

Factors Influencing Detection of American Woodcock during Singing-ground Surveys

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## Chapter 1

### Occupancy and Detection Probability of American Woodcock during Singing-ground Surveys

**OVERVIEW** During the spring breeding season, male American woodcock (*Scolopax minor*) perform a conspicuous aerial display along with a distinctive vocalization in an open area called a singing ground. The American Woodcock Singing-ground Survey (SGS) was designed to exploit these breeding-season behaviors in an effort to monitor these otherwise inconspicuous birds. The SGS was standardized in 1968 and has been conducted annually to derive an index of abundance and population trend. Counts of singing male American woodcock on the SGS have generally declined through time, but without knowledge of the relationship between counts and woodcock density and the factors affecting detection, considerable uncertainty remains in interpretation of SGS data. To address some of these issues, in the springs of 2009 and 2010, I conducted repeated surveys on 4 established SGS routes and 4 randomly selected reference routes in Pine County, Minnesota. I used SGS protocols for surveying and developed models to assess factors associated with occupancy and detection probability. The intercept-only model (i.e., constant detection and occupancy probabilities across sites and no covariates) had an overall detection probability of 0.59 (SE = 0.018) in 2009 and 0.66 (SE = 0.017) in 2010 and an overall occupancy of 0.74 (SE = 0.049) for 2009 and 0.81 (SE = 0.044) for 2010. The best-supported model of detection probability for both years combined included detection as a function of woodcock density, observer, date, disturbance level (i.e., ambient noise that interfered with detecting woodcock), and wind speed. High wind speeds were negatively related to detection, different observers had different detection

probabilities, date was quadratically related to detection, and high woodcock density and low disturbance levels were positively related to detection. These results can be used to build predictive models, which will inform interpretation of trends in counts and indices of abundance currently resulting from the SGS.

**KEY WORDS** American woodcock, *Scolopax minor*, detection probability, occupancy, Minnesota

The American woodcock (*Scolopax minor*; hereafter, woodcock) is a migratory game bird that occurs in forested landscapes in eastern and central North America. Woodcock are a cryptically-colored shorebird with a distinctive courtship performance famously described as the “Sky Dance” by Aldo Leopold in “A Sand County Almanac” (Leopold 1949). They are found in a variety of early successional forest habitats that include open areas where woodcock display. Male woodcock use a variety of these openings (natural openings, clearcuts, agricultural fields, etc.) as singing grounds for their spring courtship display.

Woodcock are pursued as game birds in southern Canadian provinces from Ontario eastward, and throughout the central and eastern U.S.; they are migratory and are managed under the Migratory Bird Treaty Act in the U.S. and Canada. Approximately 240,000 woodcock were harvested in the U.S. during the 2009-2010 hunting season (Cooper and Parker 2010). Woodcock populations are monitored using the American Woodcock Singing-ground Survey (SGS), coordinated by the U. S. Fish and Wildlife Service (FWS) and the Canadian Wildlife Service. This survey has been conducted throughout the primary woodcock breeding range since 1968 and is used as an index of

abundance and to estimate population trends. The survey consists of approximately 1,500 routes that are 3.6 miles (5.8 km) in length with 10 equally spaced listening points (Cooper and Parker 2010). Observers begin surveys shortly after sunset and record the number of woodcock heard peenting (the vocalization made during courtship displays by male woodcock) at each listening point during a 2-min period.

From 1968 to 2010, the numbers of singing male woodcock counted on the SGS declined 1.0% per year in both the Eastern (southern Quebec, the maritime Canadian provinces, and the northeast and mid-Atlantic U.S., east of the Appalachian Divide) and Central Management Regions (southern Ontario and the Midwestern U.S. south to the Ohio River Valley; Cooper and Parker 2010). Concerns about declines in the number of woodcock detected on the SGS have led to harvest restrictions (Cooper and Parker 2010), development of a woodcock conservation plan (Kelley et al. 2008), and a need to better understand how counts of woodcock on the SGS are related to woodcock abundance and population trends.

The SGS was designed to mitigate the effects of environmental factors that might influence the male mating display and in turn the counts from the survey (e.g., Goudy 1960, Duke 1966). Duke (1966:706), who was working in central southern Michigan, recommended that the surveys be confined to "...any time during the period of greatest uniformity in courtship activity." The FWS has recommended a 20-day period within which to conduct surveys based on the latitude of the survey route (Cooper and Parker 2010). Based on conditions under which woodcock were most likely to peent, Duke (1966) also recommended that the starting time for surveys should be 22 min after sunset

when cloud cover did not exceed 75% and 15 min after sunset when cloud cover exceeds 75%. This remains the guideline for starting times, with the survey to be completed within 36 min. Surveys are not to be conducted if the temperature is below 40° F (4.4° C), if there is heavy precipitation, or there is a strong wind (>12 mph; 19.3 km/hr).

One important and untested assumption underlying the SGS is that all male breeding woodcock at each listening point are heard peenting on the night of the survey, or that a constant proportion of birds present are detected among years (Thogmartin et al. 2007). However, the relationship between the number of woodcock heard on surveys and the number of woodcock present is unknown (e.g., Kozicky et al. 1954). As with most indices of abundance (Anderson 2001), the SGS is based on an assumed relationship between counts and population size that is not well documented. The primary purpose of the SGS is to monitor trends in population size of woodcock (Kelley et al. 2008), and counts from surveys are used as an index to population size. However, without knowledge about the relationship between counts and population size, and whether this relationship is constant among years, error exists in the interpretation of the SGS results. Spatial and temporal variation in detection probability introduces potentially significant noise into the relationship between counts and population size. Detection probability ( $p$ ) is the probability of detecting an object (in the case of the SGS, a displaying male woodcock) when it is present, and recent advances in statistical methods allow estimation of detection probability when it is <1 (e.g., MacKenzie et al. 2006). My objective then, was to assess detection probability and factors that affect detection of male breeding woodcock on the SGS.

Many factors can influence detection probability of displaying male woodcock during the SGS, including weather conditions, observer ability, woodcock behavior, woodcock density, ambient noise levels, and the distance from and orientation of a peenting woodcock relative to the listening point. Although the SGS has weather restrictions that preclude surveys during heavy precipitation, strong (>12 mph; 19.3 km/hr) wind, or temperatures below 40° F (4.4° C), certain weather conditions may still affect the detection of woodcock. Goudy (1960) reported that temperature was the most important climatological factor affecting woodcock displays concluding that temperatures above 40° F (4.4° C) were required for normal courtship activity. Blankenship (1957) observed that 35° F (1.7° C) was the minimum temperature required for activity by singing males, although activity did not increase proportionally with temperature. He also found that rain and snow affected woodcock counts describing that “activity became erratic and shortened, even when a light drizzle occurred” (Blankenship 1957:61) and that an increase in the intensity of precipitation led to a decrease in woodcock activity. Rain might also affect detection abilities of the observer, which Blankenship (1957:63) noted saying that “rain makes so much noise that an observer would not be able to hear all active woodcock”. Additionally, Blankenship (1957) noted that woodcock were more active if rain had occurred during the day, but stopped before the count took place. High winds are similar to precipitation in that they have the potential to affect woodcock behavior as well as observers’ abilities. Mendall and Aldous (1943), Blankenship (1957), and Goudy (1960) all asserted that high winds, especially above 12 mph (19.3 km/hr) have a negative impact on a woodcock’s propensity to display. In an experiment to

assess detection probability of breeding songbirds on point counts, Simons et al. (2007) found that the proportion of birds heard under breezy (10-25 km/hr) conditions decreased by 28%. Duke (1966) suggested that SGS counts would be more accurate when surveys occurred in optimum conditions, which included a wind velocity of 0-4 mph (0-6.4 km/hr) and temperatures between 40-60° F (4.4-15.6° C). Ambient noise level (“disturbance”) is subjective and recorded at each SGS listening point by the observer. This includes traffic noise as well as other human-caused or natural (e.g., frogs, other birds) noises that affect the observer’s ability to hear woodcock. Despite being recorded, ambient noise level is not taken into account in SGS analysis by the FWS. Another finding in the Simons et al. (2007) experiment was that the proportion of birds heard decreased by 41% in the presence of background birds (1 to 3 singing birds) and 42% with addition of 10 dB of white noise.

Certainly different observers possess different abilities to detect and count woodcock, which could also influence interpretation of SGS counts. Sauer and Bortner (1991) found that the addition of a covariate for observers decreased the mean-squared error in the linear regression of SGS counts. However, they cautioned that interpretation of short-term trends in population change when including an observer covariate because the trend may be increasing with 1 observer while decreasing with another observer. Prior to the 1980s, results from an SGS survey conducted by a new observer (one who had not surveyed that particular route the previous year) were frequently rejected because of the desire for comparable data to be used to inform trends (Tautin 1982). This prompted a study by Tautin (1982) who found that the number of singing woodcock

heard by new and prior observers did not differ significantly. More recently Sauer et al. (2008) incorporated terms for the observer-route combination and an observer's first year conducting an SGS in their hierarchical model.

Hearing tests for observers were recommended by Duke (1966) after 2 observers performed poorly in a field test and subsequently tested below normal on a clinical hearing test of the frequency range of the woodcock peent. This frequency range coincides with the frequency range of Mayfield's (1966) work, which found that in the absence of injury and disease, men, as soon as age 32, begin to show a gradually worsening loss of hearing in the higher frequencies. It has been recognized that age-related hearing loss combined with and compounded by a general increase in ambient noise in recent years has the potential to decrease detection probabilities of birds (Simons et al. 2007). This issue, despite being raised, has been largely ignored in avian survey protocols.

Behavioral studies of woodcock suggest that male breeding woodcock can display at more than 1 singing ground per night and subdominant males will display at a singing ground when dominant males are at other display sites (McAuley et al. 1993a). Godfrey (1974) also reported a minimum of 1.32 males per singing ground and that the presence of ancillary males did not reflect a lack of suitable display sites. In central Minnesota, woodcock readily abandoned singing grounds and moved from year to year among sites (Godfrey 1974). With only this 1 study using radio-marking to document the movements of males during the breeding season, there is a lack of concrete evidence on the within-year consistency and fidelity of males' use of singing grounds across the breeding range.



There is also a lack of evidence about the potential for woodcock density to affect a woodcock's likelihood or rate of display. Duke (1966) found that in some instances peenting rates were significantly greater during a 2-min listening period when woodcock were alone versus nearby 1 or 2 others. McAuley et al. (1993a) noted that dominant males peented consistently throughout the evening, whereas subdominant males remained quiet or peented intermittently. This is similar to Godfrey's (1974) finding that subdominant males moved to various singing-grounds during the evening display period and peented intermittently near the dominant male of that singing ground. Usually the subdominant male would be challenged by the dominant male after peenting and leave for another singing ground and repeat this action.

Because the relationship between counts on surveys and population size is not well defined, increases and decreases in SGS counts could result for multiple reasons. For example, a decrease in the number of singing male woodcock on an SGS route could result from (1) a decrease in the number of suitable singing grounds within the area effectively surveyed, (2) a lack of males to occupy all suitable singing grounds, or (3) males using suitable singing grounds beyond where they could be detected when the survey is conducted. Similarly, increases in counts could result from multiple conditions, as could counts that remain stationary through time. To better understand population trends in American woodcock, and to better interpret counts from the SGS, additional information is required regarding probability of detection of woodcock, and factors that affect detection.

To address these issues, my specific research objectives were to (1) estimate occupancy of American woodcock on SGS routes in Pine County, Minnesota and determine how occupancy is related to land-cover categories and (2) estimate detection probability of woodcock on the SGS and factors that might influence detection. Factors potentially related to detection include temporal, environmental, behavioral, and human-related factors considered within the current guidelines of the SGS protocol. Addressing these objectives can provide information about occupancy of woodcock on SGS routes in Minnesota and improve interpretation of SGS counts and assessment of woodcock population trends.

## **STUDY AREA**

I conducted my study in Pine County, Minnesota (Fig. 1) in the springs of 2009 and 2010. Pine County is located in east-central Minnesota in the Mille Lacs Uplands subsection, as categorized by the Ecological Classification System hierarchy (Minnesota DNR 2006). This subsection is characterized by drumlin ridges with depressions between the ridges containing peatlands with shallow organic material. There are extensive wetlands in the area with total annual precipitation of about 75 cm. Large areas in eastern Pine County are heavily forested. The county is dominated by aspen-birch (*Populus* spp.-*Betula* spp.) forest with small areas of pine (*Pinus* spp.) forests. Land ownership in the Mille Lacs Uplands subsection is 17.7% public and 82.2% private with a population density of 19.1 people per km<sup>2</sup> (Minnesota DNR 2006). Current land use is 40% forest, 24% row crop, 17% wetland-open, 13% pasture, and 6% water (Minnesota DNR 2006).

Spring weather in Pine County is variable with snowstorms possible into May. Mean maximum temperatures by month during my study ranged from 11.6° C to 19.6° C and mean minimum temperatures ranged from -1.4° C to 5.3° C (Minnesota Climatology Working Group 2010). Minnesota Ornithologists' Union (2008) records from 1985 through 2008 indicate that the median spring arrival date for woodcock in Minnesota was between 13 March and 26 March, with the spring migration being associated with warmer temperatures on their wintering grounds (Keppie and Whiting 1994).

## **METHODS**

### **Data Collection**

In April and May I surveyed the 4 established SGS routes in Pine County (routes 77, 80, 86, and 91) and 4 randomly selected reference routes following the official SGS protocol for conducting surveys, except that I initiated surveys earlier than the period prescribed by the SGS protocol (see below). Locations of established SGS routes were determined by the FWS (see Cooper and Parker 2010). I visited the starting point of each route and digitized route locations using a Geographic Information System (GIS: ArcMap 9.3<sup>TM</sup>; use of trade names does not imply endorsement by either the U.S. Geological Survey or the University of Minnesota). I located reference routes randomly by selecting a UTM coordinate within Pine County using Hawth's Analysis Tools (Beyer 2004) then locating, using a randomly selected cardinal direction (Microsoft Office Excel<sup>TM</sup> 2003), the nearest secondary road.

Five (2 in 2009, 2 in 2010, and 1 in both 2009 and 2010) different observers conducted surveys on both SGS and reference routes. Observers had their hearing

evaluated and were trained to listen for woodcock by conducting surveys along SGS routes before the start of the sampling period.

Each of the 8 routes was surveyed once on each of 4 days during 3 of the 6 weeks during the breeding-season study period, resulting in 80 points surveyed 12 times over the course of the breeding season. This design allowed me to meet the assumption of a closed population (i.e., no changes in occupancy) and to assess trends in detection throughout the spring. It took 2 weeks to survey all 8 routes, starting with the southernmost routes and working north. The 6-week seasons were 12 April - 21 May 2009 and 10 April - 19 May 2010. Surveys started earlier than the SGS-protocol-recommended 25 April because I needed a longer period to survey each route 12 times and to account for potential effects of climate change on the timing of spring behavior of birds (e.g., Murphy-Klassen et al. 2005, Jonzén et al. 2006).

Temperature, wind speed, sky condition, precipitation, and disturbance level (see below) were recorded for each survey in the same manner as the official SGS protocol. Observers also recorded general notes about the day's weather leading up to the survey, the source of ambient noise, or other unusual activities occurring during the survey. Sky condition was used to determine whether the survey would start 15 or 22 min after official sunset as indicated in the official SGS protocol. Disturbance level described the ambient noise at each listening point and was rated in 1 of 4 categories: none, low, moderate, and high. Because these categories are subjective I grouped them into quiet (none or low) and noisy (moderate or high) (e.g., Kissling et al. 2010). The official SGS protocol includes 5 categories of precipitation: none, mist, snow or heavy rain, fog, and

light rain. Because fog never occurred during surveys over the course of my 2-year study period and mist only occurred 4 times I grouped them with light rain to indicate presence of some form of light precipitation.

I included Julian date as a covariate as a quadratic variable to account for a peak in males' singing activity during the breeding season (Goudy 1960, Sheldon 1967). I also included year as a covariate when combining data from both years to indicate surveys conducted in 2009 or 2010.

I classified land-cover types at each point on all 8 routes using 2008 U.S. Farm Service Agency (FSA) aerial photos and ground observations. I classified the area as forest (> 66% forest), non-forest (> 66% non-forest), or mixed (< 66% forest or non-forest) within a 330-m radius of the survey point, which was the presumed maximum detection distance for woodcock (Duke 1966). Forest included wet or dry coniferous, deciduous, or mixed forested areas. Non-forest included row crops, pastures, prairie, shrubland, and marsh areas.

### **Statistical Analysis**

Based on the detection history at each listening point along survey routes, I estimated detection probability ( $p$ ) and occupancy ( $\psi$ ) using the approach of MacKenzie et al. (2006). This approach models the expected count of an area at a certain time [ $E(C_{it})$ ] as the product of the true number of animals in that area and time ( $N_{it}$ ) and the associated detection probability ( $p_{it}$ ).

$$E(C_{it}) = N_{it}p_{it}$$

When accounting for detection probability one can estimate the true occupancy of an area of interest.

I used program PRESENCE (Hines 2006) to estimate detection probability and occupancy and to evaluate the relationship between occupancy and land-cover covariates. I repeated this process separately for the 2009 and 2010 data and for official and randomly-determined reference routes by using route type as a covariate for occupancy and detection probability. To evaluate the relationship(s) between detection probability and factors that might influence detection probability (e.g., wind speed, observer, date; Table 1) I used logistic regression models in program R (R Development Core Team 2010). To examine these relationships I developed a candidate set of 8 *a priori* models; 7 models contained a single detection probability covariate (neighbor, wind, temperature, precipitation, observer, date, quiet):  $\psi(\cdot), p(\text{covariate})$  and 1 model was the global model:  $\psi(\cdot), p(\text{global})$ . I ranked single-covariate models using Akaike's Information Criterion (AIC) values and combined covariates from single-covariate models with low AIC-values to assess whether models with multiple covariates received substantial support (i.e., lower AIC values) compared with single-covariate models and the global model (e.g., Yates and Muzika 2006, Popescu and Gibbs 2009, Kissling et al. 2010). When the addition of a covariate did not result in a model that received substantially more support (a lower AIC-value by  $\leq 2$ ) I stopped adding covariates, similar in concept to forward selection stepwise methodology (Cook and Weisberg 1999, *sensu* Yates and Muzika 2006). I used AIC to identify the models best supported by my data and to calculate AIC model weights ( $w_i$ ) (Burnham and Anderson 2002). The best-supported model, which is

identified based on having the lowest AIC score, and models within 2 AIC units ( $\Delta\text{AIC} \leq 2$ ) of that model that also improve model fit (as measured by a decrease in model deviance if they include additional covariates, Arnold 2010), make up the set of candidate models. I also evaluated 10,000 bootstrap samples of global models to test for overdispersion of the data, which is indicated by a variance inflation factor ( $\hat{c}$ )  $> 1.0$  (Burnham and Anderson 2002). I used the variance inflation factor as needed to modify AIC by:

$$\text{QAIC} = -[2\log\text{-likelihood} / \hat{c}] + 2K.$$

## **RESULTS**

### **Occupancy**

Occupancy ( $\psi$ ) is the probability that a randomly selected sampling unit in an area of interest is occupied by a species (MacKenzie et al. 2006). In my case naïve occupancy is estimated by dividing the number of listening points along SGS routes where observers detected at least 1 woodcock on at least 1 survey by the total number of SGS listening points and does not account for detection probability ( $p$ ). Because I conducted a large number of repeated surveys (12) the naïve occupancy estimate is exactly the same as the estimated occupancy from the intercept-only model. This model with constant detection and occupancy probabilities and no covariates [ $\psi(\cdot), p(\cdot)$ ] had an occupancy of 0.74 (SE = 0.049) for 2009 and 0.81 (SE = 0.044) for 2010.

Occupancy estimates by route type [ $\psi(\text{route type}), p(\cdot)$ ] were 0.63 (SE = 0.077) in 2009 and 0.65 (SE = 0.075) in 2010 for official SGS routes. Occupancy for randomly-determined reference routes was 0.85 (SE = 0.057) in 2009 and 0.98 (SE = 0.025) in 2010. By design, I divided the sampling season into 3 2-week periods (early, mid-, and

late spring) when each route was surveyed for 4 consecutive days during each period. The model that allowed occupancy to vary by period [ $\psi(\text{period}), p(\cdot)$ ] suggested that occupancy was similar throughout the season (Figs. 2 and 3).

I used aerial photos and ground-verification to classify my listening points as forest ( $n = 33$ ), non-forest ( $n = 16$ ), or mixed ( $n = 31$ ). The occupancy model that included land-cover type as a covariate and included a constant detection probability across listening points and during surveys [ $\psi(\text{habitat}), p(\cdot)$ ] indicated that in 2009 listening points classified as mixed had significantly higher occupancy than those classified as non-forest (Fig. 4). In 2010 listening points classified as forest had significantly higher occupancy than those classified as non-forest (Fig. 5). In 2009, mixed had the highest estimated occupancy among land-cover categories and in 2010 forest had the highest estimated occupancy, although in both years the 95% confidence intervals for the 2 highest occupied land-covers (mixed and forest) overlapped.

### **Detection Probability**

The intercept-only model with detection and occupancy probabilities constant across listening points and survey routes and no covariates [ $\psi(\cdot), p(\cdot)$ ] had an overall detection probability of 0.59 (SE = 0.018) in 2009 and 0.66 (SE = 0.017) in 2010. The 95% confidence intervals for these 2 years did not overlap: (0.56, 0.63) and (0.63, 0.70) for 2009 and 2010, respectively, suggesting that detection probability was slightly lower in 2009.

Detection probability for the 4 official SGS routes was 0.49 (SE = 0.029) for 2009 and 0.60 (SE = 0.028) for 2010. Detection probability for randomly selected reference



routes was 0.67 (SE = 0.023) for 2009 and 0.71 (SE = 0.021) for 2010. The 95% confidence intervals for these 2 types of routes did not overlap in 2009 or 2010.

I divided the sampling season into 3 2-week periods (early, mid-, and late spring) when each route was surveyed for 4 consecutive days during each period. Substantial support for the model that allowed detection probability to vary by period [ $\psi(\cdot), p(\text{period})$ ] suggested that detection probability peaked during the middle of the season (Figs. 6 and 7). Detection probability peaked during the last week of April and the first week of May, based on the model that included date as a quadratic covariate (Fig. 8).

The best-supported single-covariate model of detection probability for 2009 was  $\psi(\cdot), p(\text{neighbor})$ , which ranked just below the global model ( $\Delta\text{AIC} = 6.3$ ) (Table 2). The best-supported multi-covariate model of detection probability for 2009 included the variables neighbor, observer, quiet, and wind. The Akaike model weights (AIC  $w_i$ ) indicate that this model was 7 times more likely than the second-ranked model to be the actual best model of the set. The second-ranked model included date but was not a competing model despite having  $\Delta\text{AIC} < 4$  because its fit compared with the reduced model, as measured by the model deviance, did not improve enough (no change in the log-likelihood) to warrant inclusion. Wind was negatively related to detection probability; 1 observer had higher detection probability than the other 2 (although confidence intervals overlapped), and neighbor and quiet were positively related to detection probability (Table 3). The cumulative model weights for individual covariates were neighbor = 1.0, observer = 1.0, quiet = 0.997, wind = 0.929, date = 0.137, temperature = 0.024, and precipitation = 0.024 (Table 2).

The best-supported single-covariate model of detection probability for 2010 was  $\psi(\cdot), p(\text{neighbor})$ , which ranked just below the global model ( $\Delta\text{AIC} = 7.7$ ) (Table 4). The best-supported multi-covariate model of detection probability for 2010 included the variables neighbor, date, quiet, and observer. The Akaike model weights indicated that this model was 2 times more likely than the second-ranked model to be the actual best model of the set. The second-ranked model included precipitation but was not a competing model. Again, 1 observer had a higher detection probability than the other 2 observers (although confidence intervals overlapped), date had a quadratic effect, and neighbor and quiet were positively related to detection probability (Table 5). The cumulative model weights for individual covariates were neighbor = 1.0, date = 0.999, quiet = 0.929, observer = 0.738, precipitation = 0.290, wind = 0.045, and temperature = 0.045 (Table 4).

The best-supported single-covariate model of detection probability when combining 2009 and 2010 was  $\psi(\cdot), p(\text{neighbor})$ , which ranked well below the global model ( $\Delta\text{AIC} = 23.6$ ) (Table 6). The best-supported multi-covariate model of detection probability when combining 2009 and 2010 was the global model, which had a lower deviance and a higher number of parameters than the rest of the candidate models. Wind was negatively related to detection probability, Observer 1 had a higher detection probability than the other 4 observers (although confidence intervals overlapped), date had a quadratic effect, and neighbor and quiet were positively related to detection probability (Table 7). The 95% confidence interval around the parameter estimates ( $\beta_i$ 's) included zero for year, precipitation, and temperature, suggesting they did not have a

statistically significant effect on detection probability, even though they appeared in the best-supported model. The cumulative model weights for individual covariates were neighbor = 1.0, quiet = 1.0, observer = 1.0, wind = 0.977, date = 0.855, precipitation = 0.583, and temperature = 0.339 (Table 6). Bootstrap simulations for 2009 and the 2 years combined provided no evidence of overdispersion in the data ( $\hat{c} = 0.33, 0.43$ , respectively) whereas 2010 showed slight overdispersion ( $\hat{c} = 1.2$ ).

## **DISCUSSION**

I estimated detection probability and occupancy of woodcock on SGS routes in east-central Minnesota in 2009 and 2010. Occupancy between years (0.74 in 2009 and 0.81 in 2010) was similar (based on overlapping confidence intervals), with 6 more sites occupied on SGS routes in 2010 than in 2009. Occupancy at sites along official SGS routes was lower than on randomly-selected reference routes (confidence intervals did not overlap), which suggested that at the scale of a single county in Minnesota, SGS routes may not adequately represent woodcock abundance. In my sample 1 of the official SGS routes was located in an agricultural area dominated by row crops, which is a landscape that I would not expect to support high woodcock abundance. Because of my small sample size ( $n = 4$  SGS routes) this 1 route could have contributed to a difference in occupancy between official and randomly-selected routes. Official routes had more points classified as non-forest ( $n = 13$ ) than randomly selected routes ( $n = 3$ ). At a broader spatial scale with a larger sample size, Nelson (2010) concluded that SGS routes traversed cover types most important to woodcock at rates comparable to land-cover composition in landscapes they were designed to represent.

Listening points classified as forest or mixed land cover had higher occupancy than listening points with non-forest land cover in both years. In 2009, listening points classified as mixed land cover had significantly higher occupancy than listening points classified as non-forest, whereas in 2010 listening points classified as forest had significantly higher occupancy than non-forest listening points. No significant changes in habitat along the routes occurred between years to directly explain the changes in occupancy among land-cover types. The very southern part of Pine County is dominated by row-crop agriculture, which is represented by the non-forest category, whereas the majority of the county is mixed agriculture and forest. Woodcock did not occupy areas that were strictly agricultural, but occupied areas that were a mix of agriculture and forest or predominantly forest. Occupancy and abundance of woodcock during the spring have been reported to be influenced by factors other than land-cover type such as interspersed openings, aggregation or clumping of vegetation types, soil moisture, age and stem density of forests, and urban uses (e.g., Dwyer et al. 1983, Keppie and Whiting 1994, Thogmartin et al. 2007). I did not design my study to assess the factors that influenced occupancy of woodcock, but it was interesting to note that occupancy was not static between years. Godfrey (1974) recognized that singing grounds on the landscape fluctuate with year in that some are perennial whereas others transitory, which could explain the slight changes in occupancy I observed.

The detection probabilities I estimated were considerably lower (0.59 in 2009 and 0.66 in 2010) than perfect detection ( $p = 1.0$ ). Detection probability in both years was similar despite different observers and spring weather conditions, which suggested that

detection probability may be relatively constant, at least over the conditions I encountered. However, detection probability was significantly lower along SGS versus randomly-selected reference routes. One possible explanation for this difference may be the positive influence of neighbor on detection probability. Higher occupancy likely reflects higher abundance of woodcock, and woodcock at higher densities (i.e., more likely to have a neighbor) appeared to have higher detection probability.

I also identified several factors that were related to detection probability of woodcock using the SGS protocol. Four variables were included in the best-supported detection probability models for 2009, 2010, and 2009 and 2010 combined. Neighbor, observer, date, and quiet each were associated with detection probability. Neighbor, which indicated the presence of > 1 woodcock singing at an SGS listening point during a survey, had a strong positive relationship with detection, perhaps due to social facilitation (i.e., motivation to call by the mere presence of a conspecific) and the competitive nature of male woodcock during the breeding season (Sheldon 1967). My study area in east-central Minnesota had a higher estimated abundance of woodcock than most other areas (e.g., Thogmartin et al. 2007), so whether this covariate would be related to detection at lower woodcock density is unknown. Future research might explore the use of a call-broadcast survey for woodcock to increase detection probability. Behavior of male woodcock on singing-grounds is still not well understood and the effect of density on singing and detection warrants further study (see Appendix A). Quiet, which indicated that the ambient noise level was “none” or “low” at an SGS listening point during a survey, also had a positive association with detection probability, although not as strong

as did “neighbor.” This covariate may have been confounded with precipitation because light rain, especially when leafout has occurred, can temporarily increase ambient noise during part or all of a survey. Also, on busier secondary roads where ambient noise level can be quite variable, accounting for this relationship would likely improve the accuracy of estimating short-term population trends as traffic noise during surveys likely varies among years. My models also indicated an observer effect, although approximately half the time the 95% confidence interval for these coefficients overlapped zero. Even though observers in my study were tested for hearing and possessed the ability to hear woodcock peenting (unlike the SGS, where observers are not screened for auditory acuity), I still documented observer effects. It is probably not feasible to assess the ability of SGS observers in detecting peenting woodcock, but differential ability of observers to detect woodcock likely adds considerable random variation, and approaches to control this variation may be warranted. My results also confirmed the presence of a peak in detection probability during the middle of the breeding season, as evidenced by the inclusion of a quadratic date covariate in the best-supported models of detection probability. Although to some degree, temperature is confounded with date, the quadratic form of date, with its mid-spring peak is not coincident with spring temperatures that increase essentially linearly. A mid-spring peak in detection was also evident when I plotted detection probability through time, and likely can be explained by a peak in displaying by male woodcock (Goudy 1960, Sheldon 1967). If surveys were timed to be close to this peak, detection probability would likely be higher than if surveys were conducted earlier or later in the season. However, this peak was included within the

official survey window for Pine County and it may not be logistically feasible to conduct surveys in a shorter window of time than identified in the current SGS protocol.

## **MANAGEMENT IMPLICATIONS**

Adjustments for detection probability can be incorporated into estimates of abundance and density of wildlife (MacKenzie et al. 2006). A subset of SGS routes at various locations throughout the woodcock breeding range could be surveyed repeatedly to estimate detection probability. Although my study indicated no substantial annual variation in detection probability, I only investigated this in 1 location and over 2 years. Further evaluation of temporal and spatial variation in detection probability seems warranted.

In addition to adjusting for variation in detection probability it is possible to assess detection probability covariates and recommend when and when not to survey for woodcock. Based on my assessment of factors related to detection probability of woodcock on SGS and reference routes in Minnesota, there are several factors that could be addressed to potentially improve interpretation of survey data. First, for each latitudinal region, the survey window could be evaluated and possibly condensed to ensure that surveys are being completed during the peak display period. Second, even when observers are trained and have hearing abilities within the normal range, I observed differences in detection probability among observers. Observer variation in the official SGS is likely at least as large as in my study and training and testing observers would likely reduce this variation. Third, ambient noise can be the result of many factors, some of which are more constant than others. For example, SGS listening points near wetlands

tend to have frog-call noise throughout the spring, which is constant throughout and perhaps also among springs. Road noise tends to be less constant, but can have a large impact on a survey that takes place on a busier road. Routes could be evaluated to determine if the road(s) being used have experienced increases in traffic levels since the routes were established in the 1960s. SGS routes with unsafe road conditions can be replaced through official protocol, and an assessment of continued inclusion of routes with high vehicle traffic seems warranted. Finally, detection probability of woodcock on SGS routes decreases in precipitation stronger than a mist, likely due to a decrease in the observer's ability to hear woodcock over the noise of the precipitation. Data resulting from surveys of routes on the SGS during such conditions likely under-represent woodcock abundance and should be discarded.



**Table 1.** Description of the variables used to assess factors that influence detection and occupancy of American woodcock on Singing-ground Surveys in Pine County, Minnesota, 2009-2010.

<b>Variable</b>	<b>Description</b>
Habitat	Variable used to assess occupancy. Categories were forest, non-forest, or mixed land-cover.
Year	Indicates 2009 or 2010 survey.
Observer	Five different observers were used over the 2-year study period.
Wind	Wind speed measured in mph at the time of the survey.
Date	Julian date. Includes a quadratic term to represent a peak in detections.
Temperature	Temperature in °F at the start of the survey.
Precipitation	Presence or absence of any type of light precipitation (rain, mist, fog) during the survey.
Neighbor	Presence and detection of 2 or more displaying woodcock at a listening point.
Quiet	Ambient noise level at each listening point as in official SGS protocol. An indicator variable for none or low ambient noise with null indicating moderate or high ambient noise.

**Table 2.** Covariates in models, Akaike’s Information Criterion (AIC), difference of AIC between a model and the model with the lowest AIC ( $\Delta$ AIC), model weights ( $w_i$ ), number of parameters in the model ( $K$ ), and model deviance (Dev) for the 6 candidate models I used to evaluate factors affecting detection of American woodcock on Singing-ground Surveys, 2009.

<b>Model</b>	<b>AIC</b>	<b><math>\Delta</math>AIC</b>	<b><math>w_i</math></b>	<b><math>K</math></b>	<b>Dev</b>
Neighbor+Observer+Quiet+Wind	1783.4	0.0	0.792	6	1771.4
Neighbor+Observer+Quiet+Wind+Date <sup>a</sup>	1787.3	3.9	0.113	8	1771.3
Neighbor+Observer+Quiet	1788.3	4.9	0.068	5	1778.3
Global	1790.4	7.0	0.024	10	1770.4
Neighbor+Observer	1794.8	11.4	0.003	4	1786.8
Neighbor	1796.7	13.3	0.000	2	1792.7

<sup>a</sup> Not a competing model, based on model deviance.

**Table 3.** Model-averaged parameter estimates ( $\beta$ ) and 95% confidence interval limits for detection probability covariates included in the global model of factors affecting detection probability of American woodcock, 2009.

<b>Variable</b>	<b><math>\beta</math></b>	<b>95% lower CL</b>	<b>95% upper CL</b>
Intercept/Observer3	-1.53	-2.54	-0.522
Date	-0.000219	-0.0312	0.0313
Date <sup>2</sup>	-0.0000543	-0.000835	0.000715
Observer1	0.162	-0.131	0.455
Observer2	-0.151	-0.440	0.136
Precipitation	0.0540	-0.589	0.693
Wind	-0.0554	-0.103	-0.00862
Temperature	0.00840	-0.00892	0.0258
Quiet	0.308	0.690	0.548
Neighbor	2.04	1.81	2.28

**Table 4.** Covariates in models, Akaike’s Information Criterion (QAIC), difference of QAIC between a model and the model with the lowest QAIC ( $\Delta$ QAIC), model weights ( $w_i$ ), number of parameters in the model ( $K$ ), and model deviance (Dev) for the 6 candidate models I used to evaluate factors affecting detection of American woodcock on Singing-ground Surveys, 2010.

<b>Model</b>	<b>QAIC</b>	<b><math>\Delta</math>QAIC</b>	<b><math>w_i</math></b>	<b><math>K</math></b>	<b>Dev</b>
Neighbor+Date+Quiet+Observer	1973.6	0.0	0.448	7	2351.3
Neighbor+Date+Quiet+Observer+Precip <sup>a</sup>	1974.8	1.2	0.245	8	2350.5
Neighbor+Date+Quiet	1975.3	1.7	0.191	5	2360.7
Neighbor+Date	1977.3	3.7	0.070	4	2363.1
Global	1978.3	4.6	0.045	10	2349.9
Neighbor	1986.0	12.4	0.001	2	2378.4

<sup>a</sup> Not a competing model, based on model deviance.

**Table 5.** Model-averaged parameter estimates ( $\beta$ ) and 95% confidence interval limits for detection probability covariates included in the global model of factors affecting detection probability of American woodcock, 2010.

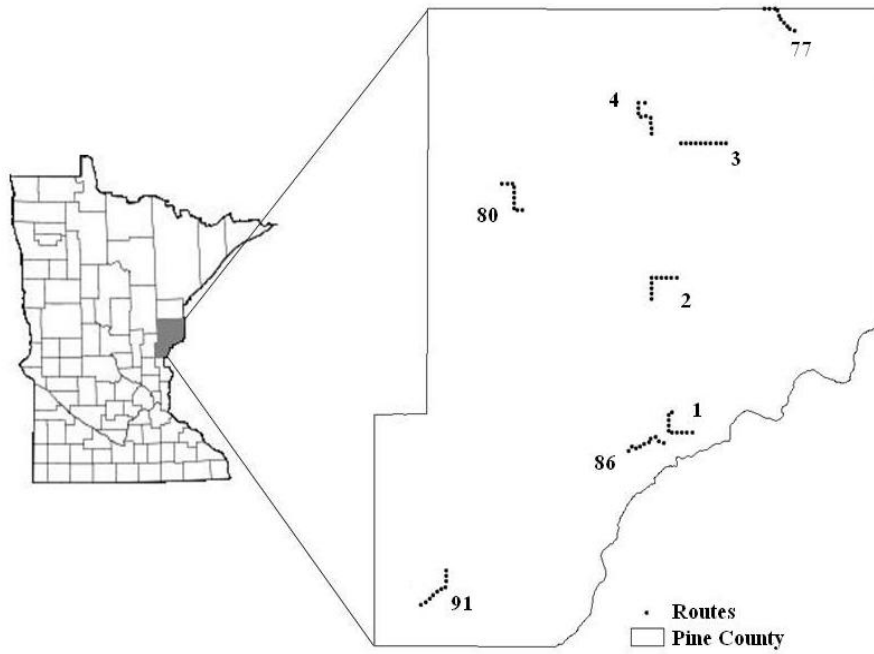
<b>Variable</b>	<b><math>\beta</math></b>	<b>95% lower CL</b>	<b>95% upper CL</b>
Intercept/Observer5	-1.48	-2.39	-0.570
Date	0.00493	-0.00586	0.0157
Date <sup>2</sup>	-0.000547	-0.000854	-0.000241
Observer1	-0.0371	-0.293	0.219
Observer4	-0.345	-0.596	-0.0951
Precipitation	-0.159	-0.634	0.305
Wind	-0.00384	-0.0926	0.0434
Temperature	0.00628	-0.0106	0.0232
Quiet	0.257	-0.359	-0.0487
Neighbor	2.16	1.96	2.36

**Table 6.** Covariates in models, Akaike’s Information Criterion (AIC), difference of AIC between a model and the model with the lowest AIC ( $\Delta$ AIC), model weights ( $w_i$ ), number of parameters in the model ( $K$ ), and model deviance (Dev) for the 7 candidate models I used to evaluate factors affecting detection of American woodcock on Singing-ground Surveys, 2009-2010.

<b>Model</b>	<b>AIC</b>	<b><math>\Delta</math>AIC</b>	<b><math>w_i</math></b>	<b><math>K</math></b>	<b>Dev</b>
Global	4153.7	0.0	0.349	13	4127.7
Neighbor+Quiet+Observer+Wind+Date	4154.2	0.5	0.272	10	4134.2
Neighbor+Quiet+Observer+Wind+Date+Precip	4154.5	0.8	0.234	11	4132.5
Neighbor+Quiet+Observer+Wind	4155.8	2.1	0.122	8	4139.8
Neighbor+Quiet+Observer	4159.1	5.4	0.023	7	4145.1
Neighbor+Quiet	4167.6	13.9	0.000	3	4161.6
Neighbor	4177.3	23.6	0.000	2	4173.3

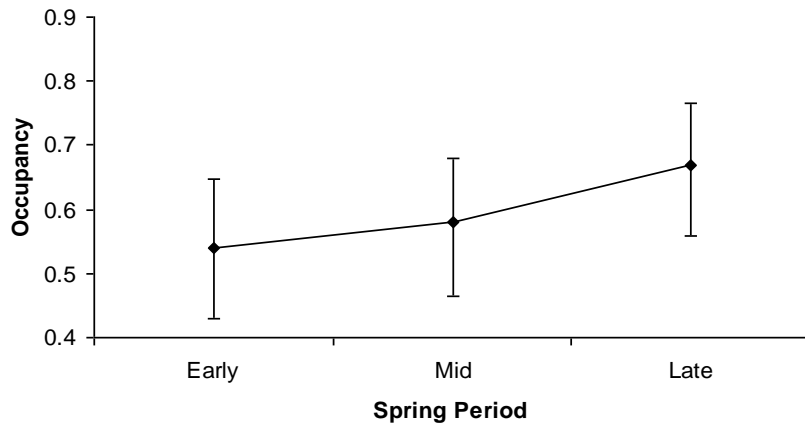
**Table 7.** Model-averaged parameter estimates ( $\beta$ ) and 95% confidence interval limits for detection probability covariates included in the global model of factors affecting detection probability of American woodcock, 2009-2010.

<b>Variable</b>	<b><math>\beta</math></b>	<b>95% lower CL</b>	<b>95% upper CL</b>
Intercept/Observer5	-1.72	-2.42	-1.03
Date	0.0216	-0.00687	0.0501
Date <sup>2</sup>	-0.000650	-0.00136	-0.0000555
Observer1	0.0485	-0.202	0.299
Observer2	-0.241	-0.625	0.143
Observer3	-0.116	-0.497	0.265
Observer4	-0.288	-0.534	-0.0416
Precipitation	-0.123	-0.494	0.241
Wind	-0.0437	-0.0816	-0.00605
Temperature	0.00896	-0.00311	0.0211
Quiet	0.283	0.122	0.445
Neighbor	2.11	1.96	2.26
Year	0.112	-0.160	0.385

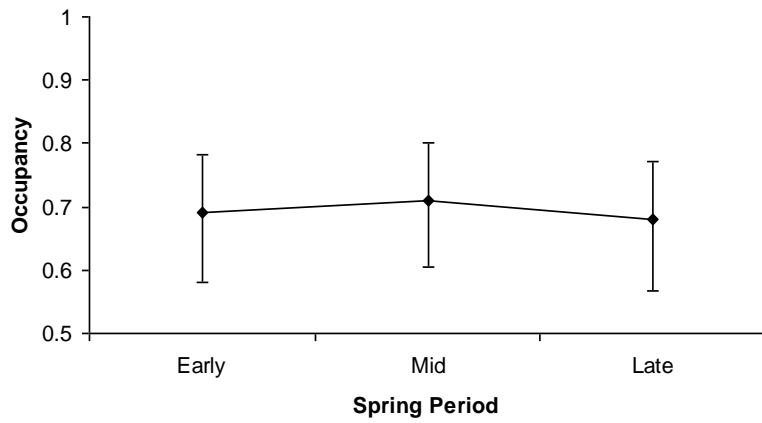


**Figure 1.** Pine County, Minnesota, USA, and the 8 survey routes where I evaluated factors influencing American woodcock detection probability in 2009-2010. Official Singing-ground Survey routes include route numbers 77, 80, 86, and 91. Reference routes include route numbers 1-4.

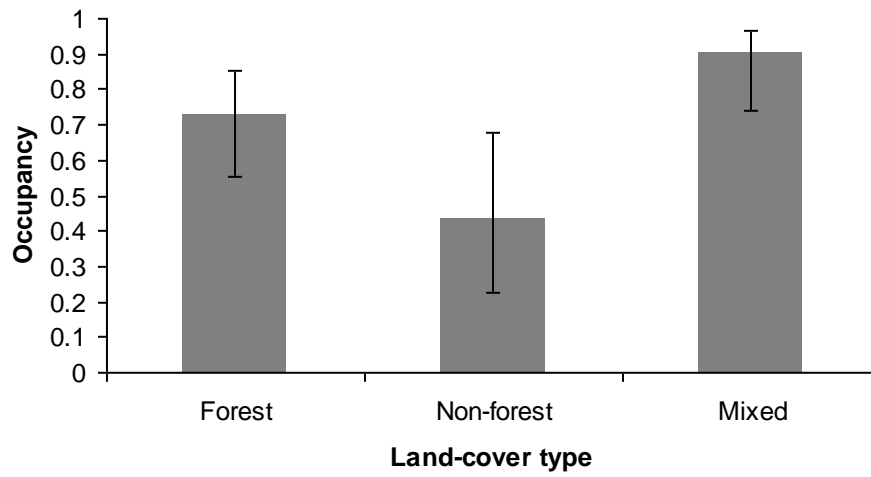




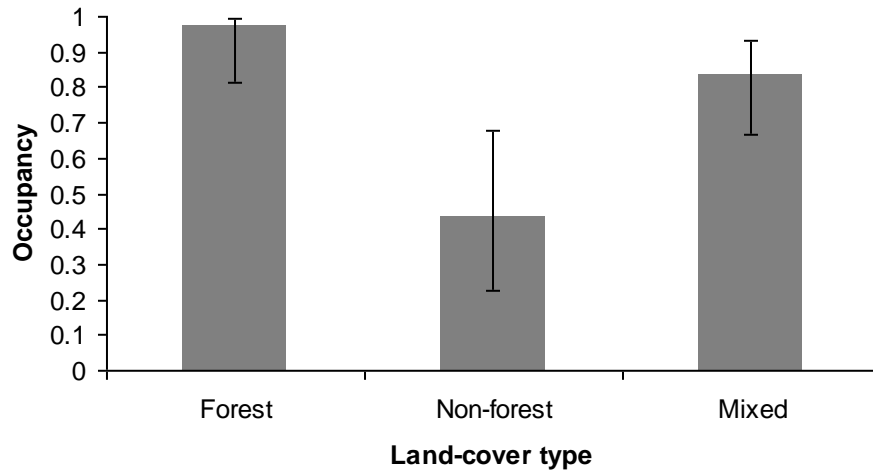
**Figure 2.** Occupancy estimates (with 95% confidence intervals) from the model  $[\psi(\text{period}), p(\cdot)]$  of American woodcock for the 3 2-week spring sampling periods (Early = 12-24 April, Mid = 26 April-10 May, Late = 10-21 May) in Pine County, Minnesota, 2009.



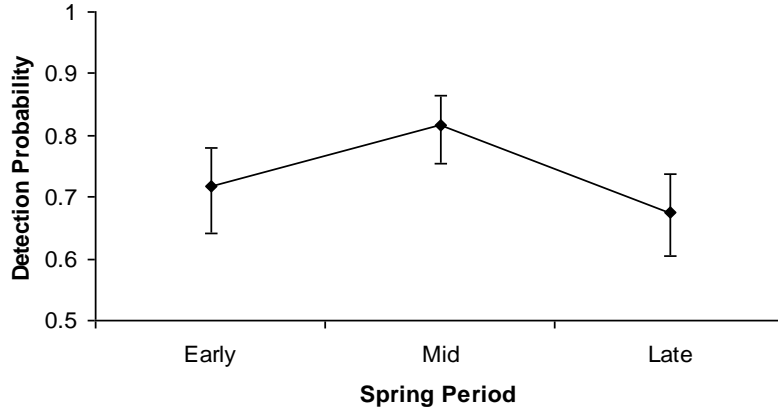
**Figure 3.** Occupancy estimates (with 95% confidence intervals) from the model  $[\psi(\text{period}), p(\cdot)]$  of American woodcock for the 3 2-week spring sampling periods (Early = 10-22 April, Mid = 22 April-6 May, Late = 5-19 May) in Pine County, Minnesota, 2010.



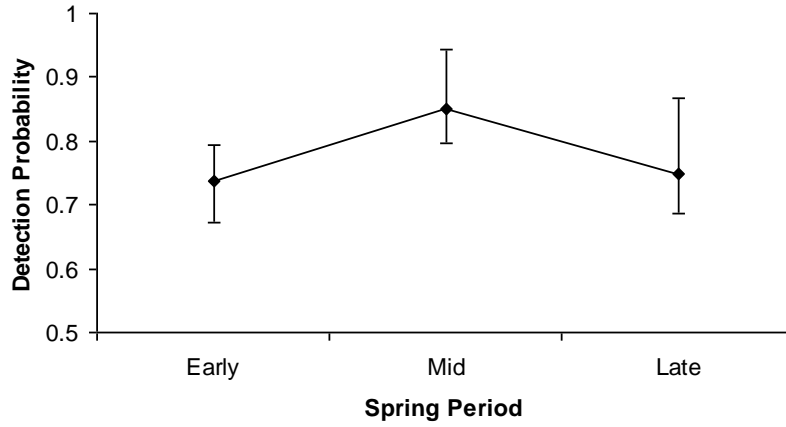
**Figure 4.** Occupancy estimates (with 95% confidence intervals) from the model  $[\psi(\text{habitat}), p(\cdot)]$  of American woodcock at listening points in different land-cover types in Pine County, Minnesota, 2009.



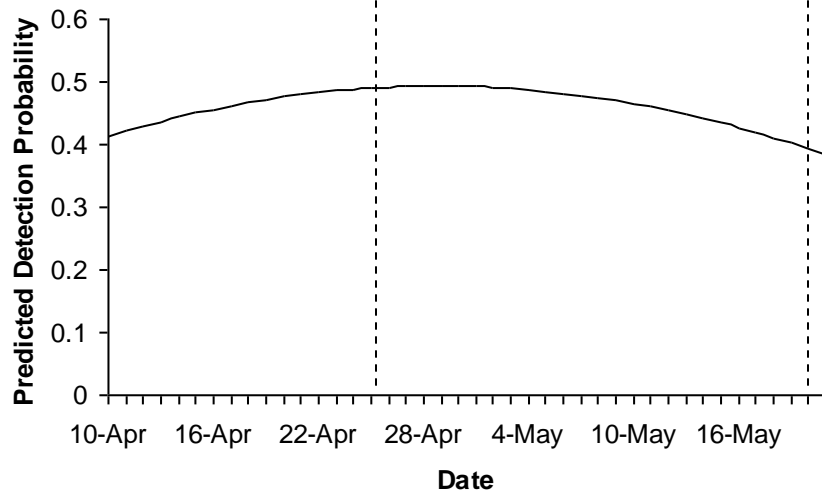
**Figure 5.** Occupancy estimates (with 95% confidence intervals) from the model  $[\psi(\text{habitat}), p(\cdot)]$  of American woodcock at listening points in different land-cover types in Pine County, Minnesota, 2010.



**Figure 6.** Detection probability estimates (with 95% confidence intervals) from the model  $[\psi(\cdot), p(\text{period})]$  of American woodcock for the 3 2-week spring sampling periods (Early = 12-24 April, Mid = 26 April-10 May, Late = 10-21 May) in Pine County, Minnesota, 2009.



**Figure 7.** Detection probability estimates (with 95% confidence intervals) from the model  $[\psi(\cdot), p(\text{period})]$  of American woodcock for the 3 2-week spring sampling periods (Early = 10-22 April, Mid = 22 April-6 May, Late = 5-19 May) in Pine County, Minnesota, 2010.



**Figure 8.** Predicted detection probability estimates by date from the model  $[\psi(\cdot), p(\text{date})]$  of American woodcock in Pine County, Minnesota, from the 2009-2010 model. Dashed lines indicate the start and end dates for official SGSs in Pine County.

## Chapter 2

### **Estimation of Density and the Effective Area Surveyed for American Woodcock**

**OVERVIEW** The Singing-ground Survey (SGS) is conducted during the American woodcock (*Scolopax minor*) breeding season and is designed to exploit the males' distinctive vocalization in an effort to monitor these otherwise inconspicuous birds. Survey points on SGS routes are set 0.4 mile (0.65 km) apart to avoid counting individual birds from >1 listening location. The effective area surveyed (EAS) at a listening point is not known, and may vary as a function of land-cover type, environmental conditions, and other factors. To define the relationship describing distance between vocalizing woodcock and detection by an observer, I broadcast a recording of woodcock vocalizations in 2 land-cover types (forest and field) at distances unknown to an observer. I evaluated the proportion of call broadcasts detected as a function of distance and fit regression curves to detection data to estimate a distance ( $r^*$ ) where the area above the curve at distances  $< r^*$  was equal to the area under the curve at distances  $> r^*$ , which allowed determination of the radius of an area where detection probability was effectively 1.0. This EAS had a radius ( $r^*$ ) of 198 m for forest, 384 m for field, and 309 m for both of these land-cover types combined and an estimated size of 12.3 ha for forest, 46.3 ha for field, and 30.0 ha for both land-cover types combined. I used this information to estimate density of displaying male woodcock based on counts from the SGS.

**KEY WORDS** American woodcock, *Scolopax minor*, effective area surveyed, detection distance, Minnesota



The American Woodcock Singing-ground Survey (SGS), coordinated by the U. S. Fish and Wildlife Service (FWS) and the Canadian Wildlife Service, is conducted during the spring breeding season of American woodcock (*Scolopax minor*). This roadside survey is conducted in the evening when males make a distinctive vocalization called peenting as part of their breeding display (Keppie and Whiting 1994). Each male occupies its own open area called a singing ground where it peents to attract female woodcock and advertise occupancy to conspecific males. Woodcock use a variety of openings (natural openings, clearcuts, agricultural fields, etc.) for this display.

The SGS has been conducted throughout the primary woodcock breeding range since 1968 and is used as an index of abundance and population trend. There are approximately 1,500 SGS routes that are 3.6 miles (5.8 km) in length and have 10 listening points spaced 0.4 miles (0.65 km) apart (Cooper and Parker 2010). Observers begin surveys shortly after sunset and record the number of woodcock heard peenting at each listening point during a 2-min listening period.

From 1968 to 2010, the number of singing male woodcock counted on the SGS has declined (Cooper and Parker 2010). Concerns about this decline have led to harvest restrictions (summarized in Cooper and Parker 2010), a woodcock conservation plan (Kelley et al. 2008), and a need to better understand how counts of woodcock on the SGS are related to woodcock abundance and population trends.

Detection of woodcock during surveys is influenced by a variety of factors (Chapter 1) and the SGS protocol is designed to maximize detection probability by defining conditions under which surveys are to be conducted. However, detection

probability on SGS surveys was not previously known, and by accounting for factors that influence detection, evaluation of trends in woodcock abundance could be improved. One factor that should influence detection is the distance from a bird to the observer. Recent experiments (see Simons et al. 2007, McClintock et al. 2010) have shown that detection probability decreases with distance, especially in the presence of ambient noise. This can lead either to misidentification, false-positive, or false-negative detections. Therefore, it is important to estimate the proportion of birds detected as a function of distance and to understand factors that influence detection (Chapter 1).

The farthest distance an observer can detect various songbirds has been investigated empirically by broadcasting recordings of calls. For example, Emlen and DeJong (1981) introduced the idea of detection threshold distances (DTDs), which they defined as the distance at which a bird song becomes inaudible in a natural setting. These could then be translated to detection areas (DAs) and applied to counts of singing birds along a survey route. A DTD would be determined for a particular species and habitat, eliminating the need for an observer to estimate the distances to singing birds during a survey. However, the use of a single threshold number was questioned by Wolf et al. (1995) when they fit a theoretical function to describe the relationship between distance and detectability. The value of interest ( $D_{50}$ ) described the distance where one-half of the birds of a given species were audible during a point count, so that the probability of hearing a bird within that distance was equal to that of missing a bird beyond that distance. These studies provided crude estimates of the farthest distance an observer

could detect various songbirds in a forest and provided a basis for evaluating detection distance on the SGS.

The SGS protocol was developed partly on evaluations conducted by Duke (1966) of factors related to woodcock peenting. Duke (1966) estimated the distance that peenting woodcock could be heard, and concluded that none were detected beyond 257 yards (235 m). He recommended that the FWS maintain a 0.4-mile (0.65 km) interval between stops on the SGS to avoid counting individual birds from >1 listening location. This resulted in a 0.2-mile (approximately 330 m) radius around each listening point and an estimated effective area surveyed (EAS) of 34.2 ha (assuming all woodcock peenting were detected). Gregg (1984) assumed that an SGS observer would hear all peenting male woodcock within a 220-yard (201 m) radius of a listening point for an EAS of 12.7 ha. However, after calculating a very low density of woodcock along Wisconsin SGS routes with this presumed area surveyed, Gregg (1984) concluded that the estimate of the area within which woodcock were detected along routes may have been too large. More recently, Zimmerman et al. (2007) suggested a listening-point radius of 250 m, which amounts to an EAS of 19.6 ha. These estimates of the area within which woodcock are detected at SGS survey locations vary widely, with the largest estimate from the current SGS protocol.

The EAS can be used to estimate density of male singing woodcock in their breeding range. Several studies have attempted to estimate density without having directly estimated the EAS for an SGS listening point. Gregg (1984) compared breeding woodcock densities in the literature based on singing-grounds/100 acres in the Midwest

and northeast United States. He assumed an occupied singing-ground was equivalent to 1 singing male woodcock. His density estimates ranged from 0.7 to 4.2 singing-grounds/100 acres (1.7 to 10.4 singing-grounds/100 ha). Dwyer et al. (1988) estimated woodcock density on Moosehorn National Wildlife Refuge in Maine by counting all singing males in a study area of known size and assuming that no birds were missed. Their density estimates ranged from 1.3 to 2.2 singing males/100 ha over a 10-year study period. In the American Woodcock Conservation Plan density estimates were made for all the counties within the breeding range of woodcock. Kelley et al. (2008) used a radius of 250 m, but this estimate was not based on empirical data. They were interested in comparing woodcock populations from 1970-1975 to those of 2000-2004 and used the average number of singing males per route during those periods. Counties were represented by their official SGS routes and the density estimates for Pine County, Minnesota, USA (the location of my study) were 0.88 singing males/100 ha for 1970-1975 and 0.75 singing males/100 ha for 2000-2004.

To date, there has not been a thorough evaluation of the relationship between distance and detection of peenting woodcock at a listening point on the SGS, which precludes using SGS data to estimate woodcock density. Furthermore, many factors are likely to influence woodcock detection probability such as land-cover type (e.g., forest, agriculture, urban, etc.), environmental conditions under which surveys are conducted, and abilities of observers. Therefore, my objectives were to estimate the EAS at SGS listening points with respect to land-cover type using both field and forested locations. I predicted that land-cover type would affect the distance at which a bird could be detected.

I also incorporated EAS and detection probability with SGS counts to derive estimates of male woodcock density in Pine County, Minnesota, USA.

## **STUDY AREA**

I derived distance-detection relationships from trials I conducted in field and forested land-cover types in Pine County, Minnesota in 2009 and 2010. Pine County is located in east-central Minnesota and my study sites were located near the town of Finlayson. Pine County is situated in the Mille Lacs Uplands subsection under the Ecological Classification System hierarchy (Minnesota DNR 2006). This subsection is characterized by drumlin ridges with depressions between the ridges containing peatlands with shallow organic material. There are extensive wetlands in the area with total annual precipitation of about 75 cm. Large areas in eastern Pine County are heavily forested. The county is dominated by aspen-birch (*Populus* spp.-*Betula* spp.) forest with small areas of jack-white-red pine (*Pinus* spp.) forests. Land ownership in the Mille Lacs Uplands subsection is 17.7% public and 82.2% private and current land use is 40% forest, 24% row crop, 17% wetland-open, 13% pasture, and 6% water (Minnesota DNR 2006).

## **METHODS**

### **Data Collection**

I conducted call-broadcast trials at 9 sites, 4 that were categorized as forest and 5 that were categorized as field. Forest sites were topographically flat and vegetated by mixed pine forest, mature aspen forest interspersed with alders (*Alnus* spp.) in a wet area, mixed pine forest and pine plantation, and mixed pine forest with birch, aspen, and a willow (*Salix* spp.) and alder wet area. Field sites were also topographically flat; 2 were

horse pasture, 2 were hayfields, and 1 was a restored native prairie. Two of the forest sites were public land, whereas the remaining sites were located on private land.

To estimate the farthest distance at which peenting woodcock could be detected by an observer, I broadcasted a recording of a woodcock peent through speakers at a sound level between 70 and 80 decibels (e.g., Brackenbury 1979, Simons et al. 2007). While 1 observer stood blindfolded on a road, another individual held a game caller (FOXPRO FX3; use of trade names does not imply endorsement by either the U.S. Geological Survey or the University of Minnesota) at a distance unknown to the observer and either played or did not play the recording. Broadcast distances were set at 50-m increments between 100 and 450 m (field) or 100 m and 300 m (forest). The observer listened for 2 min and recorded whether or not they heard peenting. I recorded wind speed, precipitation, and level of ambient noise during the trial following the official SGS protocol (e.g., trials were not conducted in heavy wind or precipitation). I conducted broadcast trials primarily in the hours during and after sunrise (0600-0900) to simulate the conditions during which the official SGS is conducted. Trials were not conducted during the hours around sunset because observers were conducting woodcock surveys as part of a companion study (Chapter 1). I conducted trials in April and May of 2009 and 2010 over multiple days and sites in the 2 land-cover types (forest and open field) to estimate detection distance and to compare detection distance between land-cover types.

### **Statistical Analysis**

I calculated the proportion of peent broadcasts detected at each distance and in each land-cover type (Fig. 1). Based on the proportion of broadcasts detected and with

the assumption that all broadcasts at 0 m from the observer were detected, I used program R to analyze 4 different curves (half normal, inverse normal, negative exponential, and logistic) to determine the detection curve with the best fit (R Development Core Team 2010). I ranked these 4 *a priori* candidate models using Akaike's Information Criterion adjusted for small sample size ( $AIC_c$ ) for the field and forest land-cover types to identify the model best supported by my data (Burnham and Anderson 2002). I then used the best-supported detection curve (half-normal) to estimate the EAS, following the procedure outlined in Roberson et al. (2005) where probability of detection is a function of distance. In that procedure, the ideal probability of detection ( $P_i$ ) is equal to 1 at a given distance (x, y) from the road (0, 0) and zero beyond that distance. The next step is to set the double integral of  $P_i$  equal to that of  $P_o$ , the probability of detection as a function of distance based on my data. I then solved for  $r^*$ , the radius of the EAS (and the x coordinate on the detection curve), which is the distance at which the area above the probability of detection curve at distances less than  $r^*$  equals the area under the curve at distances greater than  $r^*$ . For a half-normal curve the  $r^*$  can be calculated by

$$r^* = 2 \left( \int_0^{r^*} P_t(r) dr \right)$$

where  $P_t$  is the probability of detection at distance t and r is the radius from the location where the peent call was broadcast. Following integration, the equation for  $r^*$  was reduced to

$$r^* = \sqrt{2}\sigma^2$$

where  $\sigma$  is the standard deviation from a half-normal distribution. I used this radius to determine the effective area surveyed:

$$\text{EAS} = \pi(r^*)^2$$

I calculated a 95% bootstrap confidence interval with 1,000 bootstrap samples for  $r^*$  to assess uncertainty in the EAS using program R. I repeated this procedure for forest, field, and forest and field combined land-cover types.

I then used the EAS to estimate density of peenting male woodcock along woodcock survey routes in Pine County. I randomly chose 1 of the 12 surveys conducted on each of the 8 routes (see Chapter 1) for both 2009 and 2010. I restricted my surveys to those conducted within the official SGS window for central Minnesota (25 April-20 May) to make my estimated densities comparable to counts from surveys conducted as part of the SGS. I applied a detection probability ( $p$ ) of 0.625 (pooled from the 2009 and 2010 estimates of detection probability; Chapter 1) to the raw counts ( $\hat{C}$ ) of singing male woodcock from the randomly chosen surveys to obtain the estimated number of woodcock ( $\hat{N}$ ).

$$\hat{N} = \hat{C} / \hat{p}$$

I then applied the appropriate EAS estimate to each listening point on each route based on the land-cover type assigned to that point for occupancy estimation (Chapter 1). Summing the EAS estimates for all 10 listening points resulted in an EAS estimate for each route and summing the EAS estimates for all 8 routes resulted in an EAS estimate for all 8 routes in Pine County. I then calculated density by dividing the estimated number of singing male woodcock by the EAS for each route or all routes combined to obtain birds/100 ha.

## **RESULTS**

### **Effective Area Surveyed**



I conducted a total of 1,160 woodcock broadcast trials at 5 distances in the forest land-cover type and 8 distances in the field land-cover type for an average of approximately 90 trials per distance in each land-cover type. Trials took place over 19 days in 2009 and 25 days in 2010. The percentage of broadcasts detected ranged from 96.3% and 92.5% at 100 m in the field and forest land-cover types, respectively, to 12.1% at 450 m in the field land-cover type and 6.4% at 300 m in the forest land-cover type. Detection probability decreased less rapidly as a function of distance in the field land-cover type than in the forest land-cover type (Fig. 1).

The best-fit detection curve for all 3 datasets (forest, field, both land-cover types combined) was the half-normal (Table 1, Figs. 2-4). No other models received substantial support; therefore I used the parameter estimates from the half normal curve defined by my data to calculate the EAS. The EAS radius ( $r^*$ ) was 198 m (95% bootstrap CI = 174-231 m) for the forest land-cover type, 384 m (95% bootstrap CI = 321-440 m) for the field land-cover type, and 309 m (95% bootstrap CI = 273-372 m) for both land-cover types combined. The EAS for SGS listening points in Pine County was 12.3 ha (95% bootstrap CI = 9.46-16.8) for the forest land-cover type, 46.3 ha (95% bootstrap CI = 32.4-60.8) for the field land-cover type, and 30.0 ha (95% bootstrap CI = 23.4-43.4) for both land-cover types combined.

### **Density**

Counts of male singing woodcock per route from the randomly chosen surveys for each of the 8 Pine County survey routes ranged from 1 to 16 in 2009 (CV = 67.8%) and 2 to 18 in 2010 (CV = 50.9%). The average count in 2009 was 7.75 birds/route (SE = 0.66)

and in 2010 was 10.75 birds/route (SE = 0.68). Density estimates by route ranged from 0.74-10.37 birds/100 ha in 2009 (CV = 70.7%) and 0.74-11.87 birds/100 ha in 2010 (CV = 51.07%). Average density across routes was 5.40 birds/100 ha (SE = 0.48) in 2009 and 7.53 birds/100 ha (SE = 0.48) in 2010.

The total number of woodcock counted on the 8 Pine County survey routes was 62 in 2009 and 86 in 2010. Density for the Pine County routes (summed across all 8 routes) was 4.85 birds/100 ha in 2009 and 6.72 birds/100 ha in 2010.

## **DISCUSSION**

I estimated the EAS for American woodcock in field and forest land-cover types in east-central Minnesota based on call broadcast trials conducted under a variety of conditions within the limitations of the SGS protocol, in relatively flat terrain, and during the hours around sunrise. I conducted trials over many days in a variety of environmental conditions, wind speeds and directions, ambient noise levels, and precipitation.

Therefore, my estimates of the EAS should be considered averages over the conditions under which SGSs are conducted. Although these trials were conducted in the hours around sunrise, instead of sunset, I believe the substitution was acceptable because conditions were similar and male woodcock are also known to display at dawn (Sheldon 1967).

The EAS in the field land-cover types was greater than that in the forest land-cover type, likely because of sound attenuation in forest vegetation (Wiley and Richards 1982). My estimate of EAS across land-cover types (field and forest combined) was 309 m, which is similar to previous estimates of 201 m, 235 m, 250 m, and 330 m (Gregg

1984, Duke 1966, Zimmerman et al. 2007, Cooper and Parker 2010, respectively). However, only Duke's (1966) estimate was determined based on empirical data-- the farthest distance he and others could hear 3 known singing males in 28 trials. When combining data from both land-cover types, my estimate of the EAS was 30.0 ha, which extrapolates to a total of 300 ha effectively surveyed on a single SGS route (with 10 listening points).

The density estimates I derived for male singing woodcock in Pine County (5.40 in 2009 and 7.53 in 2010) are considerably greater than those previously estimated in other locations. The highest estimated density was 2.2 birds/100 ha at Moosehorn National Wildlife Refuge (NWR) in Maine (Dwyer et al. 1988). The study area on Moosehorn NWR had high quality woodcock habitat that had recently undergone management specifically for woodcock prior to the study (Dwyer et al. 1988), whereas my study was located in a mix of public and private lands that was not managed for woodcock. Estimated density for woodcock in Pine County presented in the American Woodcock Conservation Plan (Kelley et al. 2008) was also much lower than my estimates. In addition, both raw counts and density estimates showed a 39% increase in woodcock abundance on my routes from 2009 to 2010.

## **MANAGEMENT IMPLICATIONS**

Based on my estimates of EAS in forested and field land-cover types in east-central Minnesota, the 330-m radius currently used for SGS points appears adequate to ensure that woodcock are not counted on >1 survey point, unless consecutive survey points are completely surrounded by flat, open field. In that case the same bird has the

potential to be counted at consecutive survey points, which violates the assumption of independent survey points. Recording the cardinal direction and approximate distance to a peenting woodcock in this situation might prevent an observer from counting the same bird twice. I recommend that observers not count birds they heard faintly. Ignoring uncertain detections would increase confidence in (1) reducing double counting of the same bird from consecutive points and (2) counting birds only within the EAS. In contrast, in forested land-cover types observers likely would not detect woodcock beyond 198 m, suggesting that one must consider land-cover type when comparing counts between locations.

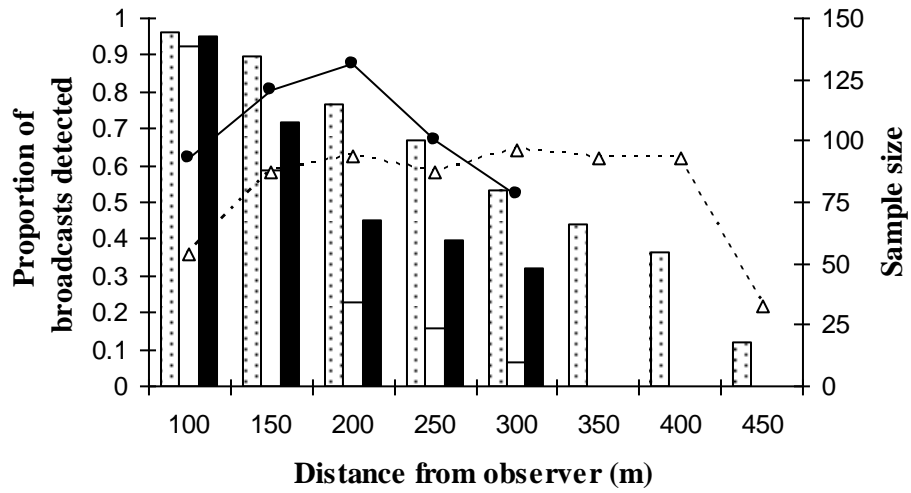
My estimates for the EAS at an SGS point can be used to calculate density of singing male woodcock. With technology such as remote sensing, SGS points may be easily classified into the 3 general land-cover categories I used in this research. The unique EAS estimates for each SGS route could be evaluated periodically to account for changes in land-cover.

**Table 1.** Akaike’s Information Criterion adjusted for small sample size ( $AIC_c$ ) and the difference in  $AIC_c$  ( $\Delta AIC_c$ ) from the best-supported model for 4 *a priori* models of the relationship between American woodcock detection and distance in a forest, field, and both land-cover types combined in Pine County, Minnesota, 2009-2010.

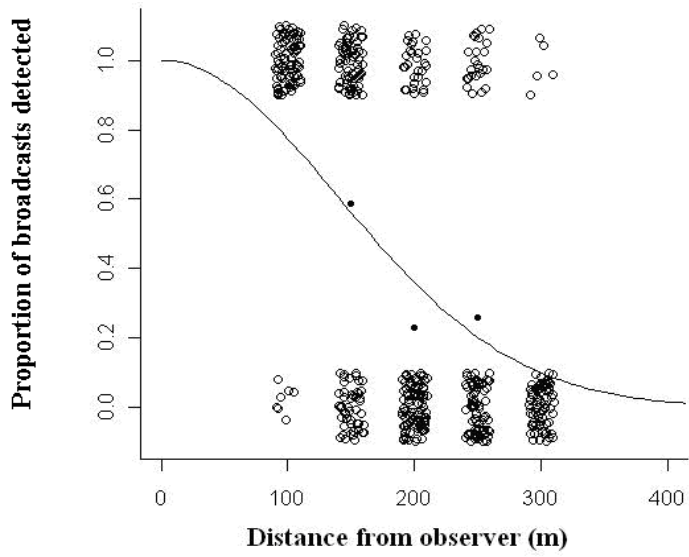
<b>Land-cover Type</b>	<b>Model</b>	<b><math>AIC_c</math></b>	<b><math>\Delta AIC_c</math></b>
Forest	Half Normal	0.6230	0.000
	Negative Exponential	6.942	6.319
	Logistic	19.17	18.55
	Inverse Normal	19.63	19.01
Field	Half Normal	-8.513	0.000
	Inverse Normal	-1.357	7.156
	Logistic	-0.8730	7.640
	Negative Exponential	3.984	12.497
Both combined	Half Normal	-6.477	0.000
	Negative Exponential	-4.707	1.770
	Logistic	-2.276	4.201
	Inverse Normal	-2.160	4.317

**Table 2.** Radius ( $r^*$ ) of the effective area surveyed (EAS), EAS estimate, and 95% bootstrap confidence interval of the EAS for American woodcock peent broadcast surveys in Pine County, Minnesota, 2009-2010.

<b>Land-cover Type</b>	<b><math>r^*</math> (m)</b>	<b>EAS (ha)</b>	<b>EAS 95% CI</b>
Forest	198	12.3	32.4-60.8
Field	384	46.3	9.46-16.8
Both land-cover types combined	309	30.0	23.4-43.4

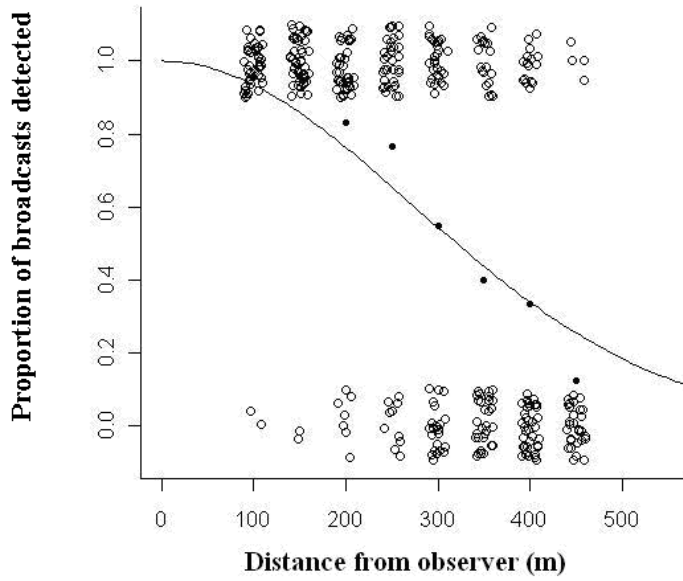


**Figure 1.** Proportion of broadcasts of American woodcock “peents” detected at increasing distance (in m) from an observer in field (dotted), forest (white), and overall (shaded) land-cover types in Pine County, Minnesota, 2009-2010. Lines shows sample sizes for field (dotted) and forest (solid) land-cover types at each distance.

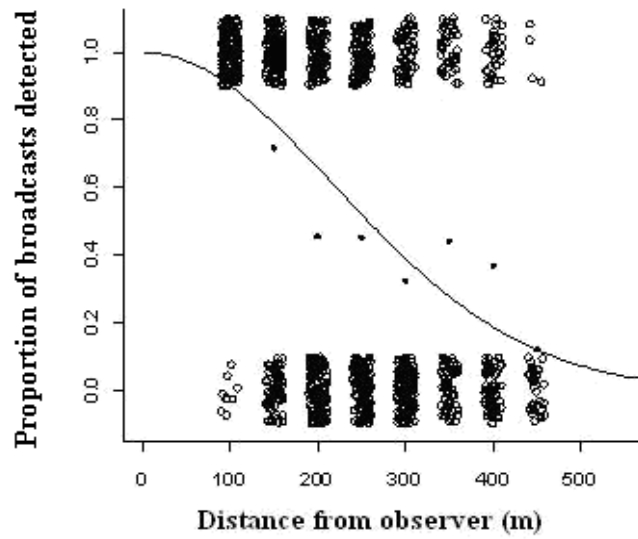


**Figure 2.** The best-supported model (half normal curve) for the regression of proportion of American woodcock call broadcasts detected as a function of distance in forest land cover, Pine County, Minnesota, 2009-2010.





**Figure 3.** The best-supported model (half normal curve) for the regression of proportion of American woodcock call broadcasts detected as a function of distance in field land cover, Pine County, Minnesota, 2009-2010.



**Figure 4.** The best-supported model (half normal curve) for the regression of proportion of American woodcock call broadcasts detected as a function of distance in field and forest land-cover types combined, Pine County, Minnesota, 2009-2010.

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## APPENDIX A.

In the spring of 2009 I conducted a pilot study to determine the feasibility of capturing and monitoring male woodcock on their singing grounds. I captured and radio-marked 5 male woodcock located on singing grounds along SGS route 77 during the weeks of 30 March and 6 April. I used techniques for capturing woodcock described by Dwyer et al. (1988) to capture males by placing mist nets around previously identified singing grounds so that male woodcock flew into the net when executing their courtship flights.

At the time of capture for radio-marking, I attempted to capture other male woodcock near the singing ground by waiting for presumed subdominant males to be captured in mist nets after the dominant male was caught and held in a cloth sack while being processed. McAuley et al. (1993*b*) found that they could capture up to 4 males per site using this procedure, but I never had multiple captures at the same net in the same night. I tracked radio-marked woodcock approximately every other day to determine if they were using the same singing ground consistently and singing every evening. I also employed a remote data logger at 1 singing ground frequented by radio-marked woodcock to determine their temporal use patterns.

I recorded the proportion of evenings radio-marked woodcock were present at specific singing grounds and the proportion of evenings radio-marked woodcock were heard peenting. Of the 5 male woodcock I captured and equipped with radio transmitters 1 died due to avian predation, I was unable to detect signals subsequent to release for 2 individuals (they likely continued migrating), and I monitored the remaining 2 woodcock



in the vicinity of the ninth point of route 77. The 2 woodcock I monitored displayed at this point 16 of 22 (73%) and 9 of 17 (53%) evenings I searched for their signals, respectively.