Influence of Habitat Type on Nest Success, Fledgling Survival, Predator Abundance, and Post-fledging Habitat-use of the Golden-winged Warbler in Northern Minnesota

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Abstract

The Golden-winged Warbler (*Vermivora chrysoptera*) is one of the most critically threatened birds in North America with a global population estimated at only 400,000 individuals of which 50% nest in Minnesota. The species relies on two distinct habitat types, shrub wetland and young forests, for breeding. Quantifying differences in demographic parameters, such as productivity and survival, between habitats is necessary to inform conservation efforts and ensure long-term population stability and growth. To better understand the breeding ecology of Golden-winged Warblers, we studied their nest success, post-fledging survival, and post-fledging habitat-use across 10 study sites in northern Minnesota, USA from 2020 to 2023. We monitored a total of 91 nests and tracked the post-fledging movements of 60 individuals from 52 broods. We used these data to determine the influence of vegetation characteristics, habitat, and landscape factors on nest success, fledgling survival, and post-fledging habitat-use. We assessed the effect of habitat type on nest and juvenile survival using a Markov likelihood framework to estimate daily survival rate as well as daily failure probabilities due to predation and weather events. Our results indicated that there was no difference in nest success and fledgling survival between young forests and shrub wetlands. Predation by sciurids, hawks, and mesocarnivores during the nesting period and the post-fledging period was the most common cause of mortality. Nest survival was lowest for nests that were close to forest edges and survival was lower for nests that were initiated later in the breeding season. Fledgling survival was also lower for birds near forest edges but increased as fledglings aged and became more mobile. Results from the habitat selection models indicated that Golden-winged Warbler fledglings used a variety of habitats including young forest stands that have retained trees and shrub wetland habitats; within stands, they select for areas with high shrub/sapling density, canopy cover, and coarse woody debris. Overall, our results showed that forest management activities that promote structural diversity in young forest stands and conservation of shrub wetland habitats is necessary to maintain stable breeding populations of Golden-winged Warblers in the region.

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CHAPTER 1

Influence of breeding habitat, landscape, and temporal factors on nest success and fledgling survival of the Golden-winged Warbler

INTRODUCTION

Widespread declines in breeding bird populations have been documented across North America (Rosenberg et al. 2016, IUCN 2022). These declines have largely been attributed to habitat loss and degradation associated with land management changes and climate change. (Betts et al. 2022). In recent history, the suppression of natural disturbances, such as flooding and wildfires, has greatly reduced the amount of early-successional forests (such as young forests and shrub wetlands) across the eastern United States and Great Lakes region (King and Schlossberg 2014, Tavernia et al. 2016). These ephemeral habitats were once maintained across the landscape by disturbance events such as wildfire, wind, and flooding from beavers (*Castor canadensis*), as well as agricultural and landscape-burning practices from Native American peoples (DeGraaf and Miller 1996, Askins 1998, Litvaitis et al. 1999). In connection with these habitat losses, there are many species that rely on early-successional habitat for breeding that have experienced population declines such as the Black-billed Cuckoo (*Coccyzus erythropthalmus*), Chestnut-sided Warbler (*Setophaga pensylvanica*), Mourning Warbler (*Geothlypis philadelphia*), and Least Flycatcher (*Empidonax minimus*) (Askins 1998, Sauer et al. 2020).

Annual recruitment into the population has been linked to habitat quality and landscape features (Martin 1992, 1993, Streby and Andersen 2011). For many birds, survival is highly variable depending on the life stage (i.e. nesting, fledgling, adult, etc.), but the nesting and post-fledging stages represent the most vulnerable life stages of most songbirds (Martin 1987, Anders et al. 1997, Streby and Andersen 2011). Specifically, for most North American, open-cup-nesting passerines, nest predation is the predominant cause of nest failure (Manolis et al. 2002, Phillips et al. 2005, Lyons et al. 2015). During the post-fledging stage, many juvenile passerines experience high mortality, especially during the first few days after leaving the nest (Yackel Adams et al. 2006, Streby et al. 2016). Multiple studies have demonstrated that landscape and habitat factors, such as edge and canopy density, are critical components of habitat quality

because they can affect nest and fledgling survival (Etterson et al. 2014, Reidy et al. 2017, Adalsteinsson et al. 2018).

Habitat quality commonly refers to the ability of an environment to provide suitable conditions for individuals and populations to persist (Hall et al. 1997). Many wildlife studies assume that increased density of a species indicates a superior habitat condition (Van Horne 1983), which may be the case in terms of food availability. However, relying solely on density as the indicator for habitat conditions neglects to account for factors that may affect the ability for individuals and populations to persist in certain habitat such as increased predator risk and abiotic environmental factors (Roy Nielsen and Gates 2007, Chiavacci et al. 2015, Rota et al. 2015). Demographic studies are needed to determine how differing variables (i.e., landscape, vegetative, or biological) impact survival and therefore recruitment (Holmes et al. 1996, Murphy 2001, Latta and Faaborg 2002). It is well documented that biological factors such as the timing of nest initiation and age of the nest can greatly impact nest survival (Martin et al. 2000, Reidy et al. 2017, Stillman et al. 2019); many recent studies have documented habitat and landscape features also influence nest and fledgling survival of forest-dwelling birds (Cohen and Lindell 2004, Peak 2007, Etterson et al. 2014). However, there is a lack of information about how these features may affect birds that breed in early-successional habitats and their relative importance compared to biological variables.

The Golden-winged Warbler (*Vermivora chrysoptera*) has experienced substantial population declines across its range and is currently under consideration for federal listing as a threatened species (Rosenberg et al. 2019, Sauer et al. 2020). Golden-winged Warblers breed in eastern North America, primarily in young forests and shrub wetlands, across the Appalachian Mountains and Great Lakes region (Confer et al. 2020). Golden-winged Warblers nest in a variety of habitats that have a combination of a partially open canopy and dense, herbaceous cover with patches of shrubs, often adjacent to a forest edge (Martin et al. 2007, Aldinger et al. 2015). Minnesota is a critical stronghold for the global Golden-winged Warbler population as it is estimated that over 50% of the population breeds in the state (Pfannmuller et al. 2022). In

Minnesota, the highest densities of breeding Golden-winged Warblers are found primarily in young forests and shrubby wetland habitats (Niemi et al. 2016, Pfannmuller et al. 2022).

In the eastern parts of their range, shrub wetland habitat with a high degree of shrub patchiness have been identified as a high priority habitat (Confer et al. 2020). These habitats have been shown to have nigh nest success and attract fewer Blue-winged Warblers where the two species are sympatric (Rush and Post 2008, Confer et al. 2010). It is possible that the combination of dense cover and the wetter conditions provides a more continuous food source during the peak of the breeding season compared to drier, upland habitats. However, there is a scarcity of knowledge associated with differences in habitat quality provided by these two distinct habitats including information related to the differences in habitat use, nest success, and post-fledging survival. Overall, understanding variation in habitat quality for breeding birds is critical to effectively guide restoration efforts and to optimize management plans for conservation (Van Horne 1983, Block and Brennan 1993, Johnson 2007).

Identifying potential differences in habitat-specific metrics associated with demographic parameters (e.g., nest success and fledgling survival) across the full breeding season is essential for quantifying habitat quality as it relates to productivity and survival to ensure long-term population stability and growth. This is a critical next step to understand how habitat influences productivity and survival and to potentially increase Golden-winged Warbler populations. To better understand the breeding ecology of Golden-winged Warblers, we studied their nest success, post-fledging survival, and post-fledging habitat-use across 10 study sites in northern Minnesota, USA from 2020 to 2023. Our specific objectives were to: 1) quantify vegetation and landscape-scale differences between nest site and daily fledgling locations among shrub wetlands and young forests, 2) assess differences in survival (using daily survival rate, DSR) of nests and fledglings between shrub wetland habitat and young forests, and 3) determine the relative importance of landscape, vegetative, and biological factors on the survival of nests and fledglings. We hypothesized that shrub wetlands would have higher vegetative density and, as a result, nest and fledgling DSR would be higher in these habitats due to decreased predation rates.

We also hypothesized that DSR would decrease closer to mature forest edges and that the same biological and vegetative factors would be important for predicting DSR for nests and fledglings.

METHODS

Study Areas

This study was conducted across three study areas with 10 study sites (n = 10) during the breeding seasons from 2019 to 2023 in northern Minnesota (Beltrami, Itasca, and Carlton Counties), near the ecotone of boreal and northern temperate forests commonly referred to as the "hemiboreal" forest (Figure 1.1). Forest cover types are dominated by aspen, lowland hardwood, mixed hardwood, lowland conifer, and upland conifer (Grinde et al. 2017). The most representative tree species are aspen (*Populus* spp.), paper birch (*Betula papyrifera*), ash (*Fraxinus* spp.), spruce (*Picea* spp.), tamarack (*Larix laricina*) and pine (*Pinus* spp.) (Hillard 2019).

At each study area, there were paired sites that consisted of upland young forests (sapling-dominated stands) and shrub wetland (shrub-dominated wetlands). Young forest sites consisted of sapling dominated quaking aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), approximately 2-5 years post-harvest, with varying levels of overstory retention. Shrubby wetland habitats were dominated by speckled alder (*Alnus incana*), willow (*salix spp.*), and black ash (*Fraxinus nigra*). Sites ranged in size from 17 to 180 acres (Table 1.1). Sites were predominantly surrounded by even-aged mature aspen, mixed hardwood, and lowland hardwood forests.

Nest searching and monitoring

Nest searching began in mid-May when adults arrived in the breeding habitat. We used a combination of systematic searching and adult behavioral cues (e.g. singing males, flushing females, nest-building females, and provisioning adults) to locate nests. In 2022 and 2023 we also target-netted female Golden-winged Warblers and attached coded VHF radio telemetry tags

(Lotek *NTQB2-1* and *NTGB2-5-1-M;* burst rate of 7.6 and 19.8, respectively), which allowed us to track them to the nest during incubation. We recorded nest locations with a handheld GPS unit and marked the nest with flagging 5-10 m away from the nest. Nest checks occurred every 3-4 days, with an increase in frequency during transitions between stages (i.e., laying, hatching, fledgling). During each nest check, we approached and departed the nest from a different direction to minimize disturbance and to prevent leaving a trail to the nest (Martin and Geupel 1993) and we recorded the status of the nest contents (i.e. number of eggs and nestlings, and estimated nestling age) until fledging or nest failure. In 2022 and 2023, we deployed motion-activated cameras to monitor nest activity and predation events. Cameras (Browning Spec Ops Elite HP4) were placed 0.5-1 m away from the nest after incubation was initiated to decrease disturbance that may lead to nest abandonment (Thompson, and Burhans 1999, Thompson 2007, Ribeiro-Silva et al. 2018). This specific trail camera model was used because they do not emit any light in the visible range that might attract predators to the nest and they have a fast trigger speed that is beneficial for detecting small species such as snakes and rodents.

Fledgling monitoring

We banded and attached radio transmitters to nestlings on the day of pinbreak (when primary pin feathers begin to open), which typically occurs one or two days prior to fledging. Banding at this age was done to decrease the likelihood of force-fledging. In instances when nests were found after pinbreak, nestlings were banded at the earliest date possible, noting that this often led to force-fledging. Nestlings were extracted from the nest and carried in a soft cloth bag 10-15 m from the nest to process. We banded all nestlings with a unique color combination involving three plastic, UV-resistant, Darvic color bands (Avinet, Dryden, NY) and one standard aluminum USGS leg band. We attached coded VHF tags (Lotek *NTQB2-1*) to two or three randomly selected nestlings using a figure-eight harness design (Rappole and Tipton 1991, Streby et al. 2015) and then replaced nestlings in the nest. Transmitters were 1.4 - 2.3% of the nestling body mass at the time of attachment. After banding and attaching tags, nests were checked daily to better estimate fledge dates. Nest fates (survived, depredated, flooded, dead nestling, abandoned) were determined using a combination of regular nest checks, video camera footage and tagged fledgling fates (i.e., tags found attached to dismembered fledglings near the nest).

Fledglings were tracked daily with handheld receivers (SRX800, Lotek Wireless, Inc.) for the first 7 days post-fledging. We located the fledglings by scanning for each signal from the previous day's location. Each day we attained visual confirmation of survival or mortality. Each daily detection was marked with a handheld GPS and flagging for later vegetation surveys. If the signal was not detected immediately we traveled 200m from the last detected area in each cardinal direction. Any tagged fledglings that were not detected within the first few days after fledging were presumed depredated, since tags emitted signal during nest checks prior to fledging, and hawks and mesocarnivores could have carried the tags out of detection range.

Landscape, vegetative and biological variables

Vegetation metrics. Vegetation metrics were collected at each nest and daily fledgling location once the nest was terminated or the fledgling moved from the location. We collected the same 11 metrics at nest and daily fledgling locations. We recorded total percent canopy cover, high percent canopy cover (canopy obstruction > 5 m tall), and low percent canopy cover (canopy obstruction < 5 m tall), averaged from four cardinal directions using a handheld densiometer. Within a 5-m-radius plot around each location, we recorded number of woody stems above 0.5 m tall and less than 8 cm DBH, as well as the percent ground coverage of low vegetation (vegetation < 0.1 m tall), high vegetation (vegetation > 0.1 m tall), woody debris, and bare ground (bare soil, gravel, or leaf litter). We recorded the number of trees (DBH > 8 cm) in a 11.3-m-radius plot at each location as well. To measure lateral vegetation density, we used a two-meter-tall lateral density board subdivided into eight, 25 cm squares. The percentage of obstruction was visually estimated from standing 5 m away at each cardinal direction. The lower 0.5 m was averaged to represent the lower strata. The upper 1.5 m was averaged to represent the upper shrub strata.

Landscape metrics. Landscape metrics were generated using ArcGIS Pro 3.2.0 (ESRI, Redlands, California, USA). Site boundaries and surrounding forests were digitized using a combination of aerial imagery (ESRI, 2021), National Wetland Inventory data (NWI), Chippewa National Forest and Carlton County Forest Inventory data, as well as ground-truthing from

tracking and vegetation surveys. We calculated the distance from each nest and daily fledgling location to the nearest road and two habitat edges (residual forest patches within the site, and exterior site boundaries) using the Euclidean Distance tool in ArcGIS Pro. For all distanced-based landscape variables we used a negative exponential transformation (with base 1.2) because edge effects may not be linear, having a greater effect close to landscape features and a rapidly diminished effect further away (Etterson et al. 2014). We use the Terrain Wetness Index layer (TWI 5 m spatial scale) to determine differences in terrain wetness by calculating average and standard deviation TWI values in 30m buffers around each nest and fledgling location.

Biological metrics. We used two biological covariates for both nest and fledgling survival: nest or fledgling age and date. For nests, age referred to the age of the nest with day 0 being when the first egg was laid. For fledglings, age referred to the days post-fledging with day 0 representing the last day in the nest. Date refers to the ordinal date that a terminal event occurred for a nest or fledgling (fledge/survive, flood, depredation, other).

Data analysis

Vegetation. We used Welch's two sample t-tests that allowed for unequal variance to compare individual vegetation variables associated with nest and fledgling locations between young forest and shrub wetland sites. Variables were assessed for normality and a log-transformation was used to meet assumptions when necessary. Differences were considered significant at $P < 0.10$ because of the relatively small samples sizes and variation in the data.

Nest and Fledgling Survival. Both nest and fledgling survival was modeled using a multistate Markov Chain method (Etterson et al. 2007). All model building and analysis was done in the program *MCestimate* (https://archive.epa.gov/med/med_archive_03/web/html/mcestimate.html). The nests we included in our analysis had four possible outcomes: survived (defined as all nestlings fledging the nest), depredated (defined as one or more nestlings being predated in the nest), failed due to the nest flooding, and failed due to dead nestlings. Because we were particularly interested in modeling nest and fledgling predation, we combined flood and dead nestling into a single category, "other" and modeled the three fates: survived, predated, and

other. Ten nests were abandoned during incubation, these were excluded from the analysis because we were not able to estimate the age of the nest. The fledglings had three possible outcomes: survived (defined as surviving 8 days post-fledging), mortality due to predation, and mortality due to flood. Covariates were only modeled for the depredated fate (Etterson et al. 2014).

Model Building and Testing. We originally considered 20 covariates categorized as three groups for modeling nest and fledgling survival: 12 vegetative, six landscape, and two biological. After testing for covariate correlation with Pearson's correlation test we eliminated low vegetative ground cover because it was negatively correlated with high vegetative ground cover (r = -0.87) and 30 m standard deviation TWI because it was positively correlated with 30 m average TWI. The remaining covariates consisted of 11 vegetative, five landscape, and 2 biological covariates. We modeled covariates from each covariate group separately and compared AICc scores of each univariate model to a null model to determine model significance (Nickerson 2000, Harrison et al. 2018). All univariate models in each group that performed better than the null model were then ranked using quasi-Akaike's information criterion corrected for small sample size (QAICc) for nest survival models because of overdispersion in the nest survival data. Akaike's information criterion corrected for small sample sizes (AICc) for fledgling survival models. We built a global model using all covariates that performed better than the null model and ran a parametric bootstrap with 1,000 iterations in order to estimate ĉ (ĉ = 1.8738) for the nest survival models. With the newly calculated ĉ, the univariate models were ranked via QAICc. For fledgling models, candidate models that performed better than the null (AICc weights > 0) were assessed for Goodness-of-Fit using the Pigeon-Heyse test (Canary et al. 2017).

RESULTS

During the breeding season from 2019 to 2023, we monitored 91 Golden-winged Warbler nests across 10 sites in northern Minnesota. Across all sites and years, 34 nests (42%) succeeded in

fledgling young without any predation, 40 nests (49%) failed due to predation or experienced partial predation of at least 1 egg or fledgling (8 partial predations and 32 full predations), and 7 nests (9%) failed due to weather or unknown fledgling mortality (rain storm, flooding, or nest found with intact, dead nestlings). Ten nests (11%) were abandoned because of nest disturbance during camera placement. Nests in 2022 and 2023 that were not abandoned after camera placement were used to document predation events. We documented 26 predation events on nests including 6 partial predations and 21 total predators including: four meso-carnivores (raccoon (*Procyon lotor*) and short-tailed weasel (*Mustela richardsonii*)), nine sciurids (eastern chipmunk (*Tamias striatus*) and Franklin's ground squirrel (*Poliocitellus franklinii*)), three black bears (*Ursus americanus*), four hawks (Broad-winged Hawk (*Buteo platypterus*) and Sharp-shinned Hawk (*Accipiter striatus*)), two Blue Jays (*Cyanocitta cristata*), two Brown-headed Cowbirds (*Molothrus ater*), two garter snakes (*Thamnophis sirtalis*), and four unknown due to camera malfunction (Table 1.2).

During the breeding season from 2021 to 2023, we monitored 75 Golden-winged Warbler fledglings for the first eight days post fledging from 32 nests across eight sites in northern Minnesota. Across all sites and years, 36 fledglings (48%) survived the first seven days post fledging, 35 fledglings (46%) were predated after fledging, and 7 fledglings (9%) experienced mortality due to rain or flooding.

Survival Models

Nest Survival. Four univariate models performed better than the null model: two landscape and two biological models (Table A1). The best performing biological model for describing nest predation was date (β = -0.111 ± 0.024 SE) which scored 7.07 QAICc units below the next biological model, age of nest (β = -0.080 ± 0.025 SE). The best performing landscape model was $1.2^{-\text{Dist.Forest}}$ (β = -1.849 ± 0.446 SE), which scored 4.47 QAICc units below the next best landscape model (β = -1.594 ± 0.566 SE) (Figure 1.2). No vegetation models performed better than the null model.

Fledgling Survival. Six univariate models performed better than the null model: two biological, two vegetation, and two landscape (Table A2). The two top models were age of fledgling (β = 0.319 ± 0.093 SE) and date (β = 0.149 ± 0.041 SE), which scored within 0.24 AICc units of each other. Percent open ground cover (%Open.GC) was the best performing vegetation model (β = 0.124 ± 0.059 SE). Habitat type was the only other vegetation model that performed better than the null ($\beta_{Shrub\ Wetland}$ = -0.530 ± 0.356 SE, $\beta_{Young\ Forest}$ = 2.505 ± 0.245 SE) but was only 0.16 AICc units less than the null model. The two landscape models that performed better than the null were $1.2^{-Dist.Forest}$ (β = -1.219 ± 0.728 SE) and $1.2^{-Dist.Site.Edge}$ (β = -1.023 ± 0.640 SE), which scored within 0.13 AICc units of each other (Figure 1.3).

Habitat Type Comparisons

Vegetation. There were several differences in vegetation metrics between young forest and shrub wetland sites with respect to both nest and fledgling locations. For nest site locations, high vegetation % ground cover was higher (t = 1.74, P = 0.09) and tree count was lower (t = 2.64, P = 0.01) in young forests compared to shrub wetlands (Table 1.3). For fledgling locations, high vegetation % ground cover (t = 3.67, P < 0.001), CWD % ground cover (t = 6.28, P < 0.001), and stem counts were higher (t = 4.23, P < 0.001), and open % ground cover was lower (t = 2.52, P = 0.01) in young forests compared to shrub wetlands (Table 1.4). We also found differences between nest site locations and fledgling locations. High vegetation % ground cover (t = 3.67, P < 0.001) was higher and CWD % ground cover (t = 3.84, P < 0.001), low % canopy cover (t = 2.80, P < 0.001), lower lateral density (t = 2.42, P = 0.02), and stem counts (t = 1.71, P = 0.09) were lower at nest locations compared to fledgling locations (Table 1.5).

Habitat Type. There was not a significant difference in nest DSR between shrub wetland and young forest sites as the 'habitat type' model did not perform better than the null model. The nest DSR, using the 'habitat model' for shrub wetland habitat was 0.944 (± 0.011 SE) and 0.947 (± 0.010 SE) for young forest habitat. There was a significant difference in fledgling DSR between shrub wetland and young forest sites as the 'habitat type' model performed better than the null model; although ΔAICc between the null and the 'habitat type' model was only 0.15. The fledgling DSR, using the 'habitat type' model, for shrub wetland habitat was 0.869 (± 0.121 SE) and 0.915 (± 0.075 SE) for young forest habitat type (Table 1.6).

DISCUSSION

The goals of this study were to quantify vegetation and landscapes-scale differences between nest site and daily fledgling locations among shrub wetland and young forests, assess differences in survival of nests and fledglings between shrub wetland habitat and young forests, and determine the relative importance of landscape, vegetative, and biological factors on the survival of nests and fledglings. We found that Golden-winged Warbler nest survival was dependent on landscape and biological factors, while fledgling survival was dependent on the same factors as nest survival in addition to vegetation factors.

In both habitats, we documented lower nest and fledgling survival closer to edges. Interestingly, we documented that both edges to exterior site boundaries and edges of residual forest patches within breeding habitat may have a negative effect on survival for both nests and fledglings. Many studies have documented lower nest and fledgling survival as a result of increased predation near edges (Peak 2007, DeGregorio et al. 2014, Streby et al. 2016, Adalsteinsson et al. 2018), likely due to increased predator abundance and activity along forest edges (DeGregorio et al. 2014, Stirnemann et al. 2015, Sosa and Lopez De Casenave 2017). For example, snakes often take advantage of edges for thermoregulation, thereby potentially increasing the likelihood of finding nests (Stake et al. 2005). Chalfoun et al. (2002) found an increase of avian and small mammal nest predators near forest edges compared to interior forest, although they did not document differences in the abundance of medium-sized mammals (sciurids and mesocarnivores) along forest edges. Other studies have suggested that medium-sized mammal abundance is likely more dependent on larger landscape patterns and relative abundance of habitat than site-level factors (Dijak and Thompson 2000). Our findings suggest that increased predations on Golden-winged Warbler nests and fledglings near edges may be associated with increased predator abundance or activity or both near forest and site exterior edges as many of the predations we documented were from species that take advantage of edges for foraging and finding prey (i.e. snakes, hawks, sciurids).

We also documented variation in survival of nests and fledglings within the breeding season. Nest survival decreased as the breeding season progressed, which is consistent with a well-documented pattern in avian nest survival (Peak 2007, Stillman et al. 2019); however, we found that fledgling survival increased as the breeding season progressed. Decreased nest survival later in the season is likely due to increased predator activity or predator community shifts that occur as the breeding season progresses, both of which are documented in nest survival studies (Schaub et al. 1992, Lyons et al. 2015). This, however, does not explain the temporal variation in fledgling survival we documented. Fledglings of many forest-dwelling species typically select areas with increased vegetative cover for evading predators (Cohen and Lindell 2004, Streby and Andersen 2013, Goguen 2019). Therefore, variation in fledgling survival could be best explained by the fact that vegetative cover increases throughout the breeding season, even though predator abundance and activity increases (Martin 1993). We also found that age of the fledgling was an important factor for survival. Ground nesting birds often leave the nest early compared to above-ground nesting birds and as a result, tend to have less developed wings and legs for escaping predators (Şahin Arslan and Martin 2022).

There were several differences in vegetation characteristics between fledgling and nest locations, including increased stem density, canopy density, lateral vegetation density, and woody debris.. These results indicate that although Golden-winged Warblers may broadly use the same habitats for these two periods for breeding, there are distinct differences in their selection of vegetation within these habitats. Fiss et al. (2021) documented similar results for Golden-winged Warblers in Pennsylvania with fledglings generally selecting for areas with greater basal area and overhead vegetative cover. There were also several differences between young forest and shrub wetland fledgling and nest locations. Nest locations in shrub wetland sites had higher tree density and lower vegetative ground cover compared to young forest locations. Fledgling locations in shrub wetland sites had lower stem density, vegetative ground cover, and woody debris and higher open ground cover compared to young forest locations. These findings suggest that shrub wetland habitat provides a uniquely different habitat features for both the nesting and fledgling periods.

We found no significant difference for nest and fledgling survival between shrubby wetland and young forest habitats. These are useful insights as shrub wetland habitat has often been excluded in habitat requirements and for land management in the conservation of the Golden-winged warbler. Increased focus on the importance of managing and conserving shrub wetlands is important for this species. Because survival of nests and fledglings may be lower near edges, land management practices should also consider surrounding habitat and the creation of mature forest edges when creating and managing habitat.

FIGURES

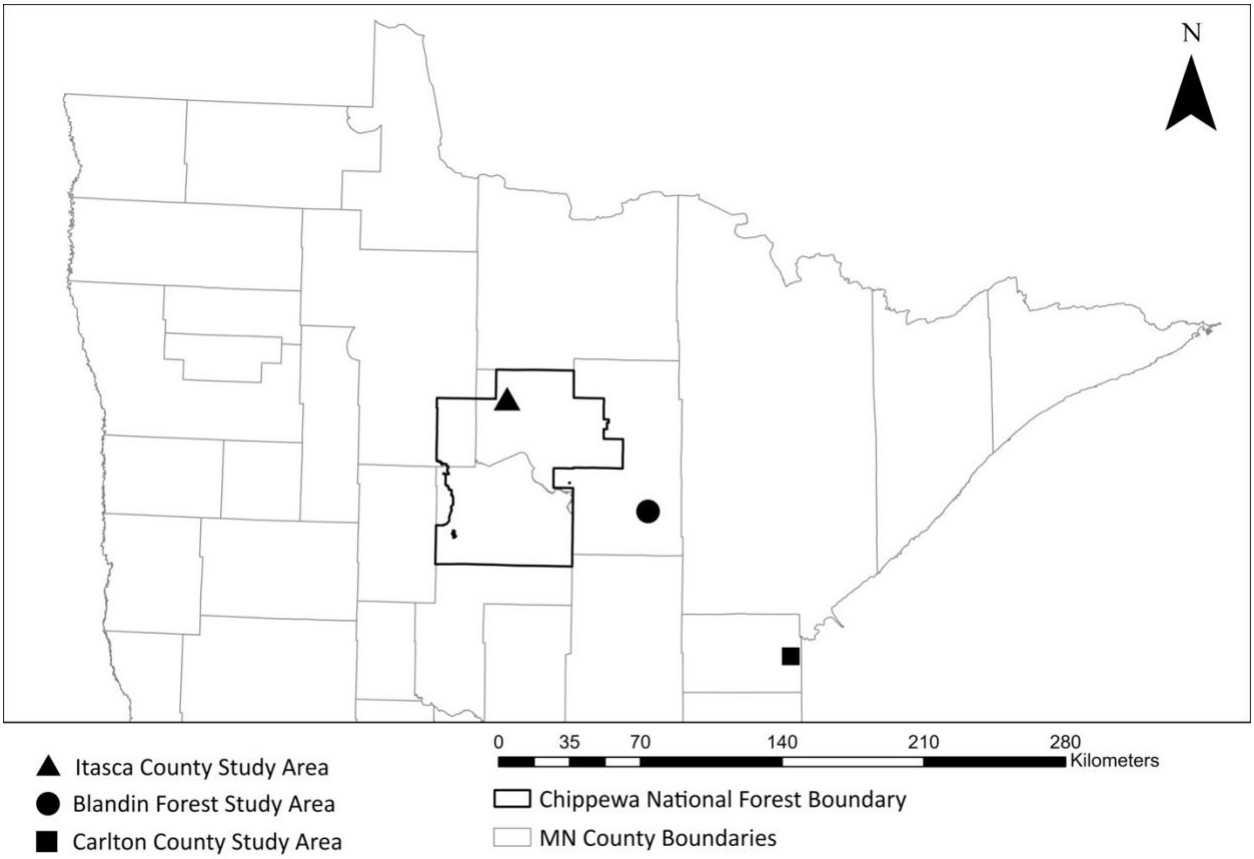

Figure 1.1. Map of northern Minnesota (MN), USA indicating the locations of study areas: Itasca study area was located within the Chippewa National Forest, Blandin Forest study area was located near Swan River, MN, USA, and Carlton County study area was located in Carlton County forest land. Golden-winged Warblers nest and fledglings were monitored throughout the duration of the breeding season (May-July) from 2019-2020 in the Blandin Forest study area, 2021-2022 in the Itasca County study area, and in 2023 in the Carlton County study area.

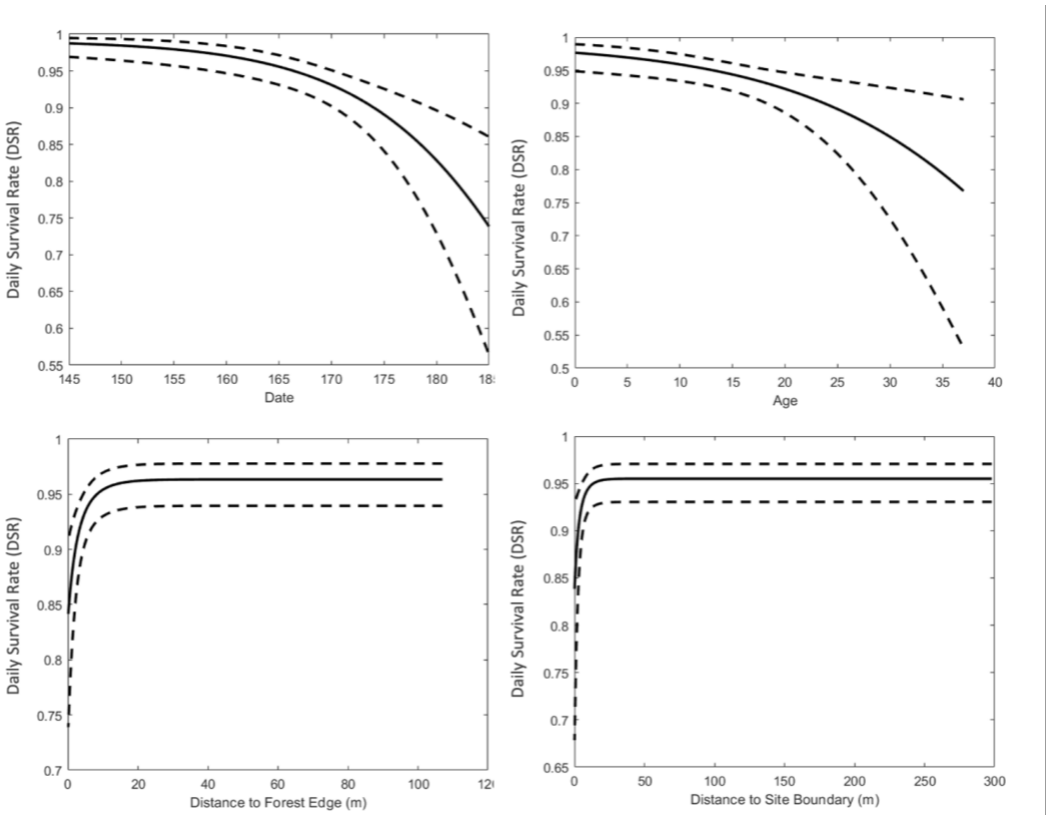

Figure 1.2. Relationships between four covariates and the daily survival rate (DSR) of Golden-winged Warbler nests in northern Minnesota based on univariate models of each covariate. Distance to forest edge and distance to site boundary are shown based on the negative exponential transformation (with base 1.2).

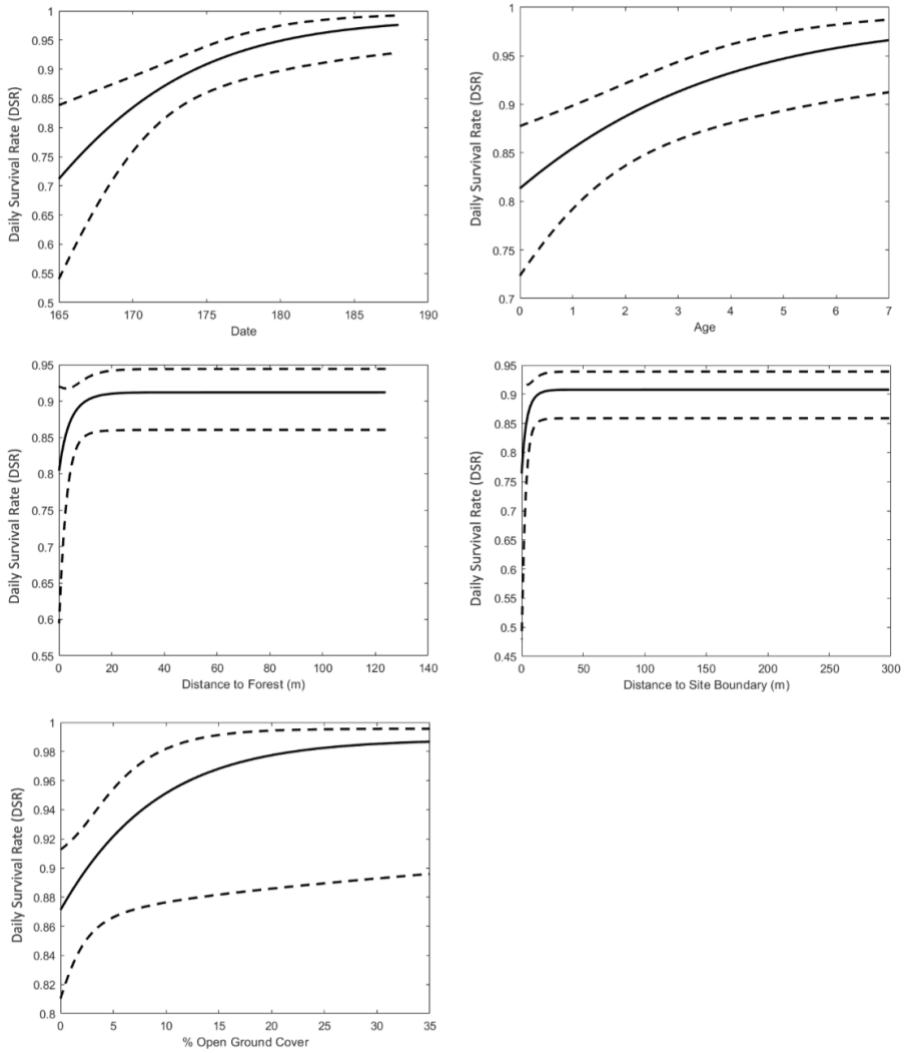

Figure 1.3. Relationships between four covariates and the daily survival rate (DSR) of Golden-winged Warbler fledglings in northern Minnesota based on univariate models of each covariate. Distance to forest edge and distance to site boundary are shown based on the negative exponential transformation (with base 1.2).

TABLES

Table 1.1. Summary of site characteristics and study areas studied in northern Minnesota, USA, during the breeding seasons from 2019 – 2023. Carter Lake was studied only in 2021 and no fledglings were monitored at this site. Blandin was not used for fledgling survival due to small sample sizes. DSR was estimate using the 'site' model.

					Nests			Fledglings (0-8 days post-fledge)		
Site	Study Area	Years	Habitat Type	Site Area (acres)	Nests	DSR	SE	Fledglings	DSR	SE
Blandin (BDN)	Blandin Forest	2019, 2020	Young Forest	45	10	0.929	0.030	-	-	-
Carter Lake (CAL)	Itasca County	2021	Young Forest	45	5	0.926	0.036	-	-	-
Dreamland Dry (DLD)	Itasca County	2022	Young Forest	56	4	0.912	0.038	1	0.741	0.210
Dreamland Wet (DLW)	Itasca County	2022	Shrub Wetland	21	4	0.944	0.046	3	0.791	0.165
Hoot'N'Holler Dry (HHD)	Itasca County	2021, 2022	Young Forest	56	12	0.960	0.016	25	0.898	0.025
Hoot'N'Holler Wet (HHW)	Itasca County	2021, 2022	Shrub Wetland	52	9	0.919	0.029	8	0.760	0.080
Rocky Road Dry (RRD)	Itasca County	2022	Young Forest	17	2	0.921	0.048	5	0.961	0.027
Rocky Road Wet (RRW)	Itasca County	2022	Shrub Wetland	41	3	0.991	0.003	3	0.847	0.122
Golden-wing of Fire (GWF)	Carlton County	2023	Shrub Wetland	129	17	0.947	0.014	18	0.902	0.028
Boy named Soo (BNS)	Carlton County	2023	Young Forest	180	25	0.963	0.012	12	0.932	0.027

Table 1.2 Summary of nest predators documented from nest camera during the breeding seasons of 2022 and 2023 in Itasca and Carlton County, MN, USA. Cameras documented 26 (n = 26) predation events. Unknown was due to camera malfunctions or cameras not placed in time to capture the predation.

Predator	Stage	Total/Partial Predation	Habitat Type	
			Young Forest	Shrub Wetland
Broad-winged Hawk	Fledgling	Both	2	1
Sharp-shinned Hawk	Fledgling	Partial	1	0
Blue Jay	Incubation	Total	0	2
Brown-headed Cowbird	Lay	Partial	1	1
Eastern Chipmunk	Fledgling	Total	3	0
Franklin's Ground Squirrel	Incubation	Total	0	2
Short-tailed Weasel	Fledgling	Total	1	0
Raccoon	Fledgling	Total	1	1
Black Bear	Fledgling	Total	2	1
Eastern Garter Snake	Fledgling	Partial	2	0
Unknown	Both	Total	1	4
Total	-	-	14	12

Table 1.3 Summary statistics for vegetation and landscape characteristics for Golden-winged Warbler nest locations in northern Minnesota during the breeding season of 2019-2023. t-tests were used to determine differences between nest locations in young forest and shrub wetland sites. Significance was assessed at P < 0.10.

			Young Forest				Shrub Wetland			
Variable	**Variable Type**	**Significance (p-value)**	**Mean**	**SE**	**Min**	**Max**	**Mean**	**SE**	**Min**	**Max**
Total % Canopy Cover	Vegetative	0.43	57.1	4.1	3.0	93.3	61.3	3.3	15.0	89.3
High % Canopy Cover	Vegetative	0.23	25.3	4.4	0.0	93.3	33.0	4.5	0.0	89.3
Low % Canopy Cover	Vegetative	0.56	31.9	4.3	0.0	89.0	28.3	4.4	0.0	86.8
High Vegetation % Ground Cover	Vegetative	0.09*	75.6	2.3	10.0	97.5	68.9	3.1	15.0	100.0
Open % Ground Cover	Vegetative	0.73	3.2	0.5	0.0	12.5	3.5	0.6	0.0	10.0
CWD % Ground Cover	Vegetative	0.69	6.4	0.8	0.0	20.0	5.8	1.1	0.0	20.0
Stem Count	Vegetative	0.48	164.0	15.2	14.0	439.0	138.0	12.0	26.0	320.0
Tree Count	Vegetative	0.01*	8.7	1.7	0.0	62.0	13.1	1.8	0.0	47.0
Lower 0.5m Lateral Density %	Vegetative	0.64	87.4	2.2	59.4	98.8	85.6	3.1	25	100
Upper 1.5m Lateral Density %	Vegetative	0.37	56.9	3.8	5.6	81.7	51.9	3.9	1.9	89
Distance Mature Forest (m)	Landscape	0.07*	21.4	3.1	1.0	107.0	19.3	3.1	0.1	75.0
Distance to Site Edge (m)	Landscape	0.15	38.1	5.0	1.0	114.0	83.3	13.3	0.1	298
Distance to Road (m)	Landscape	0.37	131.5	15.5	5.0	451.0	152.9	19.3	6	503
Average TWI 30m buffer	Landscape	<0.001*	7.4	0.3	4.4	14.7	13.5	1.2	6.9	28

Table 1.4 Summary statistics for vegetation and landscape characteristics for Golden-winged Warbler fledgling locations during the first eight days post-fledging in northern Minnesota during the breeding season of 2021-2023. t-tests were used to determine differences between fledgling locations in young forest and shrub wetland sites. Significance was assessed at P < 0.10.

			Young Forest				Shrub Wetland			
Variable	**Variable Type**	**Significance (p-value)**	**Mean**	**SE**	**Min**	**Max**	**Mean**	**SE**	**Min**	**Max**
Total % Canopy Cover	Vegetative	0.94	57.2	1.3	5.8	95.0	57.0	1.8	3.3	96.0
High % Canopy Cover	Vegetative	0.72	17.7	1.2	0.0	88.3	21.7	1.9	0.0	93.0
Low % Canopy Cover	Vegetative	0.11	39.5	1.7	0.0	94.8	35.3	2.0	0.0	94.5
High Vegetation % Ground Cover	Vegetative	<0.001*	68.7	1.3	5.0	95.0	61.0	1.6	10.0	100.0
Open % Ground Cover	Vegetative	0.01*	2.8	0.3	0.0	35.0	3.8	0.4	0.0	25.0
CWD % Ground Cover	Vegetative	<0.001*	10.4	0.5	0.0	40.0	7.1	0.6	0.0	50.0
Stem Count	Vegetative	<0.001*	190.0	5.6	11.0	492.0	156.3	5.7	3.0	429.0
Tree Count	Vegetative	0.11	8.5	0.5	0.0	56.0	8.2	0.7	0.0	43.0
Lower 0.5m Lateral Density %	Vegetative	0.92	88.6	1.0	1.4	100.0	88.5	1.3	25	100
Upper 1.5m Lateral Density %	Vegetative	0.84	61.1	1.5	1.4	95.8	61.5	1.6	1.9	93.5
Distance Mature Forest (m)	Landscape	0.04*	23.0	1.1	0.4	123.9	21.0	1.3	0.1	68.1
Distance to Site Edge (m)	Landscape	0.01*	41.4	2.2	0.4	160.7	77.1	6.2	0.1	298.7
Distance to Road (m)	Landscape	0.72	168.3	7.2	7.8	444.1	164.2	8.9	0.1	503
Average TWI 30m buffer	Landscape	<0.001*	8.3	0.1	4.7	17.4	11.7	0.4	6.7	25.2

Table 1.5 Summary statistics for vegetation and landscape characteristics for Golden-winged Warbler nest and fledgling locations (days 0-8 post-fledging) in northern Minnesota during the breeding season of 2019 - 2023. t-tests were used to determine differences between nest and fledgling locations across all years and all sites. Significance was assessed at P < 0.10.

			Nest Locations				Daily Fledgling Locations			
Variable	**Variable Type**	**Significance (p-value)**	**Mean**	**SE**	**Min**	**Max**	**Mean**	**SE**	**Min**	**Max**
Total % Canopy Cover	Vegetative	0.50	59.1	2.7	3.0	93.3	57.1	1.1	3.3	96.0
High % Canopy Cover	Vegetative	0.11	28.8	3.2	3.0	93.3	19.4	1.1	0.0	93.0
Low % Canopy Cover	Vegetative	0.03*	30.2	3.1	0.0	89.0	37.7	1.3	0.0	94.8
High Vegetation % Ground Cover	Vegetative	<0.001*	72.6	1.9	10.0	100.0	65.5	1.1	5.0	100.0
Open % Ground Cover	Vegetative	0.14	3.3	0.4	0.0	12.5	3.2	0.2	0.0	35.0
CWD % Ground Cover	Vegetative	<0.001*	6.1	0.7	0.0	20.0	9.1	0.4	0.0	50.0
Stem Count	Vegetative	0.09*	157.8	9.9	14.0	439.0	176.1	4.1	0.0	492.0
Tree Count	Vegetative	0.36	10.7	1.3	0.0	62.0	8.4	0.4	0.0	56.0
Lower 0.5m Lateral Density %	Vegetative	0.31	86.4	2.0	25.0	100.0	88.6	0.8	1.4	100
Upper 1.5m Lateral Density %	Vegetative	0.02*	54.2	2.8	1.9	54.2	61.3	1.1	1.4	95.8
Distance Mature Forest (m)	Landscape	0.06*	20.4	2.2	0.1	107.0	21.9	0.9	0.1	80.5
Distance to Site Edge (m)	Landscape	0.56	58.7	7.1	0.1	298.0	56.2	3.0	0.1	298.7
Distance to Road (m)	Landscape	0.05*	141.0	12.2	5.0	503.0	166	5.6	0.1	503
Average TWI 30m buffer	Landscape	0.85	10.2	0.6	4.4	28.0	9.7	0.2	4.7	25.2

Table 1.6 Daily survival rate (DSR) of Golden-winged Warbler nests and fledglings (days 0-8 post-fledging) between shrub wetland and young forest sites in northern Minnesota. Nest DSR is based on 81 nests (n = 81) from 2019-2023; fledgling DSR is based on 75 fledglings (n = 75) from 2021-2023.

	Nests				Fledglings (0-8 days post-fledge)			
Habitat Type	Nests	DSR	MLE (Pred)	SE	Fledglings	DSR	MLE (Pred)	SE
Shrub Wetland	37	0.944	0.048	0.011	32	0.869	0.121	0.018
Young Forest	44	0.947	0.045	0.010	43	0.915	0.075	0.027
Combined	81	0.945	0.46	0.008	75	0.898	0.092	0.016

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CHAPTER 2

Post-fledging dispersal and habitat-use of the Golden-winged Warbler

INTRODUCTION

Widespread declines in bird populations have been documented across North America (Rosenberg et al. 2019, IUCN 2022). These declines have largely been attributed to habitat loss and degradation on both the breeding and wintering grounds for many migratory birds (Rosenberg et al. 2019, Matricardi et al. 2020, Betts et al. 2022). During the breeding season, the post-fledging period is a relatively short, yet crucial time period after nesting when fledglings learn to forage and disperse before becoming independent from parental care (Pagen et al. 2000, Chandler et al. 2012, Anthony et al. 2013). For many passerines, this period can act as a "population bottleneck", limiting reproductive output and altering demographics (Naef-Daenzer and Grüebler 2016, Jones et al. 2020). Additionally, fledglings of many songbird species often utilize habitats distinct from those preferred by breeding adults, and overlooking these specific needs may lead to unforeseen negative consequences (Pagen et al. 2000, Marshall et al. 2003, Vitz and Rodewald 2010, Streby and Andersen 2011, Fiss et al. 2020). Without a thorough understanding of this life cycle stage, implementation of management or conservation strategies is likely to be incomplete (Cox et al. 2014).

Until recently, the post-fledging period remained poorly understood in many species, primarily due to technological and detectability challenges in tracking fledglings after leaving the nest (Weise and Meyer 1979). The use of radio-transmitters has allowed for consistent tracking of birds after fledging, and for some species, has revealed distinct habitat shifts between nesting and post-fledging habitat (Sillett and Holmes 2002, Naef-Daenzer and Grüebler 2016). Understanding how factors such as site-specific vegetation and landscape-level cover types influence post-fledging movements and habitat-use is crucial for accurately estimating productivity and is necessary for providing comprehensive habitat and landscape-scale recommendations.

The Golden-winged Warbler (*Vermivora chrysoptera*) has experienced substantial population declines across its range and is currently under consideration for federal listing as a threatened species (Rosenberg et al. 2019, Sauer et al. 2020). Golden-winged Warblers breed in early successional forests in eastern North America, across the Appalachian Mountains and Great Lakes region (Confer et al. 2020). Minnesota is a critical stronghold for the global Golden-winged Warbler population as it is estimated that over 50% of the population breeds in the state (Pfannmuller et al. 2022). Highest densities of breeding Golden-winged Warblers are found primarily in young forests and shrub wetland habitats in Minnesota (Niemi et al. 2016, Pfannmuller et al. 2022).

Several studies on Golden-winged Warbler post-fledging ecology have revealed distinct habitat shifts between nests and fledgling locations (Fiss et al. 2021) as well as shifts between early and late post-fledging periods (Streby et al. 2016, Fiss et al. 2020). Differences in food availability and vulnerability to predators during nesting and post-fledging periods may lead to differences in habitat selection (Moore et al. 2010, Mitchell et al. 2010, Burke et al. 2017). During the early post-fledging period (typically the first several days after fledgling) most mortalities occur as fledglings are less mobile to evade predators (Streby et al. 2016). As fledglings age into the late post-fledging stage, they become much more mobile, with daily movements documented up to 750 meters (Fiss et al. 2020). Although dispersal and habitat use have been documented in multiple studies, limited research on how differences in young forest and shrub wetland breeding habitat may impact post-fledgling ecology. Based on these differences it is important to consider both site and landscape configuration in order to account for differences in habitat selection between nesting, early and late post-fledging periods.

We studied post-fledging movement and habitat selection of Golden-winged Warblers in shrub wetland and young forest habitat across two study areas in northern Minnesota. Our objectives were to: 1) assess differences in post-fledging movement and dispersal between shrub wetland and young forest, 2) assess cover type selection during post-fledging period, 3) determine important vegetation characteristics during post-fledging period, 4) assess differences in vegetation selection between early (days 0-8) and late (days 9-30) post-fledging periods.

Because both habitats provide similar habitat structure, we hypothesized that post-fledgling movements and dispersal would be similar between both habitats. We hypothesized that dispersal and daily distances would be greater during late fledgling periods compared to the early fledgling period. We also hypothesized that fledglings would for select for cover types with increased shrub cover. Finally, we hypothesized that differences in vegetation between early and late post-fledgling periods would occur as fledglings become more mobile and less vulnerable to predators.

METHODS

Study Areas

From 2021-2022 we collected data in Itasca County in the Chippewa National Forest of northern Minnesota. In 2023 we collected data in Carlton County of northern Minnesota. Both study areas are located near the ecotone of boreal and northern temperate forests and forest cover types are dominated by aspen, lowland hardwood, mixed hardwood, lowland conifer, and upland conifer (Grinde et al, 2017). The most representative tree species are aspen (*Populus* spp.), paper birch (*Betula papyrifera*), ash (*Fraxinus* spp.), spruce (*Picea* spp.), tamarack (*Larix laricina*) and pine (*Pinus* spp.) (Hillard 2019).

Between both study areas, we collected data at five sites (n = 5): two shrub wetland sites and three young forest sites (Figure 2.1). Shrubby wetland habitats were dominated by speckled alder (*Alnus incana*), willow (*salix spp.*), and black ash (*Fraxinus nigra*). Young forest sites consisted of sapling-dominated quaking aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), approximately 2-5 years post-harvest, with varying levels of overstory retention. Sites ranged in size from 17 to 180 acres and were predominantly surrounded by even-aged mature aspen, mixed hardwood, and lowland hardwood forests.

Fledgling Tracking

Nests were located during the breeding season and monitored to determine hatch and pinbreak (when primary pin feathers begin to open) dates. Nestlings were tagged and banded on the day of pinbreak, which typically occurs one or two days prior to fledging. Banding at this age was done to decrease the likelihood of force-fledging. In instances that nests were found after pinbreak, nestlings were banded at the earliest date possible, noting that this most often led to force-fledging. Nestlings were extracted from the nest and carried in a soft cloth bag 10-15 m from the nest to process. We banded all nestlings with a unique color combination involving three plastic, UV-resistant, Darvic color bands (Avinet, Dryden, NY) and one standard aluminum USGS leg band. We attached coded VHF tags (Lotek *NTQB2-1*) to two or three randomly selected nestlings using a figure-eight harness design (Rappole and Tipton 1991, Streby et al. 2015) and then replaced nestlings in the nest. Transmitters were 1.4 - 2.3% of the nestling body mass at the time of attachment. After banding and attaching tags, nests were checked daily to estimate fledge dates. Nest fates were determined using a combination of video camera footage and tagged fledgling fates (i.e., tags found attached to dismembered fledglings near the nest).

Fledglings were tracked daily with handheld receivers (SRX800, Lotek Wireless, Inc.) until they were independent from parents (approximately 20-25 days post-fledging) or they dispersed outside of the study area. We located the fledglings by scanning for each signal from the previous day's location. Each daily detection was marked with a handheld GPS and flagging for later vegetation surveys. If the signal was not detected immediately we traveled 200 m from the last detected area in each cardinal direction. Any tagged fledglings that were not detected within the first few days after fledging were presumed predated, since tags emitted signal during nest checks prior to fledging, and hawks and mesocarnivores could have carried the tags out of detection range.

Vegetation Surveys

We implemented a vegetation sampling protocol that was modified from methods described by James and Shugart (1970) and the Breeding Biology Research and Monitoring Database (BBIRD) program field protocol (Martin et al. 1997). Vegetation metrics were collected at each flagged fledgling location once the fledgling moved from the location. We also collected the

same vegetation metrics at a paired, random point which was 30 m away from the used location in a random direction. We recorded total percent canopy cover, high percent canopy cover (canopy obstruction > 5 m tall), and low percent canopy cover (canopy obstruction < 5 m tall), averaged from four cardinal directions using a handheld densiometer. We also calculated the standard deviation of high percent canopy cover to be used as a measure of canopy cover heterogeneity. The number of trees (DBH > 8 cm) were counted within a 11.3-m-radius plot.

Within a 5-m-radius plot around each location, we recorded the average height of the dominant species and the number of woody stems by species (>0.5 m tall, <8 cm DBH), in order to calculate total woody stem count and Shannon's diversity index (*H'*) of woody stems. In the same 5-m-radius plot, we also estimated percent ground cover of: low vegetation (herbaceous vegetation <0.1m tall), high vegetation (herbaceous vegetation >0.1m tall), woody debris, and bare ground (bare soil, gravel, or leaf litter).

Cover Type Digitizing

Cover types around each of the study sites were digitized in ArcGIS Pro 3.2.0 (ESRI, Redlands, California, USA), using a combination of aerial imagery (ESRI, 2021), National Wetland Inventory data (NWI), Chippewa National Forest and Carlton County Forest Inventory data, as well as ground-truthing from tracking and vegetation surveys. We surveyed >2,800 locations throughout the study sites allowing us to confirm and adjust cover type delineations after ground-truthing. Cover types were classified into 12 categories including: ash-shrub wetland, mature aspen, mid-aged aspen, lowland ash, shrub wetland, mature hardwood, clearcut with no retention, clearcut with retention, conifer, open grassland, road, and open water (Table 2.1). We excluded open water and road from cover type selection analysis because these cover types were uncommon on the landscape and not used by fledglings.

Data Analysis

Daily movement. Using GPS locations of Golden-winged Warbler fledglings obtained from daily tracking, distances from previous points and fledglings nests were measured for each individual using package *geodist* in program R (version 4.2.1) (Padgham 2021). We compared

mean daily movement distances (from both previous points and from nests) between young forest and shrub wetland sites for early (days 0-8) and late (days 9-30) post-fledging periods. We used Welch's *t*-tests that allowed for unequal variance. Variables were assessed for normality assumption and were log-transformed to meet assumptions when necessary and were considered significant at $P < 0.05$. We also calculated a cumulative maximum daily distance traveled across all fledglings and all years which equated to the greatest daily movement ever observed for a given age (in days). We used this greatest distance traveled by any fledgling as an estimate of the maximum straight-line movement capability by every fledgling of that age.

Cover type and Vegetation Selection. To analyze fledgling cover type selection (used versus available) we used the maximum daily distance observed for each fledgling. For each age (in days) we used these daily maximum distances as radii for circular buffers around each fledgling location. We then measured the percentage of each cover type within each buffer for each fledgling. The "used" cover type percentages were determined by calculating the proportion of points in each cover type. Because cover type use was not independent among sub-broodmates (broodmates with one parent after parental splitting of the brood), we accounted for pseudoreplication by averaging use and availability percentages between sub-broodmates (Streby et al. 2016). We used compositional analysis to compare used and available habitat for each fledgling, using the package *adehabitatHS* in Program R (version 4.2.1). Compositional analysis was used because daily points for each cover type are easily used to estimate proportional use for individuals. Wilks' lambda statistic was used to test for significant selection ($P < 0.05$) and we performed a ranking analysis on each habitat class using randomization tests (500 runs). Separate analyses were done for birds fledged from young forest and shrub wetland sites to compare differences in cover type use between nesting cover types.

To compare differences in vegetation selection (used vs. available), we compared differences in vegetation characteristics between used and random plots using a binomial generalized linear mixed model (GLMM; logistic regression), using the package *lme4* in Program R (version 4.2.1). We assessed the 12 vegetation variables for collinearity and removed low vegetative ground cover as it was negatively correlated with high vegetative ground cover ($r = -0.80$). We used year

as a random effect. To assess the potential of a non-linear response, we used a quadratic transformation; if the transformation was not significant, we used the untransformed variable before removing the variable. With the remaining variables we created a global model and used backwards selection to remove non-significant variables ($P > 0.05$) until all remaining variables were significant. We determined the vegetation variable to be different between use and random points if the intercept was significantly different than zero ($P < 0.05$). The final model was tested against the null model to determine goodness-of-fit (Bolker et al. 2009). To determine if differences existed in vegetation selection between early (days 0-8) and late (days 9-30) post-fledging periods we used Welch's two sample *t*-tests that allowed for unequal variance. Variables were assessed for normality assumptions and were considered significant at $P < 0.10$.

RESULTS

We tagged and tracked 56 Golden-winged Warbler fledglings from 28 broods and 44 sub-broods, totaling 1425 fledgling locations from 2021 to 2023. We tracked 21 individuals from shrub wetland sites and 33 individuals from young forest sites. The mean number of days tracked per fledgling was 13.5 (± 1.3 SE), ranging from 1 to 33 days. Fledglings that were not tracked the full duration were mostly due to mortality; although we stopped tracking three fledglings approximately a week after fledging because they dispersed outside of the study sites.

Movement Patterns

Daily distances from previous points and from the nest increased with age; mean daily distance moved from the previous point was 82.6 m (± 3.4 SE), ranging from 0.8 to 676.9 m ($n = 654$). The mean distance moved from the nest was 170.6 (± 6.7 SE), ranging from 0.8 to 1093.3 m ($n = 704$). We calculated the running cumulative maximum movement observed for six age groups: 88 m (days 1-3), 124 m (day 4), 165 m (days 5-6), 230 (days 7-8), 510 m (days 9-20), 677 m (days 21-33).

We found no significant difference in the average distance movements away from the nest location between shrub wetland birds and young forest birds for fledglings during the early fledgling period (days 0-8) (t = 1.46, df = 254, P = 0.15). We found no significant difference in the average daily distance movements for young fledglings between shrub wetland birds and young forest birds (t = 0.53, df = 203, P = 0.57). However, there was a significant difference in the average daily distance movements for young fledglings between shrub wetland birds and young forest birds (t = 2.14, df = 117, P = 0.03) with shrub wetland birds moving 139.4 m (± 13.3 SE), daily and young forest birds moving 108.5 m (± 5.7 SE), daily, on average (Figure 2.2).However, during the late fledgling period (days 9-30), fledglings from the young forest habitats moved significantly farther distances (t = 2.46, df = 266, P = 0.01) compared to birds in shrub wetlands. Specifically, shrub wetland birds that moved an average daily distance of 214.1 m (± 16.3 SE) from the nest and young forest birds moving an average of 266.0 m (± 13.3 SE) from the nest (Figure 2.2) during the late fledgling period.

Cover type Selection

Fledglings from shrub wetland sites selected cover types disproportionately to their availability on the landscape (Λ = 0.219, df = 9, P = 2.05e-4), results showed that shrub wetland and clearcut with reserves cover types ranked highest whereas mid-aged aspen, confer, and open grassland cover types ranked lowest (Figure 2.3). Fledglings from young forest sites also selected cover types disproportionately to their availability on the landscape (Λ = 0.119, df = 9, P = 1.36e-11) with clearcut with reserves and shrub wetland cover types ranking highest and mid-aged aspen, confer, and open grassland cover types ranked lowest (Figure 2.3).

Vegetation Selection

The final global model for predicting fledgling presence was significantly different from the null model (χ^2 = 212.05, P = 2.2e-16) and contained three variables: stem count (quadratically transformed), low canopy cover (quadratically transformed), and percent ground cover of CWD. Quadratically transformed low canopy cover had the greatest success with predicting fledgling presence (Low.CC β = 20.790 ± 0.207 SE; Low.CC^2 β = -6.512 ± 2.213 SE) (Figure 2.4). Quadratically transformed stem counts had the next highest success for predicting fledgling presence (Stems β = 16.650 ± 2.525 SE; Stems^2 β = -9.555 ± 2.283 SE) (Figure 2.4). Percent

ground cover of CWD had the next lowest success for predicting fledgling presence, yet was still significant in the final global model (CWD $\beta = 0.014 \pm 0.007$ SE) (Figure 2.4).

We found several differences in vegetation characteristics comparing early (days 0-8) and late (days 9-30) post-fledging locations. Total percent canopy cover ($t = 5.27$, $P < 0.001$), woody stem height ($t = 7.52$, $P < 0.001$), and percent ground cover of bare ground ($t = 5.24$, $P < 0.001$) were higher for fledglings during the late post-fledging period compared to the early; whereas woody stem counts ($t = 1.69$, $P = 0.09$) were higher for fledgling during the early post-fledging period compared to the late post-fledging period. We did not find any differences between early and late post-fledging periods in woody stem diversity ($t = 1.64$, $P = 0.10$), percent ground cover of woody debris ($t = 0.46$, $P = 0.16$), percent ground cover of high vegetation ($t = 1.62$, $P = 0.11$), tree counts ($t = 1.58$, $P = 0.11$), high SD percent canopy cover ($t = 0.26$, $P = 0.86$), low percent canopy cover ($t = 1.60$, $P = 0.11$), and high percent canopy cover ($t = 1.60$, $P = 0.101$) (Table 2.2).

DISCUSSION

The goals of this study were to assess differences in post-fledging movement and habitat selection between early (days 0-8) and late (days 9-30) post-fledging periods as well as between fledglings from shrub wetland and young forest sites. We documented rather counterintuitive movement patterns for fledglings during the late post-fledging period. Fledglings from shrubby wetland habitat tended to move greater distances per day, yet tended to be less far away from their nest locations than fledglings from young forest habitat. These findings suggest that shrub wetlands may provide a more structurally diverse habitat that accommodates both early and late post-fledgling periods. Although there is limited research how shrub wetland and young forest habitat may differ in terms of fledgling habitat quality, Delancey and Islam (2019) found that Cerulean Warbler used riparian corridors that have denser vegetation than upland forest hypothesizing that these areas provide greater vegetative cover for predator evasion. This difference in post-fledging movement could also be attributed to differences in prey abundance

or quality. There is limited research on whether shrub wetlands provide different prey abundance or quality than young forests for insectivorous birds; however, Chandler et al. (2012) found that a number of mature forest-nesting birds were more abundant in early successional forest than mature forests during the post-fledging period, indicating that these habitats provide some benefit during this time period.

Fledglings used young forest and shrub wetland cover types disproportionately to their availability on the landscape, indicating a strong selection for these cover types in comparison to mature forest cover types (i.e., mature aspen, mature hardwood hardwoods, lowland ash, and coniferous forests). Fledglings tended to use the same cover types they fledged from, however fledglings from young forest sites did readily use shrub wetland cover types. Fledglings avoided open grassland, conifer, and ash-shrub wetland cover types which is similar to Streby et al. (2016). We found that fledglings may occasionally use but not select for mature forest (i.e. use relative to availability) which is supported by other Golden-winged warbler studies in the Appalachian range (Lehman 2017, Fiss et al. 2020). However, (Streby et al. 2016) reported Golden-winged Warbler fledglings in Minnesota readily using mature forests with complex understories consisting of aspen and hazel (*Corylus spp.*). This discrepancy may be attributed to differences in mature forest structure as most of our study area lacked structurally diverse mature forest. More research is needed to elucidate these differences in selection that may be occurring in mature forests.

In terms of vegetation selection, we found that predicted use was best explained by stem count, low canopy cover, and percent ground cover of woody debris. Similarly, Fiss et al. (2021) found that Golden-winged Warbler fledglings in Pennsylvania also selected for areas with greater lateral and overhead vegetation density provided by shrub/sapling layers, although they did not document the importance of woody debris. These findings are also congruent with fledglings of other species including Cerulean Warblers (*Setophaga cerulea*) (Raybuck et al. 2020), Acadian Flycatchers (*Empidonax virescens*) (Jenkins et al. 2016), and Wood Thrushes (*Hylocichla mustelina*) (Anders et al. 1998) which have all been associated with areas of dense understory vegetation during the post-fledging period.

We documented a handful of differences in vegetation between early and late post-fledging periods. In general older fledglings tended to select areas with greater canopy cover and a taller shrub sapling layer yet lower stem counts. In addition these areas also had higher tree counts and greater percent open ground cover. Previous studies on post-fledging habitat selection of Golden-winged Warblers have revealed that shifts in habitat selection occur at the stand level between early and late fledglings (Fiss et al. 2020); however, we show that these shifts also occur within stands at the vegetation level. These findings help to create a more comprehensive summary of habitat requirements for the Golden-winged Warbler, especially during the post-fledging period where much less is known. Ensuring management recommendations include these findings in management plans is crucial for the conservation of this species.

This is the first study on Golden-winged Warbler to investigate differences in post-fledging movement and dispersal between young forests and shrub wetland habitat. These findings indicate that shrub wetland habitat could offer higher quality and more structurally diverse habitat for fledglings. We found continued support for the fact that Golden-winged Warbler fledglings selected areas that are more structurally diverse and that differences in used habitat exists between early and late post-fledging periods. These findings support the need to include fledgling habitat-use into breeding habitat requirements and management plans. Additionally, the differences in vegetation selection between early and late post-fledgling periods indicate that breeding habitat should be structurally diverse to account for both periods of the post-fledging period. More focus on understanding shrub wetlands in the context of Golden-winged Warbler breeding habitat is needed as this habitat could provide unique structure that could benefit both nesting and early and late post-fledging periods. These findings, overall, suggest that conservation plans, aimed at increasing breeding habitat, should include shrub wetlands into plans.

FIGURES

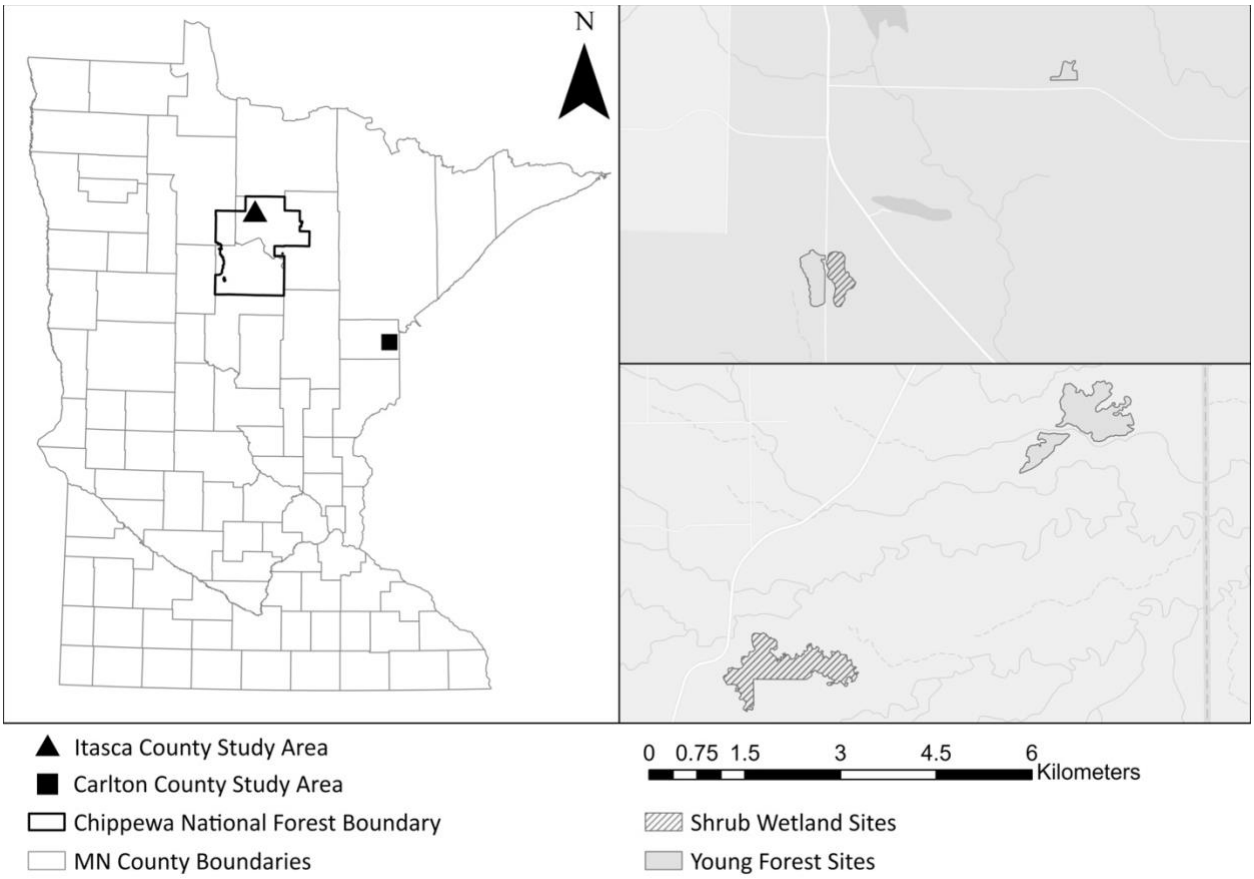

Figure 2.1. Map of Northern Minnesota (MN), USA indicating the locations of study areas: Itasca county sites located within the Chippewa National Forest and Carlton county sites located in Carlton county forest land. Study areas shown for the Itasca county sites (top-right) and Carlton county sites (bottom-right). Fledgling Golden-winged Warblers were radio-tagged and monitored throughout the duration of the dependent post-fledging period from 2021-2022 in the Itasca county study area and in 2023 in the Carlton county study area.

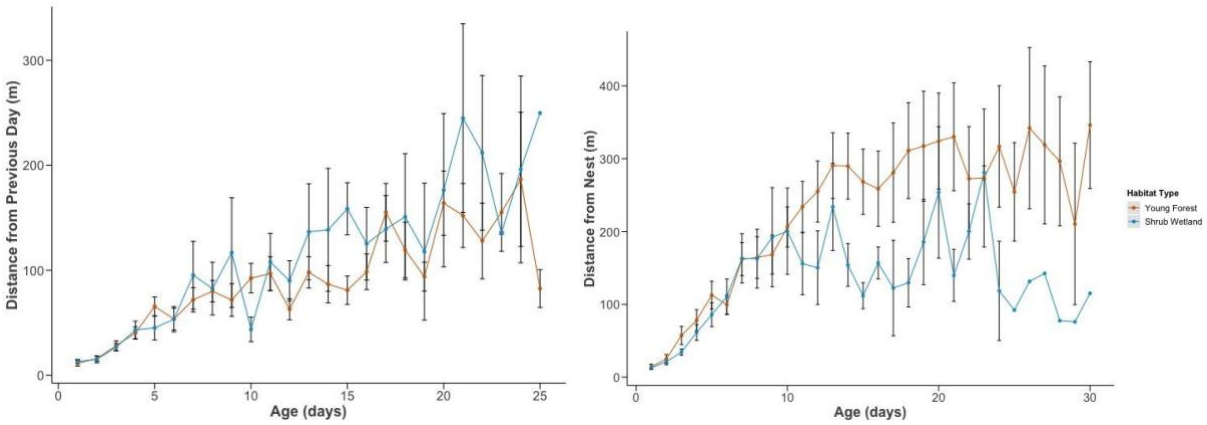

Figure 2.2. (Left) Minimum daily movement and (Right) maximum dispersal distances (i.e. distance moved from nest) by age for Golden-winged Warbler fledglings in northern Minnesota for young forest (orange lines) and shrub wetland habitat (blue lines). Habitat type distinctions are made from birds which nested and fledged from each habitat type. Error bars represent standard error around the mean.

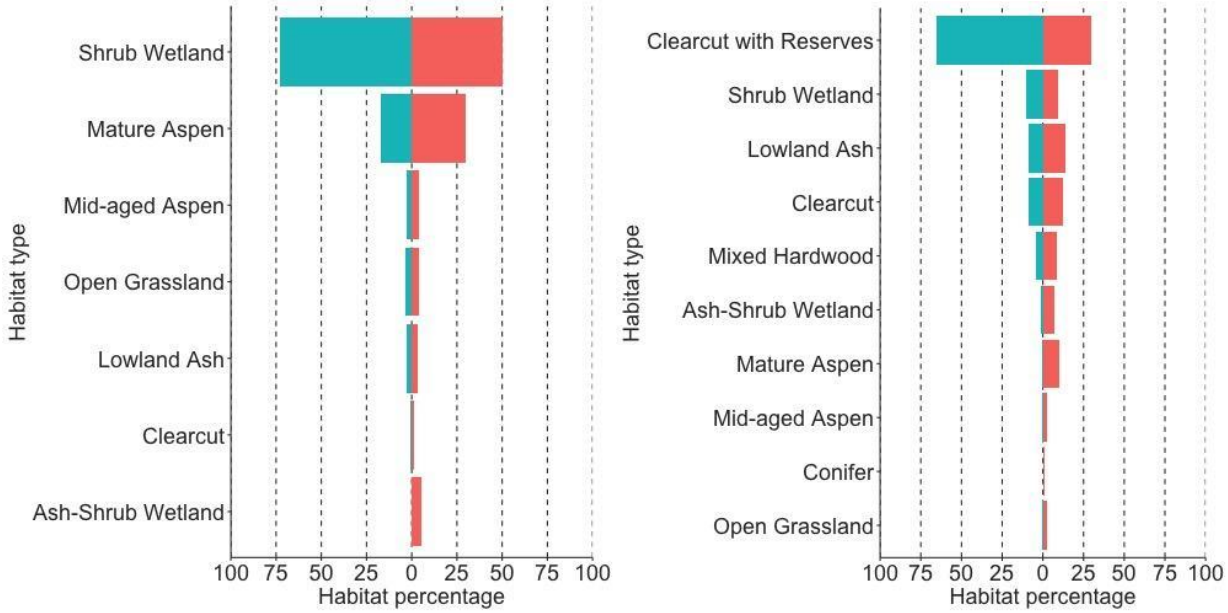

Figure 2.3. Mean proportion of cover type used (teal) and available (red) for Golden-winged Warbler fledglings in shrub wetland (left) and young forest (right) sites in northern Minnesota. Use estimates are based on the mean proportion of points for each cover type; available estimates are based on the proportion of cover types within buffers around daily fledgling locations.

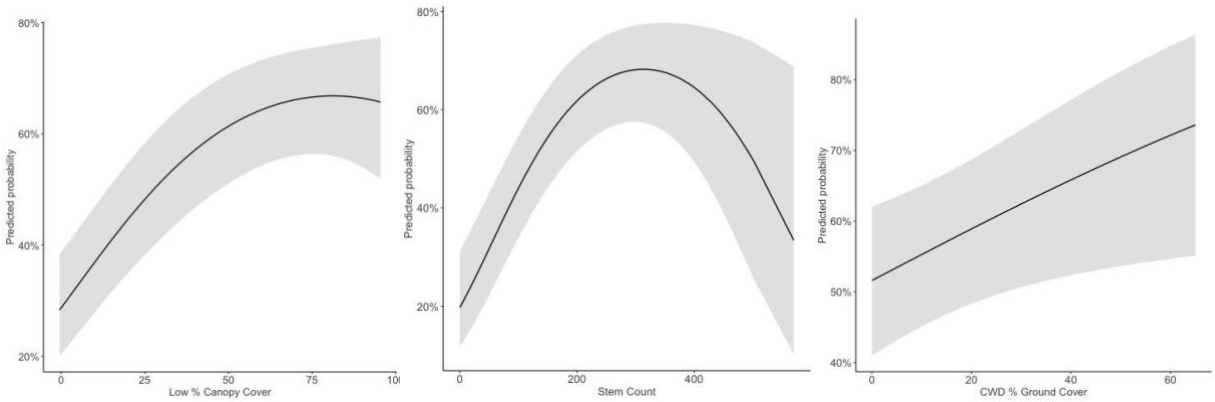

Figure 2.4. Significant variables in final global model predicting Golden-winged warbler fledgling use. Year was used as a random effect. Quadratic transformations were used on canopy cover and stems. Estimates are based on vegetation surveys from daily fledgling locations in northern Minnesota.

TABLES

Table 2.1. Description of cover types found across the Itasca and Carlton county study areas in northern Minnesota from 2021 to 2023.

Covertype	Description
Ash-shrub Wetland	Mix of old shrub wetland (3-6 m tall shrubs) and dispersed ash, paper birch, cedar, spruce trees
Mature Aspen	Aspen-dominated stands (25+ years old), typically single-aged
Mid-aged Aspen	Aspen-dominated stands (~10-25 years post-harvest)
Lowland Ash	Lowland mature forests dominated by ash
Shrub Wetland	Brushy wetland dominated by alder and willow (1-2 m tall shrubs) with interspersed overstory trees
Mature Hardwood	Forest stands dominant in coniferous species (pine, spruce, tamarack)
Clearcut with no Retention	Aspen/Balsam Poplar-dominated clearcuts (1-10 years post-harvest) with no residual overstory trees
Clearcut with Retention	Aspen/Balsam Poplar-dominated clearcuts (1-10 years post-harvest) with residual overstory trees (~16 trees/ha)
Conifer	Forest stands dominant in coniferous species (pine, spruce, tamarack)
Open Grassland	open field or marsh
Road	Gravel or paved roads
Open Water	Permanent standing water in lakes and rivers

Table 2.2. Summary statistics for vegetation characteristics used by early (days 0-8) and late (days 9-30) post-fledging periods in the Itasca and Carlton County study areas from 2021 to 2023. All characteristics were assessed within 5 m plots, except for tree counts which were done within 11.3 m (0.04 ha) plots. t-tests were used to determine differences between early and late fledgling points across all sites and years.

		Early				Late			
Variable	**Significance (*P*-value)**	**Mean**	**SE**	**Min**	**Max**	**Mean**	**SE**	**Min**	**Max**
% Canopy Cover - Total	1.8E-07	58.0	1.2	3.3	96.0	66.0	1.2	0	95.8
% Canopy Cover - Low	0.11	39.6	1.4	0	93.0	43.0	1.5	0	94.0
% Canopy Cover - High	0.11	18.3	1.1	0	94.8	23.8	1.3	0	95.5
% Canopy Cover - High SD	0.86	11.8	0.6	0	43.1	11.6	0.5	0	45.1
Tree Count	0.11	8.5	0.5	0	65.0	10.2	0.5	0	64.0
Woody Stem Height	1.7E-13	2.7	0.1	0	6.0	3.3	0.1	0	7.0
Woody Stem Count	0.09	182.3	4.5	3.0	473.0	171.7	4.2	25.0	570.0
Woody Stem Diversity (H')	0.10	1.1	0.03	0	2.2	1.0	0.02	0	2.1
% Ground Cover - High Vegetation	0.11	64.0	1.3	0	100.0	66.8	1.1	0	100.0
% Ground Cover - Bare Ground	9.5E-05	4.8	0.3	0	35.0	7.9	0.5	0	85.0
% Ground Cover - Woody Debris	0.16	10.0	0.5	0	65.0	9.7	0.5	0	60.0

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CHAPTER 3

Influence of habitat type, landscape, and temporal factors on the abundance of Golden-winged Warbler nest and fledgling predators in northern Minnesota

INTRODUCTION

Understanding what factors affect nest and fledgling survival is important as annual recruitment into the population is directly linked to survival (Martin 2002, Streby and Andersen 2011). For many birds, survival is highly variable depending on the life stage (i.e. nesting, fledgling, adult, etc.), with the nesting and post-fledging stages representing the most vulnerable life stages of most passerines (Martin 1987, Yackel Adams et al. 2006, Streby et al. 2016). Specifically, predation is the predominant cause of nest and fledgling mortalities for most North American passerines (Manolis et al. 2002, Phillips et al. 2005, Yackel Adams et al. 2006, Streby et al. 2016).

Many avian studies have documented indirect factors of predation risk by evaluating nest or fledgling survival as it relates to landscape and habitat factors. For instance, Benson et al. (2010) documented increased predation of Swainson's Warbler (*Limnothlypis swainsonii*) nests near edges. Lyons et al. (2015) found that Grasshopper Sparrow (*Ammodramus savannarum*) nests experienced fewer predations in areas with increased forb cover and multiple studies have documented increased nest predator activity near forest edges (Rudnicky and Hunter 1993, Chalfoun et al. 2002).

Additionally, predator communities can vary greatly across habitat types and over time, therefore overall predation risk may also be directly influenced by the abundance or distribution of predators (Dijak and Thompson 2000, Chalfoun et al. 2002, DeGregorio et al. 2014) (Dijak and Thompson 2000, Thompson and Burhans 2003, Ulrey et al. 2022). Indeed several studies have documented decreased nest and fledgling survival later in the breeding season, linking this to increased predator abundance and activity (Peak 2007, Jenkins et al. 2016). Specifically, higher abundance of predators may increase the probability of predation because there is an increased likelihood of interactions between predators and nests or fledglings (Martin 1993). In addition to

direct relationships between predators and avian survival, increases in mesocarnivores prey (i.e., mice, voles, and lagomorphs) in an area may attract generalist predators, thereby increasing opportunistic predation rates on nest and fledglings (Brook et al. 2008, Pöysä et al. 2016). For example, Carpio et al. (2015) found that higher rabbit abundances in olive orchards increased predation events by mesocarnivores on artificial nests. Therefore, understanding how predator abundance and distribution is influenced by landscape and habitat factors is especially important for quantifying predation risk of nests and fledglings.

There is little information about the influence of habitat type and landscape features on abundance of potential nest and fledgling predators on breeding birds. Using a variety of methodology we assessed predator abundance during the breeding season in two distinct habitat types, used by a bird species of conservation concern the Golden-winged Warbler. Our specific objectives for this study were to: 1) assess differences in predator abundance between early (mid-June) and late (early-July) nesting season, 2) assess differences in predator abundance between two early successional habitats, 3) characterize factors associated with predator abundance across Golden-winged Warbler breeding habitat. We hypothesized that predator abundance would increase from early to late breeding season as nest survival, for many passerines, tends to decrease later in the breeding season. We also hypothesized that predator abundance would be higher in young forest habitat compared to shrub wetland because wetlands may be less favorable habitat for terrestrial mammal predators. Finally, we hypothesized that predator abundance would be increased along forest edges as nest predation risk often increases near edges.

METHODS

Study Areas

This study was conducted across two study areas with twelve study sites (*n = 12*) during the spring and summer of 2022 and 2023 in northern Minnesota (Itasca and Carlton Counties) (Figure 3.1), near the ecotone of boreal and northern temperate forests commonly referred to as

the “hemiboreal” forest. Forest cover types are dominated by aspen, lowland hardwood, mixed hardwood, lowland conifer, and upland conifer (Grinde et al. 2017). The most representative tree species are aspen (*Populus* spp.), paper birch (*Betula papyrifera*), ash (*Fraxinus* spp.), spruce (*Picea* spp.), tamarack (*Larix laricina*) and pine (*Pinus* spp.) (Hillard 2019).

In both study areas we sampled across three shrub wetland sites and three young forest sites. Shrubby wetland habitats were dominated by speckled alder (*Alnus incana*), willow (*salix spp.*), and black ash (*Fraxinus nigra*). Young forest sites consisted of sapling dominated quaking aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), approximately 2-5 years post-harvest, with varying levels of overstory retention. Sites ranged in size from 17 to 180 acres and were predominantly surrounded by even-aged mature aspen, mixed hardwood, and lowland hardwood forests.

Predator Surveys

During the spring and summer of 2022 and 2023 we conducted predator camera trap surveys to determine relative abundances of mammalian predators at each of our study sites. Cameras were systematically stratified within each site at a density of one camera for every 5 acres. Camera placements were not adjusted in the field unless the point was in standing water, in which case the camera was moved to the near dry ground. Trail cameras (Meidase P50 Trail Camera) were placed on a stake, facing downward, one meter above the ground in order to reduce false triggers from moving vegetation (Glen et al. 2013). Peanut butter and black oil sunflower seeds were placed at the ground directly under the camera to serve as bait.

We conducted two camera trapping sessions at each site in order to capture seasonal variation in small mammal populations. Cameras were set out for 2 days with the first session at mid-June and the second in early-July. These two trapping sessions align closely with peak nesting and late nesting/early fledging of Golden-winged Warblers in Northern Minnesota. The cameras were set at high sensitivity and the lowest delay (0.1 seconds), and programmed to take 10 second video clips in order to provide more footage for species identification (Meek et al. 2014, Villette et al. 2016).

Videos were processed in the program *Timelapse* (https://saul.cpsc.ucalgary.ca/timelapse/) to filter out false triggers and to identify all events (i.e. any video with a mammal detection) to species. Because it is not possible to accurately identify individuals with camera trapping, we used the sequences of events to calculate hit rates (hits/camera/day) for each species per camera because hit rates can be used as an index for density (Carbone et al. 2001). We calculated hit rates for five species groups: 1) mice including *Peromyscus spp.* and jumping mice (*Napaeozapus insignis* or *Zapus hudsonius*) and voles (*Myodes gapperi* and *Microtus sp.*); 2) sciurids including eastern chipmunk (*Tamias striatus*), red squirrel (*Tamiasciuris hudsonicus*), and Franklin's ground squirrel (*Poliocitellus franklinii*); 3) mesocarnivores including raccoon (*Procyon lotor*), short-tailed weasel (*Mustela erminea*), and striped skunk (*Mephitis mephitis*); 4) lagomorphs including snowshoe hare (*Lepus americanus*) and eastern cottontail (*Sylvilagus floridanus*); and 5) shrews including *Blarina spp.* and *Sorex spp.* We used these predator groupings based on documented predation events on Golden-winged Warbler nests using nest videos (see Chapter 1). We used 90-minute hit windows for mice, voles, and shrews where videos of the same species with more than 90 minutes between videos were considered independent and categorized as an a independent hit on that camera (Villette et al. 2016). The same method was used for sciurids and lagomorphs but with a five-minute hit window (Villette et al. 2017).

During the pilot year of this study we used an array of coverboards (Kjoss and Litvaitis 2001) to assess relative density of garter snakes (*Thamnphis sirtalis*) and conducted point count surveys to document avian predators (i.e., corvids and hawks). Point count locations were greater than 250 m from the neighboring location (2-4 points per site). We conducted early morning surveys (between 05:00-09:00 AM) twice during the breeding season, around the same time as camera trapping sessions. However, we had no snake detections using the coverboards and detected few avian predator detections from point count surveys, we focused only on mammalian predators for our analyses.

Calculating Landscape Metrics

Cover types within 750 meters each of the study sites were digitized in ArcGIS Pro 3.2.0 (ESRI, Redlands, California, USA), using a combination aerial imagery (ESRI, 2021), National Wetland Inventory (NWI), Chippewa National Forest and Carlton county forest inventory layers, as well as ground-truthing from tracking and vegetation surveys (Chapter 2 Methods). We used 750 meters as this distance adequately captures variation in the landscape for multiple predators (Chiavacci et al. 2018). We surveyed >2,800 locations throughout the study sites allowing us to confirm and adjust cover type delineations after ground-truthing. We classified cover types into 8 classes including: deciduous-dominated mature forest, deciduous-dominated mid-aged forest (stem exclusion-dominated forest 10-25 years post-harvest), young forest (i.e. regenerating forest 1-9 years post-harvest), shrub wetland, coniferous dominated forest, open grassland or wetland, open water, and road. We calculated five landscape metrics for each site using the "*landscapemetrics*" package in R (Hesselbarth et al. 2019), including: patch size (ha), percent forest, site core area index, number of patches, and clumpiness. Patch size refers to the areas (hectares) of the site; percent forest is the proportion of land within the study area that is forested, excluding young forest; site core area index refers to the proportion of the site that is core area (more than 20 meters from the edge); number of patches refers the to the number of cover type patches within the study area; clumpiness refers the degree to which cover types are grouped with like cover types (i.e. 0 for randomly distributed and 1 for maximally aggregated cover types). Distances from each trail camera location to the nearest forest edge, exterior site boundary, and road were calculated using the Euclidean Distance tool in ArcGIS. Edge density (km of forest edge/ha) was calculated in ArcGIS using the Summarize Within tool. Lastly, Terrain Wetness Index layer (TWI) was used to calculate site- and camera-level (within a 50 meter buffer) averages and standard deviation.

Data Analysis

We modeled camera hit rates (hits/camera/day) across years and sites of the five species groups (mice/voles, sciurids, mesocarnivors, lagomorphs, and shrews) using linear mixed-effects models (LMM) with the *lme4* package in Program R (version 4.2.1). We used the log-transformed hit rates to meet normality assumption. We used nine covariates for modeling camera hits rates

including session number and habitat type (young forest/shrub wetland) and the seven other landscape variables (distance to road (m), distance to forest edge (m), distance to exterior site boundary (m), average TWI within 50-meter buffer, standard deviation TWI within 50-meter buffer, site patch size (ha), and edge density (km/ha)). We tested collinearity between covariates but no variables were correlated with each other ($r < 0.70$). We first created a global model and used backwards selection to remove non-significant variables ($P > 0.05$) until all remaining variables were significant. We determined the variable to be significant for predicting differences in hit rates if the intercept was significantly different than zero. ($P < 0.05$). The final model was tested against the null model to determine goodness-of-fit, using a chi-square test. We modeled average hit rates by site of potential nest predators using round, habitat type, and seven landscape metric variables: site average TWI, site standard deviation TWI, patch size (ha), percent forest, site core area index, number of patches, and clumpiness. We used the same modeling approach as camera hit rates, testing for collinearity and using backwards selection to build a global model for average hit rates by site.

We used Welch's two sample *t*-tests that allowed for unequal variance to compare differences in hit rates for each species group between shrub wetland and young forest sites. We used paired *t*-tests to compare differences in hit rates between camera trapping sessions. Variables were assessed for normality assumptions and were considered significant at $P < 0.05$.

RESULTS

Total camera trapping effort in the Chippewa NF sites (2022) was 177.5 camera-days and 90.3 camera-days in the Carlton County sites (2023). Pooling across all sites from 2022 we obtained a total of 13,968 videos; 9,776 were of mice/voles (~70%), 2,569 were of sciurids (18%), 258 were of shrews (2%), 175 were of mesocarnivores (1%), and 1,190 were of lagomorphs (8.5%). In 2023, across all sites we obtained 8,474 videos; 6,359 were of mice/voles (75%), 1,318 were of sciurids (16%), 325 were of shrews (4%), 86 were of mesocarnivores (1%), and 386 were of lagomorphs (5%).

Session and habitat differences

We found significant differences in hit rates between the first and second camera trapping sessions for mice/voles (t = 2.61, df = 91, P = 0.01), sciurids (t = 4.36, df = 91, P < 0.001), lagomorphs (t = 2.70, df = 91, P = 0.008), shrews (t = 3.80, df = 91, P < 0.001), but not mesocarnivores (t = 1.85, df = 91, P = 0.068) (Table 3.1). All hit rates were higher in the second camera trapping round. Scuirds had the greatest increase in hit rates, increasing over seven times between sessions. We also found a significant difference in hit rates between sessions for the combined nest predators (t = 4.41, df = 91, P < 0.001) and total mammal hits as well (t = 6.25, df = 91, P < 0.001) (Figure 3.2).

We found significant differences in hit rates between shrub wetland and young forest sites for mice/voles (t = 2.03, df = 115.6, P = 0.045), sciurids (t = 4.45, df = 101.9, P = 2.20e-05), lagomorphs (t = 2.62, df = 133.24, P = 0.010), shrews (t = 2.79, df = 119.4, P = 0.006), but not mesocarnivores (t = 1.19, df = 111.2, P = 0.237) (Table 3.2). Mice/voles hit rates were higher in shrub wetland sites (3.10 hits/camera/day ± 5.27 SD) than young forest sites (1.89 hits/camera/day ± 2.13 SD). Sciurid hit rates were much lower in shrub wetland sites (0.27 hits/camera/day ± 0.87 SD) compared to young forest sites (2.63 hits/camera/day ± 5.15 SD). There was a significant difference of hit rates between sessions for the combined nest predators (t = 4.42, df = 102.4, P < 0.001), but not for total mammal hits (t = 1.26, df = 184.1, P = 0.209) (Figure 3.3).

Camera hit rates

The final global model for predicting sciurid hit rates (hits/camera/day) was significantly different from the null model (χ^2 = 59.49, P < 0.001) and contained five variables: session, TWI standard deviation, patch size, distance to forest edge, and edge density. Session ($\beta_{session2}$ = 0.58 ± 0.10 SE) and edge density (β = 0.22 ± 0.05 SE) were both positively correlated with sciurid hit rates; whereas TWI stand deviation (β = -0.07 ± 0.10 SE), patch size (β = -0.02 ± 0.01 SE), and distance to forest (β = -4.7e-03 ± 2.2e-03 SE) were negatively correlated with sciurid hit rates.

The final global model for predicting mice/voles hit rates (hits/camera/day) was significantly different from the null model (χ^2 = 63.75, P < 0.001) and contained four variables: session, TWI

standard deviation, edge density, and distance to road. Session ($\beta_{session2}$ = 0.70 ± 0.0.22 SE), distance to road (β = 4.62e-04 ± 1.46e-04 SE), TWI standard deviation (β = 4.88e-02 ± 1.63e-02 SE) were positively associated with mice/voles hit rates; and edge density (β = -0.15 ± 0.06 SE) was negatively associated with mice/vole hit rates.

The variation in lagomorph hit rates (hits/camera/day) was best described by the global model containing three variables (session, TWI standard deviation, and edge density) and was significantly different from the null model (χ^2 = 23.65, P < 0.001). Edge density (β = -0.13 ± 0.03 SE) and TWI standard deviation (β = -0.03 ± 0.01 SE) were negatively correlated with hit rates; and session ($\beta_{session2}$ = 0.21 ± 0.08 SE) was positively associated with lagomorph hit rates.

The final global model for predicting shrew hit rates (hits/camera/day) contained only two variables (session and distance to road) and was significantly different from the null model (χ^2 = 48.32, P < 0.001). Distance to road (β = 4.46e-04 ± 7.63e-05 SE) and session ($\beta_{session2}$ = 0.27 ± 0.06 SE) were both positively associated with shrew hit rates. Lastly, we did not find any significant variables that described differences in hit rates for mesocarnivores.

Nest predator site hit rates

The variation in nest predator hit rates (hits/site/day) was best described by the global model containing three variables: session, average site TWI, and patch size (Figure 3.4). This final model was significantly different from the null model (χ^2 = 17.93, P < 0.001). Session ($\beta_{session2}$ = 0.78 ± 0.23 SE) was positively associated with nest predator hit rates; whereas average site TWI (β = -0.08 ± 0.02 SE) and patch size (β = -0.03 ± 0.01 SE) were negatively correlated with nest predator hit rates.

DISCUSSION

Understanding predation risk is an important, yet understudied, aspect of avian ecology. Breeding birds choose nesting sites that offer a balance between access to resources (food, nest

sites) and safety from predators. This study assessed relative differences in mammal abundances between two camera trapping sessions and between two habitat types: shrub wetland and young forest. Additionally, we modeled hit rates both at the camera- and site-level in order to determine what habitat and landscape factors are associated with mammal abundance. Characterizing differences in predation risk between habitats and in relation to habitat and landscape features is the first step in implementing habitat management that mitigates depredation events.

We hypothesized that predator abundance would increase from early to late breeding season as nest survival. Hit rates increased during the second camera trapping sessions for mice/voles, sciurids, lagomorphs, and shrews, but not mesocarnivores. This only partially supported our hypothesis as we expected mesocarnivores hit rates to also increase; however we likely had poor representation of mesocarnivores hit rates as detections were much less common than other species. Merritt et al. (2001) found similar results when comparing mice, vole, and chipmunk abundance between seasons in Pennsylvania. We also hypothesized that predator abundance would be higher in young forest habitat compared to shrub wetland. In addition to this, we documented differences in hit rates for multiple species groups between habitats. For example, , sciurid hit rates were significantly higher in young forest sites compared to shrub wetland sites. Although we did not detect a significant difference in mesocarnivores, this supported out hypothesis as sciurids were common predators of Golden-winged Warbler nests. These differences between trapping sessions and habitat types indicate that predation risk may be increased later in the breeding season and in young forests compared to shrub wetlands. Although abundance does not necessarily lead to greater predation risk, Martin and Joron (2003) found that areas with increased red squirrel abundance also had greater nest predations.

An important aspect of predation risk are the habitat and landscape features associated with nest location. Specifically, we expected fragmentation to be positively associates with predator abundance. However, we found that predator groups responded differentially to the variables we tested. Mice/vole hit rates increased positively with the distance to roads, whereas no other group hit rate responded to distance to road. Additionally, sciurid hit rates were higher closer to edges, supporting our hypothesis about increase hit rates along edges. Chalfoun et al. (2002) found

dissimilar results as they documented no difference in abundance of small- and medium-size mammals when comparing forest-pasture edges and interior forest, although this may be due to differences in regions and habitat. While we did not find any support in our models for variables that described differences in mesocarnivores camera hit rates, we did find that average nest predator hit rates at the site-level were higher in small sites and sites with lower TWI (drier sites). Cocimano et al. (2011) found higher abundances of chipmunks in dry meadows compared to wet meadows. Increased wetness has been shown to decrease terrestrial mammalian activity thereby reducing predation risk for breeding birds (Fletcher, Jr. and Koford 2004, Hoover 2006).

These findings put together demonstrate that shrub wetland habitat may have increased predation risk. Additionally, predation risk, at least by sciurids, may also increase along forest edges. Because this study was only conducted during two breeding seasons, we lack any information related to differences in predation risk related to annual population differences or population cycles. Brook et al. (2008) found that annual differences in meadow voles significantly affect predation of waterfowl nests. Continued research is needed to elucidate how annual population fluctuations may impact predation risk of Golden-winged Warbler nests in young forests and shrub wetlands. However, our results do provide evidence of increased abundance of nest predators in young forests compared to shrub wetlands, suggesting predation rates may be lower in shrub wetlands, however additional data are needed. Overall, habitat management plans should incorporate factors associated with increased predation risk when creating and managing breeding habitat for Golden-winged Warblers.

FIGURES

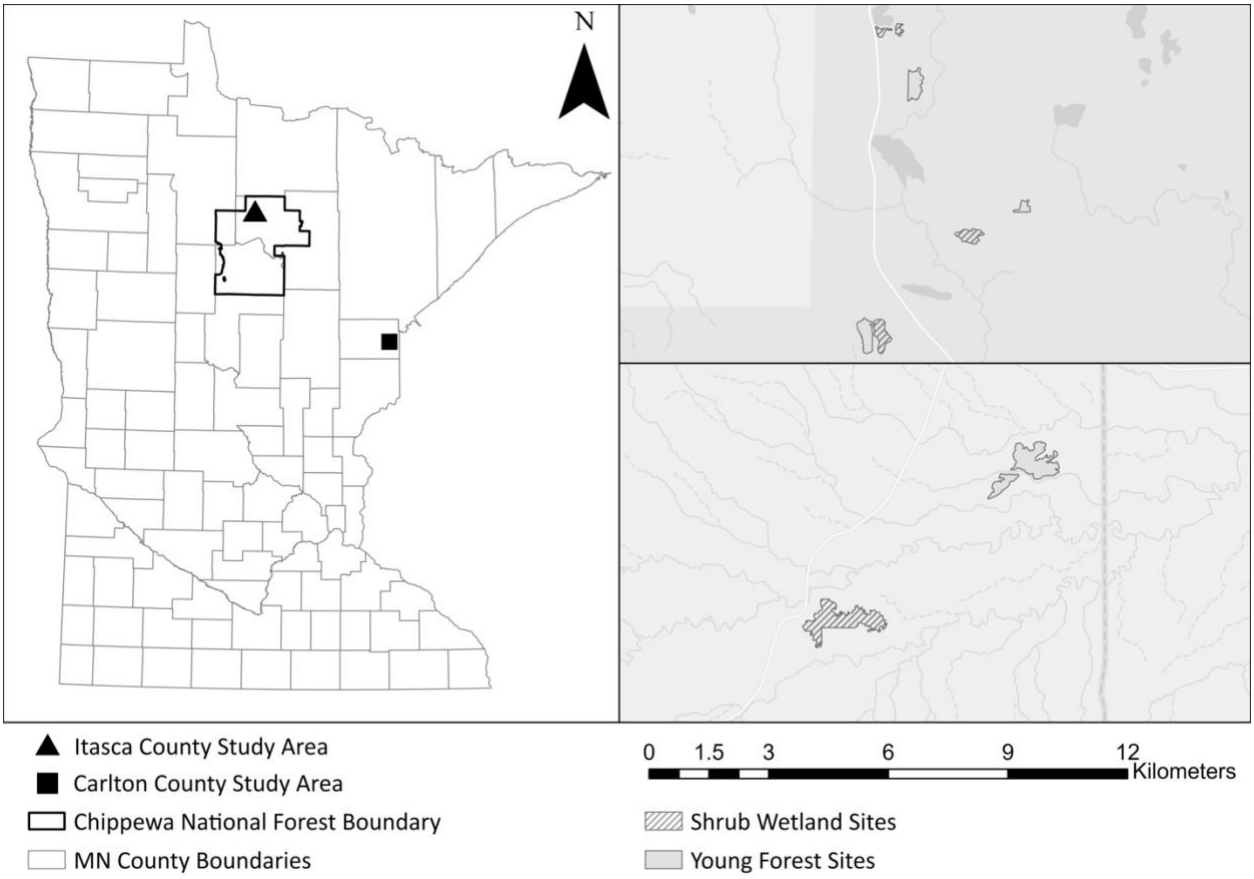

Figure 3.1. Map of Northern Minnesota (MN), USA indicating the locations of study areas: Itasca County sites located within the Chippewa National Forest (2022) and Carlton County sites located in Carlton County forest land (2023).

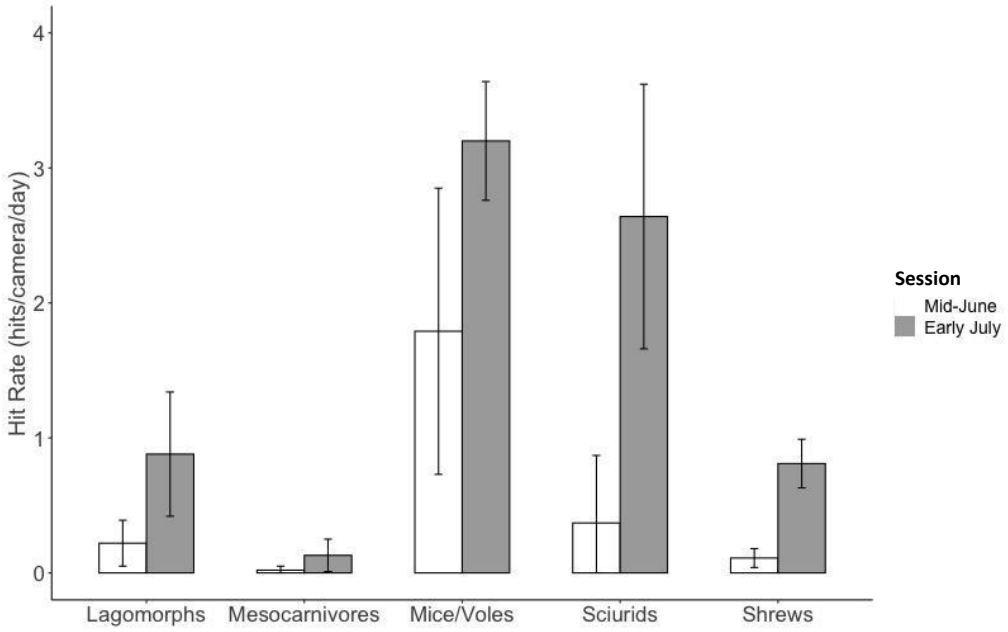

Figure 3.2. Mean hit rates (hits/camera/day) for five mammal groups in early successional habitat surveyed during two time periods: mid-June (white) and early July (gray). Two-day trail camera trapping sessions were completed during 2022 and 2023 in the Chippewa National Forest and Carlton County, MN, USA, respectively. Error bars represent 95% confidence intervals around each mean.

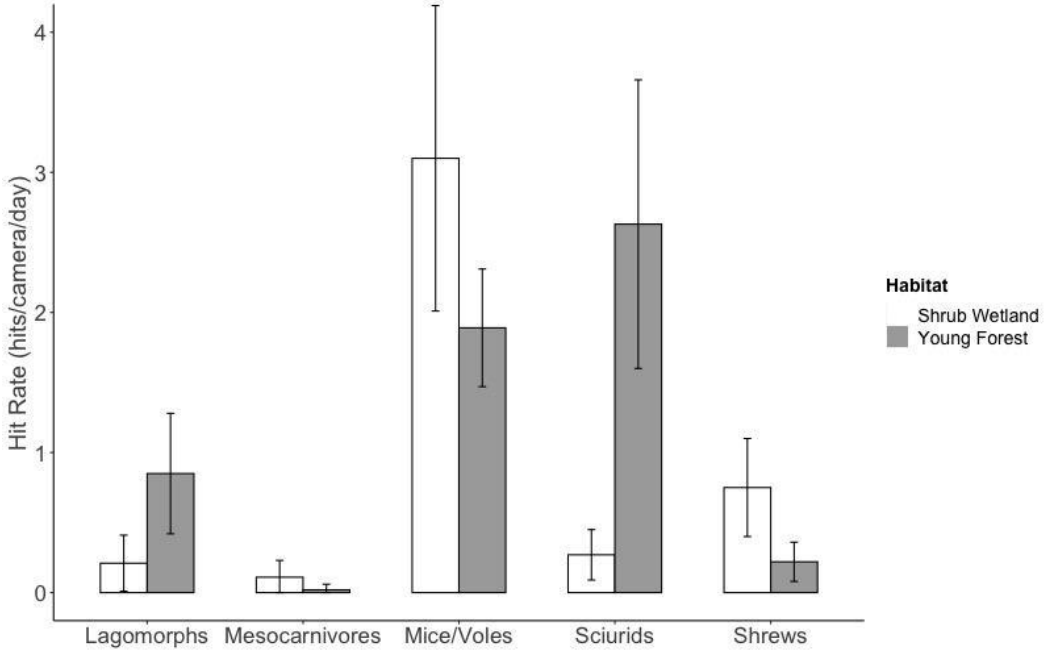

Figure 3.3. Mean hit rates (hits/camera/day) for five mammal groups in two early successional habitats surveyed in mid-June and early July. White bars represent estimates from shrub wetland sites and gray bars represent estimates from young forest sites. Error bars represent 95% confidence intervals around each mean.

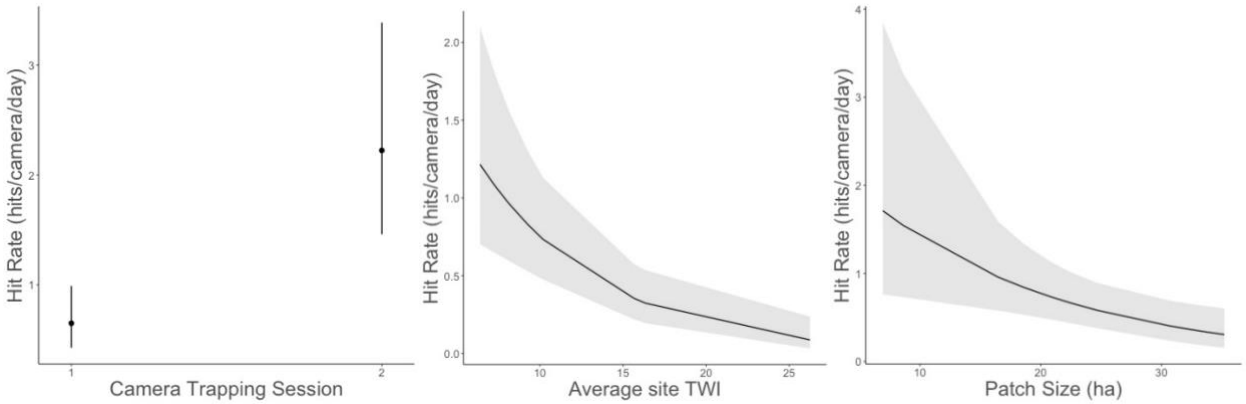

Figure 3.4. Relationship between three variables and hit rates (hits/camera/day) per site from nest predators based on a global model containing all three variables.

TABLES

Table 3.1. Summary statistics for predator group hit rates for sampling round 1 (mid-May) and round 2 (early-July). Significant differences between sessions were assessed with a paired t-test and considered significant at $P < 0.05$.

		Session 1				Session 2			
Predator Group	**Significance (p-value)**	**Mean**	**STD**	**Min**	**Max**	**Mean**	**STD**	**Min**	**Max**
Mice/Voles	0.011	1.79	5.18	0	47.10	3.20	2.17	0	10.17
Shrews	2.63E-04	0.11	0.35	0	1.94	0.81	1.73	0	9.51
Sciurids	3.38E-05	0.37	2.44	0	23.19	2.64	4.79	0	23.41
Lagomorphs	8.24E-03	0.22	0.83	0	4.66	0.88	2.27	0	12.51
Mesocarnivores	0.068	0.02	0.16	0	1.48	0.13	0.58	0	3.75

Table 3.2. Summary statistics for predator group hit rates in Shrub Wetland and Young forest habitat. Significant differences between habitat types were assessed with Welch's t-test and considered significant at $P < 0.05$.

		Shrub Wetland				Young Forest			
Predator Group	**Significance (p-value)**	**Mean**	**STD**	**Min**	**Max**	**Mean**	**STD**	**Min**	**Max**
Mice/Voles	0.045	3.10	5.27	0	47.10	1.89	2.13	0	9.20
Sciurids	2.20E-05	0.27	0.87	0	5.97	2.63	5.15	0	23.41
Mesocarnivores	0.237	0.11	0.57	0	3.75	0.04	0.21	0	1.48
Shrews	0.006	0.75	1.68	0	9.51	0.22	0.73	0	44.48
Lagomorphs	0.010	0.21	0.95	0	7.38	0.85	2.17	0	12.51

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APPENDIX

Table A1. Ranking of univariate nest survival models compared to the null model.

Model Name	Estimate	SE	NLL	QAICc	ΔQAICc	Weight
Date	-0.111	0.024	183.04	201.40	0	0.86
$1.2^{-Dist.Forest}$	-1.849	0.446	187.05	205.68	4.28	0.1
Age	-0.080	0.025	189.67	208.47	7.07	0.02
$1.2^{-Dist.Site.Edge}$	-1.594	0.556	191.24	210.14	8.75	0.01
Null	-	-	194.74	211.87	10.48	0

Table A2. Ranking of univariate fledgling survival models compared to the null model.

Model Name	Estimate	SE	NLL	QAICc	ΔQAICc	Weight
Age	0.319	0.093	131.83	269.73	0	0.52
Date	0.149	0.041	131.95	269.97	0.24	0.46
%Open.GC	0.124	0.059	135.82	277.7	7.97	0.01
$1.2^{-Dist.Site.Edge}$	-1.219	0.728	137.6	281.26	11.53	0
$1.2^{-Dist.Forest}$	-1.023	0.640	137.68	281.42	11.66	0
Habitat Type (SW)	-0.530	0.356	137.73	281.53	11.80	0
Null	-	-	138.83	281.69	11.95	0

Table A3. Beta estimates for significant covariates in final global model predicting Golden-winged warbler fledgling use. Year was used as a random effect. Quadratic transformations were used on canopy cover and stems. Estimates are based on vegetation surveys from daily fledgling locations in northern Minnesota.

Model	Estimate	Std. Error	*Z* value	Pr(>|z|)
Intercept	-0.217	0.207	-1.051	0.293
Low Canopy Cover	20.790	2.451	8.479	2e-16***
Low Canopy Cover^2	-6.512	2.213	-2.943	3.25e-03**
Stems	16.650	2.525	6.593	4.30e-11***
Stems^2	-9.555	2.283	-4.186	2.85e-05***
CWD	0.014	0.007	2.230	0.026*