# USE OF MANAGED FOREST WILDLIFE OPENINGS BY AMERICAN WOODCOCK

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## SUMMARY OF FINDINGS

American woodcock (*Scolopax minor*) were surveyed at permanently managed forest wildlife openings in northern Minnesota. Singing ground surveys conducted from mid-April through May during 2016, 2017, and 2018 indicated that 72% of openings were used by singing male woodcock during at least one year of study. Roosting ground surveys conducted from June through August during 2016 and 2018 indicated that 70% of openings were used by woodcock in at least one year of study. For both singing and roosting openings, woodcock were more likely to use larger openings with smaller perimeter-to-area ratios. In addition to woodcock surveys, vegetation data along transects were collected within openings to assess the relationship of vegetation metrics to woodcock use and management of habitat in openings. Openings used during singing ground surveys had a higher proportion of grass and lower proportions of herbaceous plants. Openings used by roosting woodcock had higher proportions of grass, lower proportions of shrubs, and shorter herbaceous vegetation. Years since management was not an important driver of singing ground use but was significant for roosting ground use. Openings managed more recently were more likely to have roosting woodcock and also had lower proportions of shrubs and shorter shrubs and trees. However, across all openings, shrubs and trees were uncommon, and most openings had been managed within the past 4 years. The proportion of woodcock habitat adjacent to openings was an important factor in determining singing ground use. The surrounding habitat may be a more important consideration than the vegetation within openings. Wildlife managers interested in creating and maintaining singing and roosting habitat for woodcock in forest-dominated areas should create openings at least 1 ac in size with a large core area, locate openings in areas with abundant woodcock habitat, and use management (mowing) as needed to decrease vegetation height and prevent the establishment of shrubs and trees.


## BACKGROUND

The American woodcock (*Scolopax minor*) is a popular migratory game bird and a Species of Greatest Conservation Need in Minnesota [Minnesota Department of Natural Resources (MNDNR) 2015]. In 2015, Minnesota had an estimated 13,500 active woodcock hunters harvesting 25,600 woodcock, ranking Minnesota third highest in the country for both woodcock hunter and harvest numbers (Seamans and Rau 2016). Annual woodcock surveys have indicated a long-term (1968-2016) decline in singing male numbers across the full breeding range (Seamans and Rau 2016). These declines have been attributed to the loss of open and early successional forest and shrub habitat due to succession, lack of disturbance, and development (Dessecker and McAuley 2001).

Woodcock require a variety of habitat components including dense young forests or shrublands and open singing and roosting grounds (Wildlife Management Institute 2009). Woodcock move frequently between these habitat types, often being found in forests during the day and open sites at night (Sheldon 1967). In the spring, male woodcock use openings as breeding sites, called singing grounds, where they perform their courtship ritual. Females nest and raise broods in the forest surrounding these openings (Sheldon 1967). Both nest and brood locations have been found to be associated with short distances to openings or forest edges (Gregg and Hale 1977, Daly 2014). In the summer, woodcock make evening crepuscular flights to open habitats to roost. Open roosting grounds provide the benefit of reduced predation risk (Masse et al. 2013). Historically, disturbance by fire, wind, Native American activities, flooding, and beavers created openings and early successional habitat for woodcock (DeGraaf and Yamasaki 2003). Many of these disturbances that created and maintained open areas are now prevented. Pastures, fields, agricultural sites, and recent clearcuts (Hale and Gregg 1978, Long and Locher 2013) can all serve as open habitat for woodcock, but in areas dominated by forest cover, managed forest wildlife openings can be used to provide this habitat component.

The secretive nature and cryptic coloration of the woodcock makes it difficult to estimate population size and management effects. There have been past studies assessing the use of openings by woodcock, but most have been focused on the wintering grounds in the southeastern United States (for example Glasgow1958, Stribling and Doerr 1985, Berdeen and Krementz 1998). Fewer studies have explored woodcock use of summer roosting grounds in the northern part of their range (though see Sheldon 1961, Sepik and Derleth 1993, Masse et al. 2013), and even fewer have incorporated habitat characteristics and management into studies of use.

The Upper Great Lakes Woodcock and Young Forest Initiative published best management practices for woodcock in 2009. Their recommendations call for establishing eight singing grounds at least 0.5 acres in size and one roosting field at least 5 acres in size per 100 acres of land (Wildlife Management Institute 2009). Open sites should cover not more than 20 percent of the area, and the remaining land should consist of abundant feeding, nesting, and brood-rearing habitat (Wildlife Management Institute 2009). The MNDNR maintains permanent forest wildlife openings to provide singing and roosting grounds for woodcock, as well as habitat for a variety of other game and non-game species such as deer and bear. These openings require regular mechanical treatment to prevent the establishment of shrubs and trees. Management is most commonly fall mowing; however, mowing in other seasons, prescribed burning, and herbicide have also been used. Wildlife managers would like to improve their management of forest openings to maximize benefit, but do not know the optimal frequency of treatment. In addition, not all managed openings are used by woodcock. Understanding the factors that influence use, such as opening size and configuration, vegetation composition and structure, and surrounding landscape characteristics would improve the creation of forest openings and focus management on those openings expected to provide the greatest benefit. This information will allow for the development of better management practices for land managers and landowners interested in providing wildlife openings for woodcock and other wildlife.

## OBJECTIVES

1. Assess woodcock use of managed forest wildlife openings with differing management history (years since mowing or burning).
2. Relate opening size and configuration, vegetation composition and height, and surrounding landscape characteristics to woodcock use and management history.
3. Develop recommendations to improve the current management of forest wildlife openings.

## METHODS

Singing ground surveys for American woodcock were conducted from mid-April through May 2016 in forest openings within the Grand Rapids, Cloquet, and Red Lake work areas as part of a pilot project and from mid-April through May 2017 and 2018 in the Grand Rapids work area. Surveys followed Singing Ground Survey (SGS) protocol where possible (Seamans and Rau 2016). Surveys generally took place 15 to 60 minutes after sunset, when temperature was above 35 F, and there was no heavy precipitation or strong wind. Openings in close proximity were grouped to allow surveying multiple openings per evening. At each opening observers recorded their GPS location (UTM coordinates), time of sunset, cloud cover, temperature, wind speed, precipitation, and any noise disturbance present at the time of the survey. Observers listened for and recorded the number of different woodcock heard peenting or observed displaying (heard and/or seen) within and over the opening during a listening period of at least 5 minutes. Observers also recorded other observations of woodcock (not within the opening) along with time and approximate location (direction and distance) of the woodcock.

Roosting ground surveys were conducted at openings June through August 2016 and 2018 using crepuscular flight surveys and spotlighting within the opening (Glasgow 1958, Berdeen and Krementz 1998). Roosting surveys were not conducted in 2017 due to funding constraints. For crepuscular surveys, the observer was positioned on the edge of the opening and recorded the number of woodcock observed flying into the opening, over the opening, or heard in the opening (when not seen). Surveys were conducted from 20 minutes before sunset to 40 minutes after sunset (a one hour period). Observers recorded their GPS location (UTM coordinates), time of sunset, cloud cover, temperature, wind speed, precipitation, and any noise disturbance present at the time of the survey. After the survey window, observers systematically walked openings using spotlights and recorded the number of woodcock flushed or spotted.

Vegetation characteristics were sampled as close as possible in time to the survey date and repeated for roosting surveys. A point intersect method (Levy and Madden 1933) was used to determine proportion and height of 5 classes of vegetation (grass, herbaceous, woody, shrub, and tree). Two transects were sampled per opening, one placed across the widest part of the opening from edge to edge, and the second placed perpendicular to the first. Observers recorded vegetation class (or other substrate type if no vegetation present) and maximum height for each class every 1.0 m along the transect. Observers also described the habitat across the entire opening (e.g., number of trees, distribution of trees, percent shrub cover) and the surrounding habitat by type (e.g., upland forest, lowland forest, upland shrub), tree or shrub species, and coarse age class (young, middle, old). Presence of tansy, or other aggressive invasive species were recorded from a visual assessment across the opening as percent cover in 10% increments. Presence of a mowed or packed trail within the opening was noted, as these may provide persistent areas of short vegetation regardless of years since management. To obtain an accurate estimate of opening size and shape, the edge of the opening was walked using a GPS unit to digitize the boundary of the opening. Forest inventory data was used to determine the proportion of the opening adjacent to woodcock habitat. For this study, woodcock habitat included the cover types young deciduous forest $\leq$18 years old, lowland and upland brush, and lowland and upland grass.

To assess the frequency of use of openings in this study by other wildlife the presence of scat encountered within 0.5 m on either side of the vegetation transects was noted. Location along the transect and species (when identifiable) was recorded for each encounter.

### Statistical Analysis

Singing and roosting ground use were analyzed separately. Because 89% of singing ground surveys and 76% of roosting ground surveys had woodcock counts $\leq$1, opening use was assessed as a binary response variable. Predictor variables included opening size (ac), opening perimeter (m), proportion of vegetation in 5 classes (grass, herbaceous, woody, shrub, and tree), average height (m) of vegetation in 5 classes, presence of a road or trail, years since management (mowing or burning), and proportion of the opening adjacent to woodcock habitat. In addition, because opening size (ac) and perimeter (m) were strongly correlated and both highly skewed toward low values, the perimeter-to-area ratio was used to represent both opening size and configuration. Student's t-tests with a significance level of $P < 0.05$ were used to explore the importance of predictor variables on woodcock use of openings. Linear regression was used to relate vegetation variables to years since management. All statistical analyses were conducted using the statistical package R (R Core Team 2018).

Following univariate analysis, models were run using the function "glmer" in the R package "lme4" (Bates et al. 2015, R Core Team 2018) to fit mixed-effect logistic regression models to the analysis dataset. To help with model convergence, size of opening, perimeter, and perimeter-to-area ratio were centered (mean subtracted) and scaled (divided by the standard deviation). Years since management was modeled as a discrete numeric variable. Because few sites had multiple surveys, we did not attempt to account for false zeros due to non-detection. Therefore, "probability of site use" is defined conservatively in this analysis. The R function "drop1" was used with AIC to conduct a stepdown variable-selection exercise. A NULL model that included an intercept term and a random effect for site was also computed. Second-order Akaike information criterion (AICc) was used to identify models with reasonable data support (i.e., $\Delta$AICc < 2), and the function "r.squaredGLMM" in the R package "MuMIn" was used to compute a marginal coefficient of determination (pseudo $R^2$) for the fixed effects in the models.

For modeling singing ground use, a subset of 61 openings surveyed in both 2017 and 2018 and under good conditions (no or light precipitation, wind < 12 mph, and temperature > 35 F) was used. For singing grounds, a principal components analysis, with a correlation matrix, was used to reduce the dimensionality of vegetation-composition metrics associated with each opening producing pc1 and pc2 scores as potential model covariates. The simplest significant vegetation metric, proportion grass (pg), was also considered as an alternative to using principal component scores. Singing ground models included the following covariates as fixed effects: years since management (yrmg), perimeter-to-area ratio (par), proportion of the opening adjacent to woodcock habitat (hab), vegetation composition metrics from a principal components analysis (pc1 and pc2), and proportion grass (pg). All models also included a random effect for site, to accommodate repeated measurements over time.

For modeling roosting ground use, a subset of 49 openings surveyed in both 2016 and 2018 and under good conditions was used. For roosting grounds, a principal components analysis was not used and the 4 vegetation metrics most related to woodcock use (pg, ps, hh, and hs) were considered. Roosting ground models included the following covariates as fixed effects: years since management (yrmg), size of the opening (ac), proportion of the opening adjacent to woodcock habitat (hab), proportion grass (pg), proportion shrub (ps), average height of herbaceous vegetation (hh), and average height of shrub vegetation (hs). All models also included a random effect for site.

## RESULTS

### Singing Ground Use

In 2016, singing ground surveys were conducted at 85 forest openings, with singing males observed at 51 openings (60%). The majority of openings with woodcock (43 of 51) had only 1 male present, 6 openings had 2 males, and 2 openings had 3 males. In 2017, singing ground surveys were conducted at 64 openings, with males observed at 41 openings (64%). At 33 openings 1 male was observed and 8 openings had 2 males present. In 2018, singing ground surveys were conducted at the same 64 openings as the previous year, with males being observed at 34 openings (53%). At 28 openings 1 male was observed, and 2 males were observed at 6 openings. Across the duration of the study, 71 of the 99 unique openings (72%) were used by singing male woodcock during at least one year of study. A limited number of repeat visits were conducted within the same year to aid in assessing detection ability. A total of 24 openings were surveyed on 2 occasions during the sample period. Presence or absence of woodcock was the same for 20 openings (83%, 9 presence and 11 absence). At the remaining openings, 2 indicated presence during the first survey and absence in the second, and 2 indicated absence in the first survey and presence in the second.

Openings surveyed ranged in size from 0.48 to 16.33 ac, with a mean size of 2.79 ± 0.29 ac. Opening size and configuration were significantly related to woodcock use. Openings used by woodcock were larger in area ($t = -4.39$, $P < 0.01$) and had greater perimeter length ($t = -4.01$, $P < 0.01$). However, perimeter-to-area ratio was significantly smaller for openings used by woodcock (i.e., shorter perimeter and larger area, $t = 4.53$, $P < 0.01$), suggesting that area is the more important driver. Despite this, woodcock were observed using openings as small as 0.63 ac.

Vegetation composition in the opening showed some relationship to woodcock use for singing (Table 1). Openings used by woodcock for singing had a significantly higher proportion of grass ($P < 0.01$) and a lower proportion of herbaceous vegetation ($P = 0.02$). Most openings were dominated by grass with few shrubs and trees. Height of the vegetation in each class was not found to be significantly related to woodcock use (Table 1). The proportion of the opening adjacent to woodcock habitat (openland, brushland, and young deciduous forest) was significantly related to woodcock use ($t = -4.62$, $P < 0.01$), with woodcock using openings with a greater proportion of adjacent habitat.

Woodcock were anecdotally observed using un-vegetated or packed down roads and trails in openings. Presence of a road or trail, however, was not significantly related to woodcock use ($t = 1.54$, $P = 0.13$). Number of years since management (mowing or burning) was also not significantly related to woodcock use ($t = 1.13$, $P = 0.26$), however nearly all surveys took place at sites that had been managed within the past 4 years, and the majority (62%) of surveys were conducted at sites managed within 2 years. Vegetation composition and height within openings was related to years since management (Table 2). The proportion of grass significantly decreased with years since management ($P < 0.01$), whereas the proportion of shrub significantly increased ($P < 0.01$). Woody height and shrub height also significantly increased with years since management ($P = 0.02$, $P < 0.01$).

The best supported model predicting probability of use of openings as singing grounds included perimeter-to-area ratio (par), proportion of the opening adjacent to woodcock habitat (hab), proportion of grass in the opening (pg), and a random intercept for site (Table 3). Smaller perimeter-to-area ratio, higher proportion of adjacent habitat, and higher proportion of grass increased the probability of woodcock use. Other supported models ($\Delta AICc < 2$) were the model including perimeter-to-area, habitat, and site and the model including perimeter-to-area, habitat, vegetation metrics (pc1), and site.

### Roosting Ground Use

Roosting ground surveys were conducted at 63 openings in 2016 and at 64 openings in 2018. In 2016, woodcock were observed at 42 openings (67%) during crepuscular surveys, and roosting woodcock were spotlighted and/or flushed at 14 openings (22%). In 2018, woodcock were observed at 27 openings (42%), and roosting woodcock were spotlighted and/or flushed at 15 openings (23%). Both survey methods provided useful information on woodcock use, thus openings with woodcock observations during either survey were used for the analysis. In 2016, 44 openings (70%) were used by woodcock and in 2018, 28 openings (44%) were used.

Across the duration of the study, 52 of the 74 unique openings (70%) were used by woodcock during at least one year of study. Roosting surveys were not repeated due to time limitations, but other research has found that the frequency of roosting field use by individual woodcock varies by month and by age and sex, peaking in June and July (Sepik and Derleth 1993). However, there was no significant relationship found between date and the number of woodcock observed at roosting openings in this study in which surveys were conducted from June through August.

Openings used by woodcock were larger in area ($t = -3.13$, $P < 0.01$) and had greater perimeter length ($t = -2.66$, $P < 0.01$). The perimeter-to-area ratio was significantly smaller for used openings ($t = 2.28$, $P = 0.01$). Despite these findings, woodcock were observed using openings as small as 0.59 ac.

Openings used by roosting woodcock showed some relationship to vegetation metrics (Table 4). Used openings had a significantly higher proportion of grass ($P < 0.01$) and a lower proportion of shrub ($P = 0.04$). Herbaceous vegetation height was also significantly lower in openings used by woodcock ($P = 0.01$). The proportion of the opening adjacent to woodcock habitat was not significantly related to woodcock use ($t = -1.86$, $P = 0.07$). Openings used by woodcock had been managed more recently (i.e., fewer years since management, $t = 2.58$, $P = 0.01$). Years since management was also positively related to proportion of shrub ($P < 0.01$) and shrub and tree height ($P < 0.01$, $P = 0.03$), but was not related to other vegetation classes (Table 5).

The best supported model predicting probability of use of openings as roosting grounds included size of the opening (ac), shrub height (hs), and a random intercept for site (Table 6). Larger area and shorter shrub height increased the likelihood of woodcock use. Other supported models ($\Delta AICc < 2$) were the model including opening size, shrub height, herbaceous height, and site and the model including opening size, shrub height, herbaceous height, proportion grass and site.

### Use of Openings by Other Wildlife

Across 3 years of study, scat from bear, coyote, deer, fox, goose, moose, opossum, porcupine, rabbit, raccoon, ruffed grouse, and wolf, as well as a woodcock nest and mallard nest, were observed along vegetation transects in forest wildlife openings. Scat was observed in at least one year of study at 74 of 99 unique openings (75%). Deer scat was the most commonly observed, with 60 openings (61%) having deer scat in at least 1 year.

## DISCUSSION

The use of forest wildlife openings as singing grounds followed expected outcomes in that woodcock were more likely to use larger openings and openings with greater amounts of surrounding woodcock habitat. However, results suggested that frequency of mowing openings (within a 5 year time period) is not important in determining use as singing grounds. Management on a longer time frame is likely still important. The majority of openings in this study had been treated within the last 5 years and were relatively free of shrubs and trees.

Vegetation metrics generally were not strongly related to woodcock use. This could be partly attributed to the low variation in vegetation metrics across openings. However, other studies have suggested that quantifying the structure and composition of the singing ground opening may be of little value compared to the surrounding habitat (Sepik et al. 1993). Male woodcock select openings with surrounding nesting habitat as they have a higher probability of attracting females (Dwyer et al. 1988). Thus, higher consideration should be placed on the surrounding habitat and its management when selecting openings for woodcock.

The use of openings as roosting grounds was more likely for larger openings, which is consistent with other studies and best management practices (Wildlife Management Institute 2009). However, best management practices recommend roosting grounds of at least 5 acres, whereas in this study woodcock were found using much smaller openings. The availability of openings on the landscape may play a role in the use of smaller openings and should be explored. In addition, females are known to use smaller forest openings for roosting to remain closer to feeding areas, and males may remain in smaller forest openings through the summer to maintain or establish singing grounds (Sepik and Derleth 1993). Nevertheless, providing small forest openings when large roosting grounds are not available will offer roosting habitat for woodcock.

Roosting grounds had higher proportions of grass and lower proportions of shrub. Open roosting grounds are thought to provide a habitat where woodcock can become aware of and escape from predators. Management frequency at openings was also related to shrub abundance and the height of shrubs and trees. Thus woodcock likely preferred to use sites managed more recently, as they provided more open habitat. Unlike singing grounds, openings used for roosting were not significantly related to adjacent woodcock habitat. Woodcock are known to make longer flights to roosting areas, so this was not unexpected.

It was noted anecdotally in 2016 that sites heavily invaded by common tansy (*Tanacetum vulgare*), an exotic invasive plant, tended to have no woodcock present. In 2017 presence of tansy and other invasive species was recorded; however, few sites had invasive plants dominating the opening, restricting statistical analysis. Future research could explore the effects of invasive species on woodcock use of openings.

Researchers have also studied the use of aspen clearcuts in Wisconsin and young pine plantations in Arkansas by woodcock in spring and summer, finding that woodcock utilize these areas (Hale and Gregg 1978, Long and Locher 2013). Forest harvest in Minnesota is common, and these areas are likely an important component of woodcock habitat. Recent forest harvests were adjacent to and in close proximity to some of the wildlife openings in this study. It was noted that woodcock were seen using the harvest sites for singing and roosting. Additional research comparing the use and characteristics of temporary openings such as clearcut harvests to permanent openings for both singing and roosting grounds would improve our understanding and provide context for management in Minnesota.

Wildlife managers interested in providing singing and roosting habitat for woodcock should continue to create and maintain wildlife openings in forest-dominated areas. Opening size should continue to follow best management practices from the Upper Great Lakes Woodcock and Young Forest Initiative (at least 0.5 ac in size), however larger openings of at least 1 ac in size with a large core area are preferred. Perhaps of more importance, openings should be located in areas with abundant woodcock habitat (young deciduous forest and brushland). Annual management (mowing) of forest wildlife openings is not necessary, however mowing should be used as needed to decrease vegetation height and prevent the establishment of shrubs and trees. A management regime consisting of mowing every 4 to 5 years should be sufficient at sites where shrub and tree establishment is slow. Forest wildlife openings are not only frequently used by woodcock, many other species of wildlife were shown to use these openings, and they also offer opportunities for wildlife viewing and hunting. Incorporating forest wildlife openings in to forest habitat management can provide multiple benefits.

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Table 1. Mean values for proportion and height (m) of 5 vegetation classes at used and un-used forest wildlife openings sampled for singing woodcock from 2016-2018 in Minnesota and results of student's t-tests for differences. Asterisk indicates a significant difference between used and un-used openings.

| Metric | Mean used | Mean un-used | t | p-value |
|---|---|---|---|---|
| Proportion grass (pg) | 0.82 | 0.72 | -3.89 | < 0.01* |
| Proportion herbaceous (ph) | 0.61 | 0.69 | 2.34 | 0.02* |
| Proportion woody (pw) | 0.14 | 0.16 | 1.63 | 0.10 |
| Proportion shrub (ps) | 0.12 | 0.12 | 0.14 | 0.89 |
| Proportion tree (pt) | 0.02 | 0.03 | 1.37 | 0.17 |
| Height grass (hg) | 0.12 | 0.12 | 0.28 | 0.78 |
| Height herbaceous (hh) | 0.10 | 0.11 | 1.01 | 0.31 |
| Height woody (hw) | 0.26 | 0.25 | -0.10 | 0.92 |
| Height shrub (hs) | 0.72 | 0.68 | -0.67 | 0.50 |
| Height tree (ht) | 1.91 | 1.46 | -1.87 | 0.06 |

Table 2. Linear regression results for proportion and height (m) of 5 vegetation classes varying with years since management at forest wildlife openings surveyed for singing woodcock use from 2016-2018 in Minnesota. Asterisks indicate a significant trend.

| Metric | Estimate | p-value |
|---|---|---|
| Proportion grass (pg) | -0.03 | < 0.01* |
| Proportion herbaceous (ph) | 0.002 | 0.90 |
| Proportion woody (pw) | 0.004 | 0.56 |
| Proportion shrub (ps) | 0.02 | < 0.01* |
| Proportion tree (pt) | 0.002 | 0.28 |
| Height grass (hg) | 0.003 | 0.49 |
| Height herbaceous (hh) | 0.006 | 0.14 |
| Height woody (hw) | 0.02 | 0.02* |
| Height shrub (hs) | 0.10 | < 0.01* |
| Height tree (ht) | 0.11 | 0.28 |

Table 3. Mixed-effect logistic regression modeling results for woodcock use of forest wildlife openings as singing grounds from 2016-2018 in Minnesota.  Model variables include fixed effects for years since management (yrmg), perimeter-to-area ratio (par), proportion of the opening adjacent to woodcock habitat (hab), vegetation composition metrics from a principal components analysis (pc1 and pc2), proportion grass (pg), and a random effect for site.

| Model | K[a] | AICc[b] | ΔAICc[c] | ModelLik | AICcWt[d] | LL[e] | Pseduo $R^2$ | Model structure |
|---|---|---|---|---|---|---|---|---|
| M5 | 5 | 139.7 | 0.00 | 1.000 | 0.361 | -64.60 | 0.39 | par + hab + pg + (1 \| site) |
| M4 | 4 | 140.3 | 0.59 | 0.746 | 0.269 | -65.98 | 0.35 | par + hab + (1 \| site) |
| M3 | 5 | 140.9 | 1.18 | 0.556 | 0.200 | -65.19 | 0.38 | par + hab + pc1 + (1 \| site) |
| M2 | 6 | 141.9 | 2.16 | 0.340 | 0.123 | -64.57 | 0.39 | par + hab + pc1 + pc2 + (1 \| site) |
| M1 | 7 | 143.8 | 4.05 | 0.132 | 0.048 | -64.39 | 0.40 | yrmg + par + hab + pc1 + pc2 + (1 \| site) |
| M0 | 2 | 160.0 | 20.30 | 0.000 | 0.000 | -77.96 | --- | 1 + (1 \| site) |

[a] K = number of parameters in the model.
[b] AICc = second-order Akaike information criterion.
[c] ΔAICc = difference in AICc relative to the best performing model.
[d] AICcWt = Akaike weight representing relative model support.
[e] LL = log likelihood value.

Table 4. Mean proportion and height (m) metrics for vegetation at used and un-used wildlife openings sampled for roosting woodcock during 2016 and 2018 in Minnesota and results of student's t-tests for differences. Asterisk indicates a significant difference between used and un-used openings.

| Metric | Mean used | Mean un-used | t | p-value |
|---|---|---|---|---|
| Proportion grass (pg) | 0.78 | 0.70 | -2.70 | < 0.01* |
| Proportion herbaceous (ph) | 0.84 | 0.85 | 0.38 | 0.70 |
| Proportion woody (pw) | 0.21 | 0.15 | -1.64 | 0.10 |
| Proportion shrub (ps) | 0.23 | 0.30 | 2.09 | 0.04* |
| Proportion tree (pt) | 0.04 | 0.03 | -1.10 | 0.28 |
| Height grass (hg) | 0.67 | 0.64 | -0.66 | 0.51 |
| Height herbaceous (hh) | 0.67 | 0.79 | 2.57 | 0.01* |
| Height woody (hw) | 0.38 | 0.40 | 0.55 | 0.58 |
| Height shrub (hs) | 0.80 | 0.92 | 1.94 | 0.06 |
| Height tree (ht) | 0.83 | 0.78 | -0.46 | 0.65 |

Table 5. Linear regression results for proportion and height (m) of 5 vegetation classes varying with years since management at forest wildlife openings surveyed for roosting woodcock use during 2016 and 2018 in Minnesota. Asterisks indicate a significant trend.

| Metric | Estimate | p-value |
|---|---|---|
| Proportion grass (pg) | -0.01 | 0.17 |
| Proportion herbaceous (ph) | -0.002 | 0.81 |
| Proportion woody (pw) | -0.01 | 0.34 |
| Proportion shrub (ps) | 0.04 | < 0.01* |
| Proportion tree (pt) | 0.002 | 0.55 |
| Height grass (hg) | 0.004 | 0.77 |
| Height herbaceous (hh) | 0.03 | 0.10 |
| Height woody (hw) | 0.009 | 0.55 |
| Height shrub (hs) | 0.10 | < 0.01* |
| Height tree (ht) | 0.06 | 0.03* |

Table 6. Mixed-effect logistic regression modeling results for American woodcock use of forest wildlife openings as roosting grounds during 2016 and 2018 in Minnesota. Model variables include fixed effects for years since management (yrmg), size of the opening (ac), proportion of the opening adjacent to woodcock habitat (hab), proportion grass (pg), proportion shrub (ps), average height of herbaceous vegetation (hh), average height of shrub vegetation (hs), and a random effect for site.

| Model | K[a] | AICc[b] | ΔAICc[c] | ModelLik | AICcWt[d] | LL[e] | Pseduo $R^2$ | Model structure |
|---|---|---|---|---|---|---|---|---|
| M5 | 4 | 124.8 | 0.00 | 1.00 | 0.31 | -58.20 | 0.29 | ac + hs + (1 \| site) |
| M4 | 5 | 125.1 | 0.27 | 0.88 | 0.27 | -57.23 | 0.33 | ac + hs + hh + (1 \| site) |
| M3 | 6 | 125.7 | 0.83 | 0.66 | 0.20 | -56.37 | 0.34 | ac + hs + hh + pg + (1 \| site) |
| M2 | 7 | 127.3 | 2.45 | 0.29 | 0.09 | -56.02 | 0.35 | ac + hs + hh + pg + yrmg + (1 \| site) |
| M1 | 8 | 129.5 | 4.62 | 0.10 | 0.03 | -55.92 | 0.35 | ac + hs + hh + pg + ps + yrmg + (1 \| site) |
| M0 | 2 | 137.8 | 12.96 | 0.00 | 0.00 | -66.84 | --- | 1 + (1 \| site) |

[a] K = number of parameters in the model.
[b] AICc = second-order Akaike information criterion.
[c] ΔAICc = difference in AICc relative to the best performing model.
[d] AICcWt = Akaike weight representing relative model support.
[e] LL = log likelihood value.