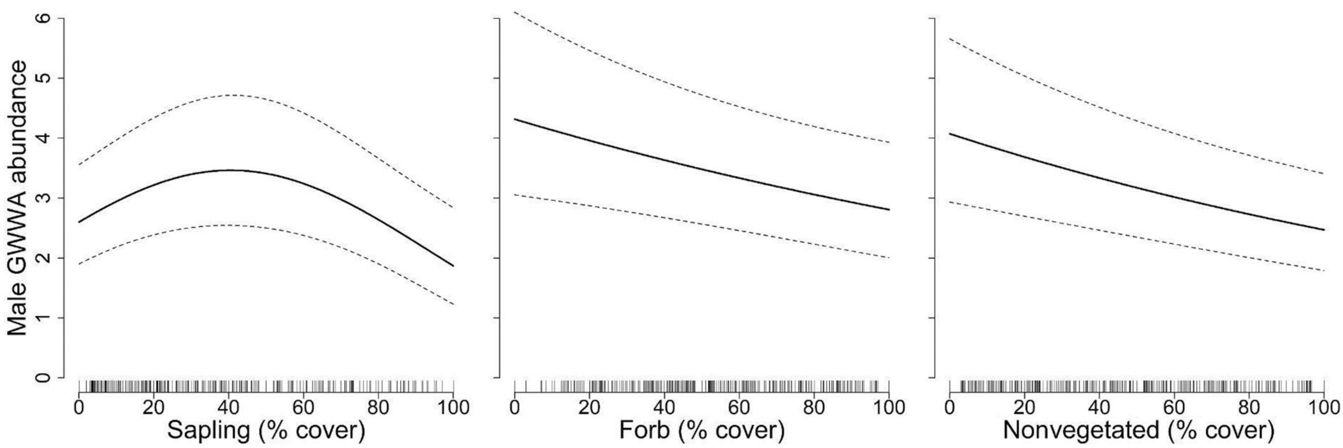

FIGURE 4 The influence of top patch-level vegetation model (<2ΔAIC_c) variables (with significant βs) on relative male Golden-winged Warbler (GWWA) abundance plotted with 95% confidence intervals. The sampling distribution for each variable is shown along the *x*-axis. Data were collected in Minnesota and Wisconsin from 2015 to 2018.

in the stand being unoccupied by nesting Golden-winged Warblers for up to 60 years. Thus, shearing following BMPs every 10–20 years, depending on site conditions, appears to be a reliable way to maintain patch-level Golden-winged Warbler abundance in stands undergoing regeneration.

Shearing resulted in immediate target species response, though the number of growing seasons postshearing did not explain much variation in abundance over the first four growing seasons. Other studies of Golden-winged Warbler ecology suggest that within regenerating woody communities, it may take multiple years after management to reach maximum male abundance (Otto & Roloff, 2012; Roth et al., 2019). Indeed, regenerating early-successional sites treated with shearing and timber harvest may be occupied for up to 16 years postharvest in other systems (e.g., Klaus & Buehler, 2001), or sometimes even mature alder shrublands may be occupied (as in this study). Initial warbler response to management may be limited at sites where all woody vegetation is sheared, increasing only after woody vegetation has had 1–2 growing seasons to regenerate. However, the BMPs recommend retaining 50% of shrubs and saplings as patches within the sheared footprint, which left ample patches of legacy woody vegetation scattered throughout the management footprint, thus immediately creating structural conditions attractive to nesting pairs (Golden-winged Warbler Working Group, 2019). This is supported by past research on aspen forests in our study region, where Golden-winged Warblers only persisted in sapling-sized stands when patches of shrubby habitat with relatively open canopy occurred within the stand (Roth & Lutz, 2004). The importance of heterogeneous microhabitat conditions (e.g., early-successional patches within otherwise more advanced successional sites) has also been found in high-elevation pastures in the Appalachian Mountains, where Golden-winged Warbler populations persisted for up to 33 years posttreatment, though density peaked much earlier (Aldinger, 2018). Given that monitoring in this study focused only on the first few years after treatment, it is highly likely that we lacked sufficient temporal variation to capture species responses to the effect of growing season progression. Regardless, the immediate response by Golden-winged Warblers observed in this study is promising, and we would expect the treatment effect to only become more pronounced as density is afforded more time to reach its maximum.

Golden-winged Warbler abundance was more influenced by patch-level vegetation attributes than plant community type. While the Golden-winged Warbler is known to have an affinity for certain forest community types (McNeil, Rodewald, Ruiz-Gutierrez, et al., 2020) and select for or against certain plant species when foraging (Bellush et al., 2016), vegetation structure is also an important habitat feature (Bakermans, Smith, et al., 2015; McNeil et al., 2018; Roth et al., 2014). When managing nesting habitat, multiple studies have reported that the plant community composition is less important than the presence of necessary habitat elements, including patches of shrubs, saplings, and herbaceous vegetation within a landscape otherwise dominated by deciduous forest (McNeil et al., 2017; Roth et al., 2019; Terhune II et al., 2016). One of the most important functional patterns we detected was the quadratic relationship between Golden-winged Warbler abundance and sapling cover, where male abundance peaks at around 40% cover. Golden-winged Warblers use saplings for song perches and for foraging substrate (Confer et al., 2020; Fiss et al., 2021). Having too few saplings results in a site that lacks the structural complexity required by the species (Roth et al., 2019), while having too many saplings can result in the herbaceous understory being shaded out. Heavy shading leads to a ground layer comprised mostly of leaf litter and bare ground, or nonvegetated cover. Herbaceous ground cover, particularly grass or sedge cover, is an important patch-level habitat feature for Golden-winged Warbler nest building and concealment (Aldinger et al., 2015; Confer et al., 2020; Terhune II et al., 2016). As indicated by our models, Golden-winged Warbler abundance is negatively associated with nonvegetated cover. Thus, a mixture of patch-level vegetation attributes (sapling cover, forb cover, and nonvegetated cover) that result in structural complexity support the highest densities of Golden-winged Warblers. This finding supports the idea that, when managing stands with a high sapling or shrub density, shearing should be conducted in such a way that some existing saplings and shrubs are retained in the stand to support structural heterogeneity (Roth et al., 2019). Additionally, previous studies have found that a diversity of forest ages and structures, including dense sapling stands unsuitable for nesting, are important foraging habitat for postfledging Golden-winged Warblers (Fiss et al., 2020, 2021; Streby et al., 2016), so maintaining patches of taller saplings within sheared areas will likely support Golden-winged Warblers during both nesting and postfledging periods.

Our study highlights the importance of pretreatment target species assessments, particularly at shrubland sites dominated by alder. Although Golden-winged Warbler abundance was higher at sheared sites than untreated sites, mature alder reference sites still regularly supported low numbers of Golden-winged Warblers. To ensure limited conservation resources are prioritized to focus on shrublands that host low warbler densities, we recommend, when possible, a pretreatment Golden-winged Warbler survey be standard practice before managing alder shrublands to ensure that potential treatment areas do not already support high territory densities. Based on our results, implementation of the shearing BMPs in the Great Lakes region is most beneficial when existing male abundance is less than 0.32 males/ha at a given site (or about 1 male per 3.14 ha survey). BMPs recommend retaining 50% of the shrubby vegetation in patches when shearing areas larger than 2 ha to maintain the desired heterogeneity (Golden-winged Warbler Working Group, 2019). Retaining some legacy structure when treating a site has been shown to increase overall bird species diversity (Hanle et al., 2020). Additionally, shearing is not recommended if the vegetation structure of small-diameter woody stems is already patchy with scattered canopy trees and interspersed with herbaceous vegetation (Roth et al., 2019), because it is unlikely that shearing will improve conditions for nesting.

Our study focused on territorial male response to shearing habitat used for nesting during the breeding season, though this demographic metric may not be the ideal indicator of habitat quality (Johnson, 2007; Van Horne, 1983). However, high Golden-winged Warbler male density (>0.2 males/ha) was indicative of relatively high pairing and nest success in aspen forests managed using the clearcut with reserves method within our study area, which suggests that high male abundance observed in the present study may be associated with high-quality habitat (Roth et al., 2014). Recent work by McNeil, Rodewald, Robinson, et al. (2020) also examined the relationship between species' response to habitat restoration (i.e., regional occupancy probability) and local nest or fledgling survival and found the two to be highly correlated. Future work that quantifies Golden-winged Warbler nest productivity and fledgling survival (i.e., full season productivity) at sheared sites would improve our understanding of the quality of the habitat created by the shearing BMPs. With that in mind, sites treated with a variety of conservation practices outlined in the Golden-winged Warbler BMPs can yield high rates of nest survival (McNeil et al., 2017; McNeil, Rodewald, Robinson, et al., 2020) and fledgling survival (Fiss et al., 2020, 2021; Streby et al., 2016).

Although our study focused on the Golden-winged Warbler, a wide variety of additional wildlife species are imperiled due to early-successional habitat loss (Askins, 1998; King & Schlossberg, 2014). Data on the responses of other species, including animals, plants, and other taxa, to the shearing of woody vegetation are needed to more fully understand both the positive and negative effects of this management practice, particularly on species of conservation concern. Federal and state agency habitat improvement programs promote shearing to improve habitat for species of conservation concern that require shrubland habitats, such as the Sharp-tailed Grouse (*Tympanuchus phasianellus*; USDA, 2007) and American Woodcock (*Scolopax minor*; Johnson, 2020; MDNR, 1994; Williamson, 2010) in the western Great Lakes and the New England Cottontail (*Sylvilagus transitionalis*; Litvaitis et al., 2021) in the Northeastern United States. Although many BMPs currently focus on charismatic birds and mammals, it is also important to understand how nontarget (and potentially overlooked) taxa respond to shearing (Litvaitis et al., 2021; Mathis et al., 2021). As the use of shearing becomes increasingly popular for shrubland management, development and refinement of science-based BMPs specific to this practice will remain important. As new information becomes available, we recommend using an adaptive management process to assess and improve shearing BMPs (Walters, 1986). Ultimately, our study provides support for the use of shearing as a conservation practice in managing habitat for Golden-winged Warblers in the western Great Lakes region.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data (Buckardt Thomas, 2022) are available from Dryad: https://doi.org/10.5061/dryad.f4qrfj70b.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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