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# Improving Conservation of Declining Young Forest Birds Through Adaptive Management

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# IMPROVING CONSERVATION OF DECLINING YOUNG FOREST BIRDS THROUGH ADAPTIVE MANAGEMENT

By

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B.S. Michigan Technological University, 2015

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Wildlife Ecology)

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The University of Maine

May 2019

Advisory Committee:

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# IMPROVING CONSERVATION OF DECLINING YOUNG FOREST BIRDS THROUGH ADAPTIVE MANAGEMENT

By Anna Buckardt Thomas

Thesis Advisor: Dr. Amber Roth

An Abstract of the Thesis Presented
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Early successional forest and shrubland habitats are collectively called young forest. Changes in disturbance regimes and land use conversion resulted in declines of young forest and associated wildlife across eastern North America. Conservation of declining young forest birds relies on the maintenance and creation of young forest habitats used for breeding. American Woodcock (AMWO; *Scolopax minor*) and Golden-winged Warbler (GWWA; *Vermivora chrysoptera*) are two declining young forest species. Conservation plans for both species use an adaptive management framework, which is an iterative process of planning, management actions, and monitoring and evaluation, in the context of species conservation goals. Adaptive management programs often fail to meet their conservation goals when monitoring and evaluation is missing or ineffective. To address this short coming, my research focuses on the monitoring and knowledge gathering aspects of the iterative process.

First, I investigated the role of landowners in monitoring the response of AMWO to habitat management on private properties. I interviewed Wisconsin landowners to determine their monitoring preferences and then developed a pilot monitoring protocol where landowner citizen scientists documented the response of male AMWO to habitat management on their properties. I conducted side-by-side AMWO monitoring with landowners followed by an interview to gauge landowner

understanding, ability, and satisfaction with the monitoring protocol. Although landowners were willing and excited to participate in AMWO monitoring, their hearing often limited their ability to collect quality data. In order to create a successful AMWO monitoring program that suits the needs of landowners and managers, I recommend in-person training, periodic hearing assessments, and flexible data submittal options.

Second, I quantified the response of male GWWA to woody vegetation shearing, a best management practice intended to create quality breeding habitat. GWWA point counts and associated patch-level vegetation surveys were conducted in three habitat management types throughout Minnesota and Wisconsin (mature alder shrubland, sheared alder shrubland, and sheared aspen sapling). Using integrated likelihood models in a distance sampling framework, I investigated the impact of 1) habitat management, and 2) patch-level vegetation characteristics, on the relative abundance of male GWWA. Habitat-management type and habitat age were included in my top supported management model, and occurrence of graminoids, no woody regeneration, and 1-2m tall woody regeneration were supported habitat factors affecting male GWWA abundance. I recommend the continuation of the shearing management practice, particularly when habitat elements are missing.

Finally, I tracked the migratory connectivity patterns of GWWA and Blue-winged Warbler (BWWA; *Vermivora cyanoptera*) in four previously unstudied populations. I used light-level geolocators deployed on male *Vermivora* to determine individual wintering ranges. Previous research has shown weak migratory connectivity structure in BWWA and strong migratory connectivity structure in GWWA, with GWWA breeding in the Great Lakes region wintering in Central America and those breeding in the Appalachians wintering in South America. I discovered previously unknown intricacies of GWWA migratory connectivity structure with birds from one site in the Great Lakes region wintering in Central

America (n=2) and South America (n=3). I propose incorporating migratory connectivity as a criterion for population segment and conservation region designation.

## DEDICATION

This thesis is dedicated to my parents Nan and Al, my siblings Luke and Emma, and my husband, Bill; the most supportive family around!

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# CHAPTER 1

# THESIS OVERVIEW

Young forest habitat, sometimes called early successional forest, is defined as open-canopy dense regenerating seedling/sapling forest which generally persists for about 20 years after disturbance (Gilbart 2012). Shrub-dominated habitats support similar wildlife species as regenerating forest, and for the purpose of this thesis, young forest refers to both forest and shrubland habitats. Over 40 species of birds in northeastern North America rely on young forest for their survival (Gilbart 2012). Young forest in North America was historically maintained and created though natural disturbances like wind, fire, and flooding from beaver (*Castor canadensis*), and by the agricultural practices of native peoples (DeGraaf and Miller 1996, Askins 1998, Litvaitis et al. 1999). Now, the frequency of many of those disturbances is greatly reduced across the landscape, and land use conversion and development are increasing, leading to a decline in the amount of young forest habitat in North America (Trani et al. 2001). Many eastern North American birds that rely on young forest have experienced population declines that parallel this loss of young forest habitat (Askins 1998, Sauer et al. 2017). In order to conserve young forest birds, species-specific conservation plans such as the *Golden-winged Warbler Status Review and Conservation Plan* (Roth et al. 2012) and the *American Woodcock Conservation Plan: A summary of the recommendations for woodcock conservation in North America* (Kelley et al. 2008), focus on maintaining and creating young forest habitat to bolster breeding populations.

My thesis focuses on the conservation of two young forest obligate bird species, the American Woodcock (*Scolopax minor*) and the Golden-winged Warbler (*Vermivora chrysoptera*). Both of these migratory species have experienced population declines likely related to the loss of young forest habitat across their breeding ranges in eastern North America (Kelley et al. 2008, Roth et al. 2012). Conservation plans for both species rely heavily on young forest habitat creation and utilize adaptive management frameworks (Kelley et al. 2008, Roth et al. 2012). Adaptive management is an iterative process of planning, management action, and evaluation and adjustment (Walters 1986). This process allows managers to incorporate current research and management monitoring to periodically update their management actions and increase conservation effectiveness for species of interest. My applied research focuses on the evaluation and monitoring aspects of adaptive management, as well as understanding basic species ecology, with the intent of improving conservation effectiveness for American Woodcock and Golden-winged Warbler.

Chapter 2 focuses on monitoring the response of American Woodcock to habitat management. Monitoring is one of the most important aspects of adaptive management, yet, insufficient monitoring is one of the main reasons adaptive management systems fail to reach their conservation goals (Aceves-Bueno et al. 2015). In many cases limited funding or personnel results in a lack of direct monitoring of management actions. Aceves-Bueno et al. (2015) argue that citizen science (volunteers collecting scientific data) can help to fill the gap in monitoring and help managers strengthen the impact and effectiveness of adaptive management. In Chapter 2, I evaluate the efficacy of landowners as citizen scientists to monitor the response of male American Woodcock to habitat management on their properties.

Chapter 3 also focuses on the evaluation stage of adaptive management, but uses professional researchers and trained technicians to monitor the response of Golden-winged Warbler to best management practices. In this chapter I asses the abundance of male Golden-winged Warbler in three different habitat management types; mature shrubland, sheared (mowed) shrubland, and sheared aspen saplings. Shearing is a best management practice used to maintain and create Golden-winged Warbler (Roth et al. 2012) breeding habitat, but very little research has focused on evaluating the response of Golden-winged Warbler to shearing. My research fills this gap in monitoring and can be used to adjust Golden-winged Warbler management strategies as needed.

For Chapter 4, I build on past research to better understand the migratory ecology of Golden-winged Warbler to aid conservation in the context of the full-annual-cycle of the species. Golden-winged Warblers are Neotropical migrants, breeding in North America and wintering in Central and South America. Golden-winged Warblers spend approximately four months on their breeding territories in eastern North America, with the remaining eight months of the year spent migrating (2-3 months) and on winter territory (Rosenberg et al. 2016). Understanding the pattern of migratory connectivity between breeding and wintering ranges is important when determining factors limiting a population and thus for Golden-winged Warbler adaptive conservation planning (Martin et al. 2007).

This thesis research was conducted with approval from the University of Maine Human Subjects Review Board under project title “2016-04-09, Exploratory Study of Family Forest Landowner Citizen Science Preferences” and Institutional Animal Care and Use Committee project “Establishing Golden-winged Warbler and Blue-winged Warbler migratory connectivity for breeding populations in Vermont, Michigan, and Wisconsin; Protocol approval number: A2016_03_06.” Additionally, all field work conducted by University of Maine researchers was conducted under USGS federal bird banding permit 23856 and a Wisconsin Scientific Collector’s Permit issued by the Wisconsin Department of Natural Resources.

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# CHAPTER 2

# HOW TO EVALUATE WOODCOCK HABITAT MANAGEMENT: ARE LANDOWNERS THE ANSWER?

## Abstract

Loss of young forest, also termed early successional forest, in North America is negatively impacting wildlife populations that rely on this regenerating forest type, especially birds. The Wisconsin Young Forest Partnership (WYFP) targets young forest management efforts to benefit American woodcock (*Scolopax minor*; hereafter, woodcock) on private lands in Wisconsin. The WYFP uses an adaptive strategy to iteratively evaluate and adjust their habitat management activities. Citizen science can be a valuable evaluation tool in this process. The WYFP aims to develop a citizen science program whereby landowners monitor woodcock in management areas on their properties. We explored the woodcock monitoring preferences and abilities of landowners through questionnaires, interviews, and pilot woodcock surveying to inform the development of a citizen science woodcock monitoring program. Landowners were enthusiastic about participating in woodcock monitoring. When creating a citizen science program for monitoring woodcock it is important to use English units for estimating distance, evaluate landowners' physical ability to hear peenting woodcock, provide in-person monitoring training, and have flexible data submittal options. Development of a successful citizen science program for monitoring woodcock requires balancing researcher goals with participant preferences and abilities.

## Introduction

Young or early successional forests, defined here as regenerating even-aged forest stands that are generally under 20 years old (Kelley et al. 2008), play an important role for many wildlife species. These cover types were historically created and maintained across the landscape by natural disturbances such as windthrow and fire; now human activities such as cropland abandonment and forest harvesting are the main sources of young forest creation (Trani et al. 2001). Young forests provide a unique vegetation structure with many dense shrubs, saplings, and herbaceous plants. This dense cover is important to a variety of species (Gilbart 2012) including bobcat (*Lynx rufus*), smooth green snake (*Opheodrys vernalis*), New England cottontail (*Sylvilagus transitionalis*), and American woodcock (*Scolopax minor*; hereafter, woodcock). Early successional forest quickly matures and becomes unsuitable for young forest wildlife species unless some form of disturbance occurs to maintain young growth (Trani et al. 2001, Gilbart 2012). Avifauna have been highly impacted by the loss of young forest cover with population declines of young forest birds paralleling changes in land use and forest succession (Trani et al. 2001).

The Young Forest Project (youngforest.org) was established to address the loss of young forest cover in the eastern United States. Through a collaborative effort by professionals, managers, and private landowners, the Young Forest Project creates young forest cover to benefit wildlife. Using best management practices, the Young Forest Project creates demonstration areas on public lands and provides resources and recommendations for management on private property. Funding opportunities for wildlife management are made available to private landowners through collaboration with the U.S. Department of Agriculture's Natural Resources Conservation Service, U.S. Fish and Wildlife Service, National Fish and Wildlife Foundation, Ruffed Grouse Society, state agencies, and other partners.

The Wisconsin Young Forest Partnership (WYFP, youngforest.org/WI) is a subgroup of the Young Forest Project, which focuses its management efforts in north-central Wisconsin. The WYFP uses the woodcock and the golden-winged-warbler (*Vermivora chrysoptera*) as focal species for their young forest management efforts. The Partnership works within an adaptive management framework (Walters 1986) that necessitates an iterative process of evaluation and appropriate adjustment to reach conservation goals for these species. Aceves-Bueno et al. (2015) suggested that insufficient monitoring and lack of stakeholder buy-in are the main reasons that adaptive management systems fail to reach their intended goals. Using citizen science, a collaborative effort between volunteers and scientists to collect data, is a potential tool for overcoming those challenges to adaptive management outcomes (Aceves-Bueno et al. 2015).

Although the term citizen science may be fairly new (Bonney 1996), the concept of non-professional and amateur scientists collecting quality avian data has a long history. The National Audubon Society's Christmas Bird Count (CBC) was started in 1900 and is a classic example of volunteers conducting long-term, large-scale bird monitoring. The North American Breeding Bird Survey (BBS, Robbins et al. 1986) is an example where professional biologists and trained enthusiasts volunteer their time to collect data following a strict scientific protocol. These kinds of volunteer survey efforts contribute to our understanding of North American bird populations and influence management decisions. Citizen science expands the temporal and spatial scales of research by including networks of non-professionals (Dickinson et al. 2010).

Of course, not all science is suitable as citizen science; the data being collected and the protocols used must be simple enough to be taught fairly quickly to a large number of volunteers. Monitoring that utilizes identification and counting of species and individuals is a popular form of citizen science. Male woodcock have a conspicuous and predictable spring mating display, making them an excellent focal species for citizen science monitoring. Woodcock have also been considered an umbrella species of young forests (Masse et al. 2015), where managing for woodcock is used as a strategy to benefit a suite of other wildlife that also use young forests (Kelley et al. 2008). Because they are considered to be an umbrella species, woodcock singing-ground surveys are used in part for assessing young forest management for many young forest species (Masse et al. 2015). Given that much of the WYFP's habitat management is conducted on private properties through collaboration with landowners, the Partnership sees a valuable opportunity to include these landowners in the evaluation stage of their adaptive management framework. They also recognize citizen science as a strategy to increase landowners' personal connection and buy-in to young forest management. This inclusion is envisioned as a landowner-based woodcock monitoring program that will help evaluate WYFP management efforts, engage landowners with their properties, and educate about young forest management. Although existing broad-scope citizen science programs like eBird (Sullivan et al. 2009) collect data on woodcock, the WYFP needs a more targeted monitoring approach to evaluate habitat management practices implemented by landowners collaborating with the Partnership. The objective of the WYFP is to create a woodcock monitoring program, where landowners survey their properties with a user-friendly woodcock monitoring protocol based on counting displaying male woodcock in spring to provide feedback to their adaptive management framework.

Creating a successful citizen science monitoring program must accommodate both the goals of research and the motivations, preferences, and abilities of citizen scientists (Greenwood 2007). To achieve this balance, Greenwood (2007) recommended clearly defining project goals and determining how best to use citizen scientists by understanding their needs, motivations, and limitations. The objective of this research was to gather landowner feedback about woodcock monitoring through interviews and pilot surveys to inform the creation of a citizen science program that suits the needs of both the WYFP and participating landowners.

## Study Area

The focal area of the WYFP's management effort is a 6-county region in north-central Wisconsin. A pilot citizen science program was designed and implemented with family forest landowners in 4 of those counties; Vilas, Oneida, Lincoln, and Langlade. These landowners owned between ~2 and 16 hectares (5 to 40 acres) of land that had either been managed for young forest habitat in the last 5 years, or had management planned for the following year. These young forest management areas were either aspen (*Populus* spp.)-dominated forest or alder (*Alnus* spp.)-dominated shrubland; both are cover types suited for young forest management in the Great Lakes region (Wildlife Management Institute 2009).

# Methods

## Data Collection

We used evaluation research methods to capture feedback on the barriers and opportunities of monitoring woodcock in a citizen science program and employed quantitative and qualitative techniques and purposive sampling (Miles et al. 2014) to gather feedback from a very specific group of Wisconsin landowners. We designed a questionnaire in 2016 to gather landowner preferences for monitoring woodcock and used these preferences in the development of a pilot woodcock monitoring program. In 2017, we asked landowners to participate in woodcock surveys using this pilot protocol. We used semi-structured interview methods to create a post-survey interview guide that prompted landowners to share specific information about their woodcock monitoring experiences, while giving landowners flexibility in how they shared that information. In this manuscript, we present social science data derived from questionnaires and interviews, and use the term 'survey' solely in reference to biological woodcock counts and protocols. This research was conducted with approval from the Protection of Human Subjects Review Board at the University of Maine (2016-04-09, "Exploratory Study of Family Forest Landowner Citizen Science Preferences").

**Woodcock Monitoring Preferences**. We used an in-person questionnaire (Table 1) to gather landowner preferences for participating in woodcock monitoring on their own properties. Participants answered questions using a 5-point Likert-style scale (Likert 1932) or by selecting from a list of options. During this in-person meeting, we also gathered basic demographic information about the participants through standardized interview questions about age, gender, working status, and education level.

**Participant Recruitment.** In May of 2016, we invited landowners or land caregivers (i.e., those family members or friends who tended a particular property in the absence of the landowner) from 21 suitable properties in the study area to participate in this questionnaire. Hereafter, the single term "landowner" includes both actual owners of the land and land caregivers. We spoke with all individuals separately, and in some cases > 1 landowner associated with each property responded to the questionnaire (e.g., husband and wife, father and son, etc.). Because our research focused on a very specific subset of landowners collaborating with WYFP, we did not intend to conduct a full statistical analysis with this questionnaire, but rather to use landowner responses to inform the creation of a 2017 pilot woodcock monitoring protocol. For that reason, and given the logistical constraints of data collection and the limited pool of properties with completed habitat management through the WYFP, our target sample size was 20 questionnaires.

**Pilot Woodcock Survey.** In 2017, we created a citizen science woodcock survey protocol and a Midwest Avian Data Center (https://data.pointblue.org/partners/mwadc/) online entry portal and database for landowners to monitor displaying male woodcock using young forest management areas on their properties. This protocol was adapted from the American Woodcock Singing-ground Survey of the U.S. Fish and Wildlife Service (Seamans and Rau 2016) and incorporated landowner feedback from the 2016 questionnaire. Woodcock surveys were a 6-min stationary count of all individual peenting (a distinctive vocalization) males detected. Observers recorded the time of first detection and estimated the distance to each peenting male detected. We included a target-diagram on the data sheet to differentiate individual male woodcock (See Appendix A). Observers also recorded environmental data (sunset time, cloud cover, wind speed on the Beaufort scale, and noise level) and metadata (date, observer, point ID). Survey points were pre-determined by the WYFP and located centrally within young forest management areas on participating landowners' property.

In early spring of 2017, landowners who were contacted for in-person questionnaires in 2016 were invited to participate in a woodcock monitoring pilot study on their properties. Prior to the survey date, we provided a detailed written woodcock survey protocol to landowners and instructed them to read the protocol prior to the time of a survey. We intentionally withheld in-person training prior to their first survey experience to remove potential variability in training and to test the effectiveness of our written protocol without additional training. Woodcock surveys were conducted using a side-by-side, but independent, 6-min singing-ground survey by an individual landowner (or small group) paired with a trained technician. Upon completion of side-by-side surveys, the technician interviewed each landowner, asking a short series of questions to gather information on their monitoring experience, their thoughts on the survey protocol, and their willingness to participate in woodcock monitoring in the future. The technicians recorded landowner responses as handwritten notes. During and after interactions with landowner(s), technicians used participant-observation strategies (Spradley 1980) to record notes and observations about their perception of the ability of landowners to conduct woodcock monitoring and any issues landowners appeared to have during the 6-min survey. Before completing interactions with landowners, technicians answered landowner protocol questions and made suggestions for improving performance and survey data quality based on their observations of landowners during the pilot survey.

The number of landowners who participated in pilot monitoring and interviews was limited by the targeted nature of our sampling and our research focus. Additional factors affecting the number of landowners able to participate in 2017 pilot woodcock surveys were the evening timing of surveys, the 20-day duration of the survey season, and the availability of 2 field technicians to conduct side-by-side surveys and interviews with landowners. Because of our fairly homogenous sample, we can reasonably expect to reach data saturation, the point where no new themes arise from additional data, at ~ 12 interviews (Guest et al. 2006).

**Data Analysis**

We summarized landowner responses to the 2016 woodcock monitoring preference questionnaire using simple averaging. We incorporated landowner feedback from the questionnaire into the 2017 pilot woodcock survey protocol and coded field notes from 2017 pilot survey interviews and field observations using elemental and affective methods, then pattern coded (Miles et al. 2014) to find reoccurring themes in the woodcock surveying experiences of landowners. We extracted quotations presented in the results from field notes.

## Results

### Woodcock Monitoring Preferences (2016)

**Participant Demographics.** Eighteen landowners completed the 2016 questionnaire (*n* = 4 female, *n* = 14 male). Participants ranged from 32 to 78 years of age, with an average age of 64 years. Four participants were working, 2 were semi-retired, and 12 were retired. Six participants had an associate's degree or no college degree, 7 had a bachelor's degree, and 5 participants held a master's degree.

**Questionnaire results.** Fifteen of 18 landowners said they would be willing to monitor displaying male woodcock on their own properties for at least 1 to 3 nights each spring (Table 2.1). Three participants were unwilling to conduct woodcock surveys on their properties. Landowners reported being slightly more likely, on average, to participate in a woodcock survey on their property if they were with a wildlife professional than without one (Table 2.1). On average, participants thought they would be as likely to conduct a woodcock survey if they had to walk 100 m into young forest as if they could survey from an easily accessible trail or road, with an average response of 3.8 out of 5 for both scenarios (Table 2.1). Given the option of estimating distance in meters, feet, or yards, most participants preferred yards (Table 2.1).

Table 2.1. Woodcock monitoring questionnaire results. In 2016, 18 Wisconsin landowners implementing young forest management on their properties were asked about their American woodcock (AMWO) monitoring preferences. Participant responses to an in-person questionnaire addressing landowner preferences for woodcock monitoring are shown here. Q1 and Q6 were multiple choice, and Q2—Q5 were answered on a 5-point Likert-style scale where 1 represented very unlikely and 5 represented very likely.

| **Response** | **Distribution of Responses by Question** | | | | | |
|---|---|---|---|---|---|---|
| | **Q1[a]** | **Q2[b]** | **Q3[c]** | **Q4[d]** | **Q5[e]** | **Q6[f]** |
| **mean response** | N/A | 3.9 | 3.3 | 3.8 | 3.8 | N/A |
| **mode response** | 1-3 days | 5 | 5 | 5 | 4 | yards |
| **0 nights** | 3 | | | | | |
| **1-3 nights** | 8 | | | | | |
| **3-5 nights** | 7 | | | | | |
| **1, very unlikely** | | 2 | 3 | 3 | 1 | |
| **2, unlikely** | | 0 | 3 | 0 | 1 | |
| **3, neutral** | | 3 | 3 | 4 | 4 | |
| **4, likely** | | 5 | 3 | 2 | 7 | |
| **5, very likely** | | 8 | 6 | 9 | 5 | |
| **meters** | | | | | | 1 |
| **feet** | | | | | | 3 |
| **yards** | | | | | | 10 |
| **feet or yards** | | | | | | 3 |
| **any unit** | | | | | | 1 |

a. How many nights would you be willing to dedicate to AMWO surveys between April 25 and May 15th?
b. How likely are you to participate in an AMWO survey on your own property if you are with a wildlife professional?
c. How likely are you to conduct an AMWO survey on your property without a wildlife professional (you can conduct the survey with family members, friends, neighbors, etc.)?
d. How likely are you to conduct an AMWO survey from a road or trail, where it is fairly accessible?
e. Which system and unit of measurement are you most comfortable using to estimate distance, meters, feet, or yards?
f. How likely are you to conduct an AMWO survey 100 meters (or 328 ft or 109 yards) off a trail or road, into the habitat?

### Pilot Woodcock Surveys (2017)

**Participant Demographics.** Between 25 April and 15 May 2017, 13 individual landowners (*n* = 7 male, *n* = 6 female) participated in a side-by-side survey and interview process. These landowners conducted a total of 29 6-min woodcock singing-ground surveys and counted 36 total male woodcock. Twelve participants were > 50 years old and 1 participant was < 50 years old. Ten of the landowners who participated in woodcock surveys completed the 2016 questionnaire, whereas 3 had not.

### Post-survey Interviews and Technician Observations

**Landowner Confidence and Ability.** After their first experience monitoring woodcock, landowners reported varying confidence in their ability to complete a woodcock survey. Confidence ranged from "nil," "not really confident: I thought we were looking for the birds not listening for them," to "I have a few questions but I understand the concept," to "fairly confident." Landowners expressed that "being able to hear a woodcock and identify it raised my confidence in doing the survey." When asked about their ability to hear woodcock peent calls, 7 landowner monitors thought they could hear peents "reasonably well." The in-person experience of listening for woodcock, not just hearing a recording, proved to be important for landowners. Landowners expressed that they "didn't know what to listen for at first but once [the technician] pointed it out" they could hear it. Listening in the field helped 1 participant realize they experience hearing issues that might affect their ability to survey; "I could hear them fine but direction takes work because I have one bad ear." Six landowners reported low confidence in being able to hearing woodcock peents: "Question mark there, my hearing is not the best," "I heard it when we got close to it but not again," "losing confidence because my ears are ringing and I'm straining to hear." Trained technicians participating in side-by-side pilot surveys with landowners were confident that 6 of 13 landowners were physically able to hear woodcock peent calls well enough to conduct a survey on their own (*n* = 4 female, *n* = 2 male).

Landowners were asked which parts of the survey were most difficult for them. Three landowners reported having difficulty with “estimating distance” to a peenting woodcock. Others said “hearing and identification” of woodcock were an issue where “knowing what to listen for,” and “too many other calls, it’s hard to focus on the woodcock” were causes for that difficulty. One landowner mentioned the difficulty of “transferring 15 mph wind speed to the 0-5 [Beaufort] scale.” Technicians observed several cases of landowners recording wind speeds in miles/hour instead of in the Beaufort scale values described on the data sheet.

**Landowner Impressions of Survey Protocol**. Overall, landowners found the survey protocol easy to follow: “on a scale of 1 to 10, 7,” “that was easy,” “real good, excellent,” “it was fine.” Several landowners expressed ease in following the protocol overall but had “some specific questions” about parts of the protocol. One landowner thought, “it was a lot to read, lots of words, but straight forward.” Six landowners offered specific suggestions for improving the survey protocol. Those suggestions included: 1) making it shorter; “break up the words, make an easy table, the info is good just too long to read,” 2) clarifying the purpose of the distance diagram on the data sheet; “the distance map…how are we supposed to mark it?” and “clarifying that the target diagram is to help with the number of individual birds,” and 3) making the web link to the woodcock sound easier to find; “biggest thing was what do I listen for? It doesn’t sound like a peent to me.” Suggestions for improving the data sheet included “larger print on the datasheet even if it took 2 pages,” and “written instructions on a second sheet to bring into the field” to help remind them of survey protocol while they were surveying.

Other general suggestions by landowners for improving their monitoring experience included: “making the time commitment required clearer to landowners,” “before we went out, play the vocalization” as a “refresher of what noise to listen for,” and “go through the form before the survey and point out the difference boxes and lines and what info goes where.”

**Future Participation in Monitoring**. Landowners were asked if they would have hesitation in conducting the same woodcock survey on their own in the future. None of the landowners reported disinterest in participating again in the future. Their responses fit into 3 categories: 1) no hesitation, 2) wanting more practice, and 3) hesitation because of hearing. Those who expressed no hesitation felt that they would "give it a shot," they were "happy to" because "it was fun!" and said they might invite company: "I'm gonna do it with my kids." Several thought that if they "had more practice [they] would do it again, 6 minutes [the time it takes to monitor one survey point] is not a big commitment." Others were "not ready to do it on my own yet," but implied with more practice they might be interested. The final group of landowners was hesitant only because of their hearing; "yeah, I would do it. Worst thing would be listening for them. I'd bring someone along," and "The hearing issue, I don't want to give you bad data, otherwise no [hesitation]."

**Landowner Preferences for Data Submittal**. Eleven participants said they would be willing to enter their data online, whereas 2 reported a preference to mail in their data sheets with 1 saying "I don't have a computer at home." Of the 11 landowners willing to enter data online, 5 registered to enter their data online and 3 took the step of entering data online. Those who entered data did so accurately.

## Discussion

The WYFP is working to create a monitoring program where landowners conduct valuable woodcock surveys and that offers education and engagement for landowners to better understand the young forest management outcomes on their properties. From our perspective as researchers, the woodcock data collected must be valid and useful to the specific goal of assessing the impact of WYFP's management efforts. Using citizen science monitoring is a valuable strategy for evaluating and updating management efforts in an adaptive management framework (Aceves-Bueno 2015). Collaborating with citizen scientists can overcome some of the financial and logistic challenges of traditional research by expanding the geographic and temporal scope of research and increasing access to private lands (Dickinson et al. 2010). Leaders of the WYFP appreciate the ecological importance and management implications of monitoring and evaluating efforts on private lands (Gibbs et al. 1999) but have limited financial means to do so. They also appreciate the social benefits of including stakeholders in the adaptive management process (Larson et al. 2013, Aceves-Bueno 2015). The citizen science program they envision creates a compromise between the lower cost and potentially lower skill level of landowners conducting surveys, with the added benefit of educating and engaging landowners through their participation. Although paid technicians likely provide higher quality ecological data, the cost of their time, and the added challenge of accessing private lands across a large geographic area, makes them an unrealistic option within the WYFP budget. By taking the time to understand the views, preferences, and limitations of Wisconsin landowners (Greenwood 2007), the WYFP is increasing the likelihood of creating a scientifically rigorous, user friendly, and engaging woodcock monitoring program that meets their monitoring and outreach objectives.

Other researchers highlight the importance of understanding volunteers (Weston et al. 2003, Greenwood 2007) and creating a sense of community among volunteers and researchers (West and Pateman 2016). Clearly explaining why the research is important and why particular variables are of interest increases volunteer interest and dedication to the project (Rotenberg et al. 2012). In our 2017 pilot survey protocol, we explained how landowner-collected data would be used, and the personal benefits of participating in monitoring: “The data you collect will help the Wisconsin Young Forest Partnership and other natural resource organizations and agencies assess the effectiveness of young forest management strategies, such as those implemented on your property. This will also give you, the observer, an opportunity to learn more about your property and the wildlife it supports.” In-person trainings are an important strategy for increasing volunteer confidence in protocols and help increase data consistency and quality (Newman et al. 2003, Gallo and Waitt 2011, Rotenberg et al. 2012). Our post-survey interviews reflected this need for in-person training, with landowners expressing a desire for additional direction prior to surveying, and several indicating that more practice or training would help encourage them to participate in the future. Reporting findings back to volunteers (Hobbs and White 2012) and giving opportunities for volunteers to provide feedback (West and Pateman 2016) also improves the volunteer experience and long-term interest in the research. The WYFP plans to create an annual report, summarizing woodcock monitoring efforts and findings, for landowners. We encouraged communication and welcomed landowner questions and feedback by clearly listing organizer contact information on our pilot survey protocol.

### Recommendations for Landowner Woodcock Monitoring

One important way to improve the consistency and quality of woodcock monitoring data is to provide in-person training for all participants (Table 2.2). We intentionally withheld pre-survey training prior to the pilot monitoring project and only provided landowners with a written protocol before attempting their first survey. Trained technicians conducting surveys alongside landowners were not confident in the consistency and quality of the data landowners were collecting after reading the written protocol alone. A possible supplement or alternative to in-person training would be to create training videos that remind landowners what to listen for and how to complete the data sheet. In a Massachusetts study, participants trained with videos were found to be as successful at identifying invasive plants as those who received in-person training, and better than those with text and photo-based training (Starr et al. 2014). Based on participant feedback and technician observations, we concluded that gaining experience through practice is key (Table 2.2). Several landowners conducted pilot surveys on 2 separate occasions. Anecdotally, these landowners seemed more confident and performed better during their second woodcock monitoring experience than their first.

Table 2.2. Recommendations for creating a landowner American Woodcock monitoring program on private lands. These recommendations are based on landowner feedback from questionnaires, interviews, and pilot woodcock surveys conducted in northcentral Wisconsin in 2016 and 2017.

| **Recommendations for Landowner Woodcock Monitoring** |
|---|
| 1. Provide in-person and/or video-based survey training for landowners. |
| 2. Standardize annual evaluation of landowners' ability to hear peenting woodcock from at least 100m away. |
| 3. Encourage pre-survey practice as this is important for landowner confidence and data reliability. |
| 4. Consider how first-time observer effects may impact data reliability and quality when conducting and interpreting data analysis. |
| 5. Provide flexible data submittal channels, both online and paper forms. |
| 6. Require submission of all hard copy data sheets to increase likelihood of receiving all survey data. |
| 7. Develop a network of non-landowner volunteers to survey at properties where landowners are unable or unwilling to survey but willing to grant access for monitoring. |

Dickinson et al. (2010) point out the importance of understanding and accounting for observer skill level and experience and recognizing “first-year” effects, where the survey skills of new observers improve over time. The BBS excludes surveys from first-year observers in their population analyses because first-time observer data has been found to artificially increase population trend estimates, as their bird detections increase with survey practice (Kendall et al. 1996). The North American Amphibian Monitoring Program (Weir 2005) requires their volunteers to take a frog call identification quiz (http://www.pwrc.usgs.gov/Frogquiz/) and score above a set threshold before they can participate in monitoring. Birder Certification Online (http://birdcertification.org/) is a similar tool that tests visual and auditory bird identification. Programs like the BBS and CBC provide learning tools and identification resources but do not require a formal evaluation of skill level before volunteers conduct surveys.

Possibly the most important aspect of creating a successful woodcock monitoring program to produce quality scientific data is to make sure that landowners who are collecting data are physically capable of hearing a peenting woodcock from ≥100 m (Table 2.2). The landowners in the potential pool of citizen scientists for the WYFP are largely retired and over the age of 50. Of the 13 landowners who participated in pilot surveys, 6 self-reported having issues hearing peent calls, and technicians felt that 7 were not able to hear woodcock peents well enough to survey on their own. Farmer et al. (2014) found that hearing and other age-related factors are a source of error in bird monitoring that could bias management decisions. To remove this bias, it is important to have some form of standardized evaluation of participants' abilities to hear peenting male woodcock well enough to conduct a survey on their own, and to continue these hearing checks through time as they continue to collect data in consecutive years. Bergh and Andersen (in press) accounted for differences in survey ability by incorporating the effect of individual observers on woodcock detection.

Developing a standardized evaluation for hearing ability and identifying woodcock will be necessary for the WYFP to meet its goal of creating a citizen science program that produces reliable data. If there is no formal evaluation of hearing ability, there will be no way to separate surveys where woodcock are absent or undetectable from surveys where landowners are physically unable to detect them. Data with such uncertainty cannot be used for making sound management decisions. If landowners are unable to hear woodcock peents to a testable standard, encouraging partner or small group monitoring, where someone who is able to hear well enough partners with someone unable to adequately hear peenting woodcock, is a more inclusive option than barring a landowner from monitoring all together. The partner monitor(s) could be a family member or friend who is trained to monitor, or even possibly an unassociated trained volunteer who would be granted access to the property for monitoring. This volunteer access strategy could also be used for properties where landowners are uninterested or unable to conduct surveys themselves but are willing to allow access to their properties for someone else to conduct woodcock surveys (Table 2.2).

Being flexible with data reporting methods also appeared important in our pilot project (Table 2.2). There are many benefits to using online databases where landowners can enter their observations in a centralized location for storage, organization, analysis, and exploration (Newman et al. 2010, Dickinson et al. 2012, Miyazaki et al. 2015). However, given the older age demographic of the landowners who may monitor woodcock, an option for returning hard-copy data seems necessary to accommodate all computer skill levels and those who may not have access to computers. After the low rate of online reporting by monitors in our pilot study, monitoring programs may benefit from making returning hard-copy datasheets a standard practice to ensure that all data collected is received (Table 2.2). Although we do not fully understand the discrepancy between the 11 landowners willing to enter online data and the 5 who actually did, training may play a role. In our pilot study, landowners were given written instructions for online submission but we provided no in-person training or demonstration. Including explicit training for data submission procedures and periodic reminders may increase online reporting by landowners.

### Future Steps for WYFP Landowner Woodcock Monitoring

The WYFP is currently reviewing its citizen science monitoring objective, using the information gathered in this study, to better align the ability and interest of the landowners with the Partnership's scientific interests. This objective will be evaluated again in the future to determine how well the program is reaching its intended research and participant goals. The next steps will be to update the survey protocol to reflect the suggestions made by pilot study landowners and the revised program objective. Developing training and outreach materials that 1) clearly and concisely lay out the goals and importance of monitoring, 2) explain the purpose and value of the citizen scientist to the Partnership's evaluation objective, and 3) educate and engage landowners, will help maintain landowner interest and participation in woodcock monitoring. Making protocols and training materials available in a centralized and user-friendly online location on the WYFP's website will enhance usability of the program. Systems for clear and simple communication and annual reporting back to landowners and a channel for gathering landowner feedback into the future will be developed to increase longevity of participation by landowners.

Revising WYFP's evaluation objective to be consistent with landowner needs and abilities is key to the successful launch and sustainability of a citizen science-based woodcock monitoring program. The strategies and recommendations from this research will help other land managers as they decide if a citizen science program is right for them as they create wildlife monitoring and habitat management evaluation programs in the future.

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# CHAPTER 3

# ARE WE SURE ABOUT SHEARING? EVALUATING THE IMPACT OF A WIDELY USED BUT POORLY ASSESSED HABITAT MANAGEMENT PRACTICE

## Abstract

Many North American bird species associated with young forests and shrublands have experienced population declines due to loss of breeding habitat. Successful conservation of these birds relies, in part, on restoring or mimicking natural disturbances to create habitat. Periodic mowing or shearing of shrubs and saplings is a strategy used by managers to create young forest or shrublands for a variety of wildlife species. However, little research has focused on evaluating avian response to shearing. I evaluated the response of Golden-winged Warbler (GWWA, *Vermivora chrysoptera*) to shearing management by quantifying relative male abundance. Breeding season point counts were conducted in 2012, 2013, and 2015-2018 at 252 sites across Minnesota and Wisconsin in three habitat-management types: mature alder shrublands, sheared alder shrublands, and sheared aspen saplings. In 2015-2018, habitat metrics were estimated at 231 of the sites. I used integrated-likelihood modeling in a distance sampling framework to assess the importance of 1) management variables (like habitat-management type, time since shearing, and cover type), and 2) vegetation metrics (such as percent occurrence of woody stems, canopy, and graminoids) on male GWWA abundance. Model selection suggested that habitat-management type and time since shearing are important predictors of male abundance, with the highest predicted abundances in mature alder shrublands and during the third season after shearing. Vegetation models showed a positive linear effect of graminoid occurrence and a negative quadratic effect of 1-2 m tall woody regeneration on male density. I found shearing to be a viable management strategy for increasing male GWWA abundance.

## Introduction

Over forty species of birds in Eastern North America rely on young forest habitats for at least part of their annual life cycle (Gilbart 2012). Young forest habitats are generally ephemeral and characterized by an open canopy and mosaic of woody and herbaceous regeneration. Young forest includes both early-successional forest and shrub-dominated habitats. Historically, young forest was maintained through disturbances such as wind events, flooding from beavers (*Castor canadensis*), wildfire, and agricultural practices and burning by native peoples (DeGraaf and Miller 1996, Askins 1998, Litvaitis 1999). More recently, the suppression of flooding and fires, and habitat loss from land use change and development, has reduced the amount of young forest habitat (Trani et al. 2001). Many young forest birds have experienced population declines in correlation with this loss of habitat (Askins 1998, Sauer et al. 2017). It is widely accepted that successful conservation of young forest birds relies, in part, on restoring or mimicking natural disturbances to create suitable breeding habitat on both public and private land (Askins 1998, Litvaitis 1999, Hunter et al. 2001, Thompson and DeGraaf 2001, DeGraaf and Yamasaki 2003, Smetzer et al. 2014, Roth et al. 2012*b*, Gilbart 2012).

One management strategy used to mimic disturbance in shrub and sapling communities is periodic mowing or shearing (Hanowski et al 1999, Sargent and Cater 1999, Zuckerberg and Vickery 2006). This method targets mature and senescent shrubs and dense homogenous stands of aging saplings (1-4 inches in diameter and in a stem exclusion stage of forest stand development) in order to reestablish desired, regenerating woody vegetation structure and increase the longevity of the habitat for young forest wildlife. Shearing can reestablish a young forest state by opening the canopy and allowing for the release of early successional herbaceous growth such as ferns, forbs, grasses, and sedges. Shearing encourages stump and root sprouting of species like *Alnus* spp., *Salix* spp., *Populus* spp., and *Acer* spp., creating patches of dense woody stems and can be used to increase vegetation structural complexity for wildlife.

Managers use shearing to create habitat for a variety of avian species. American Woodcock (*Scolopax minor*, Sepik et al. 1981, Kelley et al. 2008), Ruffed Grouse (*Bonasa umbellus*, Dessecker et al. 2006), and Golden-winged Warbler (*Vermivora chrysoptera*, Roth et al. 2012*b*) conservation plans incorporate shearing as a strategy to create and maintain young forest habitat. Although shearing is a common management practice for young forest bird conservation, little research has focused on evaluating wildlife response to shearing. In a study of young forest management, Masse et al. (2015) found that bird abundance and diversity were higher in areas managed as woodcock singing grounds than at random forest sites. However, this study combined young forest habitats created by harvest and mowing (shearing) without testing the effect of management strategy. Hanowski et al. (1999) found that bird species composition did not vary between shrub wetlands managed with burning, shearing, or shearing and burning combined, but that certain species, including Alder Flycatcher (*Empidonax alnorum*), Golden-winged Warbler, and Veery (*Catharus fuscescens*), were more abundant in unmanaged shrublands than managed shrublands. However, this study was applied to wetland shrub, and not upland shrub or sapling habitats, which inherently support different assemblages of species.

Given the lack of prior assessment of the management strategy, my research evaluates the response of Golden-winged Warbler (GWWA) to young forest created specifically through shearing. GWWA is a young forest obligate breeder and is experiencing one of the steepest population declines of any North American songbird, making it a species of conservation concern in the US (USFWS 2008) and listed as threatened in Canada (Environment Canada 2014). North American Breeding Bird Survey data suggest a range wide -2.28% (95% CI: -3.08% to -1.47%) population change per year between 1966 and 2015 (Sauer et al. 2017). Conservation efforts to stabilize GWWA populations have focused on the creation and maintenance of young forest habitats used by GWWA for nesting (Roth et al. 2012*b*).

The Golden-winged Warbler Working Group (hereafter referred to as the Working Group, www.gwwa.org) created best management practices (BMPs) to guide the creation of GWWA habitat by managers and landowners (GWWA Working Group 2013). These BMPs include specific guidelines for implementing shrubland and sapling shearing. In many cases, young forest habitat exists, but does not have the appropriate structure for breeding GWWA. For example, shrubs may be too evenly distributed, there may be too little herbaceous growth, too little edge (when residual canopy trees are not present), or there may be high herbaceous cover but low woody cover (GWWA Working Group 2013). Shearing is suggested as a BMP to treat these "symptoms" and improve habitat structure for GWWA and associated species (GWWA Working Group 2013). Once a site is identified that meets vegetation community and landscape-level habitat requirements (See GWWA Working Group 2013 page 3-4), shearing can be considered as a strategy for creating important patch-level features for GWWA. Some of these patch features include patch areas of at least 5 acres (2.02 ha), or 25 acres (10.12 ha) if the patch is greater than 1000 ft (304.8 m) from an existing GWWA breeding population, a mosaic of herbaceous openings and clumps of woody regeneration where shrubs or saplings cover 30-70% of the area, the presence of scattered overstory trees for singing perches (2-6 trees/hectare), and less than 25% cover of low woody vegetation, leaf litter, and bare ground combined (Roth et al. 2012*a*). By following BMPs, shearing can be implemented in a way that mimics natural disturbance regimes and recreates or established these patch level features, improving habitat for GWWA and other young forest wildlife.

The goal of my research is to formally evaluate the effect of shrub and sapling shearing as a management strategy for young forest bird conservation at a region-wide scale. I monitored GWWA in the Great Lakes breeding population to evaluate the effect of habitat treatment and patch-level characteristics on male abundance. I specifically addressed the questions 1) Does abundance of male GWWA vary among habitat-management types (mature alder shrubland, sheared alder shrubland, sheared aspen sapling)?, 2) Does habitat age post-harvest influence male GWWA abundance?, and 3)

Which patch-level habitat characteristics are associated with higher male GWWA abundance, among the three habitat-management types?

## Methods

### Study Area

Study sites were located across Minnesota and Wisconsin, USA from 45.1 to 48.6 degrees latitude and -89.2 to -95.6 degrees longitude (Figure 3.1). Sites were dominated by alder (*Alnus* spp.) or aspen (*Populus* spp.*)* woody species, with willow (*Salix* spp.) also commonly present in shrublands, and were located within a larger matrix of predominantly deciduous forest. Sites on both public and private land that were 0-5 years post-shear were selected for sampling and nearby mature shrublands (<10 km from the nearest sheared site) on public lands were surveyed for comparison. The three habitat-management types sampled were mature alder shrubland (alder-dominated with some interspersed canopy trees), sheared alder shrubland (alder-dominated with shrubs mowed and any canopy trees retained), and sheared aspen saplings (with aspen saplings mowed and a few dispersed canopy trees retained). Mature sites were selected based on dominant cover type, habitat age, and proximity to sheared sites, but no particular characteristics in relation to GWWA habitat needs were considered.

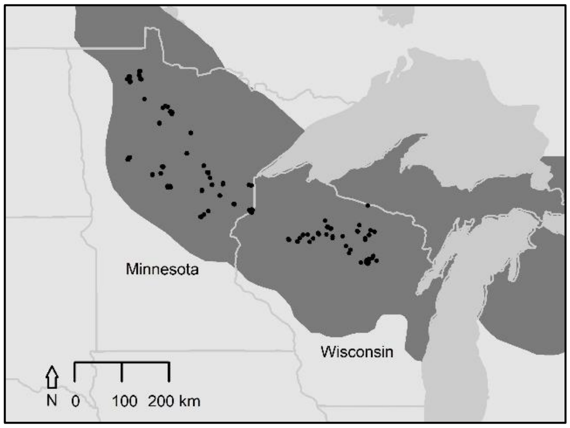

Figure 3.1. Golden-winged Warbler survey location map. Black dots indicate the 252 sites where GWWA point count surveys were conducted during the 2012-2013 and 2015-2018 breeding seasons. The dark gray polygon represents the 2011 Golden-winged Warbler breeding range, courtesy of the Golden-winged Warbler Working Group.

Sheared sites were 0.12 to 29.9 hectares in area (Figure 3.2) and ranged in age from the start of the first growing season after treatment (stand age zero) to the sixth growing season after treatment (stand age 5; Figure 1.3). Mature sites were not mechanically disturbed within the prior 20 years and were dominated by tall alder (> 3 meters) exhibiting decadent, horizontal stems, with each mature site

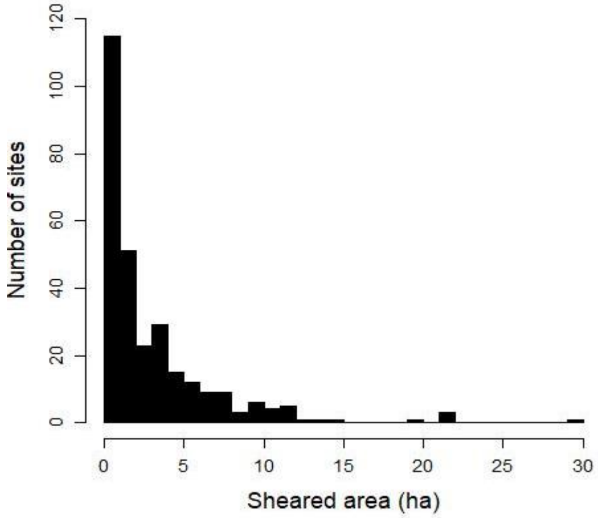

Figure 3.2. The frequency of sheared area at Golden-winged Warbler survey sites across Minnesota and Wisconsin. Mature shrubland sites (n= 58) have a sheared area of 0 ha. If a site was surveyed both before and after treatment, it is included twice in the figure as both 0 ha and a sheared area >0 ha.

Figure 3.3. A photo comparison of a post-shear site at age zero and age one. Post-shearing regeneration quickly led to distinctive changes in vegetation structure. Pictured is an alder site sheared in winter 2016 in Lincoln County, WI. Panel A shows the first growing season after treatment in early July 2016. Panel B shows the second growing season in late June 2017. Photos by A. Buckardt Thomas.

maintaining structural consistency throughout the study. The exact age of mature alder on these sites was unknown. Sapling stands in the stem exclusion stage were not surveyed, however it is well documented that GWWA densities decline as saplings reach this stage (Roth 2001, Roth and Lutz 2004, Martin et al. 2007). Soils ranged from dry upland to saturated lowland, with patches of standing water on some sites at the time of survey. Survey points were located centrally within an area of continuous mature alder or a treated area to maximize survey coverage of the habitat-management patch.

### Field Methods

GWWA relative abundance was estimated consistently across all three habitat-management types using a passive 10-minute point count. Two point count surveys were conducted at least 5 days apart at each point between 25 May and 2 July from 2015-2018, while only one survey was conducted in 2012-2013. Although only one survey point was located in each site, several sites were relatively close together so points were spaced ≥ 250 meters apart to maintain independence of observations (Ralph et al. 1995). Each point was surveyed in at least one year and for up to four consecutive years. All surveys were conducted in favorable weather conditions (no heavy precipitation, wind, or fog) and between 30 minutes before sunrise and five hours after sunrise. Metadata including weather conditions (precipitation type, Beaufort wind category, percent cloud cover among 4 categories), point location, survey start time and date, and observer were recorded before each point count began. The 10-minute passive period was subdivided into five, 2-minute time bins. Data were collected for all birds detected during the passive count including species, time bin, distance bin (0-25m, 25-50m, 50-75m, 75-100m, >100m), sex, and detection type. When a GWWA was detected, the detection type (visual, audio, both), sex, time bin, distance bin, and exact distance to the bird using a laser rangefinder were recorded. At sheared sites, only male GWWA detected within the treatment patch were recorded. Associated habitat data were collected each year a point count survey was conducted, except at mature alder sites where habitat variables were estimated only once and assumed to be consistent across the study period.

The protocol used to quantify habitat variables in 2012-2013 differed from the protocol used in 2015-2018. Although similar variables were assessed among years, methods were not comparable and only habitat variables from 2015-2018 were used in modeling the effect of habitat characteristics on male GWWA abundance. From 2015-2018, habitat elements were quantified along three 100-meter transects radiating from the survey point at 0, 120, and 240-degree azimuths. Every ten meters along the transects, an ocular tube (James and Shugart 1970) was used to record the presence or absence of bare ground, leaf litter, graminoids (grass and sedge), forbs, ferns, *Rubus*, shrubs, saplings, and canopy trees. At the same 10-meter subplots, presence or absence of woody regeneration (shrubs and saplings) was noted in four height categories (none, small (0-1m tall), medium (1-2m tall), and large (>2m tall)) within a 1-meter radius area. The no woody regeneration category included all habitat elements besides shrubs and saplings. An ideal vegetation sample resulted in records at 30 subplots. When a transect exited the sheared area or mature stand it was truncated, resulting in sites with fewer than 30 subplots. Site level occurrence values for each habitat element were estimated by summing the number of times each sampled category was present and then dividing by the total number of subplots sampled. For example, if I sampled 28 subplots, and fern was present at 15 of those subplots, the overall site estimate would be (15/28) * 100 = 53.5% fern occurrence. Percent occurrence differs from the commonly used percent cover metric, because it does not take the density of each habitat element into account, only its presence or absence throughout the site. I used a site-wide sampling approach, rather than commonly used quadrat or radial-plot sampling approaches, in order to match the scale of the point count sampling and to accomplish a rough patch-level assessment of the important habitat elements laid out in the GWWA BMPs.

Tree basal area information was gathered at the central survey point and subplots at 50 and 100m along each transect. At these seven locations, a 10 basal area factor wedge prism was used to estimate canopy tree basal area by tree species. Transects that left the sheared or mature stand were truncated and not all sites had data from seven basal area subplots. The basal area values for each subplot were averaged to generate a site-wide basal area estimate.

## Statistical Methods

I was interested in understanding both the impact of shearing management and the specific vegetation characteristics that influence male GWWA relative abundance during the breeding season. I created two distinct model sets to address these two aspects of habitat management for GWWA. The first model set (hereafter referred to as management models) focused on the impact of habitat-management type, habitat age, and cover type on GWWA abundance, and included data from all sites surveyed from 2012-2013 and 2015-2018 (n=252 sites). The second model set (hereafter referred to as habitat models) tested the impact of specific habitat characteristics on GWWA abundance and incorporated survey data and associated habitat variables from 2015-2018 (n=224 sites). The two model sets were not combined because of the inherent overlap in habitat management and the vegetation characteristics produced by management, and because habitat assessments in 2012 and 2013 differed from those in 2015-2018.

After plotting a histogram of the number of male GWWA detections by distance bin, I truncated my count data to include the four innermost distance bins (0-25m, 25-50m, 50-75m, 75-100m; Buckland et al. 2001), which eliminated the outermost 3% of detections. I decided to retain detections from the 75-100m distance bin because 16% of all detections fell within it. I reduced the number of habitat variables included in my final model sets by running Pearson's correlations between parameter combinations. When Pearson's correlation coefficient (r) values were greater than 0.55 or less than -0.55 I considered the variables correlated and maintained only one of the variables for inclusion in modeling. In cases where one variable was correlated with multiple other variables (for example, medium height woody regeneration was correlated with large woody regeneration (r = 0.60) and small woody regeneration (r = 0.58)), I retained the single variable which was correlated with the greatest number of other variables (in this example, I kept medium woody regeneration). This strategy of parameter selection allowed us to capture the influence of a group of correlated variables (small, medium, and large woody regeneration) on GWWA abundance by modeling only a single parameter. Selection between any two singly correlated variables was based on review of existing published scientific literature, assessment of biological significance of the variables, and in some cases, AIC ranking (Akaike 1974) of univariate models.

Tree basal area was correlated with percent canopy cover (r=0.61). Based on univariate abundance models of each variable, canopy cover was 2.29 ΔAIC lower than basal area, so canopy cover was retained for final modeling. Graminoid occurrence was correlated with leaf litter (r=-0.61), and based on the biological significance of grass for GWWA nesting (Aldinger et al. 2015, Confer et al. 2011) and its inclusion in previous GWWA habitat models (Terhune et al. 2016) graminoid was retained for modeling. Previous modeling efforts have found shrub and sapling cover (Bakermans et al. 2015) and woody regeneration (indiscriminate of shrub/sapling designation; Aldinger et al. 2015) to influence GWWA abundance and nest survival. Because woody regeneration is inherently a combination of shrub and sapling stems, I used Pearson's correlations to verify that woody regeneration variables and shrub and sapling occurrence were not correlated. I found that shrub occurrence was not correlated with sapling occurrence (r=0.06), and neither variable was correlated with any of the woody regeneration categories, so I retained shrub, sapling, medium woody regeneration, and no woody regeneration for final modeling. Fern occurrence was estimated at each site but I determined it was not a biologically important indicator of GWWA abundance based on literature review (eg: Bulluck and Buehler 2008, Bakermans et al. 2015), and did not include fern in final models. The list of parameters included in my final modeling process can be found in Table 3.1.

Table 3.1. Integrated likelihood distance sampling model parameters. A list and description of all parameters included in the Golden-winged Warbler abundance modeling process. Parameters are categorized by their inclusion in the detection versus abundance part of the integrated likelihood distance sampling model and whether they were included in the management or habitat model set, or both.

| | Model Parameter | Parameter Description |
|---|---|---|
| **Modeling Detection** | | |
| *Included in Both Model Sets* | Yr | Survey year; 2012, 2013, 2015, 2016, 2017, or 2018 in management models, and 2015, 2016, 2017, or 2018 in habitat models |
| | Daycat | Ordinal date of survey in three categories; day 141-155, day 156-170, or day 171-185 |
| | TSScat | Time since sunrise, calculated as the difference in survey start time and sunrise time, in 6 categories; -30-30, 30-90, 90-150, 150-210, 210-270, or 271-330 minutes |
| | Man | Management status of the survey site; either sheared or unsheared |
| | Wind | Beaufort wind force scale category; 0, 1, 2, 3, or 4 |
| | Hab.Man | Habitat management type; mature alder shrubland, sheared alder shrubland, sheared aspen saplings |
| | Cover | Cover type; alder-dominated or aspen-dominated |
| | Cloud | Percentage cloud cover during survey, in 5 categories; 0, 0-25, 25-50, 50-75, 75-100% |

| | Model Parameter | Parameter Description |
|---|---|---|
| **Modeling Abundance** | | |
| *Included in Both Model Sets* | Yr | Survey year; 2012, 2013, 2015, 2016, 2017, or 2018 in management models, and 2015, 2016, 2017, or 2018 in habitat models |
| | Day | Continuous ordinal date of survey |
| | Lat | Latitude of survey point |
| | Lon | Longitude of survey point |
| | Area | Hectares sheared at each site; with unsheared sites having 0 hectares sheared |
| | Age | Habitat age of sites in 5 categories; 0, 1, 2, 3-5, mature |
| | Cover | Cover type; alder-dominated or aspen-dominated |
| *Included in Management Model Set* | Hab.Man | Habitat management type; mature alder shrubland, sheared alder shrubland, sheared aspen saplings |
| | Man | Management status of the survey site; either sheared or unsheared |

Table 3.1. Continued

| | | |
|---|---|---|
| *Included in Habitat Model Set* | Bare | Site-level percent occurrence of bare ground at ocular tube sample points |
| | Canopy* | Site-level percent occurrence of canopy trees at ocular tube sample points |
| | Forb* | Site-level percent occurrence of forbs at ocular tube sample points |
| | Graminoid* | Site-level percent occurrence of grass and sedge at ocular tube sample points |
| | M.Regen* | Site-level percent occurrence of medium woody regeneration (woody stems 1-2m tall) based on presence/absence in 1m radius subplots |
| | N. Regen* | Site-level percent occurrence of no woody regeneration based on presence/absence in 1m radius subplots |
| | Rubus* | Site-level percent occurrence of Rubus spp. at ocular tube sample points |
| | Shrub* | Site-level percent occurrence of shrubs at ocular tube sample points |
| | Sap* | Site-level percent occurrence of saplings at ocular tube sample points |

* indicates a parameter that is included in modeling as both a linear and quadratic effect

I ran models in program R (R Core Team 2018) and assessed model rank using Akaike information criterion (AIC, Akaike 1974). Both management and habitat datasets were analyzed under a distance sampling framework (Buckland et al. 2001) using an integrated likelihood approach developed by Oedekoven et al. (2013). The integrated likelihood approach assumes that detection is perfect at the survey point but allows for imperfect detection as a function of distance and heterogeneity parameters. The integrated likelihood model simultaneously integrates the detection model with an abundance model, influenced by additional parameters, using generalized liner mixed-effect models via a log link and Poisson error structure (Buckland et al. 2001, Oedekoven et al. 2013). Key advantages of this approach are that it 1) does not assume random placement of points or transects, 2) accommodates inter-dependence of sample data (repeated counts or multiple points per site) by modeling site as a random effect, and 3) permits heterogeneity variables to influence the detection function (Oedekoven et al. 2013).

### Model Selection and Abundance Estimation

For both the management and habitat model sets, I first determining which distance function best fit the data. The half-normal and hazard rate detection functions were each combined with a null abundance model, which included parameters for the intercept ($B_0$) and a random effect of site (bj), and then ranked using AIC. The half-normal performed best for both management and habitat model sets and was used for all subsequent modeling. I then modeled stratified detection by quantifying the effect of individual categorical heterogeneity parameters (Table 3.1) in combination with the half-normal distance function and the null abundance model (Buckland et al. 2001). I considered only single-variable detection models following the example of Oedekoven et al. (2013) and selected the stratified detection model with the lowest AIC for each model set. For both the management and habitat models, the second ranked detection model was greater than 2 ΔAIC from the top model.

Next, I modeled parameter effects on abundance for the management model set while maintaining the top detection model in each model set. I used a two-stage hierarchical modeling approach (Burnham and Anderson 2002). In the first stage of modeling, I created abundance models of survey variables (Day, Year, Longitude, and Latitude) individually and in additive combinations based on AIC performance. The resulting first-stage base model was $B_0$ +bj + Day + Yr. Second stage modeling built on the first-stage base model by incorporating the remaining management variables (Age, Area, Cover, Habitat-management, and Managed) individually and in additive combinations based on AIC rank of all individual models. I never included Habitat-management and habitat Age in the same model because they are not independent of one another. Particularly because mature alder habitat is always age mature.

For the habitat model set, I used a hierarchical modeling process (Burnham and Anderson 2002) in three stages. I first modeled survey variables (Day, Year, Longitude and Latitude) individually, then in additive combination based on AIC rank, to build a first-stage base model ($B_0$ +bj+ Day + Yr). I then added individual general site variables (Age, Area, Cover) to that first-stage base, resulting in model $B_0$ +bj + Day + Yr + Cover as the second-stage base model (lowest AIC). In the final stage of model selection, I incorporated vegetation variables (Table 3.1) by adding them to the second-stage base model. Vegetation variables were modeled individually. I determined ultimate model support based on AIC rank and by examining the 95% confidence intervals of model beta values. I rejected vegetation variables with parameter coefficient confidence intervals that overlapped zero, even when they were included in models with $\Delta$AIC <2.

Relative abundance of male GWWA was estimated using parameter coefficients of supported models (≤ 2 $\Delta$AIC) and is presented as males/100m radius survey (3.14 ha). I based predictions and associated error solely on fixed effects under the assumption that the random effect is zero-centered relative to the fixed effects component of the model. When making direct comparisons between abundance estimates for a particular variable, all but the parameter of interest was held constant. For example, when comparing abundance estimates between habitat management types, day, year, and longitude were held constant and only the habitat management type was changed. Reported model estimates were based on year 2016, day 162 (middle of the survey period) and -91.4˚ longitude. I used the Delta method (Powell 2007) in R package emdbook (Bolker et al. 2019) to calculate standard errors, and derived 95% confidence intervals of estimates as SE*1.96.

## **Results**

A total of 1,229 points counts were completed at 252 sites, resulting in 1,749 male GWWA detections. Thirty-nine GWWA point counts were conducted across 21 sites in Northcentral Wisconsin over the 2012 and 2013 breeding seasons and an additional 1,190 point counts were conducted at 231 sites throughout the GWWA breeding range in Wisconsin and Minnesota (Figure 3.1) between 2015 and 2018. A total of 136 point count surveys were completed in mature alder shrubland, 861 in sheared alder shrubland, and 232 in sheared aspen sapling stands.

### Management Model Results

AIC model ranking showed support (ΔAIC ≤ 2) for two abundance models ($B_0$ + bj + Day + Year + Longitude + Habitat-management and $B_0$ + bj + Day + Year + Longitude + Age) within the management model set (Table 3.2). There was a significant negative linear effect of longitude on male GWWA abundance in both top models (beta = -0.13 ± 0.05 SE and beta = -0.21 ± 0.04 SE, respectively) meaning a higher abundance at more western sites. The parameter coefficients for sheared alder (beta = -0.01 ± 0.20 SE) and sheared aspen (beta = 0.30 ± 0.22 SE) did not differ significantly from the intercept (beta = 1.96 ± 0.20 SE), which represented mature alder. The sheared aspen habitat-management type had the highest estimate of relative abundance of male GWWA (10.58 ± 1.21 SE), though 95% confidence intervals of abundance estimates overlapped between habitat-management types (Table 3.3).

Table 3.2. Top ranked management models. The top ranked models in the management model set with cumulative model weight of 1. Detection was modeled as the half-normal distance distribution stratified by habitat-management type. The number of model parameters (K), delta AIC, model likelihood and model weight (*W*) are shown.

| **Abundance Model** | **K** | **ΔAIC** | **Likelihood** | ***W*** |
|---|---|---|---|---|
| Base* + Lon + Hab.Man | 14 | 0.00 | 1.00 | 0.39 |
| Base + Lon + Age | 16 | 0.58 | 0.75 | 0.29 |
| Base + Lat | 12 | 3.75 | 0.15 | 0.06 |
| Base + Hab.Man | 13 | 3.94 | 0.14 | 0.05 |
| Base + Lon + Man + Age | 17 | 4.32 | 0.12 | 0.04 |
| Base + Age | 15 | 4.70 | 0.10 | 0.04 |
| Base + Man | 12 | 4.57 | 0.10 | 0.04 |
| Base + Man + Age | 16 | 5.08 | 0.08 | 0.03 |
| Base | 11 | 5.33 | 0.07 | 0.03 |
| Base + Lon | 12 | 6.14 | 0.05 | 0.02 |

* Base = intercept + random effect of site + day + year

Table 3.3. Management model Golden-winged warbler relative abundance estimates by habitat management type. Estimates of relative abundance of male Golden-winged Warbler (males/100m radius site) in three habitat-management types based supported management model $B_0$ + bj + Day + Year + Longitude + Habitat-management. $B_0$ is the intercept and bj is the random effect of site. Estimates are relevant to year 2016, day 162 (the middle of the survey period) and longitude -91.4˚. Standard errors were derived using the Delta method and multiplied by 1.96 to produce 95% confidence intervals.

| | **Abundance Estimate** | **SE** | **Lower CI** | **Upper CI** |
|---|---|---|---|---|
| **Mature Alder** | 7.83 | 1.56 | 4.78 | 10.89 |
| **Sheared Alder** | 7.72 | 0.88 | 5.99 | 9.46 |
| **Sheared Aspen** | 10.58 | 1.21 | 8.20 | 12.95 |

When comparing male abundance by habitat age, the parameter coefficient for age two (beta = 0.47 ± 0.12 SE) was significantly different than the age zero parameter coefficient (represented by the intercept; beta = 1.87 ± 0.13 SE). Model-derived estimates of the relative abundance of male GWWA ranged from 7.24 ± 0.73 SE in age one habitat to 12.05 ± 1.63 SE in age two habitat (Figure 3.4). Note that all mature age habitats were alder cover type while the zero, one, two, and three-five age categories include both alder and aspen cover types.

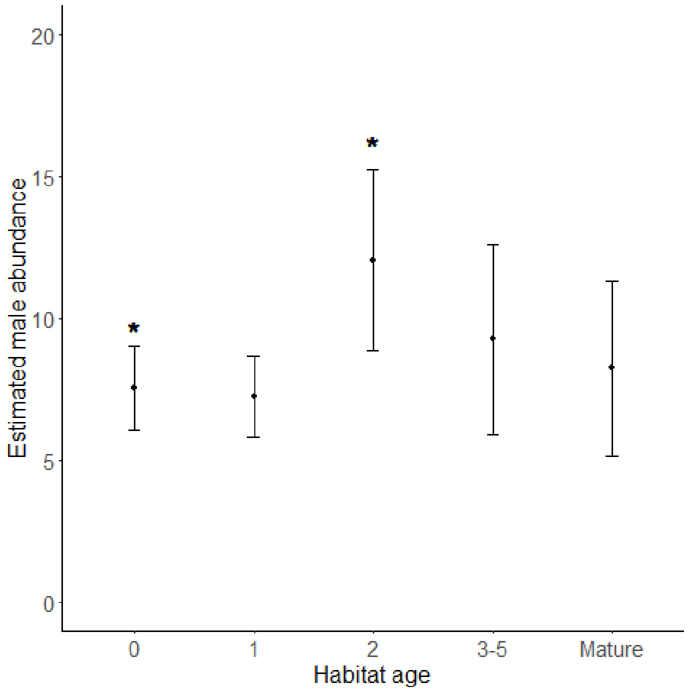

Figure 3.4. Management model estimates of Golden-winged Warbler abundance by habitat age. Estimates of relative abundance of male Golden-winged Warbler (males/100m radius site) across habitat age categories. Estimates are based on the supported management model ($B_0$ + bj + Day + Year + Longitude + Age) with year held constant at 2016, day held constant at 162 (middle of the survey period), and longitude held at -91.4˚. $B_0$ is the intercept and bj is the random effect of site. Ninety-five percent confidence intervals of estimates, derived from delta method standard errors, are displayed. Significant differences in male abundance estimates, based on model parameter coefficients, are indicated by *.

## Habitat Model Results

Five habitat models had ΔAIC ≤ 2 (Table 3.4). Among these models, I considered those with habitat element beta estimates with 95% confidence intervals that did not overlap zero to be supported, resulting in four supported models. Day, year, and cover were components of each top model. Parameter coefficients for day ranged from beta = -0.17 ± 0.03 SE to beta = -0.18 ± 0.03 SE and had a significant negative linear effect on male GWWA abundance in all models. Each year had a unique effect on male GWWA abundance. Aspen cover (parameter coefficients listed in first to fourth model rank order: betas = 0.28 ± 0.09 SE, 0.13 ± 0.09 SE, 0.20 ± 0.09 SE, 0.16 ± 0.13 SE) generally supported higher male abundances than alder, with the top and fourth ranked models showing statistical significance. The parameters graminoid (beta = 0.39 ± 0.14 SE), medium woody regeneration^2 (beta = -0.47 ± 0.13 SE), no woody regeneration (beta = 0.29 ± 0.12 SE), and no woody regeneration^2 (beta = 0.57 ± 0.12 SE) were included in supported models. Graminoids had a positive linear relationship with male GWWA abundance, medium woody regeneration had a negative quadratic effect, and no woody regeneration had support for both a positive quadratic effect and a positive linear effect on male GWWA abundance (Figure 3.5).

Table 3.4. Top ranked habitat models. The top ranked models in the habitat model set with cumulative model weight of 1, and the first-stage base model for comparison. Detection was modeled as the half-normal distance distribution stratified by management status. The number of model parameters (K), delta AIC, model likelihood and model weight (*W*) are shown.

| **Abundance Model** | **K** | **ΔAIC** | **Likelihood** | ***W*** |
|---|---|---|---|---|
| Base* + Cover + Graminoid | 10 | 0.00 | 1.00 | 0.22 |
| Base + Cover + M.Regen ^2 | 10 | 0.26 | 0.88 | 0.19 |
| Base + Cover + N.Regen | 10 | 0.57 | 0.75 | 0.16 |
| Base + Cover + N.Regen^2 | 10 | 0.97 | 0.62 | 0.13 |
| Base + Cover + M.Regen † | 10 | 1.86 | 0.39 | 0.09 |
| Base + Cover + Forb† | 10 | 3.02 | 0.22 | 0.05 |
| Base + Cover + Bare † | 10 | 3.76 | 0.15 | 0.03 |
| Base + Cover | 9 | 4.25 | 0.12 | 0.03 |
| Base + Cover + Graminoid^2 | 10 | 4.30 | 0.12 | 0.03 |
| Base + Cover + Canopy † | 10 | 5.08 | 0.08 | 0.02 |
| Base + Cover + Rubus^2 | 10 | 5.87 | 0.05 | 0.01 |
| Base + Area | 9 | 6.47 | 0.04 | 0.01 |
| Base + Cover + Forb^2 † | 10 | 6.73 | 0.03 | 0.01 |
| Base + Cover + Canopy^2 † | 10 | 7.34 | 0.03 | 0.01 |
| Base | 8 | 7.63 | 0.02 | 0.00 |

* Base = intercept + random effect of site + day + year

† beta confidence intervals cross zero

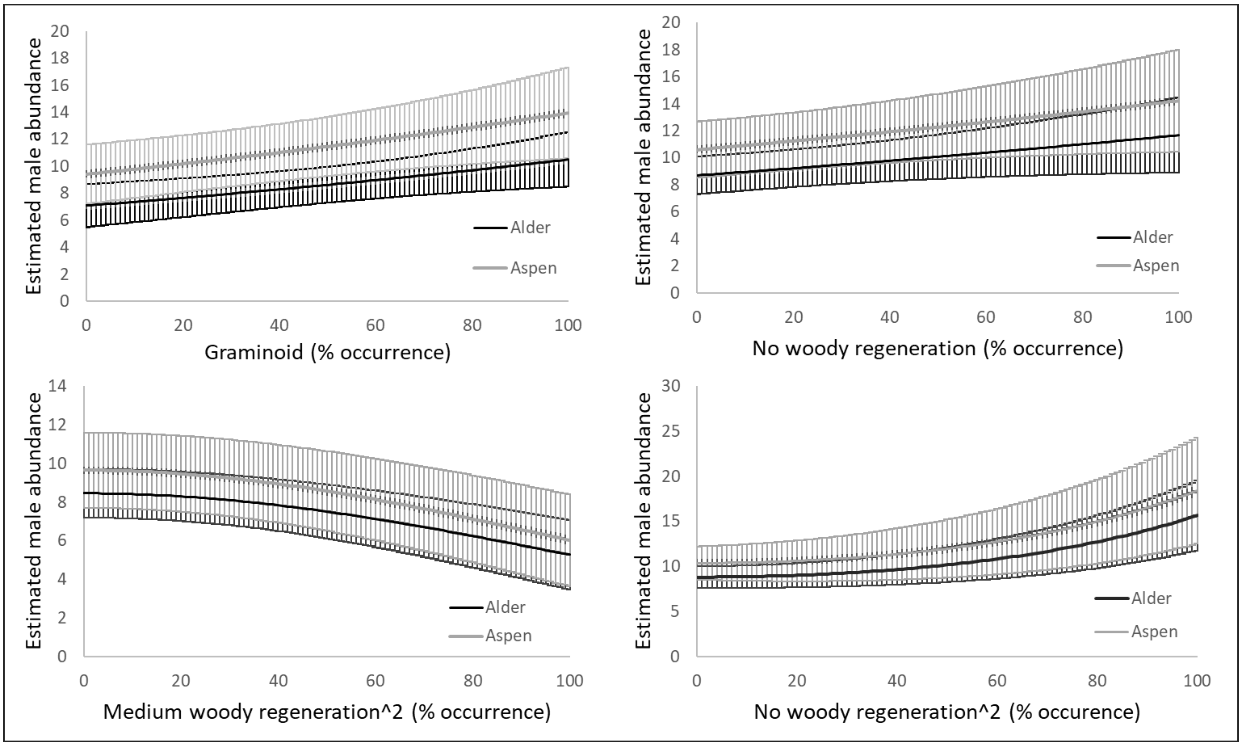

Figure 3.5. The influence of vegetation characteristics on estimated male Golden-winged Warbler abundance in alder and aspen cover types based on the four supported habitat models. For all models, year was held constant at 2016 and day at 162 (middle of the survey period). Ninety-five percent confidence intervals derived from delta method standard errors are displayed.

## Discussion

### Habitat-Management Type and Habitat Age

My regional-scale assessment compared the relative abundance of male GWWA among three habitat-management types (mature alder shrubland, sheared alder shrubland, and sheared aspen saplings) and across habitat ages (0-5 years post-shear, and mature). Based on parameter inclusion in my two supported management models, I found that longitude, habitat-management type and habitat age influence male GWWA abundance. Male GWWA abundance was significantly higher in more western sites. This aligns with Breeding Bird Survey data (Sauer et al. 2017) which documented a higher relative abundance of GWWA (per year per survey route) in Minnesota than Wisconsin from 2011-2015. Model-derived estimates of male GWWA relative abundance were highest in sheared aspen, however this difference was not statistically significant. One aspect of survey design that may have influenced this finding is that only males detected within sheared patches were counted. This eliminated any males singing from the edge of the sheared patch or nearby mature habitat. A study in the Appalachians found the average 100% minimum convex polygon male GWWA home range to be 6.3 ha ± 1.7 SE and the average spot-mapped territory size of the same individuals to be 1.7 ha ± 0.2 SE (Frantz et al. 2016). With 155 of my sheared sites under five hectares, is it likely that individual GWWA home ranges included both sheared and neighboring mature areas. My sampling did not include males unless they were directly detected within the sheared area, and so may be underestimating the response of males to shearing. This is especially likely at age zero sites, where vegetation is just starting to regenerate after shearing and is short and sparse, necessitating use of residual habitat for structural complexity needs. Additionally, as sheared shrubland areas get larger, BMPs recommend a mix of mature and sheared areas to provide the appropriate habitat structure for breeding GWWA (Roth et al. 2012*a*), further supporting the idea that bordering mature habitat may be used by GWWA.

Another aspect of survey design that may have influenced the modeled effect of habitat-management type was the selection of mature alder sites. Mature sites were selected based on dominant cover type (alder), habitat age (>20 years since disturbance), and proximity to sheared sites. Habitat structural complexity and other GWWA habitat requirements were not initial criterion for inclusion in sampling. Thus, mature alder sites included a range of habitat structures with some exhibiting important GWWA habitat elements (these sites would probably not be good candidates for shearing management) and some that lacked important habitat elements (good potential candidates for shearing management). The non-significant difference in male relative abundance among habitat-management types was likely influenced by this range in suitability for GWWA. If all mature alder sites had been selected because they were missing key GWWA habitat elements, my results may have been different.

A recent publication by Streby et al. (2018) reported a reduction in the number of breeding pairs of GWWA following the implementation of shearing management at their Minnesota study area. They compared the number of breeding territories found annually during the four breeding seasons before management (n=62) to the number of breeding pairs found annually during the two breeding seasons following shearing management (n=45). Based on this change in territory count and associated models of population recruitment, Streby et al. (2018) concluded that the implementation of shearing following best management practices reduced recruitment, and therefore may have a lasting negative impact on GWWA populations. Although my study does not quantify breeding territories or recruitment, my abundance modeling based on a region-wide sample of over 250 sites shows no statistical decrease in relative abundance of males in sheared alder and aspen sites compared to mature alder shrubland.

Habitat age was included in one top supported management model, making it an important predictor of male GWWA relative abundance. I found that age two habitat had significantly higher male abundance than age zero habitat. GWWA BMPs indicate ideal shrub heights between one and four meters (Roth et al. 2012*a*). Habitat age is directly related to vegetation height and stem density (Roth 2001), and the speed and height of regeneration varies by site. In a Minnesota study, Hanowski et al. (1999) reported a lower average abundance of GWWA for at least three years after shearing compared to unmanaged sites. Smetzer et al. (2014) found that abundance peaked for six shrubland bird species between four and eight years post-treatment in wildlife openings maintained with mechanical disturbance, with only White-throated Sparrow (*Zonotrichia albicollis*) abundance peaking immediately after treatment. A similar effect of time since treatment has been observed in harvested aspen stands, with GWWA abundance peaking somewhere between 4 and 7 years post-harvest (Martin et al. 2007) and in habitats with seedling size (<2.5 cm diameter at breast height) aspen (Roth and Lutz 2004). My modeling suggested that male GWWA abundance may be highest in the third breeding season following management (age two), making a case for patience when quantifying the response of GWWA to shearing.

### Habitat Characteristics

Based on my habitat modeling, I found that occurrence of graminoids, medium woody regeneration, and no woody regeneration, in combination with day year and cover type, had an effect on male GWWA abundance. Although, not statistically significant, aspen cover had higher estimates of male GWWA abundance in all models. Previous research in Wisconsin found a similar trend with higher abundance of male GWWA in young aspen stands (0.75 males/station) than in shrub swamps (0.29 males/station; Martin et al. 2007).

In my models, graminoid occurrence had a positive linear relationship with male abundance. This result contradicts the conclusion by Streby et al. (2018) that grassy and non-woody structure is bad for GWWA. A study in the Cumberland Mountains of Tennessee found that GWWA nest sites had a significantly higher percent cover of grass (70.2 ± 2.5 SE) than non-nest sites (62.4 ± 1.9 SE) (Bulluck and Buehler 2008). Bakermans et al. (2015) found that percent cover of grass and forbs had a positive linear relationship with the number of male GWWA observed per survey in regenerating forest stands in the Appalachians. Graminoid occurrence had a linear effect on male abundance in my study, suggesting that the presence of graminoid throughout the patch is important. Other studies have found a more nuanced effect of grass and sedge, with a potential limit to the positive effect. For example, a combined study of GWWA nest site selection in Minnesota, New York, North Carolina, Pennsylvania, Tennessee, West Virginia, and Wisconsin found that GWWA selected for grass cover with nest sites in forest-derived cover having higher grass cover (21% ± 1.7 SE) than paired random sites (16% ± 1.4 SE) (Terhune et al. 2016). However, in grass-dominated cover (such as an old field or pasture), nest sites tended to have less grass cover (22% ± 1.1 SE) than paired sites (24% ± 1.5 SE; Terhune et al. 2016). This study also found that GWWA selected nest sites with between 0 and 37% grass cover in grassland-derived habitats.

My habitat modeling showed support for a positive linear and a positive quadratic effect of the occurrence of no woody regeneration on male GWWA abundance. The percent occurrence of no woody regeneration is the percent of 1-m radius subplots across a site where woody regeneration of any kind or size was absent, i.e. an estimate of woody-free areas. This includes both areas of herbaceous and graminoid growth and vegetation-free substrate (leaf litter, bare ground, woody debris). Although my modeling suggests a higher male GWWA abundance when no woody regeneration occurrence is high throughout a site, that does not mean a site with no woody regeneration at all would support GWWA. For instance, at age zero sites there may be no woody regeneration in the sheared area, but GWWA may still breed there, incorporating both neighboring mature vegetation and the herbaceous regeneration of the sheared area as part of their territory. Because 30% of all point count surveys occurred at age zero sites, the GWWA response to no woody regeneration may be exaggerated in my modeling.

The final vegetation component supported by my habitat modeling (<2 ΔAIC), was the percent occurrence of medium woody regeneration (1-2 m tall). There was a negative quadratic effect of medium regeneration on male GWWA abundance, with the highest relative abundance associated with 0% occurrence of medium regeneration. This trend differed from a study which found that GWWA in grassland-derived sites in the Appalachians selected for woody cover, with nest sites having higher woody cover (9% ± 1.0 SE) than random paired sites (6% ± 0.7 SE) (Terhune et al. 2016). However, in another study of GWWA nest site selection at reclaimed mines, the opposite was observed at multiple scales (Bulluck and Buehler 2008). Nest sites had a lower percent cover of saplings (31.4% ± 2.8 SE) than random non-nest sites (44.5% ± 2.1 SE) at the plot level (11.3m radius) and lower cover of woody regeneration (nest sites:34.5% ± 3.0 SE, random non-nest sites: 47.2% ± 2.2 SE) at the subplot level (1m radius) (Bulluck and Buehler 2008). This indicates that there may be a range of percent woody cover suitable for nesting, with ~6% being too low (Terhune et al. 2016) and ~35-45% being too high (Bulluck and Buehler 2008). A similar range of selection was observed by Terhune et al. (2016) with top supported models indicated GWWA nest site selection between 0 and ~30% woody cover in grassland-derived habitats, with selection peaking around 15%. A study of male density in harvested aspen stands showed a significant positive linear relationship between density of territorial male GWWA and the density of aspen suckers (Roth 2001), while yet another study found lower sapling density at sites occupied by GWWA than unoccupied sites (4,445 versus 5,271 stems/ha; Klaus and Buehler 2001). In all of these studies, regardless of habitat selection scale, woody cover is an important feature of GWWA habitat. In my study, 100% occurrence of medium woody regeneration indicates a homogenous stand with 1-2m tall woody regeneration throughout the site. Based on GWWA BMPs (Roth et al. 2012*a*) and the research listed above, GWWA prefer heterogeneity in patch structure, thus high medium regeneration occurrence indicates a lower relative abundance of male GWWA.

When looking at all four supported habitat elements together, they suggest the importance of structural heterogeneity within a site. The positive relationships between graminoid and no woody regeneration and male GWWA abundance indicate the importance of non-woody cover at the patch-scale, and the role that shearing plays in generating these elements. The negative relationship between 1-2 m tall woody regeneration and abundance, highlights the negative impact of a homogenous woody habitat. Rossell et al. (2003) found that patchiness and structural complexity were important components of GWWA territory selection in mountain wetlands. This was supported by studies in New York which found that herbaceous areas were an important component of GWWA territories, with a variety of vegetation types and visible vegetation clumping and patchiness within territories (Confer and Knapp 1981, Frech and Confer 1987).  This study investigates the management-patch-level response of male GWWA to occurrence of habitat elements, therefore it cannot speak directly to the influence of the surrounding habitat. If my sample unit was male GWWA territories, rather than managed patches, results may be different and more representative of GWWA response to habitat characteristics. Another difference between my study and many others is the scale of habitat selection. Nest site selection, for example, is a fourth order process while male abundance relates more to second order selection (Johnson 1980). Nest site selection is also largely dictated by female GWWA (Confer et al. 2011). This indicates the importance of the scale of selection, and also highlights the possibility that male and female GWWA may have different criteria for habitat selection.

### Management Implications

The GWWA breeding season conservation plan focuses on maintaining and creating quality young forest and shrubland breeding habitat across the breeding range, with a goal of 2.33 million acres (942,918 ha) of GWWA breeding habitat by 2020 (Roth et al. 2012*a*). Accompanying this habitat acreage goal, the GWWA Working Group established best management practices for creating and maintaining quality breeding habitat in a variety of land cover types including abandoned fields, forests and wetlands. Across these cover types, shearing is suggested as a strategy to increase patch-level heterogeneity, promote woody or herbaceous regeneration as desired, and create feathered edges with surrounding forest stands (Roth et al. 2012*a*). Although shearing is a key part of best management strategies for GWWA, little effort has been made to directly quantify the response of these birds to habitats managed with shearing.

Based on my large-scale study of male GWWA abundance in response to habitat management and vegetation characteristics, I have several recommendations for GWWA management. I recommend the continuation of shearing as a best management practice to establish GWWA breeding habitat. Model estimates from my supported management model did not show statistically significant differences in male GWWA abundance by habitat-treatment, suggesting no negative impact of the management. The intent of shearing following BMPs is to positively influence GWWA abundance by restoring missing GWWA habitat elements, such as herbaceous and grassy openings which contribute to patch-level heterogeneity (GWWA Working Group 2013). My management models showed a significant negative effect of longitude on male GWWA abundance. This indicates the possibility of range-wide differences in the response of male GWWA to shearing, where higher relative abundance would be expected at more western sites. I recommend keeping this longitudinal effect in mind when evaluating the success of shearing management. In my habitat models, site-scale vegetation characteristics that influenced male GWWA abundance were graminoid occurrence, medium height woody regeneration occurrence, and no woody regeneration (non-woody) occurrence. Graminoid and non-woody occurrence were positively associated with male GWWA abundance. All of these indicate the importance of patch heterogeneity, which can be established through the practice of shearing. I recommend keeping an open canopy to allow sunlight to reach the understory, which will encourage the growth of grasses, sedges, and herbaceous species. For highest male GWWA abundance, medium height woody regeneration occurrence should not exceed 40%.

Smetzer et al. (2014) found that shrubland bird species were more abundant in wildlife openings maintained by burning or mechanical treatments (including shearing) than silvicultural openings (such as clearcuts). They suggest that a shrubland bird management strategy based solely on silviculture would require a significantly larger amount of area than a strategy that also includes wildlife openings (Smetzer et al. 2014). In shrubland and sapling areas where a decrease in GWWA has been observed, or where there is a lack of habitat heterogeneity, implementing shearing following BMPs should be used to reestablish missing habitat elements and may increase abundance at these sites. I found no statistical support for removing shearing as a best management practice for GWWA habitat creation and recommend monitoring and evaluating management efforts in relation to BMP elements during the third breeding season following management to best quantify GWWA response to shearing.

While this study quantified patch-level habitat elements, it did not investigate the extent to which these elements aligned with BMP recommendations. Although all shearing was intended to follow BMPs, this study did not measure of how well BMPs were followed. Additionally, mature alder sites in this study encompassed a variety of structural complexities from dense homogenous stands with shaded understories to mature alder with interspersed herbaceous patches. Different patch structures of mature alder likely provide varying habitat quality for GWWA based on their alignment with GWWA vegetation structural needs (GWWA Working Group 2013). Incorporating a measure of mature alder structural complexity and sheared site BMP alignment in modeling may more clearly indicate the benefits of shearing based on BMP implementation.

Future evaluation of the demographic response of GWWA to shearing, specifically nest and reproductive success, will be critical to quantifying the impact of the shearing management practice on GWWA demographics. Implementing before-after-control-impact study designs should be used to understand how GWWA breeding populations compare at a specific site before and after shearing while accounting for factors outside of those estimated during habitat sampling. Sites in a before-after-control-impact study should also be assessed in relation to GWWA habitat requirements and should only be included in the study if they are a good candidate for shearing management (i.e., missing key GWWA habitat elements). Using this study design and site criteria will give a better assessment of the impact of the shearing BMPs. Ultimately, it is important to remember that no two sites are alike.  Regenerating vegetation characteristics following shearing will vary due to soils, vegetation species composition, microclimates, and elevation, thus site-specific management prescriptions are important for reaching conservation goals.

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# CHAPTER 4

# CONSERVATION IN THE CONTEXT OF MIGRATORY CONNECTIVITY: A *VERMIVORA* CASE STUDY

## Abstract

Understanding migratory connectivity is a difficult challenge, yet, it is central to effective full-annual-cycle conservation of migratory species. Golden-winged Warbler (*Vermivora chrysoptera*) is a Neotropical migrant with two distinct breeding populations in the Great Lakes and Appalachian Mountains, and is a species of conservation concern. There is a growing body of research suggesting strong migratory connectivity structure in the species, with Great Lakes breeders wintering primarily in Central America and Appalachian breeders wintering almost exclusively in northern South America. This research fills geographic gaps in past studies by deploying archival light-level geolocators on male Golden-winged Warblers and closely related Blue-winged Warblers (*Vermivora cyanoptera*) at four previously unmonitored breeding areas near the edge of the breeding range. Bird were tagged in northern Wisconsin, western Upper Peninsula of Michigan, northwestern Vermont, and southeastern New York. I expected to either confirm strong migratory connectivity structure found in other studies or uncover new intricacies of Golden-winged Warbler migratory connectivity. Analysis of light-level data from 17 male Golden-winged Warblers revealed some exceptions to the well-accepted patterns of Golden-winged Warbler connectivity. Notably, a lack of distinct migratory connectivity structure, with birds breeding in the Upper Peninsula of Michigan wintering in Panama (n=1) and Colombia (n=1), and Vermont breeders wintering in Costa Rica (n=1), Panama (n=2) and Colombia (n=2). Despite these exceptions, I propose re-examining the way Golden-winged Warbler populations and associated conservation regions are defined by including migratory connectivity structure as a criterion.

## Introduction

Wildlife conservation is a challenge which becomes even more complex when focal species are migratory. Many conservation plans focus on the breeding range of migratory species, yet for Neotropical migrants like warblers and thrushes, significantly more time is spent in the non-breeding range (6-8 months) and during migration (2-3 months), than in their North American breeding range (3 months; Greenberg and Marra 2005). Conservation across a broad geographic range and with temporal specificity becomes logistically complex, yet highly important for successful conservation (Marra et al. 2011). For migratory birds, full-annual-cycle conservation and the importance of understanding migratory connectivity and carry over effects are at the forefront of conservation planning and management (Norris et al. 2006, Marra et al. 2011, Rockwell et al. 2012, Dybala et al. 2015, Hostetler et al. 2015, Robinson et al. 2017, Saunders et al. 2018).

Migratory connectivity is the geographic linking of individuals or populations of a given species throughout its range, for example from breeding to nonbreeding locations (Marra et al. 2011). Understanding connectivity can help determine the demographic factors limiting a population, which is key to successful full-annual-cycle conservation. Identifying these linkages makes it possible to investigate patterns in carry-over effects which occur when environmental conditions in one part of the range (e.g. winter rainfall) influence behavior and demographic rates in a different part of the range (e.g. arrival dates and breeding success). Carry-over effects have been documented in American Redstart (*Setophaga ruticilla*; Reudink 2008, Studds et al. 2008), Louisiana Waterthrush (*Parkesia motocilla*; Latta et al. 2016) and Kirtland's Warbler (*Setophaga kirtlandii*; Rockwell et al. 2012) among other Neotropical migrants. Establishing patterns, or lack thereof, of migratory connectivity for Neotropical migrant species is an important first step towards full-annual-cycle understanding and conservation and has been established by Partners in Flight and others as a priority research need (Donovan et al. 2002, Martin et al. 2007).

The Golden-winged Warbler (*Vermivora chrysoptera*) is a Neotropical migrant and a species of conservation concern (Roth et al. 2012). It has experienced one of the steepest population declines of any North American songbird, with an average population trend of -2.28% per year (95% CI: -3.08% to -1.47%) between 1966 and 2015 across its range (Sauer et al. 2017). Blue-winged Warbler (*Vermivora cyanoptera*) is a closely related species which occupies similar habitat with a breeding range that overlaps with the southern region of the Golden-winged Warbler breeding range. Conversely, its nonbreeding range overlaps with the northern extent of the Golden-winged Warbler nonbreeding range (Gill et al. 2001). Blue-winged Warbler has a long-term population trend of -0.70% (95% CI: -1.34 to 0.07) between 1966 and 2015 (Sauer et al. 2017). Competition and hybridization between the two species is thought to contribute to Golden-winged Warbler decline (Buehler et al. 2012). Recent monitoring and conservation efforts, led by the Golden-winged Warbler Working Group and its international sister group, Alianza Alas Doradas, have resulted in a range-wide Golden-winged Warbler Atlas project and the creation of the *Golden-winged Warbler Status Review and Conservation Plan* (Roth et al. 2012). Efforts to better understand the full-annual-cycle of the species have resulted in a large body of research on migration and nonbreeding ecology.

The Golden-winged Warbler breeding range has experienced a dramatic shift over the last 150 years, with a peak in range extent and population size between 1930 and 1950 (Buehler et al. 2012). The breeding range has since contracted and shifted north and west (Buehler et al. 2012). The Blue-winged Warbler range has experience a simultaneous shift northward and eastward; where overlap and hybridization occur, the Golden-winged Warbler is usually extirpated within 50 years (Gill 1980). It was estimated that the hybrid zone in New York was shifting at a rate of 3-6 km/year through the mid-20th century (Confer and Larkin 1998). Golden-winged Warbler now occupies two isolated breeding regions, with nearly 90% of the breeding population in the Great Lakes region which encompassed parts of southern Saskatchewan, Manitoba, and Ontario; northern regions of Minnesota, Wisconsin, and

Michigan; and the St. Lawrence and Champlain Valleys of New York and Vermont (Rosenberg et al. 2016). The remaining approximately 10% of the breeding population occupies the Appalachian region extending from northern Georgia and the Cumberland Mountains in Tennessee to southeastern New York (Rosenberg et al. 2016). Based on the natural break in the breeding range located through central New York State and the ecologically similar broad-scale habitat characteristics of each region, the Golden-winged Warbler Working Group designated the Great Lakes and Appalachian populations as two distinct conservation regions (Roth et al. 2012).

Current knowledge of Golden-winged Warbler migration suggests that the Appalachian and Great Lakes populations exhibit strong structure in migratory connectivity. Hobson et al. (2016) used stable isotopes to derive the breeding location of Golden-winged Warblers captured across the nonbreeding range. They found evidence of migratory connectivity with birds captured in Nicaragua and Costa Rica primarily breeding in northern parts of the breeding range, Honduran birds breeding in more southern parts of the breeding range, and birds captured in Venezuela and Colombia breeding primarily in the Appalachians and some Southern breeding extents in the Great Lakes (Hobson et al. 2016). With the recent advancement and weight reduction of geolocator technology, other studies have used light-level data to track Golden-winged Warbler and Blue-winged Warbler migration (Bennett et al. 2017, Kramer et al. 2017, 2018, Larkin et al. 2017). In a study including 21 male Golden-winged Warblers from three breeding populations, Kramer et al. (2017) found that birds breeding in Minnesota wintered in Central America from Nicaragua to the Yucatan Peninsula of Mexico, and birds from the Appalachian Mountains in Tennessee and Pennsylvania wintered in northern Venezuela and northeastern Colombia. A study of geolocators deployed on male Golden-winged warblers wintering in Nicaragua revealed connections to breeding destinations in the western Great Lakes region (Larkin et al. 2017).

My research aims to expand the knowledge of Golden-winged Warbler and associated Blue-winged Warbler migration and connectivity, by monitoring migration in previously unstudied breeding populations in both conservation regions. Given the recent range contractions and shifts for both species, populations at the geographic limits should be studied. The possible alternative outcomes of this study include 1) support of current knowledge about migratory connectivity in *Vermivora* species, or 2) discovery of previously unknown aspects of *Vermivora* migratory connectivity through expanded study. If the first outcome is supported, I would expect all Blue-winged Warblers in my study and Golden-winged Warblers breeding in the Great Lakes population to winter in Central America, and Golden-winged Warblers breeding in the Appalachian region to winter in northwest South America. Alternatively, if the second outcome is supported, I would expect to find a different structure or less structure to migratory connectivity. I expect birds near the edges of the contracting range to be more likely to unveil new characteristics and patterns of migration connectivity than those in the core of the breeding range.

## **Methods**

### Study Area

Study sites were located in Houghton and Baraga Counties, Michigan (MI), Oneida County, Wisconsin (WI), Orange County, New York (NY), and Addison, Chittenden, and Rutland Counties, Vermont (VT) across the breeding range of the Golden-winged Warbler in the eastern United States. All study sites were dominated by young forest and shrubland typical of Golden-winged Warbler breeding habitat (Roth et al. 2012) including some sites specifically managed for Golden-winged Warbler.

Sites in northern MI were on the Sturgeon River Sloughs State Wildlife Management Area and private family-owned land. Sites were either reclaimed abandoned farmland and homesteads or shrubland transition zones between open water (such as streams or impoundments) and aspen forests.

Sites were dominated by alder *(Alnus* sp.*)*, red-osier dogwood (*Cornus sericea*), and willow (*Salix* sp.) with low densities of aspen (*Populus* sp.), black spruce (*Picea mariana*), and paper birch (*Betula papyrifera*) interspersed. Herbaceous cover was primarily grasses and sedges with invasive reed canary grass (*Phalaris arundinacea*) present at some sites. Goldenrod (*Solidago* sp.) and bracken fern (*Pteridium aquilinum*) were also common. Shrubland sites were often bordered by extensive aspen-dominated forest.

NY sites were located on public lands managed under the authority of Palisades Interstate Park Commission, specifically at Harriman and Sterling Forest State Parks. Although each park differs in its management history, they are both similar in their high abundance of wetland systems, lakes, and large areas of contiguous forestland. *Vermivora* occupied a variety of habitats including managed forest wetlands, managed powerline rights-of-way (~60 m wide), abandoned farm fields, and two timber harvests (roughly 10 and 35 years post-harvest). Managed wetlands have undergone 2-4 years of invasive species management and were dominated by red maple (*Acer rubrum*) speckled alder (*Alnus incana* subspecies *rugosa*) tussock sedge (*Carex stricta*) and a variety of wetland forbs. Forests surrounding the wetlands were dominated by oak (*Quercus*). Rights-of-way were maintained by thinning and herbicide application on a 5-year cycle. Rights-of-way in Sterling Forest were dominated by native shrubs and forbs (alder, witchhazel (*Hamamelis virginiana*), goldenrod, and *Rubus* sp.) while those in Harriman State Park were dominated by invasive plants such as oriental bittersweet (*Celastrus orbiculatus*), autumn olive (*Elaeagnus umbellate*), Japanese barberry (*Barberis thunbergii*) and mugwort (*Artemisia* sp.). Abandoned farm fields were naturally succeeding, with a mixture of native and invasive vegetation with little hardwood regeneration. Harvested forest areas were dominated by birch (*Betula* sp.), cherry (*Prunus* sp.), aspen, and locust (*Robinia* sp.), with a suite of native and non-native shrubs, forbs, and grasses.

VT study sites were regenerating agricultural lands with public and private ownership. Woody regeneration on these sites was a combination of native species such as dogwood (*Cornus* sp.) and *Viburnum* sp. and invasive species such as exotic honeysuckle (*Lonicera* sp.), buckthorn (*Rhamnus* sp.), and some multiflora rose (*Rosa multiflora*) with hardwood and some red cedar (*Juniperus virginiana*) saplings throughout. All locations were adjacent to hardwood-dominated forest stands with a small component of pine (*Pinus* sp.) and hemlock (*Tsuga canadensis*).

WI sites were in the northcentral part of the state and dominated by regenerating aspen forest. These sites were predominantly county forest lands, but also included state and private forests. All stands had been harvested within the past 15 years, with most sites less than 7 years post-harvest. Sites had sparsely retained overstory trees, usually northern red oak (*Quercus rubra*), red maple, or eastern white pine (*Pinus strobus*), and a mosaic of grasses, forbs, ferns, and shrubs (primarily *Corylus*, *Viburnum*, and *Vaccinium* sp.) accompanying sapling regeneration. Sites were primarily bordered by mature aspen forest.

### Field Methods

In late April through early July 2016, target mist-netting was conducted using audio lures to capture morphologically distinguished Golden-winged Warblers, Blue-winged Warblers (*Vermivora cyanoptera*) and their hybrids. The sex, age, and mass of each captured *Vermivora* was recorded along with additional morphometric measures. Each bird received a numbered USGS aluminum band and a unique combination of 1 to 3 plastic color leg bands for future identification and resighting of individuals. Males ≥ 9 grams were fitted with a stalkless Biotrack M-Series archival light-level geolocator using a modified Rappole and Tipton (1991) leg-loop harness (Streby et al. 2015). Previous research found no negative impact of this geolocator and harnesses combination on Golden-winged Warbler survival (Peterson et al. 2015, Streby et al. 2015). The combined weight of the harness and geolocator in my study averaged 0.47 grams. All female and underweight male *Vermivora* captured were banded and then released without geolocators to serve as controls.

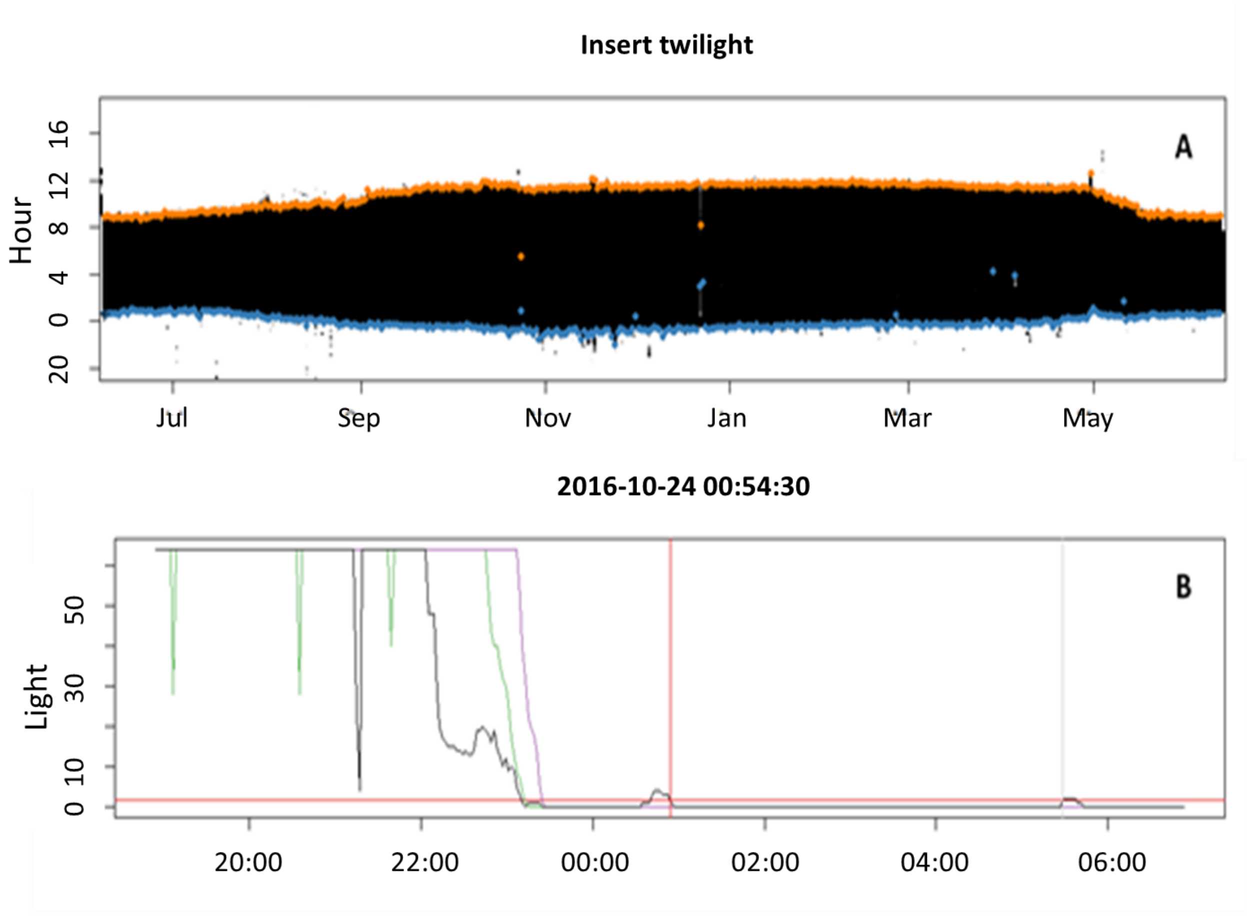
My study, like all reported Golden-winged and Blue-winged Warbler geolocator-based migratory research (Peterson et al. 2015, Streby et al. 2015, Bennett et al. 2017, Kramer et al. 2017, 2018, Larkin et al. 2017), exclusively tagged males. There are several reasons geolocators are not generally deployed on females. First, female *Vermivora* have been shown to exhibit lower site fidelity than males (Vallender et al. 2007, Schlossberg 2009, Bulluck et al. 2013), making it less likely to recover a geolocator deployed on a female. Second, secretive behavior displayed by females during nesting and their lack of territorial singing (Gill et al. 2001, Confer et al. 2011) makes them more difficult to relocate and recapture. Third, the small mass of *Vermivora* warblers (on average <10 grams during breeding; Gill et al. 2001, Confer et al. 2011) does not allow for the deployment of a tag that can both collect light-level data and be relocated by VHF, which if possible, would make female relocation easier. Because of the logistic difficulties surrounding geolocator deployment on female *Vermivora*, there is no light-level derived location and migration data specific to females.

In May and June 2017, field teams conducted a thorough search for all banded birds in the locations where birds where captured in 2016 and suitable habitat within 300 meters. Teams used both passive and playback-assisted re-sighting to locate and identify individuals. When an individual carrying a geolocator was found, target mist-netting with an audio lure was conducted to recapture the bird. Once birds were recaptured, geolocators were removed and the mass of the bird and other standard measures were recorded before release.

Geolocators collected and archived the maximum ambient light-level detected every two minutes for the life of the geolocator (or until data download) and had a running timer which started at a known tag activation time. Light-levels were collected on an arbitrary 0-64 scale and used in accordance with the time stamp to determine sunrise and sunset times (to estimate day length) and solar noon of each day. Day length is an indicator of latitude, and solar noon indicates longitude (Hill and Braun 2001). Biotrack M-series tags do not provide accurate latitude estimates for 2-3 weeks surrounding each solar equinox because day length is approximately the same globally during that time; however longitude estimates are always reliable (Biotrack Ltd. 2013).

### Statistical Methods

I downloaded and decompressed all light-level data from geolocators using M-series BASTrak software (Biotrack, Wareham, UK). I analyzed light-level data in Program R, version 3.4.3 (R Core Team, 2017) following the general methods of Cooper et al. (2017) and Bennett et al. (2017). I used the threshold method (Hill and Braun 2001) to estimate sunrise and sunset (twilight) times with function “preprocessLight” in package TWGeos (Wotherspoon et al. 2016) with a twilight threshold of 1.5. I made only minimal adjustments to TWGeos generated twilight times (fewer than 5 twilight edits per geolocator) and only when there were extreme outliers (twilights > 1 hour different than neighboring twilight times). One geolocator had several occasions during the nonbreeding season where periods of light occurred during the middle of the night, resulting in drastically inaccurate twilight times, thus I manually adjusted these twilight times (>10 twilights) using the “preprocessLight” function in TWGeos (Figure 4.1).


Insert twilight

2016-10-24 00:54:30

Figure 4.1. Example light-level data collected by a geolocator deployed on a male Golden-winged Warbler from spring 2016 to spring 2017. Panel A and B were taken from the processing windows of “preprocessLight” function in package TWGeos (Wotherspoon et al. 2016). Panel A shows the light-level data collected over the life of a geolocator. The dark area on the figure indicates night. The orange dots represent sunrise times and the blue dots represent sunset times defined by R package TWGeos. The colored dots which indicate twilight times in the middle of night were manually adjusted using a light level plot (example in panel B). In panel B, the horizontal red line at the bottom of the Figure indicates the twilight threshold of 1.5, and the black green and purple lines show the light-levels recorded by the geolocator for three different wavelengths of light. When the light levels are above the red threshold line, it is daytime. The time when the light levels dip below the threshold line is designated as sunset. The vertical red line is the twilight time automatically designated by the TWGeos function “preprocessLight”. You can see in panel B that an errant blip in the light level around 01:00 hours causes an approximately two-hour shift in twilight time compared to when the three light wavelengths first drop below the threshold. I manually adjusted all middle of night twilight times to align with the initial drop in light levels below the threshold line, instead of errant blips of light during night.

I calibrated each geolocator's dataset using the period between geolocator deployment and 20 July 2016 (individual calibration periods ranged from 20 to 54 days), a time when I were confident birds were at their stationary breeding locations (Lisovski et al. 2012, Bennett et al. 2017). Light-level data from one Golden-winged Warbler breeding in Wisconsin indicated an early departure from the breeding area, so I ended the calibration period for that individual on 10 July 2016. I used light-level data collected during the calibration period to create a log-normal density distribution of twilight error (i.e., the difference between known twilight times at the known breeding location and geolocator indicated twilight times) for each bird (Yamaura et al. 2017). I calculated the zenith angle for the calibration period (breeding) of each bird using package GeoLight (Lisovski and Hahn 2012). Breeding zenith angles ranged from 90.49˚ to 93.73˚. I assigned an initial nonbreeding zenith angle of 90.9˚ (the mean zenith value of known-location nonbreeding Golden-winged Warbler observed in a variety of nonbreeding habitats by R. Bennett (personal communication)) for all birds and adjusted incrementally for each bird if its initial path indicated a nonbreeding range over water. This resulted in a range of nonbreeding zenith angles from 89.8˚ to 93.0˚. I defined the zenith angle during migration periods as the average between a bird's breeding and nonbreeding zeniths.

I conducted further location modeling within a Bayesian framework in R package Solar/Satellite Geolocation for Animal Tracking (SGAT; Wotherspoon et al. 2016). SGAT uses Markov Chain Monte Carlo (MCMC) simulations to estimate bird location and quantify light-level geolocation error based on 1) an initial path with threshold method-derived location estimates, 2) the twilight error distribution during the calibration period, 3) a bird movement model defining probable flight speed, and 4) a spatial mask which may constrain long-term locations to land or within a geographic region. My movement model assumed birds were stationary most of the year, except for large-distance migratory movements and had a gamma distribution with shape=7 and scale=0.08. My spatial probability mask defined the probability of locations on land to be four times greater than locations over water, and was geographically limited between 50˚ and -2˚ latitude and -140˚ and -45˚ longitude based on the global range of Golden-winged Warbler (Rosenberg et al. 2016). Five Golden-winged Warbler geolocators and one Blue-winged Warbler geolocator experienced errors which resulted in models predicting their wintering locations to be in Ecuador, south of the known nonbreeding ranges for both species (Gill et al. 2001, Rosenberg et al. 2016). For these birds, I tried several variations of spatial masking (see Appendix B) and ultimately chose to model their locations with an unconstrained model which had no geographic limits and the same probability of occurring on land as over water.

I used a total of 255,000 iterations sampled across three independent chains for each bird. The first three chains of 15,000 iterations were removed as burn-in, the next 60,000 iterations across three chains were used for model tuning, and the final three chains of 10,000 iterations were used to define the posterior distribution and location estimates. Following Bennett et al. (2017), I visually inspected model convergence by plotting the mean value of the final three chains of 10,000 iterations against the 2.5% and 97.5% confidence intervals for each day. Model convergence was high except during the three-week buffer around each equinox.

I calculated the nonbreeding location of each individual using the “slice” function in SGAT (Larkin et al. 2017). Nonbreeding location was defined as the 95th percentile of locations between 10 November 2016 and 10 February 2017. A winter centroid location was calculated based on daily estimated locations (not constrained to the 95th percentile) for each bird during the nonbreeding period. Standard errors surrounding the winter centroid were calculated for both longitude and latitude.

## Results

Across my study sites in 2016, 71 geolocators were deployed on male Golden-winged Warbler, 24 geolocators were deployed on male Blue-winged Warbler, and one geolocator was deployed on a hybrid *Vermivora* in New York. Twenty-eight Golden-winged Warblers, four Blue-winged Warblers, and one hybrid *Vermivora* were banded as controls in 2016.

### Return and Recovery Rates

Of the 71 geolocators deployed on male Golden-winged Warblers in 2016, 22 were relocated (20 recovered) in 2017 (Figure 4.2). Golden-winged Warbler geolocator return rates varied from 22% in MI to 67% in NY (Table 4.1). Twenty-four male Blue-winged Warblers received geolocators in 2016 and 5 were relocated (3 recovered) in 2017 (Figure 4.2). BWWA geolocator return rates varied from 11% in VT to 50% in NY (Table 4.1). A single geolocator was deployed on a hybrid *Vermivora* in NY in 2016 and was relocated, but not recovered, in 2017.

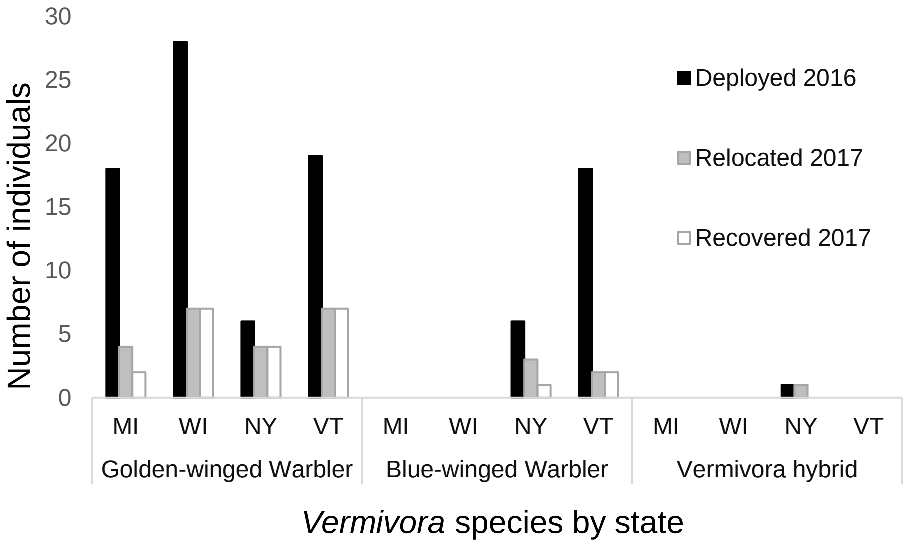


Figure 4.2. Geolocators deployed (2016), return rates (2017), and geolocator recovery rates (2017) for male *Vermivora* sp. Tagged During the 2016 Breeding Season, Stratified by Phenotypic Species and State of Deployment.

Table 4.1. The return rates (1= 100% returning) of geolocator equipped (tagged) and control (no geolocator; untagged) *Vermivora* sp. Birds were banded in May-July 2016 and re-sighted in breeding season 2017. Return rates are stratified by species (Golden-winged Warbler: GWWA, Blue-winged Warbler: BWWA, or GWWA x BWWA hybrid cross: Hybrid) and state. All geolocator birds (n=96) were male, and control birds (n=34) were predominantly male.

| **Species** | **Region** | **# Tagged Warblers (n)** | **Geolocator return rate** | **# Untagged Warblers (n)** | **Control return rate** |
|---|---|---|---|---|---|
| GWWA | MI | 18 | 0.22 | 3 | 0.33 |
| | WI | 28 | 0.25 | 21 | 0.24 |
| | NY | 6 | 0.67 | 0 | - |
| | VT | 19 | 0.37 | 4 | 0.00 |
| | **Combined** | **71** | **0.31** | **28** | **0.21** |
| BWWA | MI | 0 | - | 0 | - |
| | WI | 0 | - | 1 | 0.00 |
| | NY | 6 | 0.50 | 0 | - |
| | VT | 18 | 0.11 | 4 | 0.00 |
| | **Combined** | **24** | **0.21** | **5** | **0.00** |
| Hybrid | MI | 0 | - | 0 | - |
| | WI | 0 | - | 0 | - |
| | NY | 1 | 1.00 | 0 | - |
| | VT | 0 | - | 0 | 1.00 |
| | **Combined** | **1** | **1.00** | **1** | **1.00** |

A total of 28 Golden-winged Warblers were banded in 2016 as controls and thus did not receive geolocators (Table 4.1). Six of these control birds were resighted in 2017 (1 in MI, 5 in WI). Five Blue-winged warblers were banded as controls in 2016 (Table 4.1) and none were relocated in 2017. One hybrid control was banded in VT in 2016, and was resighted in 2017.

Of the 23 geolocators recovered in 2017, I downloaded usable light-level data from 19 Golden-winged Warblers and 3 Blue-winged Warblers. Nine Golden-winged Warbler geolocators recorded a complete year of data, four failed mid-way through spring migration 2017, five failed during winter, and one failed before fall migration in late August 2016 (this bird is excluded from all further results and analyses). Two Blue-winged Warbler geolocators collected a full year of data, and one stopped collecting data mid-way through spring migration 2017. This resulted in estimated winter locations for three Blue-winged Warbler and 17 Golden-winged Warbler.

**Wintering Locations**

Six Golden-winged Warbler geolocators deployed in Oneida County, Wisconsin were recovered with data spanning from spring deployment in 2016 to between 3 April and 26 May 2017. This allowed me to calculate 95th percentile winter ranges and centroids for each of these individuals. Of the male Golden-winged Warblers breeding in Wisconsin, two wintered in Honduras, two in Nicaragua, and two in Panama (Figure 4.3, Table 4.2). Two geolocators recorded data from deployment to 17 March and 24 April 2017, on male Golden-wined Warblers breeding in Houghton County, Michigan. One of these birds wintered in Panama and one wintered in Colombia (Figure 4.3, Table 4.2). Four geolocators were recovered from male Golden-winged Warbler breeding in New York. All of these geolocators stopped collecting data between 8 March and 2 April 2017. Three of these birds wintered in Colombia and one in northern Venezuela (Figure 4.3, Table 4.2). Six geolocators were recovered from male Golden-winged Warbler breeding in the southern Champlain Valley of Vermont. One geolocator stopped collecting data on 11 November 2016, and I was unable to calculate a winter centroid and 95th percentile winter range, however visual mapping of early November locations indicated a wintering range near Honduras or Nicaragua. The remaining five geolocators recorded data from deployment in spring 2016 to between 8 February and 14 June 2017. Of these five Golden-winged Warblers, one wintered in Costa Rica, two in Panama, and two in Colombia (Figure 4.3, Table 4.2).

Two geolocators recorded data for male Blue-winged Warbler breeding in the southern Champlain Valley of Vermont. Data were recorded from deployment in late May 2016 to recovery on the breeding territory in May 2017. One Blue-winged Warbler wintered in Nicaragua and one in western Panama (Figure 4.4, Table 4.2). A single geolocator recorded data between 20 June 2016 and 13 April

2017 for one Blue-winged Warbler breeding in Orange County, New York. This bird wintered in Nicaragua (Figure 4.4, Table 4.2).

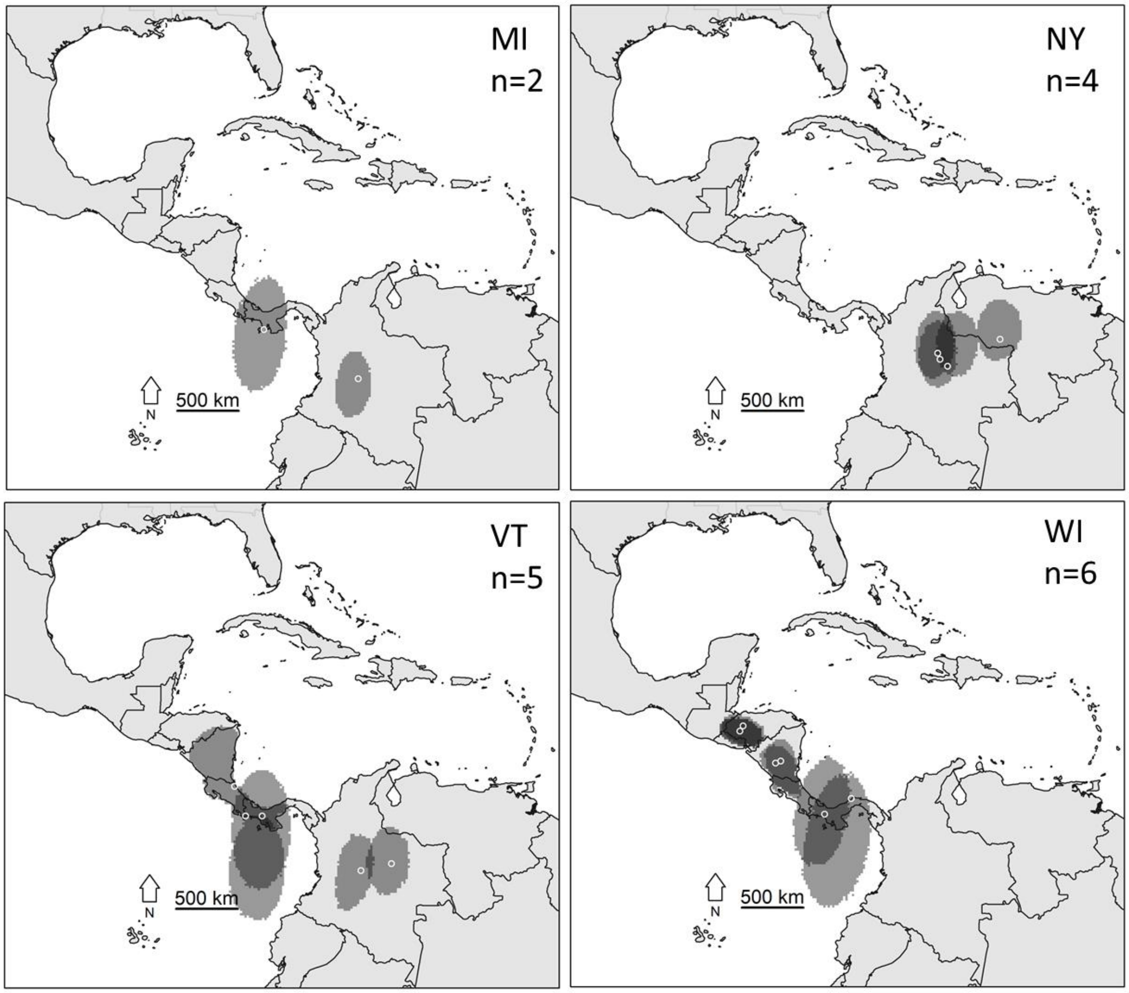


Figure 4.3. Light-level geolocator-derived wintering locations of male Golden-winged Warbler. The 95th percentile winter ranges (grey polygons) and centroid locations (white circles) are shown for male Golden-winged Warblers from breeding populations in Michigan (MI), New York (NY), Vermont (VT), and Wisconsin (WI), USA. Darker grey indicates overlap between individual ranges. Ranges were derived from light-level geolocator data analyzed in R package SGAT and calculated for the period 10 November 2016 through 10 February 2017, with the exception of one bird from Vermont where geolocator data (and the modeled winter period) ended on 8 February 2017.

Table 4.2. Light-level geolocator derived nonbreeding centroid locations of male Golden-winged Warbler (GWWA) and Blue-winged Warbler (BWWA). Birds were captured on the breeding grounds in 2016 and recovered in 2017. Centroids were calculated based on the daily modeled locations between 10 November 2016 and 10 February 2017. Modeling was conducted in a Bayesian framework using Markov Chain Monte Carlo models in R package SGAT. Locations are given in decimal degrees and standard errors for centroid latitude and longitude are reported.

| Breeding Location | Species | Nonbreeding Latitude ± SE | Nonbreeding Longitude ± SE | Nonbreeding Country |
|---|---|---|---|---|
| Michigan | GWWA | 7.480889 + 0.2088313 | -81.434812 + 0.08682986 | Panama |
| | GWWA | 3.867908 + 0.07641931 | -74.28152 + 0.05373664 | Colombia |
| New York | BWWA | 11.34369 + 0.09053752 | -84.18782 + 0.06081813 | Nicaragua |
| | GWWA | 5.744402 + 0.08255249 | -73.204488 + 0.06214529 | Colombia |
| | GWWA | 6.758053 + 0.04024282 | -68.485465 + 0.05585492 | Venezuela |
| | GWWA | 5.285786 + 0.06493439 | -73.015774 + 0.05067631 | Colombia |
| | GWWA | 4.778466 + 0.1320057 | -72.446361 + 0.1956382 | Colombia |
| Vermont | BWWA | 11.28642 + 0.09700213 | -84.31838 + 0.08057645 | Nicaragua |
| | BWWA | 7.645088 + 0.1451411 | -82.756203 + 0.06835292 | Panama |
| | GWWA* | 10.48297 + 0.10558 | -83.59795 + 0.09783572 | Costa Rica |
| | GWWA | 8.31309 + 0.1521697 | -82.74997 + 0.06624425 | Panama |
| | GWWA | 4.303551 + 0.1096919 | -74.055806 + 0.08137512 | Colombia |
| | GWWA | 4.811371 + 0.0677161 | -71.740759 + 0.07152556 | Colombia |
| | GWWA | 8.311195 + 0.2938456 | -81.502645 + 0.07060706 | Panama |
| Wisconsin | GWWA | 9.505592 + 0.4552415 | -79.736917 + 0.166728 | Panama |
| | GWWA | 14.84249 + 0.07260642 | -87.91413 + 0.1282045 | Honduras |
| | GWWA | 8.352319 + 0.1696394 | -81.75671 + 0.1034668 | Panama |
| | GWWA | 12.11945 + 0.09486241 | -85.46201 + 0.1344338 | Nicaragua |
| | GWWA | 12.26362 + 0.09181675 | -85.0596 + 0.08856122 | Nicaragua |
| | GWWA | 14.46275 + 0.05496383 | -88.15331 + 0.1657154 | Honduras |

* This geolocator stopped collecting data on 8 February 2017, therefore the nonbreeding centroid is calculated from the 95th percentile of location between 10 November 2016 and 8 February 2017.

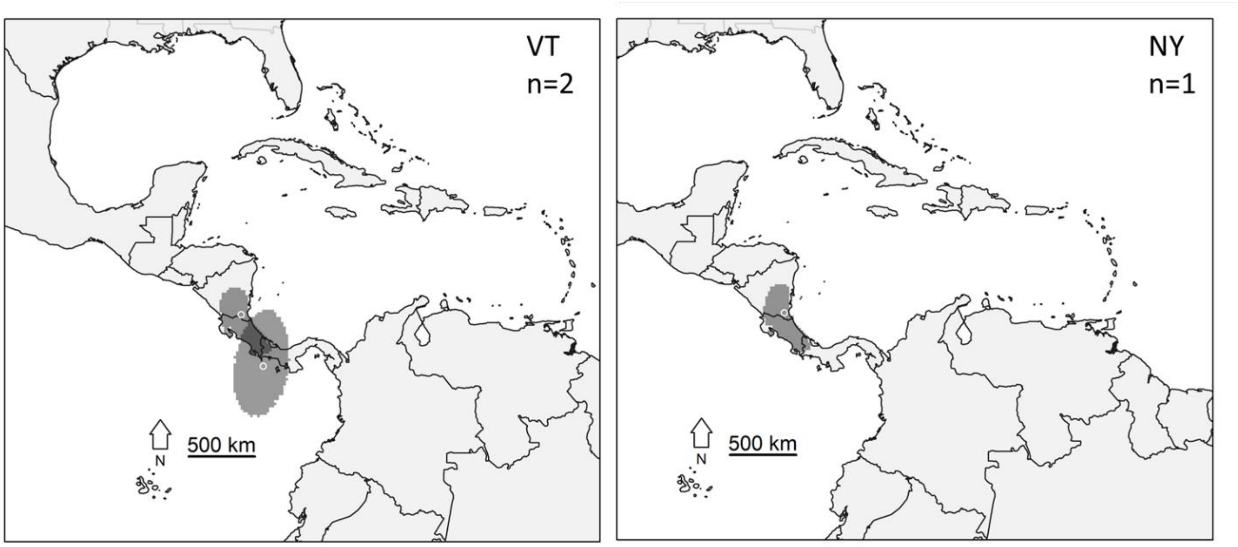


Figure 4.4. Light-level geolocator-derived wintering locations of male Blue-winged Warbler. The 95th percentile winter ranges (grey polygons) and centroid locations (white circles) are shown for male Blue-winged Warbler from breeding populations in New York (NY) and Vermont (VT), USA. Darker grey indicates overlap between individual ranges. Ranges were derived from light-level geolocator data analyzed in R package SGAT and calculated for the period 10 November 2016 through 10 February 2017.

## **Discussion**

Previous studies of *Vermivora* migration have found strong range-wide structure for migratory connectivity in Golden-winged Warbler and weak structural connectivity in Blue-winged Warbler (Bennett et al. 2017, Kramer et al. 2017, 2018, Larkin et al. 2017). A study by Kramer et al. (2018) documented Blue-winged Warblers from across the breeding range (n=25) wintering between southern Mexico and northern Panama, with one bird wintering in Venezuela, but with no clear connectivity structure between breeding and nonbreeding locations. A study of Golden-winged Warbler across their nonbreeding distribution (n=171) used hydrogen stable isotope analysis of feather samples to determine probable breeding or natal locations of individuals (Hobson et al. 2016). They found strong migratory connectivity structure which suggested a migratory divide between the Great Lakes and Appalachian breeding populations; with Great Lakes birds wintering in Central America, and Appalachian birds wintering in northern South America. Another study used light-level geolocator technology to track the migratory connectivity of male Golden-winged Warbler from three distinct breeding populations

(Kramer et al. 2017). They also found a distinct geographic divide, with Minnesota breeders (n=12) wintering between the Yucatan Peninsula and Nicaragua, Tennessee breeders (n=7) wintering in northwestern Venezuela and northwestern Colombia, and Pennsylvania breeders (n=2) wintering in northern Venezuela (Kramer et al. 2017). These same general patterns also appeared in a breeding-range-wide study of 42 male Golden-winged Warblers where Great Lakes breeders wintered throughout Central America and Appalachian breeders wintered in South America (Kramer et al. 2018).

My sample of Blue-winged Warbler geolocator data, though small (n=2 from VT and n=1 from NY), had no clear structural patterns in connectivity. Blue-winged Warblers breeding in both Vermont and New York wintered between Nicaragua and Panama, with the centroids of a Vermont and New York bird almost overlapping in Nicaragua. These findings parallel the weak migratory connectivity structure observed in other studies of Blue-winged Warbler migration (Kramer et al. 2018).

Given the repeated and consistently strong patterns in Golden-winged Warbler connectivity structure between breeding and wintering locations, I expected male Golden-winged Warblers in this study to exhibit the same sort of connectivity structure, with Great Lakes birds (WI, MI, VT) wintering in Central America, and Appalachian birds (NY) wintering in South America. This pattern was supported in the Wisconsin and New York breeding populations, however, I found exceptions to the typical patterns of Golden-winged Warbler migratory connectivity in Michigan and Vermont breeding populations. Although only two geolocators were recovered from male Golden-winged Warbler in the Upper Peninsula of Michigan, one bird wintered in Panama and one in Colombia. This finding is an exception to the typical pattern of Great Lakes breeders wintering in Central America. A larger sample of geolocator data should be obtained in this region to determine how frequently birds in this part of the Golden-winged Warbler breeding range winter in South America.

The sample of Golden-winged Warblers breeding in Vermont also exhibited unexpected patterns with wintering locations split between Central America (n=3) and South America (n=2). There are several factors that may be contributing to the weak migratory connectivity structure observed in the Vermont study area. The first is hybridization. The Vermont study area is occupied by successfully interbreeding Golden-winged Warblers, Blue-winged Warblers, and hybrid *Vermivora*. The designation of species at this study site was based on phenotype alone, and no genetic analysis was conducted. Introgression is common across the Golden-winged Warbler breeding range, with almost no populations devoid of Blue-winged Warbler mitochondrial DNA (Vallender and Bull 2016). This introgression is not always detected by morphologic analyses alone and cryptic hybrids can easily go unnoticed (Vallender et al. 2009). Bennett et al. (2017) investigated the migratory connectivity of genetically assigned Golden-winged Warbler, Blue-winged Warblers, and their hybrids from a breeding population in southern New York. They found that hybrids had an intermediate winter location near Nicaragua, while Blue-winged warblers wintered in southern Mexico and Golden-winged wintered in Colombia (Bennett et al. 2017). If my sample of Golden-winged Warblers from the Vermont study area included introgressed cryptic hybrids, they may experience a similar migratory response as those in Bennett et al. (2017) and thus winter in Central America rather than South America.

However, my New York study area had similar sympatry and hybridization between Golden-winged and Blue-winged Warbler, but geolocator analysis showed all four phenotypic male Golden-winged Warblers wintering in South America. Additionally, Kramer et al. (2018) used plumage to assign birds as Golden-winged Warbler, Blue-winged Warbler, or hybrid at 14 study sites across the breeding range. Geolocator data from 41 individual phenotypic male Golden-winged warblers resulted in only one individual from the Great Lakes population wintering in South America and all other individuals following the expected winter range divide between the Great Lakes and Appalachian populations (Kramer et al. 2018). Given this migratory consistency, even when Golden-winged Warblers are phenotypically identified, the inconsistent wintering locations of Vermont Golden-winged Warblers observed in my study are likely not exclusively explained by hybridization.

Another possible factor influencing the wintering locations of Vermont Golden-winged Warbler in this study is Golden-winged Warbler range shift and dispersal. As recently as 1980, the whole of New York State was included in the Golden-winged Warbler breeding range (Rosenberg et al. 2016). Since then, a distinct range separation has occurred with the eastern extent of the Great Lakes population persisting in the Lake Champlain Valley of northern New York and Vermont and the northeastern extent of the Appalachian population breeding in the Hudson River Valley in southeastern New York (Rosenberg et al. 2016). These two edges of the breeding regions are approximately 165 km apart. The Great Lakes population has been shifting northward and westward through time, while the Appalachian population has been contracting and moving higher in elevation (Rosenberg et al. 2016). Although it is difficult to directly measure and monitor juvenile dispersal, scientists known that adult male Golden-winged Warblers display high site fidelity (Schlossberg 2009) and that juvenile dispersal is likely a driving mechanism of the species' range shifts (Koonce 2005, López-Calderón et al. 2019). Schlossberg (2009) reported a site fidelity of 0.00 ± 0.09 SE for yearling Golden-winged Warblers. This yearling component of the population disperses away from natal areas to find new breeding locations. Based on songbird dispersal distances (Tittler et al. 2009), it is possible that yearling Golden-winged Warblers from the Appalachian breeding region in southern New York could disperse to the next nearest population center in the Champlain Valley of northern New York and Vermont, part of the Great Lakes breeding population. A recent study analyzed stable isotopes from feather samples of five populations of Golden-winged Warbler and found that individuals who immigrated to a population generally originated from south or southeast of that population (López-Calderón et al. 2019). This indicates that dispersal of Appalachian breeding Golden-winged Warblers (South American wintering) to the Great Lakes breeding population in the Champlain Valley is biologically likely and may account for the South American wintering ranges I observed for two birds in the Vermont study area.

Additionally, López-Calderón et al. (2019) found that populations with a lower (or more negative) long-term Breeding Bird Survey (BBS) population trend were more likely to have a larger proportion of immigrants in the population. Although there are no reported BSS trend data for Vermont, BBS data indicate a long-term Golden-winged Warbler population trend (1966-2015) of -5.76% annually (-7.41, -3.97 95% CI) for the neighboring state of New York and -11.77% annaully (-19.89, -3.98 95% CI) for the New England/mid-Atlantic Coast region (which includes Vermont; Sauer et al. 2017). Based on model predictions from López-Calderón et al. (2019), the probability of a Golden-winged Warbler being an immigrant in a population with a -5% annual population growth rate is greater than 50%. The overall negative long-term Golden-winged Warbler population trend in northern New York and Vermont suggests a strong likelihood that there is a large number of immigrants within the Champlain Valley population. Immigrants sourced from the Appalachians could potentially explain some of the birds in the Vermont study area that wintered in Colombia. There may also be some residual mixing of South American and Central American wintering populations in the Vermont study area given that, as recently as the 1980s, a single contiguous breeding population of Golden-winged Warbler existed in New York.

Although clear patterns of wintering connectivity exist among the Great Lakes and Appalachian breeding populations, it is not unreasonable that there may be an area of the breeding range where transition or overlap of wintering location occurs, and that region may be the Champlain Valley of Vermont and New York. In order to investigate this further, additional studies should be conducted in the eastern extent of the Great Lakes breeding region. Collecting both migratory and genetic data for the same individuals and populations should produce a better understanding of the influence of hybridization and juvenile dispersal on Golden-winged warbler migratory connectivity in the region.

Recent and long-term Golden-winged Warbler population trends show a much steeper decline in the Appalachian population than in the Great Lakes population (Sauer et al. 2017). Kramer et al. (2018) attributed this disparity in regional demographics to nonbreeding location, where birds wintering in South America (breeding in the Appalachians) are experiencing steeper declines than those breeding in Central America (breeding in the Great Lakes region). They also indicated that geographic diversity of wintering locations was higher among the Great Lakes population than for the Appalachian population, and that migratory distance (and therefore risks associated with migration) was greater for Appalachian populations, both possibly contributing to differences in population rates (Kramer et al. 2018). Given this connection, defining the breeding range transition from South American wintering to Central American wintering birds is important to the full-annual-cycle conservation of Golden-Winged Warbler.

The lack of migratory data on female *Vermivora* is a major gap in full-annual cycle knowledge. Many migratory species are known to exhibit winter range segregation based on sex and or age (Cristol et al. 1976, Komar et al. 2005) which may result in segregated carryover effects impacting fitness and survival (Reudink 2008). Based on an extensive 2009-2012 winter survey effort across the nonbreeding range, Rosenberg et al. (2016) detected female Golden-winged Warblers throughout the geographic distribution of males, suggesting no latitudinal segregation by sex. They did find, however, spatial segregation with females occupying lower elevation and drier habitats than males (Rosenberg et al. 2016). In a stable isotope analysis that showed strong Golden-winged Warbler migratory connectivity structure, 16 of 171 samples were from females and 16 were from birds of unknown sex (Hobson et al. 2016). A study of 45 Nearctic-Neotropical species wintering in Mexico, found strong sexual segregation in 9 species, with females wintering farther south than males, despite the presence of females throughout the range (Komar et al. 2005). Given the lack of research focused on female migration, I think it is unwise to assume that female *Vermivora* connectivity structure matches the structure documented for males, but I think connectivity patterns documented for males are a good reference point for further investigation. Male connectivity patterns represent the best current information available for making full-annual-cycle conservation decisions for Golden-winged and Blue-winged Warblers.

Based on my study, there are intricacies of male Golden-winged Warbler migratory connectivity, particularly in Northern Michigan and the Champlain Valley of Vermont and New York, that need additional study. Especially because sample sizes as small as 2 (MI) and 5 (VT) Golden-winged Warblers revealed connectivity inconsistencies, these anomalies may be more common than we realize. Additionally, research should be dedicated to understanding how ongoing *Vermivora* range shifts influence migratory connectivity structure. The large body of work showing strong migratory patterns across the entire breeding population of Golden-winged Warbler reinforces the need for full-annual-cycle conservation of the species. Given the apparent link between nonbreeding location and regional population trends in breeding populations (Kramer et al. 2018), conservation plans should have a stronger emphasis on migration and nonbreeding periods. Understanding the limiting factors during migration and in the nonbreeding range should be a priority for future research. Arguably, delineation of breeding conservation regions should be designated not only by breeding habitat similarity, but also by connectivity to wintering location. Although the current Golden-winged Warbler breeding conservation regions were not designated based on migratory connectivity, they do generally align with segregation between wintering regions. Creating conservation plans that incorporate connectivity-related factors such as migration routes, timing, distance, and stopover locations will be most effective when applied to breeding populations based on their connectivity to wintering locations. Additional investigations of Golden-winged Warbler migratory structure in the Upper Peninsula of Michigan and the Champlain Valley of New York and Vermont may warrant a new delineation of breeding conservation regions to better align with migratory patterns and more effectively accomplish full-annual-cycle conservation. Investigating the connectivity structure of populations along the New York/Canada border may help to define the extent of wintering region overlap in the far eastern portion of the Great Lakes breeding population, and can be used to further tailor conservation. Considering the rapid shifts in *Vermivora* ranges, delineation of population segments may need to be flexible through time. In order to more fully integrate conservation throughout breeding, migration, and nonbreeding periods, conservation planners could redefine Golden-winged Warbler breeding populations as Central American, South American, and mixed, rather than Great Lakes or Appalachian.

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## APPENDIX A: WOODCOCK SURVEY DATA SHEET FOR THE 2017 LANDOWNER PILOT SEASON

UMaine 2017 American Woodcock **Landowner Data Sheet**

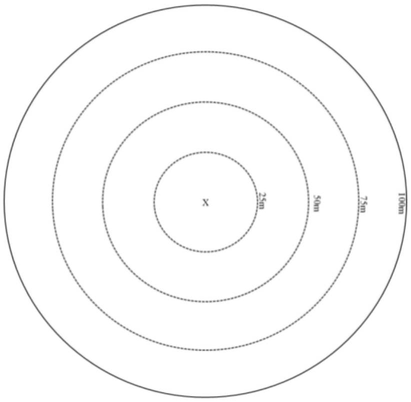
| | | | | |
|---|---|---|---|---|
| Property Owner/Site: | Point ID: | Month: | Day: | Year: |
| State: | County: | Visit (circle): 1 2 | Observer: | |
| *Sunset + Sky Cond Addition =*<br>**Earliest Possible Start time**:<br>___:____+____=____:_____<br>*<Sunset> <15 or 22 min>*<br>**This survey began at:**<br>_____ : ________pm | Sky Cond (check one):<br>0 ☐ clear<br>1 ☐ 1/4 overcast<br>3 ☐ 1/2 overcast<br>5 ☐ 3/4 overcast<br>Add 22 min to start time<br>7 ☐ >3/4 overcast --Add 15 min | Estimated Temperature:<br>°F<br>Wind (0-5): | Noise Disturbance:<br>**none** ☐ no effect on count<br>**low** ☐ slightly affecting count<br>**moderate** ☐ moderately affecting count<br>**heavy** ☐ seriously affecting count<br>Source(s) of disturbance:<br>*i.e.: frogs, traffic* |  |
| Precip: **none** ☐ **fog** ☐ **mist** ☐ **light rain** ☐ **heavy rain** ☐ **snow** ☐ | | | | |

*Wind*: 0=smoke vertical, 1=smk drift, 2=wind on face, 3=twg constant motion, 4=sm branches move, 5= trees sway

*Disturbance* Examples: *None* = e.g., crow occasionally calling; *Low* = e.g., distant traffic noise; *Moderate* = e.g., intermittent traffic noise, soft chorus of spring peepers; *Heavy* = e.g., continuous traffic, loud chorus of peepers

| Bird ID  | Distance from Observer (yards) | "Peenting" First Detection Time | | | Outside managed patch? **check if true** | Range Finder Used? **check if true** |
|---|---|---|---|---|---|---|
| | | 0 – 2 mins | 2 – 4 mins | 4 – 6 mins | | |
| 1 | | | | | ☐ | ☐ |
| 2 | | | | | ☐ | ☐ |
| 3 | | | | | ☐ | ☐ |
| 4 | | | | | ☐ | ☐ |
| 5 | | | | | ☐ | ☐ |
| 6 | | | | | ☐ | ☐ |
| Total AMWO | | | | | | |

Use the diagram to help keep track of individual peenting male woodcock, 25 yard rings are shown.



| OPTIONAL: Other Nocturnal Bird Detections | | | | | | |
|---|---|---|---|---|---|---|
| Nocturnal Bird Species | Distance from Observer (yards) | First Detection Time | | | Outside managed patch? **check if true** | Range Finder Used? **check if true** |
| | | 0 – 2 mins | 2 – 4 mins | 4 – 6 mins | | |
| | | | | | ☐ | ☐ |
| | | | | | ☐ | ☐ |
| | | | | | ☐ | ☐ |
| | | | | | ☐ | ☐ |

**Notes:**

Remember that surveys begin at calculated start time and continue for no longer than 38 minutes each night.

# APPENDIX B: THE INFLUENCE OF SPATIAL MASK SETTINGS ON MODELED WINTERING LOCATIONS

The spatial mask is one component of the Markov Chain Monte Carlo Estelle movement model used in program SGAT (Wotherspoon et al. 2016) to predict the location of birds based on light-level data. There are two aspects of the spatial mask, geographic limits (latitudinal and longitudinal boundaries for modeled locations) and a land mask (setting the probability of a bird being on land versus water). These two aspects are used to restrict the modeled locations to areas within the known range of a species and, for land birds, to only allow stationary locations on land. This masking helps the model produce biologically reasonable location estimates. However, the land mask also “forces” locations that occur over water to the nearest landmass, which can become an issue if the error surrounding light-level data causes locations over water.

The land mask “forcing” locations to land became a problem in my study, particularly for birds that wintered in Panama. Panama occurs between approximately -77.2˚ and -83.0˚ longitude and the western coast of Ecuador is the first landmass due south of much of Panama, spanning from -78.8 ˚ to -81.0˚ longitude. Panama is also a very narrow land mass spanning only 177 kilometers north to south at its widest point. When I ran models using a land mask which made locations four times more likely on land than over water, light-level data would routinely predict locations over the ocean south of Panama, and then these locations would be “forced” to the nearest land mass, Ecuador (Figure B.1). This resulted in the model predicting that six birds (1 Blue-winged Warbler and 5 Golden-winged Warblers) wintered in Ecuador, which is far outside the range of nonbreeding Blue-winged Warbler (Gill et al. 2001) and on the very southwestern edge of known locations of wintering Golden-winged Warbler (Rosenberg et al. 2016).

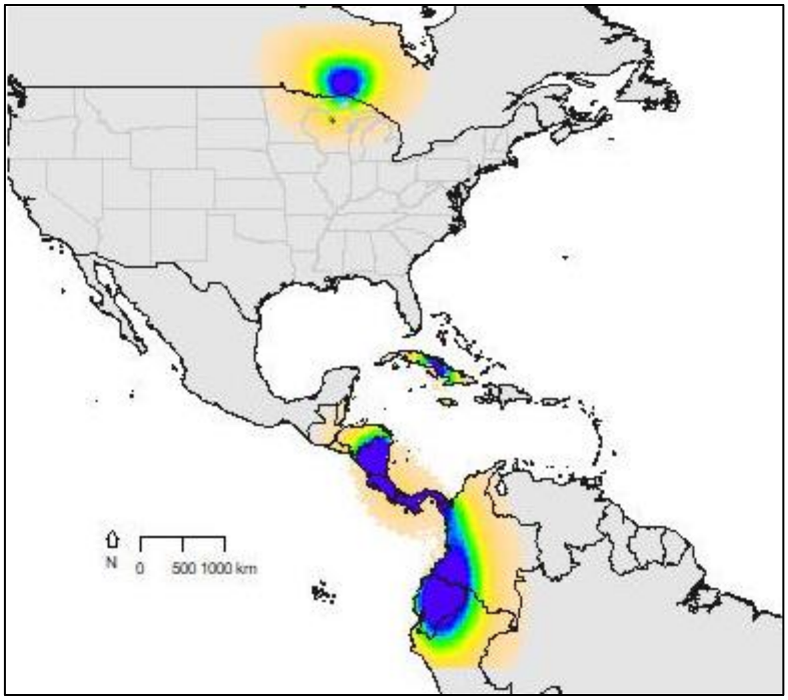


Figure B.1. Light-level geolocator-derived breeding and nonbreeding locations of a male Golden-winged Warbler. This individual was captured on breeding territory in Wisconsin, USA in summer 2016 and recaptured there in 2017. Analysis was conducted in R package SGAT. I applied a land mask which made it four times more likely for locations to occur on land than over water, but locations were not otherwise geographically limited. The blue area on the heatmap is the 95th percentile of the modeled locations of the bird based on the amount of time spent there. The darker the color, the more likely the breeding/nonbreeding location. This particular map indicates a breeding area along the USA Canada border (the known breeding location is the red dot) and a nonbreeding location in both Costa Rica/Panama and Colombia/Ecuador.

In order to determine the most reasonable wintering location, and the best models to use for final interpretation for these six birds, I compared the output of four models of a single Golden-winged Warbler run with different spatial mask settings. Spatial mask settings were either 1) four times more likely on land with no geographic limit, 2) four times more likely on land with a geographic limit between 50˚ and -2˚ latitude and -140˚ and -45˚ longitude (based on the known Golden-winged Warbler range; Rosenberg et al. 2016), 3) ten times more likely on land with no geographic limit , or 4) totally unconstrained with no land mask or geographic limit.

Results from this model comparison indicated the best visual model convergence for the unconstrained spatial model (Figure B.2). Ecuador was included as a predicted wintering location in four times land mask models both with and without geographic limits (Figure B.3). In the ten times land mask model, Ecuador was not a predicted wintering location, but errors that occurred over water north of Panama, resulted in a predicted wintering range which included both parts of Central America and Cuba (Figure B.3). Cuba is a very rare winter location for Golden-winged Warbler, with movement between Cuba and Central America during winter being even more unlikely (Rosenberg et al. 2016). The unconstrained spatial model output predicted wintering locations centered in Panama with possible locations in the ocean north and south of Panama, but never in South America (Figure B.3). Golden-winged Warblers cannot winter over water, so I determined Panama to be the most likely breeding location for this bird. Based on these results, I decided to run models with unconstrained spatial masks for all six birds for which initial modeling predicted a wintering range in Ecuador. All results and interpretations reported for these six birds were drawn from models with unconstrained spatial masks.

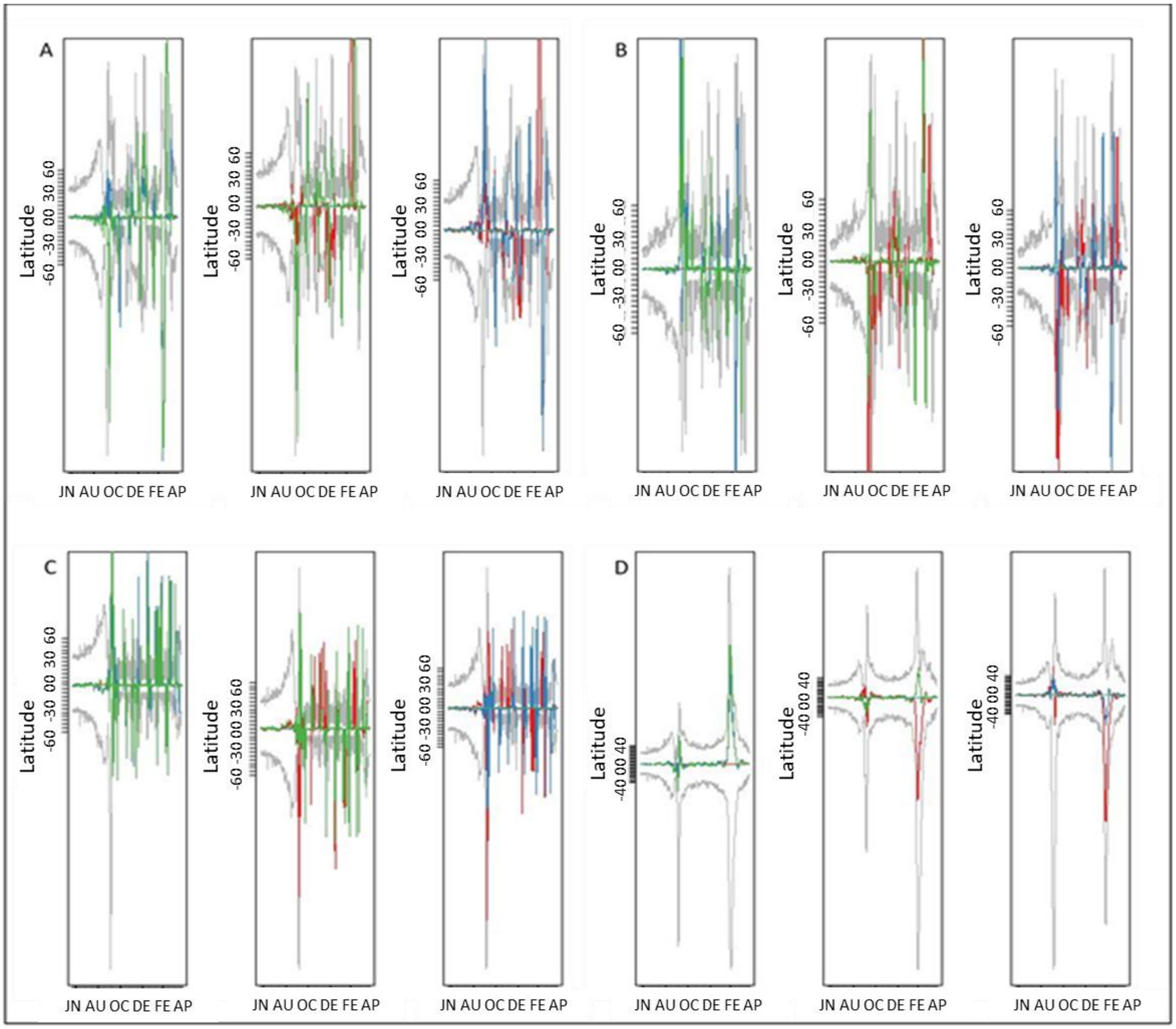


Figure B.2. Markov Chain Monte Carlo model convergence figures of the posterior distribution of daily latitude estimates of a single male Golden-Winged Warbler modeled in R package SGAT. Date is on the x axis and latitude is on the y axis. The mean value of the final 10,000 iterations (colored lines) are plotted against the 2.5% and 97.5% confidence intervals (gray lines) for each day. Figures indicate high model convergence when colored location estimates remain within the bounds of the grey confidence intervals. Panel A shows the convergence of a model which makes it four times more likely for locations to occur on land than over water and has no geographic limit. Panel B shows the convergence of a model which makes it four times more likely for locations to occur on land than over water and is geographically limited, based on the known range of Golden-winged Warbler, to between 50˚ and -2˚ latitude and -140˚ and -45˚ longitude. Panel C shows the convergence of a model which makes it ten times more likely for locations to occur on land than over water and has no geographic limit. Panel D shows the model convergence of a spatially unconstrained model, with the same likelihood of locations over land and water and no geographic limits.

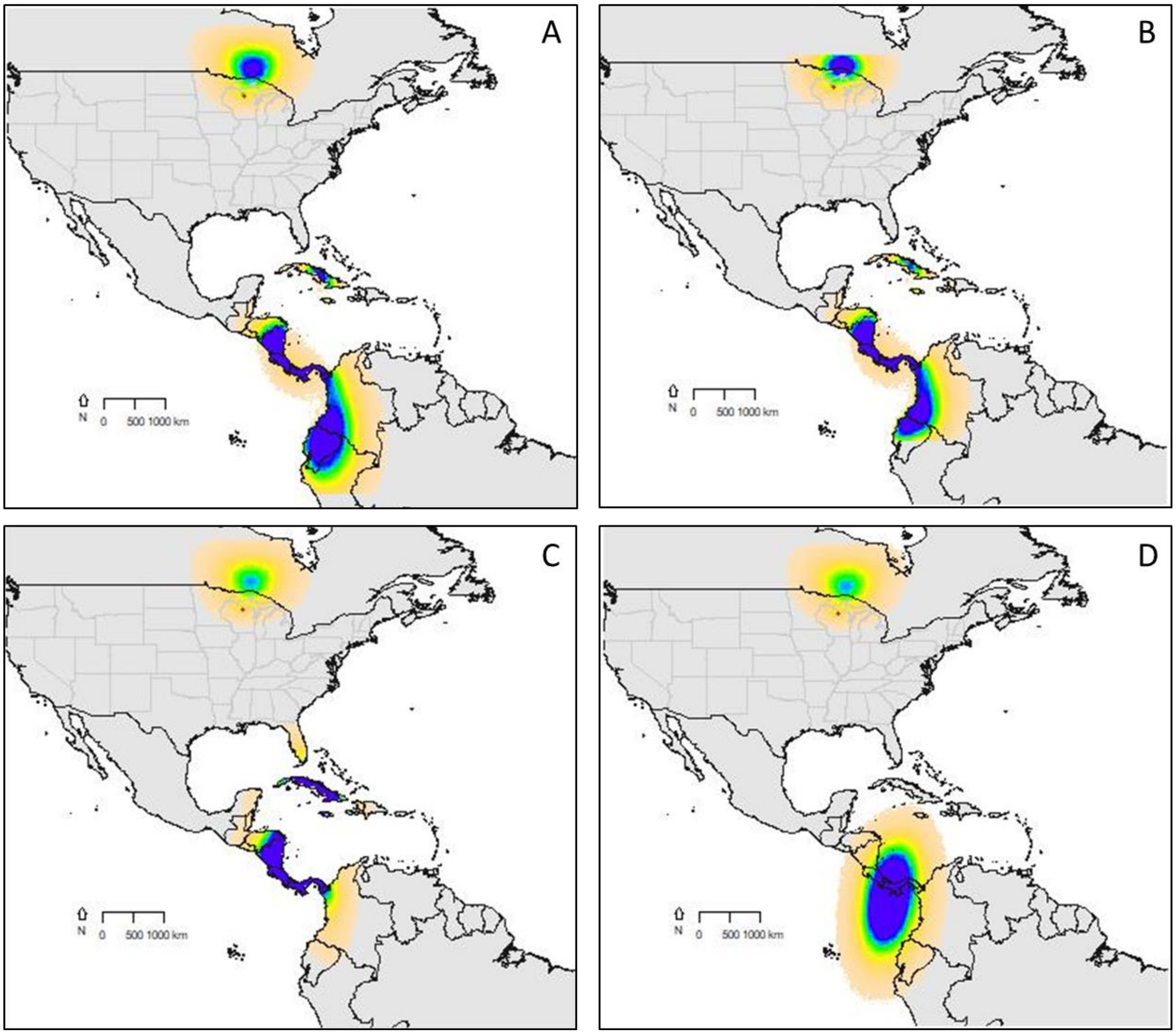


Figure B.3. Heatmaps showing the modeled breeding and nonbreeding range of a single male Golden-winged Warbler breeding in Wisconsin based on light-level data analyzed using Markov Chain Monte Carlo models in package SGAT in program R. The blue area on the heatmap is the 95th percentile of the modeled locations of the bird based on the amount of time spent there. The darker the color, the more likely the nonbreeding location. Modeled breeding locations are displayed between geolocator deployment (4 June 2016) and 20 July 2016. Modeled wintering locations are displayed between 10 November 2016 and 10 February 2017. Panel A shows the output of a model which makes it four times more likely for locations to occur on land than over water and has no geographic limit. Panel B shows the output of a model which makes it four times more likely for locations to occur on land than over water and is geographically limited, based on the known range of Golden-winged Warbler, to between 50˚ and -2˚ latitude and -140˚ and -45˚ longitude. Panel C shows the output of a model which makes it ten times more likely for locations to occur on land than over water and has no geographic limit. Panel D shows the output of a spatially unconstrained model, with the same likelihood of locations over land and water and no geographic limits.

# BIOGRAPHY OF THE AUTHOR

Anna Buckardt Thomas was born in Highland Park, Illinois on February 19, 1993. She was raised in Deerfield, Illinois and graduated from Stevenson High School in 2011. She attended Michigan Technological University in Houghton, Michigan and graduated in 2015 with a Bachelor of Science degree in Wildlife Ecology and Management and Applied Ecology and Environmental Science. She moved to Maine and entered the Wildlife Ecology graduate program in the Department of Wildlife, Fisheries, and Conservation Biology, at The University of Maine in the summer of 2016. Anna is a candidate for the Master of Science degree in Wildlife Ecology from the University of Maine in May 2019.