American Woodcock Singing-ground Surveys in the western Great Lakes region: assessment of woodcock counts, forest cover types along survey routes, and landscape cover type composition

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Chapter 1

Trends in Counts of American Woodcock on Singing-ground Surveys in Minnesota and Wisconsin: Relating Counts to Land Cover

Abstract: Counts of American woodcock (*Scolopax minor*) on the annual Singing-ground Survey (SGS) have undergone long-term declines in both the Eastern and Central Management Regions. However, interpreting these trends is confounded by a lack of information regarding the relationship between counts and habitat. Therefore, I assessed the relationship between woodcock counts and land-cover composition along survey routes using an Information-Theoretic modeling framework. The amount of early successional forest, open space, and a landscape metric Interspersion and Juxtaposition Index (IJI) best explained counts in Wisconsin; in Minnesota, the amount of mature forest, water and models that included open space, wetlands, and early successional forest together best explained counts. These results are, in general, consistent with woodcock-habitat relations described in published literature, and suggest that woodcock counts along SGS survey routes in Minnesota and Wisconsin reflect the amount and composition of land cover along routes, especially the amount and juxtaposition of early successional forest and open space, which were the variables included in competing models for both states.

Key Words: shorebird, American Woodcock, *Scolopax minor*, Central Management Region, Minnesota, Wisconsin, land cover

Introduction

The American woodcock (*Scolopax minor*; hereafter woodcock) is a small, migratory game bird that is estimated to provide over a half million days of recreational hunting annually in the U.S. (Cooper and Parker 2009). In the U.S., woodcock are under federal management jurisdiction and are managed in cooperation with Canada, with the objectives of maintaining populations and providing harvest opportunities. One of the primary information sources used to assess the annual status of woodcock populations is the Singing-ground Survey (SGS), which is conducted annually across the primary woodcock breeding range in the eastern U.S. and southern Canada. Since 1968, the SGS has been used to monitor woodcock population trends by counting the number of displaying male woodcock heard along approximately 1,500 5.4-km routes. When the SGS was initially implemented, survey routes were located along secondary roads within randomly selected 10-minute latitude-longitude geographic blocks (Sauer and Bortner 1991, Straw et al. 1994) across the primary breeding range of woodcock. Route locations, however, were not selected randomly, but were placed along secondary roads near the center of the 10-minute latitude-longitude block. Each route has 10 locations where observers count the number of singing (“peenting”) male woodcock heard during a 2-minute interval. In spring, volunteers conduct counts during the peak of courtship, and the number of woodcock heard annually on these surveys is used to estimate the population trend of woodcock in North America (Cooper and Parker 2009).

Between 1968 and 2009, the number of singing male woodcock heard on the SGS declined an average of 1.1% per year in the Eastern and Central Management Regions (Cooper and Parker 2009), which prompted concerns about the population status of woodcock. These concerns led to reductions in hunting bag limits and season length, delays of hunting season opening dates, and the development of a management plan to increase woodcock population size (Kelly et al. 2008). The declines in woodcock heard during the SGS are difficult to interpret without additional information, especially their relationship to land-cover composition along survey routes. For example, woodcock use early successional vegetation within forested landscapes for courtship and breeding (e.g., Steketee et al. 2000), and a negative trend in survey counts may reflect changes in vegetation composition along survey routes, rather than changes in woodcock population size across a broader spatial scale.

Woodcock are managed as 2 populations, one in the Eastern Management Region (east of the Appalachian Divide) and one in the Central Management Region (west of the Appalachian Divide). These management units are based on band recovery data that suggest little movement between these populations (Owen et al. 1977). Woodcock habitat use during the breeding season has been extensively studied in the Eastern Management Region, but not so in the Central Management Region. Dwyer et al. (1983) found that woodcock were positively associated with early successional vegetation (e.g., abandoned fields and alders [*Alnus* spp.]) and negatively to urban development across 9 states located in the Eastern Management Region. In West Virginia, Steketee et al. (2000) compared land-cover composition around points where woodcock were flushed to random points to estimate the relationship between used and available land-cover types. They found that woodcock used early successional vegetation (e.g., areas with high stem densities). Compared with the Eastern Management Region, relatively few studies have examined woodcock habitat use in the Central Management Region. However, in

Wisconsin, Hale and Gregg (1976) suggested that woodcock use aspen clear cuts, although they did not compare use relative to available land-cover types.

My objectives were to evaluate the relationship between woodcock counts and land-cover composition in the Central Management Region along SGS routes in Minnesota and Wisconsin and to suggest how those relationships could improve (1) interpretation of SGS trends, (2) future monitoring efforts, and (3) the effectiveness of management efforts. I modeled the relationship between counts of woodcock from the SGS and land-cover types and landscape metrics to determine how various land-cover types related to and potentially influenced SGS counts.

Study Area

My sample universe was defined by existing SGS routes in the Central Management Region in Minnesota and Wisconsin. One hundred twenty-three SGS routes exist in Minnesota and 117 routes exist in Wisconsin, and routes are distributed throughout the woodcock breeding range of these states. For my analysis, I used a subset of SGS routes that represented the primary forested areas of each state based on the U. S. Environmental Protection Agency's (U.S. EPA) ecoregions (Fig. 1). This region is comprised of deciduous forests that transitions to coniferous forests and is interspersed with lakes and wetlands over gradual elevation changes (U.S. EPA 2007).

In Minnesota, the amount of forested land declined from approximately 7.28 million ha in 1962 to 6.83 million ha in 2008; however, this was an increase from a low of 6.55 million ha in 2003 (Miles et al. 2007, Miles 2010). In Wisconsin, forested land increased from approximately 6.07 million ha in 1963 to 6.47 million ha in 2004 (Perry et al. 2008). Over relatively the same period (1968 – 2009), trends in counts of woodcock declined on SGS routes in Minnesota by 0.05% per year and in Wisconsin by 0.69% per year (Cooper and Parker 2009).

Methods

Data Collection:--I used SGS counts and high-resolution land-cover data to develop and evaluate models relating woodcock counts along SGS routes to land-cover composition in Minnesota and Wisconsin. The U.S. Fish and Wildlife Service (FWS; Keri Parker, personal communication) provided paper maps of route locations, which I digitized using a Geographic Information System (GIS: ArcMap 9.3™; use of trade names does not imply endorsement by either the U.S. Geological Survey or the University of Minnesota). I then provided paper maps that included digitized routes, listening-stop locations, roads, and a high resolution aerial photograph background to the SGS regional coordinator (Sean Kelly, FWS), who sent them to survey volunteers who then verified the accuracy of digitized listening-stop and route locations. The volunteers verified locations either by providing latitude and longitude coordinates or by indicating corrections on paper maps.

The FWS also provided SGS count data, which consisted of woodcock counts for each listening stop along routes in Minnesota and Wisconsin. For my analyses of the factors related to woodcock counts, I used SGS counts by stop; for routes with duplicate counts (n = 12), I used the highest count for that year. To minimize the influence of annual variation in counts at each stop, I used the average count for 2004-2006 (Wisconsin) and 2007-2009 (Minnesota) in models relating counts of woodcock to land-cover composition (see below).

Land-cover data were classified by an independent contractor (Brick Fevold, Brick Fevold, Inc.) based on habitat attributes important to woodcock (e.g., following Dwyer et al. 1983, Steketee et al. 2000) using U.S. National Agriculture Imagery Program (NAIP) color aerial photographs (1-m resolution) to delineate land-cover types for Wisconsin (2005 photos) and color infrared aerial photographs (1-m resolution) to delineate land-cover types for Minnesota (2008 photos). Land-cover types were delineated under a modified Anderson Land Cover Classification scheme (Anderson et al. 1976) and included estimates of canopy height (Appendix A; see below for description of canopy height estimates) for the area within a 330-m radius around each listening stop, which is the presumed maximum detection distance for woodcock (Duke 1966).

The Anderson et al. (1976) classification scheme has 3 hierarchical levels. Level-1 classification is landscape-level categories (e.g., forest, wetlands, water, etc.) and is the level I used in my analyses. The Anderson scheme does not include canopy height as an attribute of land-cover types, but canopy height is related to structural characteristics important to woodcock (e.g., stem density). Because structural characteristics of vegetation could not be assessed directly from aerial photographs, I estimated canopy height from aerial photographs as a surrogate for early successional forest land cover. There is no standard maximum height definition for early successional forest. Cade (1985) included woody vegetation <5 m in his woodcock habitat suitability model and Steketee et al. (2000) included vegetation categories 0-1 m, 1-3 m, 3-6 m, 6-9 m and >9 m in models relating woodcock presence to land-cover types. I classified early successional forest to have canopy height <5 m (Appendix A) and used additional data layers (Appendix B) to aid in photo interpretation and delineation of land-cover types.

I randomly selected a subset of 60 routes (30 in Minnesota and 30 in Wisconsin; Fig. 1) located in the predominantly forested area of Minnesota and Wisconsin (110 forested routes, 68 in Minnesota and 42 in Wisconsin; Fig. 1) to use for models relating counts of woodcock to land-cover composition. I excluded 21 routes (14 in Minnesota and 7 in Wisconsin) that were in constant-0 status for 8 or more years between 1990 and 2006 (this time period was selected to accommodate additional analysis, see Chapter 2). Constant-0 routes are defined by the SGS protocol as routes with 2 consecutive years with counts of 0 males, after which the route is not surveyed for 5 years (Cooper and Parker 2009). For example, Minnesota route number 66 was in constant-0 status in 1990 - 1994, surveyed from 1995 through 2003, and re-entered constant-0 status in 2004, and was therefore excluded from the sample.

Land-cover Type Delineation Accuracy:--I evaluated accuracy of land-cover type delineation by comparing classification resulting from photo interpretation to land-cover type determined by visits to random points along SGS routes. I tested accuracy assessment protocol on 1 route in Minnesota and 1 route in Wisconsin, which I selected because they traversed primarily public-owned land, which allowed access on foot to random points. On these 2 routes, I walked to random points and/or viewed them from the road to assess land-cover type and canopy height. I visually classified land-cover type and canopy height based on the modified Anderson et al. (1976) classification scheme. At each random point I classified vegetation with waist-high canopy height as category 11, (0-1 m [see Appendix A]), and head-high canopy height as category 12 (1-3 m). I estimated canopy height greater than head-high using a laser range finder, and classified those canopy-height estimates as category 12 (1-3 m), 13 (3-5 m), or 2 (>5 m). If random points were visible from the road, I also classified land-cover type and canopy height from the road, and used these estimates to inform future classification that occurred only from the road.

Following classification of land-cover composition along the initial 2 routes, I selected 6 routes in Minnesota and 6 routes in Wisconsin that were both convenient to survey and located throughout the forested portions of each state (to include all land-cover types occurring in the survey area). For each of these routes, I randomly selected 100 points within 30 m of the road (a distance that allowed consistent classification of land-cover composition) using Hawth's Tools (Beyer 2004). I then used a GPS to find these random points. I viewed each random point from the road, and used a laser range finder to determine the approximate location of the point. For each point, I classified land-cover type and canopy height to the finest class in the Anderson scheme, but only used the first level classification for analysis.

I calculated accuracy of my air photo classifications using error matrices and the Kappa statistic (Congalton and Green 1999) based on classification of random points along survey routes. I did not include data from the 2 initial test routes in error matrices because I used these routes to assess survey protocols, and points along these routes were not assessed consistently (i.e., I modified the assessment procedures as I gained experience along these routes).

Because error rates derived from random points along the 6 Minnesota routes were unacceptably high (accuracy <40%) for some land-cover types, I selected 4 additional routes in Minnesota to improve delineation precision of roads (poorly represented in the original sample of random points) and wetlands (high initial error rates). On these 4 routes, I placed assessment points in all areas classified as wetlands or roads and selected routes with the highest number of polygons classified as wetlands. I calculated final error matrices by combining level-1 land-cover data and level-1 canopy-height data for each state (10 routes in Minnesota and 6 routes in Wisconsin) and derived land-cover types that reflected habitat used by woodcock. I combined the Anderson classes of non-forest, agricultural lands, and barren areas into a single land-cover type called open space and split forested land-cover into 2 land-cover types based on canopy height; early successional (canopy height <5 m, see above) and mature forest.

Statistical Analyses:--I assessed models relating woodcock counts to land cover along survey routes using an Information-Theoretic framework (Burnham and Anderson 2002) based on Akaike's Information Criterion (AIC: Akaike 1973) to identify models best-supported by the data. I created a suite of models *a priori* to the analysis that I based on woodcock ecology and previously published literature. I evaluated these models comparing woodcock counts to land-cover data using PROC GLIMMIX in program SAS v.9.2 (The SAS Institute, Inc. © 2007; Tables 1 and 2). The models related land cover within 330 m (Duke 1966) of SGS stops to the average SGS count for a 3-year period (Wisconsin 2004-2006, Minnesota 2007-2009). Because available land-cover data were from different years in Minnesota and Wisconsin, I evaluated the same set of models independently for each state. The general linear mixed model for a single parameter model was:

$$\mathrm{Log}(Y_{ij}) = \beta_0 + \log(X_{ij} + 1) + U_i$$

where Y_{ij} is the average SGS count for stop *i* at time *j*. For Minnesota, time *j* was the period 2007-2009, and for Wisconsin *j* was 2004-2006. I log-transformed counts to reflect a Poisson distribution associated with count data. X_{ij} is the proportion of a land-cover type at stop *i* and time *j*, which I log+1 transformed to convert to a Poisson distribution and to allow inclusion of land-cover types with 0% coverage at a stop. U_i allowed for correlation within routes at the stop level and assumed that route-level data were independent and normally distributed. I also included multiple parameter models in the suite of *a priori* models as linear combinations (see below for description of *a priori* model development).

I considered the following land-cover types in developing models relating SGS counts with land-cover composition surrounding listening stops:

D: Urban or developed land

Increased urban or developed land cover has been associated with a decline in woodcock numbers (Dwyer et al. 1983). Developed land provides little useable habitat for woodcock. I hypothesized that counts would be lower where the proportion of developed land surrounding a SGS listening stop was higher.

$\mathbf{P^2}$: Open space

In landscapes dominated by forest land-cover types or when open space occurs as a low proportion of the landscape the amount of open space has been associated with high woodcock numbers. However, when a high proportion of the landscape is open space or when forest land-cover types are a low proportion of the landscape, woodcock numbers are lower (Dwyer et al. 1983, Steketee et al. 2000). Open space provides breeding habitat (singing grounds) for woodcock. I hypothesized that the proportion of open space around SGS listening stops would be positively correlated with woodcock counts when open space occurred in low amounts, and would be negatively correlated with woodcock counts when it occurred in higher amounts. Therefore, I represented open space in models with a squared term ($P\text{-}P^2$) to account for this relationship.

R: Early successional forest

Amount of early successional forest and high stem density have been associated with higher woodcock numbers (Gutzwiller et al.1983, Steketee et al. 2000). Woodcock use early successional forest as foraging, breeding, and roosting habitat. I hypothesized that woodcock counts at SGS listening stops would relate positively to the amount of early successional forest surrounding those locations.

F: Mature forest

As a forest matures, it becomes less suitable for woodcock; higher amounts of mature forest have been associated with lower woodcock abundance (Dobell 1977, Keppie and Whiting 1994). I hypothesized that the proportion of mature forest in the landscape surrounding SGS listening stops would be negatively associated with woodcock counts.

W: Open water

Large bodies of water (ponds, lakes, and rivers) are not used by woodcock, and as the proportion of a landscape that is comprised of this land-cover type increases, woodcock abundance would be expected to decrease. I hypothesized that woodcock counts and the proportion of open water surrounding SGS listening stops would be negatively associated.

L: Wetlands

Woodcock abundance and abundance of wetlands are thought to be positively associated (Klute et al. 2000) because wetlands provide foraging habitat and potential sites for singing grounds. I hypothesized that the proportion of the area surrounding SGS stop locations comprised of wetlands would be positively associated with woodcock counts.

I also considered landscape parameters in models of woodcock counts to account for the configuration and/or the composition of land-cover types. I calculated landscape parameters using FRAGSTATS (http://www.umass.edu/landeco/research/fragstats/fragstats.html) at the stop level (330-m radius around each listening stop), and included the following parameters in *a priori* models:

Contag: Contagion Index

Contagion Index measures both interspersion (the intermixing of land-cover types) and dispersion (the spatial distribution of a land-cover type) of a landscape using a scale from 0 to 100. The contagion index is calculated by the sum of the probability that a cell belongs to class "a" and that an adjacent cell belongs to class "b" (McGarigal and Marks 1995). A landscape that has high interspersion will have a lower contagion value, whereas a landscape that has high dispersion (i.e., clumped) will have a higher contagion value. The importance of interspersion and dispersion is suggested by Gutzwiller et al.'s (1983) work, where they found that opening size and distance to multiple landscape features were consistent among sites used by woodcock. I hypothesized that lower values of the Contagion Index, indicating that landscapes were well interspersed but not clumped, would be positively associated with higher counts of woodcock. This configuration would be characterized by large patches of a land-cover type adjacent to multiple land-cover types, providing woodcock with areas that meet all of their habitat needs.

IJI: Interspersion and Juxtaposition Index

The Interspersion and Juxtaposition Index (IJI) measures interspersion on a scale from 0 - 100. This is similar to the Contagion Index, but dispersion is not included in the index's value allowing assessment of the effect of interspersion alone. IJI is calculated using land-cover patches rather than cells. A landscape that is well interspersed will have a higher IJI value. Based on Gutzwiller et al.'s (1983) work, I hypothesized that woodcock counts would be positively associated with high values of IJI.

FRAC_MN: Mean Fractal Dimension Index

The Mean Fractal Dimension Index (FRAC_MN) measures land-cover patch shape on a scale of 1 to 2. Simple shapes (e.g., a square) have values that approach 1, whereas complex shapes, with an increased amount of edge, have values that approach 2. Fractal Dimension Index is a measurement of edge that is minimally affected by scale and is calculated for each patch with a mean for a landscape, making it an appropriate measure of edge at the scale of the area surveyed around listening stops (where the number of patches was often <20; McGarigal and Marks 1995) . Steketee et al. (2000) found that FRAC_MN was higher at points used by woodcock, but did not suggest how FRAC_MN would be related to woodcock counts. I hypothesized that woodcock counts would increase with increasing FRAC_MN because increased edge is often associated with early successional vegetation.

To evaluate collinearity among land-cover parameters, I calculated a correlation matrix for the 6 land-cover types included in models of woodcock counts (Table 3). The correlation between mature forest and open space was the only statistically significant correlation ($r > 0.5$) among land-cover parameters. Based on this correlation, I did not include both mature forest and open space in any model other than the full model. I used all 6 land-cover types and 3 landscape metrics to create 19 *a priori* models relating land cover or landscape metrics at listening stops along SGS routes to woodcock counts at those stops. I evaluated models independently for Minnesota and Wisconsin because the land-cover data were derived from aerial photographs taken during different years (see Data Collection). The *a priori* suite of models included 9 single-factor models, 6 2-factor models, 2 3-factor models, the full model, and an intercept-only model (Table 2). The null model did not include any land-cover types or landscape metrics and the full model included all land-cover types, but no landscape metrics. Landscape metrics were not included in the full model to avoid duplicate measurements with in a single model (e.g., CONTAG and IJI both measure landscape interspersion). The single-factor models were included to assess the relationship of each land-cover type or landscape metric to SGS counts. Two-factor and 3-factor models combined land-cover types that related similarly to woodcock counts (e.g., positively or negatively). Two-factor and 3-factor models allowed me to determine whether a combination of similar land-cover types had an additive effect on woodcock counts (e.g., woodcock counts were greater when open space and early successional forest were both present than when only a single land-cover type was present). These multiple-factor models were represented as pairs; 1 model included the additional land-cover type as an additive term and the second included the additive term and an interaction term. This allowed me to determine if the presence of land-cover types in conjunction with other land-cover types had a greater effect on counts than either land-cover type on its own.

Results

I compiled and evaluated models based on 30 randomly selected SGS routes in Minnesota and 26 randomly selected SGS routes in Wisconsin (land-cover type delineation was not completed for 4 routes in the Wisconsin sample due to funding limitations and time constraints). In Minnesota, counts of woodcock at listening points on these routes ranged from 0-4 with a 3-year average that ranged from 0-3.33, with 488 woodcock counted along the selected routes over the 3-year period. In Wisconsin, counts ranged from 0-5 with a 3-year average that ranged from 0-3.66, with 414 woodcock counted along the selected routes over the 3-year period.

Land-cover Type Delineation Accuracy:-- I used land-cover data from 1,527 random points to calculate error matrices. I did not include points that were not visible from the road in error matrices. Accuracy of land-cover type delineation was 74% for Minnesota and 86% for Wisconsin with Kappa values of 0.69 and 0.83, respectively (Table 4). Classification accuracy of individual land-cover types in Minnesota ranged from 40 to 100% as follows: developed land (96.3%), open space (85.6%), mature forest (87.8%), permanent water (100%), wetland (50.8%), and early successional forest (40%). In Wisconsin the accuracy of individual land-cover types was; developed (90.3%), open space (44.2%), mature forest (93.7%), permanent water (100%), wetland (68.2%), and early successional forest (48%).

Model Summary:-- In Minnesota, the best-supported model of woodcock counts at stops along SGS routes included the proportion of open space (P^2), wetlands (L), and early successional forest (R) in the landscape surrounding listening stops (Table 1). There were 4 other competing land-cover models (ΔAIC ≤ 2, Table 1); (1) the single-factor model including the proportion of water (W) in the landscape surrounding listening stops (w = 0.17); (2) the 3-factor model including the proportion of L, P^2, R, and the interaction term L*P^2*R (w = 0.14); (3) the full model including the proportion of developed land (D), L, P^2, R, and mature forest (F) (w = 0.11); and (4) the single-factor model including the proportion of F (w = 0.08). The single-factor models that included only wetlands (β = 0.82, Confidence Interval (CI) [-0.38, 2.02]; Table 5) or early successional forest (β = 1.14, CI [0.00, 2.28]; Table 5) both exhibited a positive relationship with woodcock counts. Developed land (β = -1.12; CI [-5.51, 3.27]), mature forest (β = -1.18; CI [-2.22, -0.14]), and water (β = -10.89; CI [-21.40, -0.38]) all were related negatively to counts (Table 5). Open space (β = 0.87; CI [-1.25, 2.99]) was positively related to counts, but because open space was included in the model with a negative squared term, it indicated an increase followed by decrease that was not statistically significant. The best-supported model of woodcock counts in Minnesota received 10 times the weight of the intercept-only model, and was slightly under-dispersed (χ^2/degrees of freedom = 0.44), indicating reasonable model fit.

In Wisconsin, the best-supported model included only the proportion of early successional forest surrounding listening stops and had a model weight of 0.25 (Table 2). There were 2 competing models (ΔAIC ≤ 2, Table 2); (1) a model including only IJI (w = 0.22), and (2) a 2-factor model that included the proportion of R and P^2 (w = 0.21; Table 5). In single-factor models, wetlands (β = 0.75; CI [-2.03, 3.53]) and early successional forest (β = 2.25; CI [0.96, 3.54]) both related positively to counts. Developed land (β = -

2.01; CI [-6.38, 2.36]), mature forest (β = -1.19; CI [-2.39, 0.01]), and water (β = -2.31; CI [-10.27, 5.65]) all related negatively to counts. Open space (β = 0.44; CI [-1.97, 2.85]) was positively related to counts, but because open space was included in the model with a negative squared term, it indicated an increase followed by decrease that was not statistically significant. The best-supported model of woodcock counts in Wisconsin received more than 20 times the weight of the intercept-only model and was slightly under-dispersed (χ^2/degrees of freedom =0.55), indicating reasonable model fit.

Discussion

In Minnesota and Wisconsin, counts of woodcock at stops along SGS routes were related to land-cover type and a landscape metric related to interspersion and amount of edge. Mathematical models relating woodcock counts to land-cover type and composition at stops along SGS routes were consistent with expected woodcock-habitat relations identified in the published literature (e.g. Dwyer et al. 1983, Steketee et al. 2000). Early successional forest and open space were the only 2 land-cover types included in the competing models in both Minnesota and Wisconsin (ΔAIC ≤ 2, Tables 1 and 2). This suggests that early successional forest and open space are the 2 land-cover types that best explain counts across broad regions. In addition, my analyses suggested additional woodcock-habitat relations not previously identified; a negative relationship between amount of water and woodcock counts in Minnesota, a positive relationship between IJI (an index of juxtaposition and interspersion of cover-class patches) and woodcock counts in Wisconsin, and a relative lack of association between woodcock counts and the amount of developed land around stops.

It is important to note that the accuracy of the land-cover classification for early successional forest in Minnesota (40%) and Wisconsin (48%) was lower than for most other land-cover types. These accuracy rates reflect the difficult nature of determining forest height from aerial photographs. Most (Minnesota 91% and Wisconsin 100%) of the misclassifications were of classifying early successional forest as mature forest (Table 4), which suggests that forest height was often misclassified. Misclassifying mature forest as early successional forest likely affected my results, because the amount of mature forest and early successional forest relate inversely to SGS counts and the inclusion of mature forest with early successional forest would therefore decrease the magnitude of the relationship between SGS counts and early successional forest. Under those circumstances, I likely underestimated the magnitude of the relationship between early successional forest and counts of woodcock on SGS routes.

The magnitudes and direction of relationships between individual land-cover types and landscape metrics and woodcock counts on SGS routes is indicated by parameter estimates of single-parameter models (Table 5). In Minnesota, the model that only included the proportion of water in the landscape was the second-best-supported model (ΔAIC = 0.3, w = 0.17; Table 1). Several studies have considered distance to water (e.g., Gutzwiller et al. 1983, Steketee et al. 2000), but no other published studies have considered the amount of water in the landscape as a factor related to woodcock counts or abundance. The area surrounding most (93%) SGS stops located in Minnesota and Wisconsin was comprised of < 5% water. However, water occurred in a large percentage of a few stops (e.g., maximum of 38% in Minnesota and 20% in Wisconsin). Permanent water offers no direct resources to woodcock and is effectively non-habitat, decreasing the amount of area available to woodcock along a SGS stop. I suspect that this lower amount of potential habitat surrounding SGS listening stops drives the negative relationship between amount of water and woodcock counts.

In Wisconsin, the model that only included the landscape metric IJI was the second-best supported model (ΔAIC = 0.23, *w* = 0.22; Table 2). The IJI measures the interspersion of land-cover patches. Gutzwiller et al. (1983) suggested that landscape parameters, such as distance to the nearest opening and size of opening, related to woodcock use of an area. Steketee et al. (2000) found distance to the nearest wooded wetland and the degree of slope to be the best predictors of woodcock habitat suitability in West Virginia. Woodcock use multiple land-cover types during the breeding season; open space for displaying, wetland for feeding, and early successional forest for cover. High interspersion of land-cover types in the landscape may decrease the distance woodcock need to travel to obtain resources, thereby creating more suitable locations within the area surrounding a single SGS stop.

In both Minnesota and Wisconsin, urban or developed land was not strongly related to woodcock counts at SGS stops (Tables 1 and 2). Dwyer et al. (1983) reported that the amount of urban land had a negative effect on woodcock counts across their 9-state (Maryland, New Jersey, New York, Pennsylvania, Vermont, New Hampshire, Connecticut, Massachusetts, and Maine) study area in the Eastern Management Region. Furthermore, the conversion of other land-cover types to urban or developed land is thought to be a large part of why woodcock populations have shown a declining trend in the Eastern Management Region (Owen et al. 1977, Steketee et al. 2000). In my study, however, only 8 stops in Wisconsin and 7 in Minnesota were comprised of ≥ 20%

developed land, with a maximum of 49.8% in Wisconsin and 36.6% in Minnesota. SGS routes in the Central Management Region, particularly in Minnesota and Wisconsin, appeared to include relatively low amounts of developed land cover—the majority of this land-cover type consisted of roads (unpublished data). The significant negative relationship between urban land cover and woodcock use found in other studies may be present in Minnesota and Wisconsin, but was not evident in my sample of routes.

Best-supported models relating land-cover types along SGS survey routes to woodcock counts were different in Minnesota and Wisconsin (Tables 1 and 2). In Minnesota the combination of the land-cover types open space, wetlands, and early successional forest, which related positively to counts, were present in 3 of the competing models, including the best-supported model. The remaining 2 competing models in Minnesota that included proportion of water and mature forest, both related negatively to SGS counts (Table 1). In Wisconsin, early successional forest was included in 2 of 3 competing models, including the best-supported model. The remaining competing model included only IJI (Table 2). All of the competing models in Wisconsin related positively to counts. These results suggest that woodcock may be responding to different land-cover characteristics in different areas, indicating that management efforts may need to focus on different land-cover types in different areas. For example, it may be more appropriate to manage for early successional forest in Wisconsin and for the combination of open space, early successional forest, and wetlands in close proximity in Minnesota. Alternatively, the relationships I observed between woodcock counts and different land-cover types in Minnesota and Wisconsin may be a function of woodcock abundance or population growth. Woodcock counts in Minnesota increased (0.18% per year) from

1999 – 2009, whereas in Wisconsin, counts decreased (1.08% per year) over the same period (Cooper and Parker 2009). Therefore, woodcock may respond differently to landscape composition as a function of woodcock abundance or population growth rather than local land-cover composition.

Management Implications:-- The American woodcock conservation plan (Kelley et al. 2008) is based on the premise that the best way to return woodcock densities to those observed in the late 1970s and to halt the apparent decline in woodcock populations is to increase the amount of woodcock habitat on the landscape. Early successional forest and open space were the 2 land-cover types that were included in the best-supported models and related positively to SGS counts in Minnesota and Wisconsin. The landscape parameter IJI was also related positively to SGS counts and was included in the best-supported model in Wisconsin, whereas in combination, 3 land-cover types (open space, wetland, and early successional forest) were included in 3 of the competing models in Minnesota. Based on these results, management efforts that focus on creating well-interspersed early successional forest and open space at the landscape level in Minnesota and Wisconsin are likely to result in increased densities and population size of woodcock.

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Figure 1. Distribution of American woodcock Singing-ground Survey routes in Minnesota and Wisconsin and an example of the area surveyed by a single route. Routes selected for analyses of relationships between land-cover type and woodcock counts are in black; all other routes are indicated in white. A full description of the level III ecoregions can be found at U.S. EPA (2007).

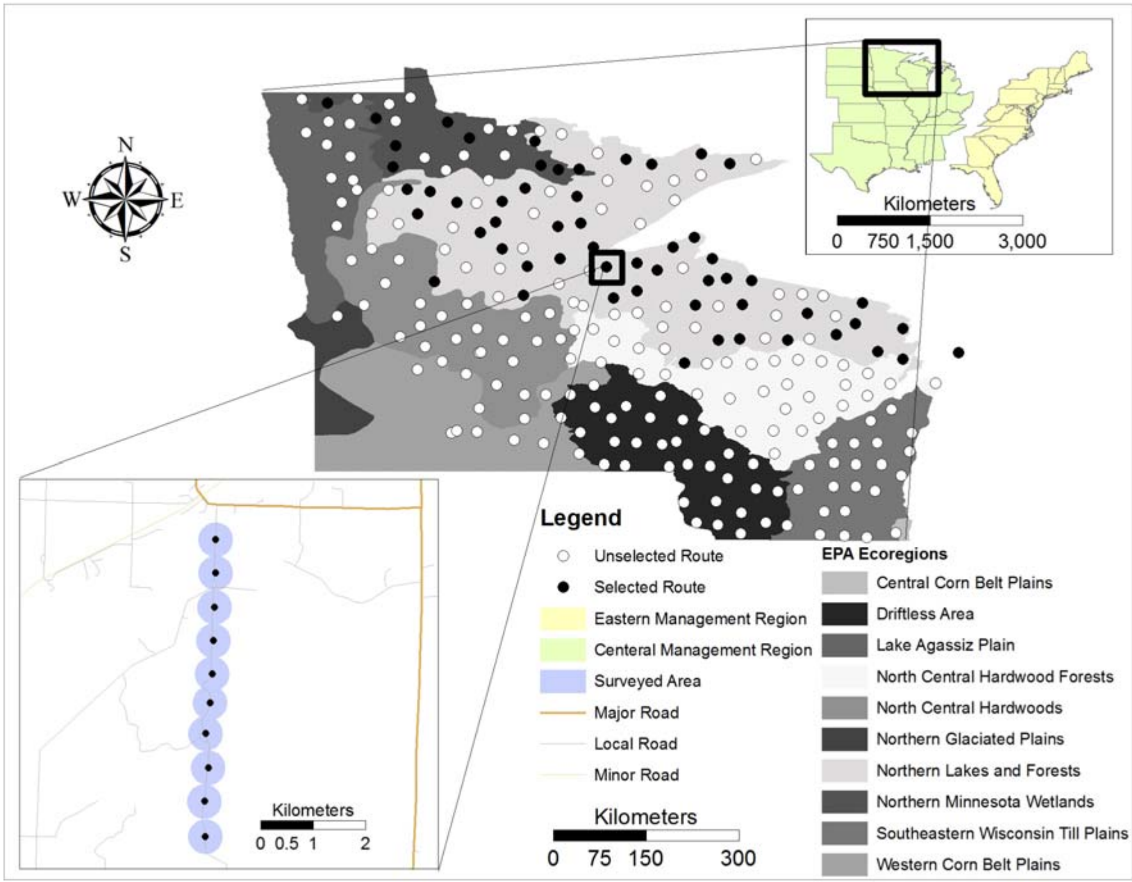

Table 1. Number of parameters (K), Akaike's Information Criterion (AIC), and model weights (w_i) for models of American woodcock counts (3-year average of Singing-ground Survey count) in Minnesota.

Model	**K**	**AIC value**	**ΔAIC**	w_i
Minnesota				
P^2,L,R[a]	4	536.88	0	0.20
W	2	537.18	0.30	0.17
P^2,L,R,P^2*L*R	5	537.63	0.75	0.14
D,P^2,F,W,L,R	7	538.13	1.25	0.11
F	2	538.6	1.72	0.08
P^2,L,P^2*L	4	539.51	2.63	0.05
P^2,R	3	539.81	2.93	0.05
D,F	3	539.99	3.11	0.04
R	2	540	3.12	0.04
D,F, D*F	4	541.54	4.66	0.02
CONTAG	2	541.56	4.68	0.02
(.)	1	541.61	4.73	0.02
L	2	541.79	4.91	0.02
P^2,L	3	542.82	5.94	0.01
Frac_MN	2	542.95	6.07	0.01
P^2	2	542.96	6.08	0.01
D	2	543.35	6.47	0.01
IJI	2	543.49	6.61	0.01
P^2,R,P^2*R	4	544.81	7.93	0.00

[a] D=developed, P=open space, F=mature forest, R= early successional forest, W=water, L=wetland, (.)=random intercept, see text for descriptions.

Table 2. Number of parameters (K), Akaike's Information Criterion (AIC), and model weights (w_i) for models of American woodcock counts (3-year average of Singing-ground Survey count) in Wisconsin.

Model	K	AIC value	ΔAIC	w_i
Wisconsin				
R[a]	2	459.21	0	0.25
IJI	2	459.44	0.23	0.22
P^2,R	3	459.61	0.40	0.21
P^2,L,R	4	461.24	2.03	0.09
P^2,R,P^2*R	4	461.61	2.40	0.08
P^2,L,R,P^2*L*R	5	462.77	3.56	0.04
D,F, D*F	4	463.46	4.25	0.03
CONTAG	2	463.5	4.29	0.03
D,F	3	465.03	5.82	0.01
D,P^2,F,W,L,R	7	465.45	6.24	0.01
F	2	465.83	6.62	0.01
(.)	1	467.44	8.23	0.00
D	2	468.56	9.35	0.00
W	2	469.1	9.89	0.00
L	2	469.17	9.96	0.00
P^2	2	469.31	10.10	0.00
Frac_MN	2	469.44	10.23	0.00
P^2,L	3	471.01	11.80	0.00
P^2,L,P^2*L	4	471.03	11.82	0.00

[a] D=developed, P=open space, F=mature forest, R= early successional forest, W=water, L=wetland, (.)=random intercept, see text for description.

Table 3. Correlation coefficients of the proportions of land-cover class within 330-m of stops along American woodcock Singing-ground Survey routes in Minnesota and Wisconsin.

	Land-Cover Type					
Land-Cover Type	**Developed**	**Open Space**	**Mature Forest**	**Water**	**Wetland**	**Early Successional Forest**
Minnesota						
Developed (D)	1					
Open Space (P^2)	0.09	1				
Mature Forest (F)	-0.15	-0.62	1			
Water (W)	0.19	-0.14	0	1		
Wetland (L)	-0.05	-0.1	-0.44	-0.05	1	
Early Successional Forest (R)	-0.17	-0.31	-0.15	-0.02	-0.27	1
Wisconsin						
Developed (D)	1					
Open Space (P^2)	0.35	1				
Mature Forest (F)	-0.47	-0.75	1			
Water (W)	0.21	-0.1	-0.09	1		
Wetland (L)	-0.08	-0.1	-0.23	0.15	1	
Early Successional Forest (R)	-0.11	-0.17	-0.37	-0.09	0	1

Table 4. Land-cover classification error matrices along American woodcock Singing-ground Survey routes in Minnesota and Wisconsin. Rows represent the classification of points based on photo interpretation. Columns represent the classification of a point from site visits. Accuracy is the proportion of photo interpretation points classified to the same land-cover type as site visit points.

	Site Visit Land-Cover Type							
Photo Interpreted Land-cover Type	**Developed**	**Open**	**Mature Forest**	**Water**	**Wetlands**	**Early Successional Forest**	**Photo Interpreted Accuracy by class (%)**	**Photo Interpreted Overall Accuracy (%)**
Minnesota								
Developed (D)	130	0	4	0	0	1	96.3	
Open Space (P^2)	4	161	17	0	2	4	85.6	
Mature Forest (F)	2	9	244	0	1	22	87.8	
Water (W)	0	0	0	4	0	0	100.0	
Wetlands (L)	0	37	52	0	127	34	50.8	
Early Successional Forest (R)	3	2	52	0	0	38	40.0	
								74.1
Wisconsin								
Developed	28	1	2	0	0	0	90.3	
Open Space (P^2)	2	23	22	0	2	3	44.2	
Mature Forest (F)	0	1	415	1	0	26	93.7	
Water (W)	0	0	0	4	0	0	100.0	
Wetlands (L)	0	0	6	1	15	0	68.2	
Early Successional Forest (R)	0	0	13	0	0	12	48.0	
								86.1

Table 5. Land-cover type and landscape metric coefficient estimates for single-parameter models relating land-cover type or landscape metric to woodcock counts (3-year average) with 95% confidence interval.

Land-cover class	Estimate of Coefficient	Standard Error	Lower Confidence Limit	Upper Confidence Limit
Minnesota				
Developed (D)	-1.12	2.24	-5.51	3.27
Open Space (P^2)	0.87	1.08	-1.25	2.99
Mature Forest (F)	-1.18	0.529	-2.22	-0.14
Water (W)	-10.89	5.36	-21.40	-0.38
CONTAG	-0.01	0.009	-0.03	0.00
Frac_MN	-2.77	3.435	-9.51	3.96
IJI	0.002	0.005	-0.01	0.01
Wetland (L)	0.82	0.61	-0.38	2.02
Early Successional Forest (R)	1.14	0.58	0.00	2.28
Wisconsin				
Developed (D)	-2.01	2.23	-6.38	2.36
Open Space (P^2)	0.44	1.23	-1.97	2.85
Mature Forest (F)	-1.19	0.61	-2.39	0.01
Water (W)	-2.31	4.06	-10.27	5.65
CONTAG	-0.02	0.008	-0.04	0.00
Frac_MN	-0.01	2.80	-5.50	5.47
IJI	0.02	0.005	0.01	0.03
Wetland (L)	0.75	1.42	-2.03	3.53
Early Successional Forest (R)	2.25	0.66	0.96	3.54

Appendix A. Modified Anderson Classification scheme including field description, class description, and classification value. Field description describes the class of measurement. Class Description describes 3 hierarchical levels of land-cover classes and 2 hierarchical levels of forest height. Classification value indicates the numerical value coded that corresponds to class description (Anderson et al. 1976).

Field Description	Class Description	Classification Value
Land Cover	Urban and Developed Areas	1
-	Residential	11
-	Multi-family	111
-	Single family/duplex	112
-	Mobile home parks	113
-	Farmstead	114
-	Other residential	119
-	Commercial, Services and Institutional	12
-	Industrial	13
-	Transportation, Communications and Utilities	14
-	Air transportation	141
-	Rail transportation	142
-	Water transportation	143
-	Paved road transportation	144
-	Communications	145
-	Utilities	146
-	Unpaved road transportation	147
-	Other	149
-	Mixed Use	16
-	Extractive	17
-	Open and other Urban	19
-	Outdoor cultural	191
-	Outdoor public assembly	192
-	Outdoor recreation	193
-	Cemeteries	194
-	Other	199

Appendix A. Continued

Field Description	Class Description	Classification Value
Land Cover	Agricultural Lands	2
-	Cropland, Rotation and Permanent Pasture	21
-	Cultivated crops	211
-	Hay and pasture	212
-	Orchards, Bush-Fruits and Vineyards	22
-	Confined Feeding Operations	23
-	Livestock	231
-	Poultry	232
-	Other	239
-	Other Agriculture	29
-	Cranberry fields	291
-	Non-forest (Non-forest, non-ag., non-developed, open space)	3
-	Grassland	31
-	Shrub land	32
-	Recently harvested clear cut	33
-	Forest Land	4
-	Broadleaved Forest	41
-	Upland hardwoods	411
-	Aspen, white birch, and assoc.	412
-	Lowland hardwoods	413
-	Coniferous Forest	42
-	Upland conifers	421
-	Lowland conifers	422
-	Mixed Conifer-Broadleaved Forest	43
-	Upland hardwoods and pine	431
-	Aspen/birch with conifers	432
-	Lowland hardwoods with conifers	433
-	Upland conifers with hardwoods	434
-	Lowland conifers with hardwoods	435

Appendix A. Continued

Field Description	Class Description	Classification Value
Land Cover	Water	5
-	Streams and Waterways (width)	51
-	Small streams and rivers (0-15 feet)	511
-	Medium streams and rivers (15-50 feet)	512
-	Large streams and rivers (>50 feet)	513
-	Lakes (area)	52
-	Ponds (0- 1.9 ha)	521
-	Small lakes (2- 9.9 ha)	522
-	Medium lakes (10-99.9 ha)	523
-	Large lakes (>100 ha)	524
-	Great Lakes	54
-	Wetlands	6
-	Wooded Wetlands	61
-	Wooded swamps (USE forest = 413, 422, 433, 435)	611
-	Shrub swamps	612
-	Non-wooded Wetlands	62
-	Marshland meadow	621
-	Mudflats	622
-	Shallow marshes (water depth 〈6 inches)	623
-	Deep marshes (water depth 6 in. to 3 ft.)	624
-	Barren Areas	7
-	Salt flats	71
-	Beaches and Riverbanks	72
-	Sand other than beaches	73
-	Bare Exposed Rock	74
Canopy Height	Young (0-5 m)	1
-	Clear cut (0-1 m)	11
-	Early regeneration (1-3 m)	12
-	Late regeneration (3-5 m)	13
-	Mature (≥5 m)	2

Appendix B. Source digital imagery and collateral data layers used to assist with delineation and classification of land-cover types along American woodcock Singing-ground Surveys routes in Minnesota and Wisconsin.

	Minnesota				Wisconsin			
Category	**Data Layer Name**	**Format**	**Source[a]**	**Year**	**Data Layer Name**	**Format**	**Source[a]**	**Year**
County Boundaries	County	Vector	MN DNR	Accessed 2009	County	Vector	WI DNR	Accessed 2009
Roads	State Roads	Vector	MN DNR	Accessed 2009	State Roads	Vector	WI DNR	Accessed 2009
Hydrography	MN 24k streams	Vector	MN DNR	Accessed 2009	WI 24k Hydro	Vector	WI DNR	Accessed 2009
Wetlands	MN NWI wetlands	Vector	MN DNR	Accessed 2009	DWWI	Vector	WI DNR	Accessed 2009
Soils	SSURGO 2003	Vector	USDA DataMart	2003	SSURGO 2003	Vector	USDA DataMart	2003
Aerial Photography	FSA 4-Band DOP RGBCIR 2008	Raster	NAIP	2008	FSA 3-Band DOP RGB 2005	Raster	FSA	2005
Aerial Photography	FSA 3-Band RGB DOP 2006	Raster	NAIP	2006	FSA 3-Band RGB DOP 2001-2003	Raster	FSA	2001-2003
Aerial Photography	FSA 3-Band B/W DOP 1991	Raster	USGS	1991	FSA 3-Band B/W DOP 1991-1996	Raster	FSA	1991-1996

[a]MN DNR = Minnesota Department of Natural Resources, USDA = U.S. Department of Agriculture, FSA– Farm Service Agency, USGS = U.S. Geological Survey, WI DNR – Wisconsin Department of Natural Resources.

Chapter 2

Changes in Counts of American Woodcock in Relation to Changes in Land Cover along Singing-Ground Survey Routes in Wisconsin: 1992 to 2005

Abstract: Counts of American woodcock (*Scolopax minor*) on the annual Singing-ground Survey (SGS) have undergone long-term declines in both the Eastern and Central Management Regions, declining at an average rate of 1.1% per year in both regions from 1968 - 2009. However, few studies have examined how well or if the SGS survey effectively detects changes in woodcock abundance, and whether changes in woodcock counts are related to changes through time in land cover along survey routes. To assess these relationships, I evaluated models relating changes in land cover to changes in woodcock counts using an Information-Theoretic framework for SGS routes in Wisconsin between 1992 and 2005. Changes in the height, amount, and juxtaposition of forest land cover best explained changes in counts of woodcock between 1992 and 2005 on SGS routes in Wisconsin. Declines in counts of woodcock along SGS routes over the same period were best explained by land-cover becoming mature forest. Increases in counts were best explained by land-cover becoming early successional forest, open space, or wetlands. These results are consistent with woodcock-habitat relations described in published literature (i.e., woodcock use early successional forest with moist soils containing open areas for courtship and avoid mature forest), and suggest that changes through time in counts of woodcock on SGS routes are related to changes in habitat along routes that influence woodcock abundance.

Key Words: shorebird, American Woodcock, *Scolopax minor*, Central Management Region, Minnesota, Wisconsin, land cover change

Introduction

The American woodcock (*Scolopax minor*; hereafter woodcock) is a small, migratory game bird that is estimated to provide over a half million days of recreational hunting annually in the U.S. (Cooper and Parker 2009). In North America, woodcock are managed by the U.S. Fish and Wildlife Service in cooperation with Canada, with the objectives of maintaining populations and providing harvest opportunities. A primary source of information used to assess the status of woodcock in North America is the Singing-ground Survey (SGS), which is conducted annually across the bird's primary breeding range in the central and eastern U.S. and adjacent southern Canada. Since 1968, the SGS has been used to monitor woodcock population trends by counting the number of displaying male woodcock heard along approximately 1,500 5.4-km routes. When the SGS was initially implemented, survey routes were located along secondary roads within randomly selected 10-minute latitude-longitude geographic blocks (Sauer and Bortner 1991, Straw et al. 1994). Route locations, however, were not selected randomly, but were placed along secondary roads near the center of the 10-minute latitude-longitude block. Each route has 10 locations where observers count the number of singing ("peenting") male woodcock heard during a 2-minute interval. In spring, volunteers conduct counts during the peak of courtship, and the number of woodcock heard annually on these surveys is used to estimate the population trend of woodcock in North America (Cooper and Parker 2009).

Between 1968 and 2009, the number of singing male woodcock heard on the SGS declined an average of 1.1% per year in the Eastern and Central Management Regions (Cooper and Parker 2009), prompting concern about the population status of woodcock.

These concerns have led to reductions in hunting bag limits and season length, delays in opening dates of hunting seasons, and the development of a national woodcock management plan (Kelly et al. 2008). Counts on SGS routes are presumed to reflect woodcock abundance, and changes in counts through time are presumed to reflect changes in woodcock abundance. Woodcock abundance is related to amount, distribution, and availability of resources (e.g., food availability, amount and juxtaposition of cover important to reproduction and survival; Steketee et al. 2000), and as conditions change along survey routes, abundance of woodcock (and therefore, counts) is also expected to change (e.g., Hale and Gregg 1976). However, the relationship between change in woodcock counts along SGS routes and changes in land cover along routes is not well documented. Amount, distribution, and juxtaposition of land-cover types in the Central Management Region has changed since SGS routes were established. In Wisconsin, the amount of forested land increased from 6.19 million ha in 1983 to 6.59 million ha in 2006 (Miles 2010). Although the overall amount of forested land increased from 1983 to 2006, the amount of young (0-5 years) aspen (*Populus* spp.) and birch (*Betula* spp.) in Wisconsin declined by 56% over the same period (Miles 2010). Presumably, these changes in land-cover composition are reflected in woodcock counts along SGS routes, although this relationship has not been assessed in the Central Management Region. In the Eastern Management Region, Dwyer et al. (1983) compared changes in land cover to changes in woodcock counts and reported that only the change in the amount of developed land related significantly to changes in woodcock counts.

My objective was to evaluate how changes in woodcock counts along SGS routes in Wisconsin related to changes in land-cover composition along survey routes, to assess what factors were related to trends in woodcock counts over time. To accomplish this objective, I modeled the relationship between the change in SGS counts from 1991-1993 to 2004-2006 in Wisconsin and the change in the land-cover composition along routes from 1992 to 2005.

Study Area

I defined my study area as the area represented by existing SGS routes in Wisconsin. There are 117 SGS routes in Wisconsin distributed throughout the entire state. For my analysis, I used a subset of SGS routes that represented the primary forested area of the state based on the U. S. Environmental Protection Agency's (U.S. EPA) ecoregions (Fig. 1). This region is comprised of deciduous forests transitioning to coniferous forests and is interspersed with lakes and wetlands over gradual elevation changes (U.S. EPA 2007). In Wisconsin, forested land has increased from approximately 6.07 million ha in 1963 to 6.47 million ha in 2004 (Perry et al. 2008). Over relatively the same period (1968 – 2009), the trends in counts of woodcock on SGS routes in Wisconsin have declined at a rate of 0.69% per year (Cooper and Parker 2009). When considering a shorter period, the trends in the amount of forested land and change in SGS counts are similar. From 1996 to 2005 the amount of forested land increased from 6.43 million to 6.51 million ha (0.06% per year; Miles 2010) and counts of woodcock on Wisconsin SGS routes declined by 0.2% per year from 1995 to 2004 (Kelley 2004).

Methods

Data Collection:--I used SGS counts and high-resolution land-cover data to develop and evaluate models relating changes in woodcock counts along SGS routes to changes in land-cover composition. The U.S. Fish and Wildlife Service (FWS; Keri

Parker, personal communication) provided paper maps of routes, which I digitized using a Geographic Information System (GIS: ArcMap 9.3™; use of trade names does not imply endorsement by either the U.S. Geological Survey or the University of Minnesota). I then provided paper maps that included digitized routes, listening-stop locations, roads, and a high resolution aerial photograph background to the SGS regional coordinator (Sean Kelly, FWS), who sent them to survey volunteers and asked the volunteers to verify the accuracy of digitized listening-stops and route locations. Volunteers verified locations either by providing latitude and longitude coordinates (derived using a hand-held GPS) or by indicating corrections on paper maps.

The FWS also provided SGS count data, which consist of woodcock counts for each listening stop by year. For my analyses I created a change-in-counts field that I derived by subtracting the average SGS count for the final period (2004-2006) from the average count of the initial period (1991-1993) for each stop; for routes with duplicate counts in the same year (n = 8), I used the highest count for that year. I used the average count for 3-year periods to minimize the influence of annual variation in counts at each stop.

I contracted for the 2004-2006 classification of land-cover types of the area surrounding SGS routes (land-cover types were classified and delineated by B. Fevold, Brick Fevold, Inc.). Land-cover types along survey routes were classified using aerial photography interpretation, and based on habitat attributes important to woodcock (e.g., Dwyer et al. 1983, Steketee et al. 2000). Land-cover types along SGS routes for the final period (2004-2006) were classified using 2005 U.S. National Agriculture Imagery Program (NAIP) color aerial photographs with 1-m resolution. I delineated land-cover types for the initial period (1991-1993) using a mosaic of early 1990s black and white, 1-m resolution aerial photographs [primarily comprised of 1992 photographs obtained from Wisconsin View (2009)]. I classified land-cover types based on a modification of the Anderson Land Cover Classification scheme (Anderson et al. 1976) that incorporated estimates of canopy height (Appendix A; see below for description of canopy height estimates). I classified land-cover type for the area within a 330-m radius around each listening stop—the presumed maximum detection distance for woodcock (Duke 1966)--and I used ArcMap's buffer tool to create a 330-m radius circle buffer around each listening stop.

The Anderson et al. (1976) scheme is a classification of land cover at 3 hierarchical levels. Level-1 classification is landscape-level categories (e.g., forest, wetlands, water, etc.) and is the level I used in my analyses. The Anderson scheme does not include canopy height as an attribute of land-cover types, but canopy height is related to structural characteristics important to woodcock (e.g., stem density). Because I could not assess structural characteristics of vegetation directly from aerial photos, I estimated canopy height from aerial photographs as a surrogate for early successional cover types (e.g., early successional forest). I estimated canopy height with the aid of adjacent features (e.g., telephone poles, buildings), visual cues (e.g., shadow length), and collateral data layers (e.g., contrasting texture, etc. [Appendix B]). There is no standard maximum height definition for early successional forest. Cade (1985) included woody vegetation <5 m in his woodcock habitat suitability model and Steketee et al. (2000) included vegetation categories 0-1 m, 1-3 m, 3-6 m, 6-9 m and >9 m in models relating woodcock presence to land-cover types. I classified early successional forest as having canopy height <5 m (Appendix A) and used additional data layers (Appendix B) to aid in photo interpretation and delineation of land-cover data.

I randomly selected a subset of 26 routes to be used for modeling (Fig. 1). To be eligible for selection routes need to be located in the forested portion of Wisconsin (U.S. EPA 2007) and could not be in constant-0 status for 8 or more years between 1990 and 2006. I excluded 7 routes due to constant-0 status. Constant-0 status is defined by the SGS protocol as 2 consecutive years with 0 counts, after which the route is not surveyed for 5 years (Cooper and Parker 2009). To quantify land-cover changes between 1992 and 2005, I combined the land-cover data for the 2 periods using the UNION function in ArcMap, which combines 2 vector data layers into a single data layer. The resulting data layer represented change in land-cover between periods.

Land-cover Type Delineation Accuracy:--I evaluated accuracy of land-cover delineation based on 2005 aerial photos by comparing classification from aerial photograph interpretation with land-cover type determined by visits to 700 (100 per route) random points along 7 SGS routes. I tested and refined accuracy assessment protocol along a single route, which I selected because it primarily traversed public-owned land, which allowed unrestricted access to random points (n = 100). On that single route, I walked to random points and/or viewed them from the road to assess land-cover type and canopy height. I visually classified land-cover type and canopy height based on standing vegetation using the Anderson et al. (1976) classification scheme. At each random point I classified vegetation with waist-high canopy height as category 11, (0-1 m [see Appendix A]), and head-high canopy height as category 12 (1-3 m). I estimated canopy height greater than head-high using a laser range finder, and classified those canopy-height estimates as category 12 (1-3 m), 13 (3-5 m), or 2 (>5 m). If random points were visible from the road, I also classified land-cover type and canopy height from the road and used these estimates to inform future classification that occurred only from the road. I classified land-cover type and canopy height at all random points.

Following land-cover type and canopy height classification along the initial route, I selected 6 routes in Wisconsin that were both convenient to survey and located throughout the forested portions of the state (to include all land-cover types occurring in the survey area). I randomly identified 100 points within 30 m of the road (the distance at which I could consistently classify land-cover type and canopy height) using Hawth's Tools (Beyer 2004) for each route and used these 600 points to determine the accuracy of land-cover delineation. I used a handheld GPS unit to locate each of these points to assess land-cover type and canopy height. I viewed each random point from the road and used a laser range finder to determine the approximate location of the point. For each point, I classified land-cover type and canopy height to the finest class in the Anderson scheme, but only used the level-1 classification for analysis due to the poor accuracy of level-2 and level-3 land cover data.

I calculated accuracy of land-cover delineation from 2005 aerial photographs using error matrices and the Kappa statistic (Congalton and Green 1999) derived from visits to random points along survey routes. I did not include data from the initial test route (*n* = 100 points) in error matrices because I used this route to assess survey protocols, and points along these routes were not assessed consistently (i.e., I modified the assessment procedures as I gained experience at points along this route). I calculated final error matrices by combining level-1 land-cover data and level-1 canopy-height data and derived land-cover types that reflected habitat used by woodcock while maintaining a high level of accuracy. I combined the Anderson et al. (1976) classes of non-forest, agricultural lands, and barren areas into a single land-cover type called open space and divided forested land-cover types into 2 categories based on canopy height; early successional (canopy height <5 m, see above) and mature forest.

I was unable to calculate error matrices for 1992 as I lacked historical land-cover data along SGS routes in Wisconsin. However, I was able to assess the relative accuracy of land-cover type classification for 1991-1993 by evaluating accuracy of photo interpretation of similar photographs in areas with existing land-cover classification. I obtained historical stand data from 1992 for Minnesota from the Minnesota Department of Natural Resources (MN DNR) and classified 147 points at locations of known historical land-cover types using the techniques utilized in Wisconsin (e.g., 1992 NAIP black-and-white, 1-m resolution aerial photographs). Points were randomly selected using Hawth's Tools in 50 point increments until all land-cover types were represented (Beyer 2004). A few points (n = 3) were removed from the sample because they could not be classified based on the aerial photograph (e.g., cloud cover obstructed the ground). I then calculated error matrices based on the historical stand data and the land-cover types classified from aerial photos.

Statistical Analyses:--I assessed models relating woodcock counts to changes in land-cover type along survey routes using an Information-Theoretic framework (Burnham and Anderson 2002). Based on woodcock biology and available land-cover and landscape data I considered the following covariates to create *a priori* models:

D: Developed or urban land

Increased developed or urban land cover has been associated with a decline in woodcock numbers (Dwyer et al. 1983) in the Eastern Management Region, likely because woodcock generally avoid developed land for breeding.

P: Open space

Amount of open space has been associated with increasing woodcock numbers in landscapes dominated by forest land-cover types or when open space occurs as a low proportion of the landscape. However, when a high proportion of the landscape is open space or when forest land-cover types are a low proportion of the landscape, woodcock numbers decline (Dwyer et al. 1983, Steketee et al. 2000). Open space provides breeding habitat (singing grounds) for woodcock.

R: Early successional forest

Amount of early successional forest and high stem density have been associated with higher woodcock numbers (Gutzwiller et al.1983, Steketee et al. 2000). Woodcock use early successional forest as foraging, breeding, and roosting habitat.

F: Mature forest

As forested land cover matures, it becomes less suitable habitat for woodcock; higher amounts of mature forest have been associated with lower woodcock abundance (Dobell 1977, Keppie and Whiting 1994).

W: Water

Large bodies of water (ponds, lakes, and rivers) are not used by woodcock, and as the proportion of a landscape that is comprised of this land-cover type increases, woodcock abundance would be expected to decrease.

L: Wetlands

Woodcock abundance and abundance of wetlands are thought to be positively associated (Klute et al. 2000) because wetlands provide foraging habitat and potential sites for singing grounds.

I also considered a landscape configuration parameter in models of woodcock counts. I calculated landscape parameters using FRAGSTATS (http://www.umass.edu/landeco/research/fragstats/fragstats.html) at the stop level (330-m radius around each listening stop), and included the following landscape covariates in *a priori* models:

Contag: Contagion Index

Contagion Index measures both interspersion (the intermixing of land-cover types) and dispersion (the spatial distribution of a land-cover type) of a landscape using a scale from 0 to 100. The contagion index is calculated by the sum of the probability that a cell belongs to class "a" and that an adjacent cell belongs to class "b" (McGarigal and Marks 1995). A landscape that has high interspersion will have a lower contagion value, whereas a landscape that has high dispersion (i.e., clumped) will have a higher contagion value. The importance of interspersion and dispersion is suggested by Gutzwiller et al.'s work (1983), where they found that opening size and distance to multiple landscape features were consistent among sites used by woodcock.

Using these covariates I created general linear mixed models to assess the change in counts of woodcock between periods relative to the changes in habitat between those two periods. The model related change in land-cover type from 1992 to 2005 within 330 m (Duke 1966) of SGS stops to the change in the average SGS counts for 3-year periods around 1992 and 2005. The general linear mixed model is:

$$Y_i = \beta_0 + \log(X_i + 1) + U_i$$

Where

$$Y_i = Y_{iT2} - Y_{iT1}$$

And Y_i is assumed to have a normal distribution.

Y_{iT1} is the average SGS count for stop *i* at the initial period T_1 (1991-1993). Y_{iT2} is the average SGS counts for stop *i* at the final period T_2 (2004-2006). X_i is the proportion of a land-cover type for each change in land-cover type (e.g., the amount of land that changed from early successional forest to mature forest) at stop *i* between1992 to 2005, and is log+1 transformed to allow the inclusion of changes in land-cover type with 0% coverage at a stop. U_i allows for correlation within routes at the stop level and assumes that route-level data were independent and normally distributed.

A preliminary review of the data revealed that 11 potential land cover changes did not include a sufficient amount of change to evaluate (Table 1). Land cover changes that comprised <10% (3.42 ha) of a single stop for the sum of the change in land-cover type across all 26 routes were deemed to have insufficient data. There is very little published literature that relates change in land cover over time to change in woodcock counts; therefore, I included all 1-variable models (25 land-cover type changes, 1 landscape covariate, and the null model) in the suite of *a priori* models. I evaluated the 27 *a priori* models using SAS v.9.2 (The SAS Institute, Inc. © 2007) PROC GLIMMIX (Table 2) and ranked them using Akaike's Information Criterion (AIC: Akaike 1973). I expected several *a priori* models to relate to SGS counts similarly and I grouped these into 8 categories:

Land-cover that did not change from 1992 to 2005

D to D: Developed or urban land that remained in this land-cover type

F to F: Mature forest that remained in this land-cover type

W to W: Open water that remained in this land-cover type

P to P: Open space that remained in this land-cover type

R to R: Early successional forest that remained in this land-cover type

L to L: Wetland that remained in this land-cover type

Land-cover type that does not change over time is not likely to affect woodcock counts, unless the land cover changed in a way that influenced woodcock use, but did not change the classification of the land-cover type (e.g., maturing forest). Of the land-cover types I considered, both developed or urban land (D) and mature forest (F) could potentially be used less by woodcock through time, as habitat characteristics important to woodcock (e.g. high stem density) may change. How woodcock counts are related to presence of water (W) likely does not change over time, although water condition may change within and between years. Open space (P) and early successional forest (R) are likely to change to another land-cover type over a 14-year period, as open space becomes invaded by woody vegetation and early successional forest matures. However, if these land-cover types remain constant, open space and early successional forest may be positively associated with change in woodcock counts (e.g., Dwyer et al. 1983, Steketee et al. 2000). Wetlands are less likely to change to another land-cover type in 14 years than open space or early successional forest.

Land cover classified as developed in 1992 that changed to another land-cover type by 2005

D to P: Developed or urban land that changed to open space

D to F: Developed or urban land that changed to mature forest

Only change in land-cover type from developed or urban to open space or mature forest had sufficient amounts of land-cover change to be evaluated. Land-cover change from developed to open space would likely be positively related to changes in woodcock counts, as open space relates positively to SGS counts at a single time (e.g., Dwyer et al. 1983). Changes from developed or urban land cover to mature forest would likely not be associated with change in woodcock counts, as both of these land-cover types relate negatively to SGS counts at a single time (e.g., Dwyer et al. 1983).

Land-cover type change to developed or urban land in 2005

F to D: Mature forest that changed to developed or urban land

R to D: Early successional forest that changed to developed or urban land

P to D: Open space that changed to developed or urban land

Only changes in land-cover type from mature forest, early successional forest, or open space to developed had sufficient amounts of land-cover change to be evaluated. Developed or urban land cover offers few resources to woodcock and is likely negatively associated with changes in woodcock counts (e.g., Dwyer et al. 1983). Therefore, any change from another land-cover type to developed or urban land cover would be negatively associated with woodcock counts. An exception may be when mature forest changes to developed land cover if openings are created that woodcock can utilize during breeding.

Land cover classified as water in 1992 that changed to another land-cover type by 2005

W to F: Water that changed to mature forest

W to L: Water that changed to wetland

W to R: Water that changed to early successional forest

Only changes in land-cover type from water to mature forest, early successional forest, or wetland had sufficient amounts of land-cover change to be evaluated. Changes from water to other land-cover types likely relate positively to changes in woodcock counts as other land-cover types provide more resources to woodcock than open water.

Land-cover type change to mature forest in 2005

P to F: Open space that changed to mature forest

R to F: Early successional forest that changed to mature forest

L to F: Wetland that changed to mature forest

As other land-cover types change to mature forest, counts of woodcock would be expected to decrease, based on established woodcock-habitat relations (e.g., Dobell 1977, Keppie and Whiting 1994).

Land cover classified as mature forest in 1992 that changed to another land-cover type by 2005

F to P: Mature forest that changed to open space

F to L: Mature forest that changed to wetland

F to R: Mature forest that changed to early successional forest

As land-cover type changes from mature forest to open space, wetlands, or early successional forest, abundance of woodcock would be expected to increase (e.g., Hale and Gregg 1976). Open space, wetlands, and early successional forest all are used by woodcock to a greater extent than mature forest (Dwyer et al. 1983, Steketee et al. 2000).

Change to or from open space, wetlands, and early successional forest in 2005

P to R: Open space that changed to early successional forest

R to P: Early successional forest that changed to open space

L to R: Wetland that changed to early successional forest

R to L: Early successional forest that changed to wetland

L to P: Wetland that changed to open space

P to L: Open space that changed to wetland

As land-cover type changes to or from open space, early successional forest, or wetlands, woodcock use of these sites could change. However, all of these land-cover types are used by woodcock, and factors that influence abundance as these changes occur are likely at the scale of characteristics of individual patches. Therefore, it is not clear whether changes between these land-cover types would be related to changes in woodcock abundance, and there is little or no published information regarding the nature of any relationship between these changes and changes in woodcock abundance. However, because the effects of these changes in land-cover type on woodcock are not clear, I included these factors in *a priori* models to assess potential relationships.

Change in the landscape metric from 1992 to 2005

Δ Contag: The difference between the value of the Contagion Index from 1992 to 2005.

When Δ Contag is negative it indicates that the interspersion of the landscape has increased. This would likely correspond to an increase in SGS counts as Gutzwiller et al. (1983) suggested that woodcock use landscape with high interspersion.

I developed 27 *a priori* models, including 25 single-factor land-cover change models, the null model, and a single landscape-metric model (Table 2). The null model did not include any land-cover change variables, and I included this model as a reference for models that included cover-type and landscape variables. I assessed support for these models in an Information-Theoretic framework (Burnham and Anderson 2002)

I then used the results of the single-variable *a priori* models to guide in developing models *post hoc* that included multiple variables that were biologically relevant. Prior to creating multiple-variable models I evaluated collinearity between all possible pairs of land-cover type change variables and the contagion metric by calculating a correlation matrix (Appendix C). I then combined non-correlated variables into a single model, and evaluated model fit using AIC.

Results

I assessed 27 *a priori* models using the change in woodcock counts, and landscape or land-cover-type data from 1991-1993 and 2004-2006 from 26 SGS routes in Wisconsin. Woodcock SGS counts for the initial period (1991-1993) ranged from 0-4 at listening stops with a 3-year average per stop that ranged from 0-2.33. Woodcock counts along the 26 routes averaged 116.3 woodcock per year (range 100 to140 per year) during 1991 - 1993. During 2004-2006, woodcock counts at stops along Wisconsin SGS routes ranged from 0-5 with a 3-year average per stop that ranged from 0-3.66. Woodcock counts along the 26 routes averaged 137.7 woodcock per year (range 127 to 158 per year) during 2004 - 2006. From 1991-1993 to 2004-2006, the average number of woodcock counted along these 26 routes increased by 21.33 woodcock or 0.85 woodcock per route (18.3%). Of the 260 stops for the initial period, woodcock were present on an average of 80 stops (range 69 to 94 stops) during 1991 – 1993 and on an average of 92 stops (range 83 to 106 stops) during 2004 - 2006.

Approximately 25% (24.9%) of area included in my sample changed land-cover type between woodcock survey periods. However, because land-cover types could change from or to any other land-cover type, net change (increase or decrease in a land-cover type that was not offset by an equal, but opposite change in land-cover type) in land-cover composition was 11.94% of the area surrounding listening stops. The net change in land-cover ranged from -4.13% to 3.08% across land-cover type and relative change (the amount of a given land-cover type that has changed over time divided by the amount of the given land cover type at the initial period) ranged from -31.53% to 36.5% (Table 3).

Land-cover Types Classification Accuracy:-- I classified land-cover type at 577 of the 600 random points along 6 SGS routes (33 of the random points were not visible from the road), and based on these points, overall land-cover type classification accuracy for 2005 was 86% (Kappa-value = 0.83, Table 4). The accuracy of classification of individual land-cover types ranged from 44 – 100% (Table 4). I determined the accuracy of land-cover type classification from 1992 aerial photographs from Minnesota to be 87% (Kappa-value = 0.84; Table 4), based on assessment of 147 points for which historical land-cover data were available. The accuracy of individual land-cover type classification ranged from 56 – 100%, suggesting that land-cover type classification for 1992 in Wisconsin was comparable to that from the 2005 (Table 4).

Model Summary:-- Nine models, including 2 models with variables representing land-cover type that did not change between 1992 and 2005, 5 models that included variables that representing change in land-cover type, 1 landscape model, and 1 multivariable model, had lower AIC values than the intercept-only model (Table 5). The best-supported *a priori* model of change in woodcock counts between periods included Δ Contag with a model weight (w) of 0.17, >5 times the weight of the intercept-only model (Table 2). There were 5 competing models ($\Delta AIC \leq 2$, Table 2), including: unchanged mature forest (F) (w = 0.12), F to early successional forest (R) (w = 0.10), developed or urban (D) to open space (P) (w = 0.08), unchanged wetland (L) (w = 0.10), and R to F (w = 0.08). Three variables (Δ Contag; β=-0.008, 95% Confidence Interval (CI) = [-0.014, -0.002] F; β = -0.679, CI = [-1.268, -0.092]: R to F; β = -0.944, CI = [-1.842, -0.038]) were related to decreases in SGS counts from 1991-1993 to 2004-2006 (Table 6). Four variables (F to R; β = 1.048, CI = [0.129, 1.971]: D to P; β = 22.004, CI = [1.498, 42.502]: L; β = 1.956, CI = [0.137, 3.783]: P to R; β = 1.967, CI = [-0.029, 3.969]) were related to increases in SGS counts between periods (Table 6). Combining single-variable models *post hoc* resulted in 1 additional model, which included land-cover type change from F to R and R to F (w = 0.19). Including this model reduced the number of competing models to 3 ($\Delta AIC \leq 2$, Table 5); including: Δ Contag (w = 0.14), F (w = 0.09), and F to R (w = 0.08).

Discussion

Few analyses have related changes in land-cover type to changes in woodcock counts, but considerable information is available regarding woodcock-habitat relations. I was able to quantify change in land-cover type along SGS routes in Wisconsin from 1992 to 2005 and relate those changes to changes in woodcock counts from 1991-1993 to 2004-2006. Based on the results of previous studies relating woodcock abundance to land-cover type and changes in land-cover type through time, I expected to find a relationship between land-cover type change and woodcock counts. Dwyer et al. (1983) found that developed land cover was significantly related to woodcock counts in the Eastern Management Region; however, that was the only land-cover type they found that significantly related to woodcock counts. In contrast, my results suggested that several changes from 1 land-cover type to another were associated with changes in woodcock counts indicating that the SGS tracks changes in woodcock abundance associated with change in land-cover composition.

Dwyer et al. (1983) compared change in land-cover type to change in counts, but did not consider initial land-cover type. I examined change to and from land-cover types to assess how land-cover type change was related to change in counts, which may in part explain differences in results between Dwyer et al. (1983) and my study. For example, in my study I found that the change from regenerating to mature forest was negatively related to change in SGS counts whereas other land-cover type changes that resulted in mature forest at the final time period (P to F, L to F, W to F, and D to F) were not associated with change in SGS counts. Dwyer et al. (1983) combined all of these land-cover-type changes into a single category, which may also explain why their results differed from mine. By considering the initial and final land-cover type I was able to assess whether there were relationships between specific land-cover type changes and changes in SGS counts (Table 2).

Developed or urban land has been shown to be negatively related to woodcock counts or abundance in other studies (Dwyer et al. 1983, Steketee et al. 2000). However, I was unable to detect the same correlation in my study (Table 2). These conflicting results may be due to the extent or type of developed land measured. The amount of developed land cover along SGS routes in my study was < 7% of the landscape during both periods but was 36% higher in 2006, relative to 1992. This relative increase in the amount of developed land cover is comparable to the average relative increase reported by Dwyer et al. (1983) of 33.4% (range = 13.4 % – 41.1%). However, Dwyer et al. (1983) did not report the proportion of the landscape they evaluated that was comprised of developed land, making it difficult to directly compare relative increases across studies. If developed land accounted for a higher proportion of the landscape studied by Dwyer et al. (1983), then the relative increase would indicate a much larger increase in the area of developed or urban land surveyed by SGS routes. The category of developed or urban land is also very broad and includes land-cover types such as dirt roads and high-density residential areas. The type of developed or urban land may also differ among studies, again making comparison difficult.

In Wisconsin, change in SGS counts appeared to be related to the amount, height, and juxtaposition of forest. When including the *post hoc* model, all of the competing models (Δ AIC < 2.0; Table 5) either included mature forest or variables correlated with mature forest (e.g., Δ Contag, $r = 0.18$, $P < 0.05$), suggesting that changes in counts of woodcock along SGS routes are associated with changes in the surrounding landscape related to mature forest cover.

Management Implications:--There are 2 basic management implications of this study. First, counts of woodcock at stops along SGS routes track changes in woodcock abundance that are related to changes in land-cover over time, suggesting that the SGS tracks changes in woodcock abundance that are related to changing habitat conditions. Second, when managing to affect woodcock abundance, it is important to consider the initial and final land-cover types when manipulating landscapes. My results indicate the changes in land-cover type that increase the amount of early successional forest and decreasing the amount of mature forest (e.g., R to F), while increasing the interspersion of land-cover types in the landscape are likely to increase woodcock counts.

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Figure 1. Distribution of American woodcock Singing-ground Survey routes in Wisconsin and an example of the area surveyed by a single route. Routes selected for analyses of relationships between land-cover type and woodcock counts are in black; all other routes are indicated in white. A full description of the level III ecoregions can be found at U.S. EPA (2007).

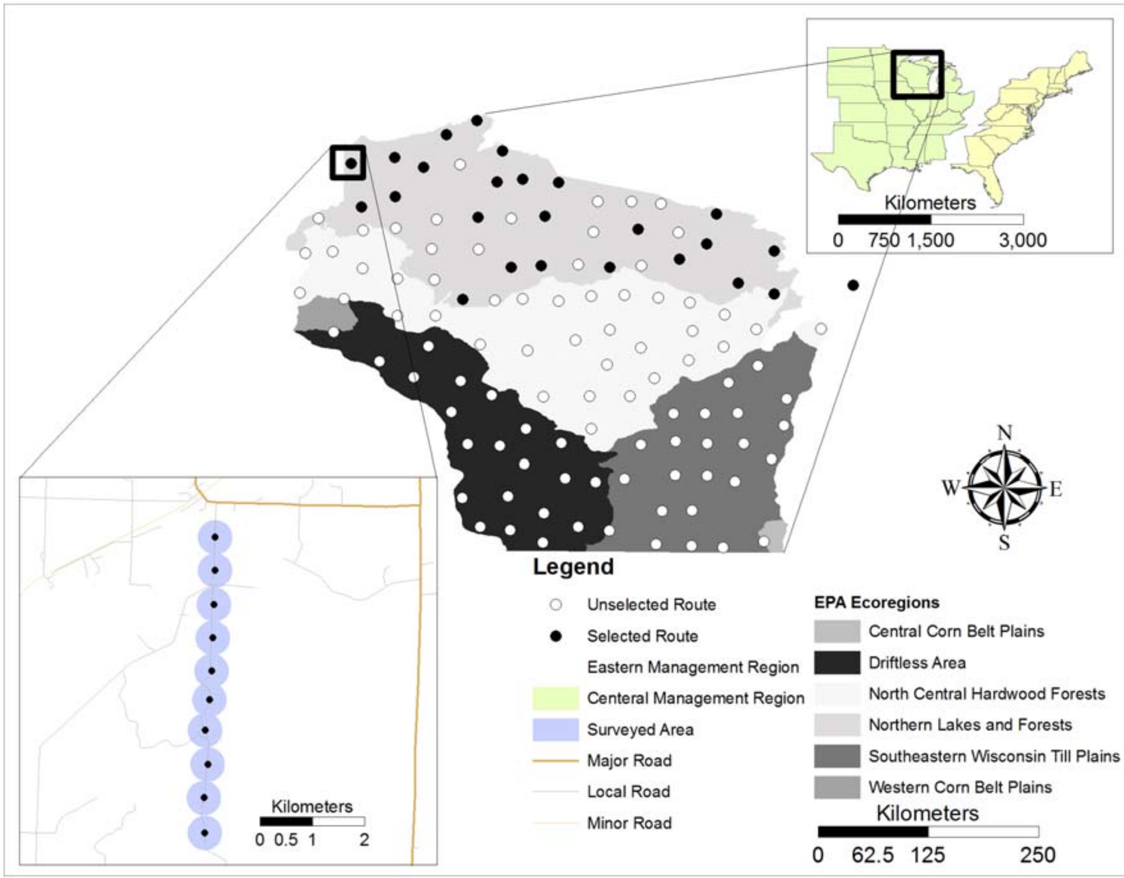

Table 1. The sum of the area for the change in each land-cover type from 1992 to 2005 along 26 Singing-ground Survey routes in Wisconsin. The first land-cover type indicates the land-cover type in 1992 and the second land-cover type indicates the land-cover type in 2005. A single land-cover indicates that the land-cover type remained the same between 1992 and 2005.

Land-cover Type Change	**Area (ha)**	**Land-cover Type Change**	**Area (ha)**
F[a]	4874.13	R to P	33.92
P	823.60	D to F	24.81
R to F	573.82	R to D	11.53
F to R	425.21	L to P	11.35
D	347.32	D to P	9.64
P to F	251.40	W to F	5.65
L	186.24	L to R	5.46
F to L	155.22	W to R	4.00
L to F	144.01	D to R [b]	3.23
P to R	109.28	F to W [b]	2.95
R	102.01	W to D [b]	2.50
W	87.69	L to D [b]	2.45
F to D	83.46	D to L [b]	1.79
P to D	80.97	L to W [b]	1.37
F to P	69.45	W to P [b]	0.84
R to L	42.46	P to W [b]	0.75
P to L	35.87	R to W [b]	0.16
W to L	35.19	D to W [b]	0.11

[a] D=developed, P=open space, F=mature forest, R= early successional forest, W=water, L=wetland, (.)=random intercept

[b] Insufficient area to allow for analysis (i.e., < 10% of a single stop)

Table 2. Number of parameters (K), Akaike's Information Criterion (AIC), and model weights (w_i) for *a priori* models of change of American woodcock counts at points along Singing-ground Survey routes related to change in land-cover types in Wisconsin from 1991-1993 to 2004-2006.

Model	K	AIC Value	ΔAIC	w_i
Δ Contag [a]	2	511.73	0.00	0.17
F	2	512.51	0.78	0.12
F to R	2	512.74	1.01	0.10
D to P	2	513.19	1.46	0.10
L	2	513.21	1.48	0.09
R to F	2	513.43	1.70	0.07
P to R	2	513.9	2.17	0.03
D to F	2	515.45	3.72	0.03
(.)	1	515.57	3.84	0.03
P	2	515.71	3.98	0.02
W to F	2	516.13	4.40	0.02
F to L	2	516.13	4.40	0.02
L to F	2	516.27	4.54	0.02
L to R	2	516.28	4.55	0.02
W	2	516.59	4.86	0.02
W to L	2	516.61	4.88	0.02
F to D	2	516.63	4.90	0.02
R	2	516.93	5.20	0.02
P to L	2	516.96	5.23	0.01
R to D	2	517.01	5.28	0.01
R to P	2	517.13	5.40	0.01
P to F	2	517.14	5.41	0.01
P to D	2	517.21	5.48	0.01
F to P	2	517.44	5.71	0.01
R to L	2	517.48	5.75	0.01
D	2	517.52	5.79	0.01
L to P	2	517.55	5.82	0.01
W to R	2	517.57	5.84	0.01

[a] Contag = Contagion Index, D=developed, P=open space, F=mature forest, R= early successional forest, W=water, L=wetland, (.)=random intercept

Table 3. Land-cover composition for1992 and 2005 and change in land-cover type from 1992 to 2005 in Wisconsin along 26 Singing-ground Survey routes. Land-cover type change is the net percent change (an increase or decrease in a land-cover type that is not offset by an equal, but opposite change in land-cover type) and relative percent change (the amount of a given land-cover type that has changed over time divided by the amount of the given land cover type at the initial time period 1992).

	Land-cover Composition (%)		**Land-cover type Change (%)**	
Land-cover Type	**1992**	**2005**	**Net**	**Relative**
Developed	4.53	6.18	1.65	36.53
Open space	15.23	11.10	-4.13	-27.12
Mature forest	65.62	68.70	3.08	4.70
Water	1.59	1.09	-0.50	-31.53
Wetland	4.10	5.34	1.24	30.17
Early Successional Forest	8.93	7.59	-1.34	-15.02

Table 4. Land-cover classification error matrices along American woodcock Singing-ground Survey routes in Minnesota (1992) and Wisconsin (2005). Rows represent the classification of points based on photo interpretation. Columns represent the classification of a point from visits to random points along survey routes (Wisconsin) or Minnesota Department of Natural Resources land-cover type mapping (Minnesota). Accuracy is the proportion of photo interpretation points classified to the same land-cover type as visited points (Wisconsin) or historical land-cover data (Minnesota).

	Land-Cover Type (visit or historical data)							
Photo Interpreted Land-cover Type	**Developed**	**Open**	**Mature Forest**	**Water**	**Wetlands**	**Early Successional Forest**	**Photo Interpreted Accuracy (%)**	**Overall Accuracy (%)**
2005								
Developed	28	1	2	0	0	0	90	
Open	2	23	22	0	2	3	44	
Forest	0	1	415	1	0	26	93	
Water	0	0	0	4	0	0	100	
Wetlands	0	0	6	1	15	0	68	
Early Successional Forest	0	0	13	0	0	12	48	
								86
1992								
Developed	2	0	0	0	0	0	100	
Open	0	5	0	0	0	4	55	
Forest	0	0	71	0	0	9	88	
Water	0	0	0	4	0	0	100	
Wetlands	0	0	1	1	20	1	87	
Early Successional Forest	0	0	1	0	2	26	90	
								87

Table 5. Number of parameters (K), Akaike's Information Criterion (AIC), and model weights (w_i) for *post hoc* and *a priori* models of change of American woodcock counts at points along Singing-ground Survey routes related to change in land-cover types in Wisconsin from 1991-1993 to 2004-2006.

Model	**K**	**AIC Value**	**ΔAIC**	w_i
F to R, R to F[a]	3	511.09	0	0.19
Δ Contag	2	511.73	0.64	0.14
F	2	512.51	1.42	0.09
F to R	2	512.74	1.65	0.08
D to P	2	513.19	2.10	0.07
L	2	513.21	2.12	0.07
R to F	2	513.43	2.34	0.06
P to R	2	513.9	2.81	0.05
D to F	2	515.45	4.36	0.02
(.)	1	515.57	4.48	0.02
P	2	515.71	4.62	0.02
W to F	2	516.13	5.04	0.02
F to L	2	516.13	5.04	0.02
L to F	2	516.27	5.18	0.01
L to R	2	516.28	5.19	0.01
W	2	516.59	5.50	0.01
W to L	2	516.61	5.52	0.01
F to D	2	516.63	5.54	0.01
R	2	516.93	5.84	0.01
P to L	2	516.96	5.87	0.01
R to D	2	517.01	5.92	0.01
R to P	2	517.13	6.04	0.01
P to F	2	517.14	6.05	0.01
P to D	2	517.21	6.12	0.01
F to P	2	517.44	6.35	0.01
R to L	2	517.48	6.39	0.01
D	2	517.52	6.43	0.01
L to P	2	517.55	6.46	0.01
W to R	2	517.57	6.48	0.01

[a] D=developed, P=open space, F=mature forest, R= early successional forest, W=water, L=wetland, (.)=random intercept

Table 6. Coefficient estimates for single-variable models relating change in land-cover type to change in woodcock counts along Singing-ground Survey (SGS) routes in Wisconsin between 1991-1993 and 2004-2006. Woodcock counts are the 3-year average for points on 26 SGS routes (n = 260) with 95% confidence intervals.

Land-Cover Change	Coefficient Estimate	Standard Error	Lower Confidence Limit	Upper Confidence Limit
Δ Contag[a]	-0.008	0.003	-0.014	-0.002
(.)	0.09	0.07	-0.047	0.227
F	-0.68	0.3	-1.268	-0.092
F to L	-1.62	1.35	-4.266	1.026
F to P	-0.72	1.95	-4.542	3.102
F to R	1.05	0.47	0.129	1.971
F to D	2.43	2.5	-2.470	7.330
F to W	22.36	29.1	-34.676	79.396
L	1.96	0.93	0.137	3.783
L to F	1.18	1.03	-0.839	3.199
L to P	-0.96	6.59	-13.876	11.956
L to R	10.44	9.17	-7.533	28.413
L to D	19.48	17.24	-14.310	53.270
L to W	8.92	41.36	-72.146	89.986
P	0.49	0.35	-0.196	1.176
P to F	-0.48	0.73	-1.911	0.951
P to L	2.6	3.33	-3.927	9.127
P to R	1.97	1.02	-0.029	3.969
P to D	1.27	2.11	-2.866	5.406
P to W	25.74	45.8	-64.028	115.508
R	0.87	1.09	-1.266	3.006
R to F	-0.94	0.46	-1.842	-0.038
R to L	0.77	2.57	-4.267	5.807
R to P	1.75	2.65	-3.444	6.944
R to D	6.98	9.3	-11.248	25.208
R to W	-202.17	196.71	-587.722	183.382
D	0.33	1.48	-2.571	3.231
D to F	-10.53	7.21	-24.662	3.602
D to L	4.48	32.8	-59.808	68.768
D to P	22	10.46	1.498	42.502
D to R	15.46	24.79	-33.128	64.048
D to W	-60.1	220.82	-492.907	372.707
W	-1.57	1.58	-4.667	1.527
W to F	16.44	13.69	-10.392	43.272
W to L	2.48	2.52	-2.459	7.419
W to P	-21.69	56.84	-133.096	89.716
W to R	0.5	5.93	-11.123	12.123
W to D	-15.1	16.15	-46.754	16.554

[a] D=developed, P=open space, F=mature forest, R= early successional forest, W=water, L=wetland, (.)=random intercept

Appendix A. Modified Anderson Classification scheme including field description, class description, and classification value. Field description describes the class of measurement. Class Description describes 3 hierarchical levels of land-cover types and 2 hierarchical levels of forest height. Classification value indicates the numerical value coded that corresponds to class description (Anderson et al. 1976).

Field Description	**Class Description**	**Classification Value**
Land Cover	Developed and Developed Areas	1
-	Residential	11
-	Multi-family	111
-	Single family/duplex	112
-	Mobile home parks	113
-	Farmstead	114
-	Other residential	119
-	Commercial, Services and Institutional	12
-	Industrial	13
-	Transportation, Communications and Utilities	14
-	Air transportation	141
-	Rail transportation	142
-	Water transportation	143
-	Paved road transportation	144
-	Communications	145
-	Utilities	146
-	Unpaved road transportation	147
-	Other	149
-	Mixed Use	16
-	Extractive	17
-	Open and other Developed	19
-	Outdoor cultural	191
-	Outdoor public assembly	192
-	Outdoor recreation	193
-	Cemeteries	194
-	Other	199

Appendix A. Continued

Field Description	Class Description	Classification Value
Land Cover	Agricultural Lands	2
-	Cropland, Rotation and Permanent Pasture	21
-	Cultivated crops	211
-	Hay and pasture	212
-	Orchards, Bush-Fruits and Vineyards	22
-	Confined Feeding Operations	23
-	Livestock	231
-	Poultry	232
-	Other	239
-	Other Agriculture	29
-	Cranberry fields	291
-	Non-forest (Non-forest, non-ag., non-developed, open space)	3
-	Grassland	31
-	Shrub land	32
-	Recently harvested clear cut	33
-	Forest Land	4
-	Broadleaved Forest	41
-	Upland hardwoods	411
-	Aspen, white birch, and assoc.	412
-	Lowland hardwoods	413
-	Coniferous Forest	42
-	Upland conifers	421
-	Lowland conifers	422
-	Mixed Conifer-Broadleaved Forest	43
-	Upland hardwoods and pine	431
-	Aspen/birch with conifers	432
-	Lowland hardwoods with conifers	433
-	Upland conifers with hardwoods	434
-	Lowland conifers with hardwoods	435

Appendix A. Continued

Field Description	Class Description	Classification Value
Land Cover	Water	5
-	Streams and Waterways (width)	51
-	Small streams and rivers (0-15 feet)	511
-	Medium streams and rivers (15-50 feet)	512
-	Large streams and rivers (>50 feet)	513
-	Lakes (area)	52
-	Ponds (0- 1.9 ha)	521
-	Small lakes (2- 9.9 ha)	522
-	Medium lakes (10-99.9 ha)	523
-	Large lakes (>100 ha)	524
-	Great Lakes	54
-	Wetlands	6
-	Wooded Wetlands	61
-	Wooded swamps (USE forest = 413, 422, 433, 435)	611
-	Shrub swamps	612
-	Non-wooded Wetlands	62
-	Marshland meadow	621
-	Mudflats	622
-	Shallow marshes (water depth 〈6 inches)	623
-	Deep marshes (water depth 6 in. to 3 ft.)	624
-	Barren Areas	7
-	Salt flats	71
-	Beaches and Riverbanks	72
-	Sand other than beaches	73
-	Bare Exposed Rock	74
Canopy Height	Young (0-5 m)	1
-	Clear cut (0-1 m)	11
-	Early regeneration (1-3 m)	12
-	Late regeneration (3-5 m)	13
-	Mature (≥5 m)	2

Appendix B. Source digital imagery and collateral data layers used to assist with delineation and classification of land-cover types along American woodcock Singing-ground Surveys routes in Minnesota and Wisconsin.

	Minnesota				Wisconsin			
Category	**Data Layer Name**	**Format**	**Source[a]**	**Year**	**Data Layer Name**	**Format**	**Source[a]**	**Year**
County Boundaries	County	Vector	MN DNR	Accessed 2009	County	Vector	WI DNR	Accessed 2009
Roads	State Roads	Vector	MN DNR	Accessed 2009	State Roads	Vector	WI DNR	Accessed 2009
Hydrography	MN 24k streams	Vector	MN DNR	Accessed 2009	WI 24k Hydro	Vector	WI DNR	Accessed 2009
Wetlands	MN NWI wetlands	Vector	MN DNR	Accessed 2009	DWWI	Vector	WI DNR	Accessed 2009
Soils	SSURGO 2003	Vector	USDA DataMart	2003	SSURGO 2003	Vector	USDA DataMart	2003
Aerial Photography	FSA 4-Band DOP RGBCIR 2008	Raster	NAIP	2008	FSA 3-Band DOP RGB 2005	Raster	FSA	2005
Aerial Photography	FSA 3-Band RGB DOP 2006	Raster	NAIP	2006	FSA 3-Band RGB DOP 2001-2003	Raster	FSA	2001-2003
Aerial Photography	FSA 3-Band B/W DOP 1991	Raster	USGS	1991	FSA 3-Band B/W DOP 1991-1996	Raster	FSA	1991-1996

[a]MN DNR = Minnesota Department of Natural Resources, USDA = U.S. Department of Agriculture, FSA– Farm Service Agency, USGS = U.S. Geological Survey, WI DNR – Wisconsin Department of Natural Resources.

Appendix C. Correlation coefficients of change in land-cover type between 1992 and 2005 in Wisconsin along 26 Singing-ground Survey routes. The first land-cover type indicates the land-cover type in 1992 and the second land-cover type indicates the land-cover type in 2005. Single land-cover types indicate that the land-cover type remained the same between 1992 and 2005.

Land-cover Types	D	P	F	W	L	R	D to P	D to F
D	1							
P	0.43	1						
F	-0.4	-0.59	1					
W	0.13	-0.13	-0.1	1				
L	-0.1	-0.08	-0.11	0.09	1			
R	-0.01	-0.08	-0.11	-0.08	-0.04	1		
D to P	0.45	0.27	-0.29	0.03	-0.07	-0.08	1	
D to F	0.39	-0.02	-0.07	0.36	-0.11	-0.02	0.44	1
D to W	0.06	-0.05	-0.06	0.01	-0.04	-0.03	0.03	0.11
D to L	0.06	-0.01	0.02	-0.01	0.2	-0.03	0	-0.02
D to R	0.17	-0.02	-0.23	0.18	-0.05	0.02	0.07	0.15
P to D	0.28	0.23	-0.13	0.03	-0.05	-0.02	0.08	0.09
P to F	0.09	0.13	-0.21	-0.03	-0.05	-0.07	0	0
P to W	-0.02	0	-0.03	-0.01	-0.04	0	-0.01	-0.01
P to L	0.05	0.19	-0.17	-0.04	-0.01	-0.02	0.26	-0.07
P to R	0.1	0.04	-0.15	0.11	-0.04	0.03	0.02	0.04
F to D	0.18	-0.13	0.07	0.2	-0.09	-0.09	0.1	0.19
F to P	-0.04	-0.06	-0.23	-0.04	-0.09	-0.06	0.06	-0.02
F to W	-0.06	-0.04	-0.07	0.12	-0.01	-0.06	-0.02	0.01
F to L	-0.05	-0.08	-0.17	0	0.21	-0.01	-0.05	-0.09
F to R	-0.13	-0.16	-0.26	0.08	-0.06	-0.04	-0.11	-0.13
W to D	0.5	0.01	-0.13	0.17	-0.03	-0.02	0.3	0.2
W to P	0.02	0.21	-0.13	0.03	0.08	-0.02	0.04	-0.04
W to F	-0.04	-0.09	0	0.19	0.04	-0.03	-0.03	0.04
W to L	-0.05	0.07	-0.11	0.07	0.09	-0.02	0.03	0.03
W to R	-0.06	-0.05	0.07	-0.01	-0.02	-0.03	-0.03	-0.04
L to D	0.17	-0.02	-0.07	0.05	-0.04	-0.05	0.04	0.02
L to P	0.14	0.22	-0.31	0.03	0.04	0.2	0.05	0
L to F	-0.07	-0.12	-0.08	0.06	0.08	0.08	-0.02	-0.08
L to W	-0.03	-0.1	0.03	0.2	0.1	-0.05	-0.07	0.12
L to R	-0.07	-0.09	-0.13	-0.04	0.01	-0.03	0.04	-0.05
R to D	-0.08	-0.06	-0.06	0.02	-0.04	0.05	-0.07	-0.06
R to P	-0.02	-0.06	-0.12	0.01	-0.02	0.02	0.07	-0.01
R to F	-0.13	-0.15	-0.2	-0.09	-0.01	0.14	-0.13	-0.04
R to W	-0.07	-0.03	-0.08	-0.02	-0.03	-0.02	-0.03	-0.03
R to L	0.03	-0.04	0.01	-0.05	0	0.04	0.02	-0.04
Contag	-0.08	-0.04	0.18	-0.02	0.02	0.05	-0.06	0.08

Appendix C. Continued

Land-cover Types	D to W	D to L	D to R	P to D	P to F	P to W	P to L	P to R
D								
P								
F								
W								
L								
R								
D to P								
D to F								
D to W	1							
D to L	-0.01	1						
D to R	0.02	-0.03	1					
P to D	-0.02	-0.02	-0.02	1				
P to F	0.01	-0.01	0.01	0.06	1			
P to W	0.2	-0.01	-0.02	-0.01	-0.01	1		
P to L	0.13	0.09	0.03	0.06	0.02	0.39	1	
P to R	0.05	-0.02	0.26	0.04	0.13	-0.02	0.08	1
F to D	0.09	-0.01	0.2	0.09	-0.02	-0.06	-0.08	0.18
F to P	0.13	-0.03	0.01	-0.05	0.09	0.08	-0.02	-0.02
F to W	0.65	-0.01	-0.03	-0.01	0.02	0.19	0.13	0.04
F to L	0.25	-0.02	0.07	0.01	0.07	0.12	0.11	-0.01
F to R	-0.04	-0.05	0.32	-0.12	-0.04	-0.07	-0.02	0.1
W to D	0.07	-0.01	0.02	0.16	0	-0.01	-0.01	0.01
W to P	-0.01	-0.01	0.01	-0.01	-0.02	0.04	0.13	-0.02
W to F	-0.01	-0.02	0.08	-0.04	-0.02	-0.03	-0.05	0
W to L	-0.02	-0.01	0	-0.01	0.04	-0.02	-0.01	0.03
W to R	-0.01	-0.01	-0.01	-0.03	-0.03	-0.01	-0.02	-0.02
L to D	0.03	-0.02	0.22	0	0.09	0.02	-0.03	0.27
L to P	-0.01	0	0.15	0.09	0	0.16	0.09	0.13
L to F	-0.04	0.02	-0.02	-0.07	0.04	-0.04	-0.04	-0.08
L to W	-0.02	0.02	-0.05	0.04	-0.01	0.21	0.09	-0.03
L to R	-0.02	-0.02	0.23	-0.04	0.07	-0.03	0.07	0.02
R to D	-0.03	-0.01	-0.03	0	0.02	-0.03	-0.04	-0.04
R to P	-0.02	-0.03	-0.05	-0.05	-0.02	0.03	-0.04	-0.04
R to F	-0.04	-0.05	-0.07	-0.04	-0.02	-0.04	-0.08	-0.07
R to W	0.79	-0.01	-0.02	-0.02	0.01	0.26	0.18	-0.01
R to L	-0.02	-0.02	0.13	-0.03	-0.04	-0.01	-0.02	-0.03
Contag	-0.12	0.02	-0.12	0.02	0.01	-0.01	-0.04	-0.03

Appendix C. Continued

Land-cover Types	F to D	F to P	F to W	F to L	F to R	W to D	W to P	W to F
D								
P								
F								
W								
L								
R								
D to P								
D to F								
D to W								
D to L								
D to R								
P to D								
P to F								
P to W								
P to L								
P to R								
F to D	1							
F to P	0.03	1						
F to W	-0.02	0.12	1					
F to L	-0.04	0.07	0.32	1				
F to R	0.03	-0.03	-0.05	0.05	1			
W to D	0.33	0	-0.01	-0.02	-0.02	1		
W to P	-0.05	-0.02	-0.02	-0.01	-0.02	-0.01	1	
W to F	0.05	-0.04	0.05	-0.02	0.1	0.02	-0.02	1
W to L	0	0.04	0.06	0	-0.03	-0.01	0	0.09
W to R	-0.01	-0.03	-0.02	-0.03	0.06	-0.01	0.02	0
L to D	0.15	-0.01	0.01	-0.04	0.07	0.05	0	-0.01
L to P	-0.05	0.13	-0.02	0.12	-0.08	-0.02	0.03	0.01
L to F	0.01	-0.08	-0.05	-0.06	0.02	0.1	-0.01	0.02
L to W	0.06	-0.05	0.11	-0.02	-0.07	-0.01	-0.02	0.02
L to R	0.02	0.01	-0.04	0.07	0.25	0.05	0	-0.03
R to D	0.02	-0.03	-0.02	-0.04	-0.04	-0.02	-0.02	-0.02
R to P	-0.09	0.06	0.05	-0.06	-0.11	-0.02	-0.02	-0.03
R to F	-0.12	-0.04	-0.06	-0.11	-0.1	-0.03	-0.04	0.02
R to W	-0.03	0.17	0.81	0.35	-0.04	0	-0.01	-0.02
R to L	-0.05	-0.03	-0.03	0.01	-0.02	-0.01	-0.01	-0.01
Contag	-0.07	-0.34	-0.11	-0.28	-0.49	-0.04	-0.01	0.01

Appendix C. Continued

Land-cover Types	W to L	W to R	L to D	L to P	L to F	L to W	L to R	R to D
D								
P								
F								
W								
L								
R								
D to P								
D to F								
D to W								
D to L								
D to R								
P to D								
P to F								
P to W								
P to L								
P to R								
F to D								
F to P								
F to W								
F to L								
F to R								
W to D								
W to P								
W to F								
W to L	1							
W to R	-0.01	1						
L to D	-0.02	0.08	1					
L to P	0.24	-0.03	0.02	1				
L to F	-0.03	-0.03	-0.01	0.1	1			
L to W	0.12	-0.02	0.44	-0.03	0.04	1		
L to R	-0.01	0.11	0.05	0.05	0.15	-0.02	1	
R to D	0.08	-0.02	-0.03	-0.01	0.14	0	0.03	1
R to P	0.04	-0.02	-0.03	-0.03	0.02	-0.01	-0.04	-0.05
R to F	0.02	-0.04	-0.06	-0.04	0.05	-0.04	-0.01	0.35
R to W	-0.01	-0.01	-0.01	-0.02	-0.03	-0.01	-0.02	-0.01
R to L	-0.02	-0.01	0.21	0	-0.02	-0.01	-0.03	0.03
Contag	0.04	-0.04	-0.06	0.04	0.2	0.06	-0.08	0.11

Appendix C. Continued

Land-cover Types	R to P	R to F	R to W	R to L	Congtag
D					
P					
F					
W					
L					
R					
D to P					
D to F					
D to W					
D to L					
D to R					
P to D					
P to F					
P to W					
P to L					
P to R					
F to D					
F to P					
F to W					
F to L					
F to R					
W to D					
W to P					
W to F					
W to L					
W to R					
L to D					
L to P					
L to F					
L to W					
L to R					
R to D					
R to P	1				
R to F	0.02	1			
R to W	-0.01	-0.03	1		
R to L	0.08	0.01	-0.01	1	
Contag	0.02	0.49	-0.15	0	1

Chapter 3

Land cover along American woodcock Singing-ground Survey routes in Minnesota and Wisconsin: how well do routes represent the broader landscape?

Abstract: Counts of American woodcock (*Scolopax minor*) on the annual Singing-ground Survey (SGS) have undergone long-term declines in both the Eastern and Central Management Regions of North America, declining at an average rate of 1.1% per year in both regions from 1968 - 2009. However, interpreting these trends is difficult without additional information, such as whether land-cover characteristics along survey routes are representative of those in the broader landscape. Few studies have examined how well land cover along SGS routes currently represents that in the broader landscape, and results of these studies have been mixed. Therefore, I compared land-cover composition along SGS routes to land-cover composition of the broader landscape in Minnesota and Wisconsin. Developed land was over-represented among cover types along SGS routes whereas wetlands and water land-cover types were under-represented relative to the landscape. Open space, early successional forest, and mature forest along SGS routes were represented in proportion to their composition in the broader landscape.

Key Words: shorebird, American woodcock, *Scolopax minor*, Central Management Region, Minnesota, Wisconsin, Singing-ground Survey, compositional analysis

Introduction

The number of singing male American woodcock (*Scolopax minor*; hereafter woodcock) heard on the Singing-ground Survey (SGS) declined an average of 1.1% per year between 1968 and 2009 in the Eastern and Central Management Regions, which has raised concern about the population status of woodcock (Cooper and Parker 2009). In part, these concerns led to reductions in hunting bag limits and season length, delays of hunting-season opening dates, and the development of a management plan to increase continental woodcock population size (Kelley et al. 2008). However, declines in the number of woodcock heard during the SGS have been difficult to interpret without additional information, such as the relative composition of land-cover along SGS routes compared to the broader landscape. When the SGS was implemented, survey routes were located along secondary roads within randomly selected 10-minute latitude-longitude geographic blocks (Sauer and Bortner 1991, Straw et al. 1994). Routes have remained largely static since the SGS was established, and few assessments have been conducted to determine if land-cover composition along SGS routes is representative of the broader landscape. If SGS routes do not adequately represent the broader landscape, declining trends in counts derived from the SGS may reflect changes in woodcock abundance related to changes in land-cover composition along survey routes, rather than changes in woodcock population size across a broader spatial scale.

Several recent studies have examined how the broader landscape is represented by land cover along SGS routes, with mixed results. In Pennsylvania, Klute et al. (2000) found that the landscape along SGS routes differed from the broader landscape at several spatial scales. In Michigan, Jentoft (2000) found that land-cover composition along SGS routes was generally similar to the broader Michigan landscape. In New Brunswick, Morrison et al. (2006) found that land cover changed along SGS routes differently than it changed in the broader landscape. Furthermore, Morrison et al. (2006) reported that woodcock singing-grounds and nesting and feeding cover increased throughout the broader landscape and declined along SGS routes.

My objective was to compare relative land-cover composition along SGS routes and the broader landscapes within Minnesota and Wisconsin. Previous analyses (Chapter 1) suggested that woodcock abundance along SGS routes in Minnesota and Wisconsin was related to land-cover type and that changes in woodcock abundance along Wisconsin SGS routes were related to changes in land cover (Chapter 2). Combining those results with an assessment of how well land-cover composition along SGS routes represents land-cover composition of the broader landscape provides an assessment of how well trends in the SGS counts represent trends in woodcock abundance at broader spatial scales in the western Great Lakes region. To make my assessment, I used a modification of compositional analysis to compare land-cover composition between SGS routes and the broader landscape.

Study Area

My sample universe was defined by existing SGS routes in the Central Management Region in Minnesota (n = 123) and Wisconsin (n = 117), which were distributed throughout the woodcock breeding range in these states. For my analysis, I used all SGS routes with verified locations in Minnesota (n = 120) and Wisconsin (n = 62) (Fig. 1). The majority of this distribution was comprised of forested areas with gradual elevation changes and interspersed with lakes and wetlands (U.S. EPA 2007).

The southern portions of both Minnesota and Wisconsin were comprised mostly of agricultural lands. In Minnesota, corn (*Zea mays*) and soybeans (*Glycine max*) were the dominant crops of the southern agricultural region, whereas the agricultural area in southern Wisconsin was dominated by feed grains to support livestock and dairy farming (U.S. EPA 2007).

In Minnesota, the amount of forested land has declined from approximately 7.28 million ha in 1962 to 6.83 million ha in 2008; however, this was an increase from a low of 6.55 million ha in 2003 (Miles et al. 2007, Miles 2010). In Wisconsin, forested land has increased from approximately 6.07 million ha in 1963 to 6.47 million ha in 2004 (Perry et al. 2008). Over relatively the same period (1968 – 2009), the trend in counts of woodcock on SGS routes in Minnesota declined at a rate of 0.05% per year and in Wisconsin, declined at a rate of 0.69% per year (Cooper and Parker 2009).

Methods

Data Collection:--I digitized SGS survey routes in Minnesota and Wisconsin, based on paper maps provided by the U.S. Fish and Wildlife Service (FWS; Keri Parker, personal communication). I digitized these paper maps using a Geographic Information System (GIS: ArcMap 9.3™; use of trade names does not imply endorsement by either the U.S. Geological Survey or the University of Minnesota), and then provided paper maps that included digitized routes and listening-stop locations with roads and a high-resolution aerial-photograph background to the SGS regional coordinator (Sean Kelly, FWS). The SGS regional coordinator then sent the maps to volunteers who conducted woodcock surveys and requested volunteers to verify the accuracy of digitized listening-stop and route locations. Volunteers verified locations either by providing latitude and longitude coordinates or by indicating corrections on paper maps. Only verified routes were included in the analysis.

I used LANDFIRE land-cover data to estimate the land-cover composition for both the routes and the broader landscape (LANDFIRE 2006). LANDFIRE data are ultimately generated from LANDSAT imagery and have a resolution of 30 m. Minnesota and Wisconsin were covered primarily by 2 LANDFIRE mapping zones (i.e., mapping zone 41 and 50). The LANDFIRE model accuracy, as determined by cross-validation, ranged from 66% to 98% for existing land-cover types and from 80% to 90% for forest height (Appendix A). The LANDFIRE data have 37 categories of land-cover type across Minnesota and Wisconsin. I reclassified LANDFIRE land-cover data into 6 land-cover types to reflect similar land-cover types included and described in previous woodcock studies (Dwyer et al. 1983, Steketee et al. 2000, Chapters 1 and 2). These 6 land-cover types included urban or developed land, open space, mature forest, water, wetlands, and early successional forest (Appendix B).

Statistical Analyses:-- I used compositional analysis to estimate differences in land-cover composition between SGS routes and in the broader landscape (Aebischer et al. 1993). Aebischer et al. (1993) described compositional analysis as an approach for assessing habitat selection of animals based on used and available habitat. For my purposes, habitat use was analogous to land-cover composition along routes and available habitat was analogous to land-cover composition of the broader landscape. If the SGS routes represented land cover proportionally to that available in the landscape, then it would be the same as random use of habitat, or no habitat selection. Thus, land-cover composition along routes would reflect land-cover composition of the broader landscape, and is represented mathematically by

$y_R = y_L$

where y_R is the land-cover composition along SGS routes and y_L is the land-cover composition of the broader landscape. I defined the land-cover types surveyed by SGS routes as the area within a circle of 330-m radius (i.e., the presumed maximum detection distance of a displaying woodcock [Duke 1966]) around each listening stop; I used ArcMap to create these 330-m radius circles. I represented the surrounding landscape for each route as a 10-minute latitude-longitude block, which was the original block size that was randomly selected to represent the entire landscape around each SGS route (Sauer and Bortner 1991, Straw et al. 1994).

Following Aebischer et al. (1993), I transformed the proportion of each land-cover type at the route (y_{Ri}) and landscape (y_{Li}) levels to ensure that each land-cover type was linearly independent. My transformation for the route level was

$y_{Ri} = \ln (x_{Ri} / x_{RD})$

and for landscape level it was

$y_{Li} = \ln (x_{Li} / x_{LD})$

where x_{Ri} and x_{Li} are the proportions of land-cover type *i* along a single route and corresponding landscape, and where x_{RD} and x_{LD} are the proportions of the Dth land-cover type along a single route and corresponding landscape, to which all other land-cover types are compared. The Dth term may be any land-cover type that occurs along every route and within every landscape and is the same for all transformations, whereas *i* changes for each land-cover type. I used the land-cover type mature forest as the Dth term.

To estimate whether there was a difference in land-cover composition between SGS routes and landscape land-cover composition I used Hotelling's-T test to test the null hypothesis that land-cover composition along SGS routes was equivalent to land-cover composition of the landscape. To calculate Hotelling's T, I calculated the pair-wise difference

$d = y_{Ri} - y_{Li}$

assuming d has a multivariate normal distribution

$d \sim N_{D-2} (\mu_d , \sum_d)$

where N_{D-2} is the number of dimensions, with D representing the total number of land-cover types, μ representing the mean vector, and $\sum$ the covariance matrix.

Based on this pair-wise difference the null hypothesis is

$d = 0$

Hotelling's-T test simultaneously tests to determine if all of the land-cover types are proportionally represented between the broader landscape and SGS routes and was calculated using program R (R Development Core Team 2009). To determine if a single land-cover type along SGS routes proportionally represented land cover of the broader landscape, I conducted student's-*t* tests for each land-cover type, again using program R. The results of the individual *t*-tests can be used to rank land-cover types from most over-represented to most under-represented. However, because it is necessary to transform the proportional representation of land-cover types to a proportion of the Dth land-cover type, it is not possible to compare all of the land-cover types simultaneously using a single land-cover type as a reference. To compare all land-cover types simultaneously, I used a second transformation that followed the same formulas, but used a different Dth term. For this second transformation, I used the developed or urban land-cover type as the Dth term. This allows for the complete ranking of the representation of all land-cover types. Further descriptions of the transformation calculations are in Aebischer et al. (1993).

Compositional Comparison--I tested for proportional representation of land-cover composition between SGS routes and the broader landscape for 4 subsets of SGS routes: Minnesota and Wisconsin combined, Minnesota, Wisconsin, and across the forested portions of each state as represented by EPA ecoregions (Fig. 1). I included Minnesota and Wisconsin together as a full data set using all 181 verified routes. I also separated Minnesota (119 routes) and Wisconsin (62 routes) because they represent administrative units that may be managed for woodcock differently. I then combined the forested area of Minnesota and Wisconsin (139 routes) to represent woodcock habitat in which woodcock might be expected to respond to changes in a similar way (i.e., as representative of a portion of the Central Management Region).

Results

For all my comparisons, cover-type composition along survey routes differed from that of the broader landscape (Hotelling's-T < 0.001, Table 1). Developed or urban land-cover was significantly over-represented on SGS routes relative to the broader landscape for all comparisons, whereas wetlands and water were both under-represented on SGS routes for all comparisons (Table 2). Representation of land-cover types on SGS routes compared to the broader landscape ranked in decreasing order as follows:

developed or urban, open space, early successional forest, mature forest, wetlands, and water for Minnesota, Wisconsin, and Minnesota and Wisconsin combined (Table 2). For the forested portions of Minnesota and Wisconsin, early successional forest ranked second and open space ranked third, and all other cover types ranked in the same order as they did based on state boundaries (Table 2).

I calculated the percent of each land-cover type on SGS routes and in the broader landscape for each data subset (Table 3). Among all comparisons, the percent composition of individual land-cover types in the broader landscape ranged from 0.4% (early successional forest in the Wisconsin subset) to 50.6% (mature forest in the Wisconsin subset [Table 3]), whereas the percent composition of individual land-cover types along SGS routes ranged from 0.9% (early successional forest in the Wisconsin subset) to 50.1% (mature forest in the Wisconsin subset [Table 3]). I compared the percent composition of individual land-cover types based on both the difference (broader landscape minus the area along SGS routes) and the relative difference (the difference divided by the percent composition of the broader landscape) between SGS routes and the broader landscape. The difference between percent composition of individual land-cover types along SGS routes and the broader landscape ranged from -5.7% (water in the forested subset) to 5.6% (open space in the Minnesota subset) and the relative difference ranged from -85.3% (water in the Wisconsin subset) to 127.4% (developed land in the Minnesota subset [Table 3]).

Discussion

Land-cover composition on SGS routes in Minnesota and Wisconsin differed from composition in the broader landscape. This result was largely a function of the amount of developed or urban land, wetlands, and water along SGS routes. Developed or urban land cover was over-represented on SGS routes and water and wetlands were under-represented compared to their presence within landscapes. However, the composition of open space, early successional forest, and mature forest was similar between SGS routes and the broader landscape; all of these land-cover types had the potential to influence abundance of woodcock (e.g., Chapters 1 and 2). Therefore, although several land-cover types were over- or under-represented on SGS routes relative to the broader landscape, land-cover types most important to woodcock appeared to be represented on SGS routes similarly to their representation in landscapes.

Previous studies (Dwyer et al. 1983, Steketee et al. 2000, Chapter 1) reported that the land-cover types that best explained woodcock counts included early successional forest, mature forest, water, and developed or urban. In the Eastern Management Region (Dwyer et al. 1983), developed or urban land cover was negatively related to woodcock counts along SGS routes; however, this land-cover type was not among the land-cover types that best explained SGS counts throughout Minnesota and Wisconsin (Chapter 1). In Minnesota and Wisconsin, the land-cover types most strongly associated with counts of woodcock on SGS routes (open space and early successional forest) were similar between SGS and the broader landscapes, suggesting that SGS routes in Minnesota and Wisconsin are currently representative of the random blocks within which they were established.

It is difficult to assess how the over- and under-representation of some land-cover types along SGS routes in Minnesota and Wisconsin may influence inferences about woodcock abundance or population trends across the broader landscape. Developed or urban land cover was over-represented along SGS routes in Minnesota and Wisconsin, and was negatively associated with woodcock counts (Dwyer et al. 1983) in the Eastern Management Region. However, in my study, roads comprised approximately 2.6% ($\bar{x}$ = 2.63%, SD = 1.0%) of area along SGS routes in Minnesota categorized as developed, with land cover categorized as developed other than roads occurring at approximately half of the stops. Developed land cover other than roads comprised approximately 5% ($\bar{x}$ = 5.17%, SD = 5.2%) of the areas surrounding stops when present. Water was under-represented along SGS routes and was negatively associated with woodcock counts in Minnesota (Chapter 1). However, I was unable to assess the magnitude of either of these misrepresentations as they relate to interpreting counts or trends in counts of woodcock along SGS routes in Minnesota or Wisconsin.

My results are similar to those of Klute et al. (2000) and Morrison et al. (2006) in that they indicate that not all land-cover types are represented along SGS routes in the proportions that they comprise the broader landscape. The land-cover types that I found to differ significantly between SGS routes and the broader landscape across Minnesota and Wisconsin were also identified by Klute et al. (2000) in Pennsylvania to be significantly different between SGS and random routes. Klute et al. (2000) found that developed land, water, and wetlands were significantly different from random routes at multiple spatial scales. However, the methods used by Klute et al. (2000) make it difficult to determine if the differences they identified were due to the misrepresentation of land cover along SGS routes or habitat selection by woodcock. Klute et al. (2000) did not include all SGS stops along routes; rather, they selected stops that were used by woodcock.

Morrison et al. (2000) also concluded that land-cover composition along SGS routes was not representative of the broader landscape. However, their study differed from mine in that they determined that the SGS did not capture changes in land-cover composition in the broader landscape over time. Over a period of roughly 10 years (1982-1986 to 1993-2000), Morrison et al. (2000) found that representation of land-cover types related to singing grounds and nesting and feeding cover declined along SGS routes, as the abundance of these land-cover types increased in the broader landscape.

The only other assessment of representation of land-cover types along SGS routes compared with land-cover composition in the broader landscape in the Central Management Region was conducted by Jentoft (2000). Jentoft (2000) compared the land-cover composition along SGS routes in Michigan to the land-cover composition of the entire state. He reported that the land cover along SGS routes was similar to the land cover of the entire state; however, his methods did not compare these proportions statistically to determine which land-cover types were over- or under-represented along SGS routes. My use of a modification of compositional analysis (Aebischer et al. 1993) to compare land-cover composition along SGS routes with land-cover composition in the broader landscape in Minnesota and Wisconsin allowed me to statistically assess which land-cover types were over- or under-represented. This approach allowed additional insight into how land-cover types associated with woodcock abundance were represented along SGS routes. In addition, this approach could be applied broadly across the extent of the SGS, where land-cover composition data (e.g., LANDFIRE data, which are available for the entire U.S.) are available.

Management Implications:-- In Minnesota and Wisconsin SGS routes do not represent all land-cover types in proportion to their occurrence in the broader landscape, but do proportionally represent the land-cover types that are most used by woodcock. Land-cover types that best explain woodcock counts (e.g., early successional forest and open space [Chapter 1]) occur along SGS routes in Minnesota and Wisconsin in proportion to their occurrence in the landscapes that the SGS was designed to represent. As a result, it is likely that counts resulting from the SGS provide a reasonable source of information for tracking changes in woodcock abundance at the landscape scale, although it may be possible to improve representation by adjusting for land-cover composition change in the broader landscape.

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Figure 1. Distribution of American woodcock Singing-ground Survey routes in Minnesota and Wisconsin and an example of the area surveyed by a single route. Routes with a verified location are in black; all other routes are indicated in white. A full description of the level III ecoregions can be found at U.S. EPA (2007).

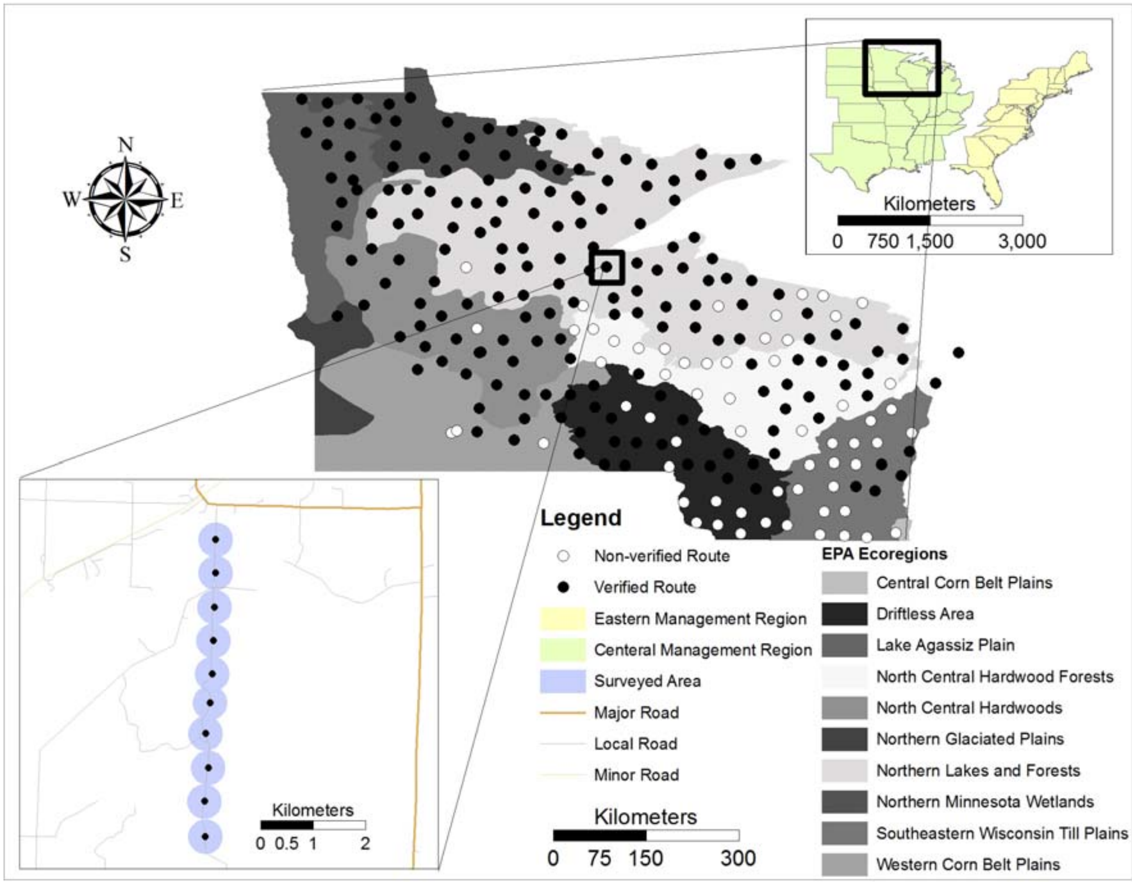

Table 1. Comparison of land-cover composition along Singing-ground Survey (SGS) routes in Minnesota and Wisconsin and that in the broader landscape, based on compositional analysis (Aebischer et al. 1993). Hotelling's-T test is used to assess whether all land-cover types along SGS routes are representative of land-cover composition of the broader landscape, based on LANDFIRE data.

	Hotelling's T
Dataset	P -value
Minnesota and Wisconsin	<0.001
Minnesota	<0.001
Wisconsin	<0.001
Forested Area	<0.001

Table 2. Comparison of land-cover composition along Singing-ground Survey (SGS) routes in Minnesota and Wisconsin and that in the broader landscape, based on compositional analysis (Aebischer et al. 1993). LANDFIRE (2006) data were used to determine land-cover type. The rank of each land-cover type is based on confidence intervals calculated from individual Student's-*t* tests and indicates over- (positive) and under- (negative) representation based on the D^{th} term.

	Land-Cover Type											
	Developed or Urban				**Open Space**				**Mature Forest**			
Dataset	**Rank**	**Mean**	**Lower CI**	**Upper CI**	**Rank**	**Mean**	**Lower CI**	**Upper CI**	**Rank**	**Mean**	**Lower CI**	**Upper CI**
Minnesota & Wisconsin	1*				2				4			
D^{th} Mature Forest		1.16	1	1.32		0.11	-0.19	0.42				
D^{th} Urban						-1.05	-1.32	-0.78		-1.16	-1.32	-1
Minnesota	1*				2				4			
D^{th} Mature Forest		1.32	1.11	1.53		0.48	0.22	0.74				
D^{th} Urban						-0.84	-1.04	-0.63		-1.32	-1.53	-1.11
Wisconsin	1*				2				4			
D^{th} Mature Forest		0.86	0.62	1.1		-0.6	-1.32	0.12				
D^{th} Urban					-1.46		-2.15	-0.77		-0.86	-1.1	-0.62
Forested Area	1*				3				4			
D^{th} Mature Forest		1.11	0.94	1.27		-0.09	-0.46	0.27				
D^{th} Urban						-1.2	-1.55	-0.85		-1.11	-1.27	-0.94

D^{th} term is the land-cover type used to transform all other land-cover types.

* indicates a ranking significantly different from all other rankings.

Table 2. Continued

	Land-Cover Type											
	Water				Wetlands				Early Successional Forest			
Dataset	**Rank**	**Mean**	**Lower CI**	**Upper CI**	**Rank**	**Mean**	**Lower CI**	**Upper CI**	**Rank**	**Mean**	**Lower CI**	**Upper CI**
Minnesota & Wisconsin	6*				5*				3			
D^{th} Mature Forest		-3.63	-4.15	-3.11		-0.46	-0.64	-0.27		0.16	-0.03	0.35
D^{th} Urban		-4.79	-5.32	-4.27		-1.61	-1.83	-1.41		-1	-1.2	-0.8
Minnesota	6*				5*				3			
D^{th} Mature Forest		-3.74	-4.38	-3.11		-0.46	-0.71	-0.21		0.23	0.08	0.39
D^{th} Urban		-5.06	-5.72	-4.41		-1.78	-2.07	-1.5		-1.09	-1.29	-0.88
Wisconsin	6*				5*							
D^{th} Mature Forest		-3.41	-4.33	-2.5		-0.44	-0.72	-0.15		0.02	-0.46	0.51
D^{th} Urban		-4.27	-5.15	-3.4		-1.29	-1.57	-1.03		-0.84	-1.28	-0.4
Forested Area	6*				5*				2			
D^{th} Mature Forest		-3.94	-4.55	-3.32		-0.42	-0.58	-0.27		0.13	-0.06	0.32
D^{th} Urban		-5.04	-5.68	-4.41		-1.53	-1.74	-1.32		-0.98	-1.2	-0.76

D^{th} term is the land-cover type used to transform all other land-cover types.

* indicates a ranking significantly different from all other rankings.

Table 3. Landscape composition along Singing-ground Survey routes in Minnesota and Wisconsin, categorized as all routes, Wisconsin routes, Minnesota routes, and routes in the forested portions of Minnesota and Wisconsin combined. For each category, the landscape surveyed by the Singing-ground Survey is identified as “route”, the landscape of the broader landscape is identified as “broader”, the “difference” is the percent of a land-cover type along routes landscape minus the percent of a land-cover type of the broader landscape, and “relative difference” is the land-cover type difference divided by the percent of the land-cover type in the broader landscape.

		Land-cover Type (%)					
Dataset	**Landscape**	**Developed Land**	**Open Space**	**Mature Forest**	**Water**	**Wetland**	**Early Successional Forest**
Minnesota and Wisconsin							
	Route	8.2	35.73	39.15	1.13	14.81	0.97
	Broader	3.95	31.21	39.9	5.66	18.6	0.69
	Difference	4.25	4.53	-0.75	-4.52	-3.79	0.28
	Relative Difference	107.48	14.5	-1.87	-79.94	-20.35	41.3
Wisconsin							
	Route	8.63	31.82	50.12	0.63	7.96	0.85
	Broader	4.77	29.68	50.62	4.28	10.23	0.41
	Difference	3.86	2.14	-0.5	-3.65	-2.27	0.43
	Relative Difference	80.94	7.2	-0.99	-85.27	-22.23	104.3
Minnesota							
	Route	7.99	37.61	33.9	1.38	18.1	1.03
	Broader	3.51	32.02	34.18	6.39	23.07	0.83
	Difference	4.48	5.59	-0.28	-5.02	-4.97	0.2
	Relative Difference	127.4	17.45	-0.82	-78.46	-21.53	23.72
Forested portion of Minnesota and Wisconsin							
	Route	7.83	24.88	47.09	1.32	17.76	1.13
	Broader	3.5	20	46.83	7.02	21.93	0.73
	Difference	4.33	4.88	0.26	-5.7	-4.17	0.4
	Relative Difference	123.85	24.41	0.55	-81.16	-19.03	54.39

Appendix A. Model accuracy of LANDFIRE data determined by cross-validation for zones that primarily represent Minnesota and Wisconsin. Models include existing vegetation type and height. Groups are determined by LANDFIRE. Number of classes is the number of land-cover or height classes included in each group (see Appendix B for a listing of LANDFIRE classes). These data can be found in their entirety at http://www.landfire.gov/accuracy_files.php.

Zone Number	Model Description	Group	Number of Classes	Number Records	Cross-Validation (%)	Standard Error (%)
41	Existing vegetation type	Stratification	8	20140	70.92	0.24
41	Existing vegetation type	Group 1 (Upland Closed-Canopy, Deciduous)	4	10974	70.06	0.38
41	Existing vegetation type	Group 2 (Upland, Open-Canopy, Deciduous/Mixed)	4	645	93.86	0.62
41	Existing vegetation type	Group 3 (Upland, Closed-Canopy, Evergreen/Mixed)	5	4767	75.26	0.54
41	Existing vegetation type	Group 3 - no 2534 (Upland, Closed-Canopy, Evergreen/Mixed)	4	4724	72.62	0.54
41	Existing vegetation type	Group 4 (Wetland Forest)	4	3557	83.56	0.62
41	Existing vegetation type	Group 5 (Shrub)	4	2187	87.76	0.66
41	Existing vegetation type	Group 6 (Upland Herbaceous)	3	329	74.40	2.30
41	Existing vegetation type	Group 7 (Wetland Herbaceous)	5	495	75.84	1.08
41	Existing vegetation type	Group 7 - no 2492 (Wetland Herbaceous)	4	462	88.06	1.24
41	Existing vegetation type	Group 8 (Riparian)	3	373	75.96	1.82
41	Existing vegetation type	wetlands	2	21770	85.82	0.16
41	Existing vegetation type	2301_2302	2	10959	75.06	0.46
41	Existing vegetation type	2311_2314	2	291	80.14	1.56
41	Existing vegetation type	2477_2481	2	3584	86.48	0.64
41	Height	Forest	4	16765	80.05	0.12
41	Height	Shrub	4	4469	67.22	0.34
41	Height	Herbaceous	3	4575	62.72	0.66
41	Height	Max Height	4	15615	72.02	0.20

Appendix A. Continued

Zone Number	Model Description	Group	Number of Classes	Number Records	Cross-Validation (%)	Standard Error (%)
50	Existing vegetation type	Stratification	8	3806	69.26	0.82
50	Existing vegetation type	Group 1 (Upland, Closed-Canopy, Deciduous)	5	1708	81.16	0.90
50	Existing vegetation type	Group 2 (Upland, Open-Canopy, Deciduous)	5	522	81.38	1.92
50	Existing vegetation type	Group 2_no2517 (Upland, Open-Canopy, Deciduous)	4	256	87.02	2.28
50	Existing vegetation type	Group 3 (Upland, Closed-Canopy, Evergreen/Mixed)	5	493	65.88	1.74
50	Existing vegetation type	Group 3_no2534 (Upland, Closed-Canopy, Evergreen/Mixed)	4	365	71.94	2.10
50	Existing vegetation type	Group 5 (Upland Herbaceous)	3	326	95.70	0.92
50	Existing vegetation type	Group 6 (Wetland Forest)	4	467	77.70	1.88
50	Existing vegetation type	Group 7 (Wetland Herbaceous)	4	440	81.30	1.84
50	Existing vegetation type	Group 8 (Riparian)	3	310	83.16	1.66
50	Existing vegetation type	2301_2302	2	1201	98.76	0.36
50	Height	Forest	4	1398	89.56	0.44
50	Height	Herbaceous	3	352	60.84	2.00

Appendix B. Reclassification of LANDFIRE land-cover types to reflect land-cover types related to woodcock as demonstrated in published studies. "Reclassified Land-cover Type" categorizes the land-cover types that have been found to be related to woodcock abundance or counts. "LANDFIRE Land-cover Type" are the land-cover categories in LANDFIRE data across Minnesota and Wisconsin.

Reclassified Land-cover Type	**LANDFIRE Land-cover Types**
Developed	Developed, Open Space
-	Developed, Low Intensity
-	Developed, Medium Intensity
-	Developed, High Intensity
Open Space	Barren Land
-	Shrub/Scrub
-	Herbaceuous
-	Hay/Pasture
-	Cultivated Crops
-	Northwestern Great Plains Mixedgrass Prairie
-	Introduced Upland Vegetation-Perennial Grassland and Forbland
-	Great Lakes Wooded Dune and Swale
-	Paleozoic Plateau Bluff and Talus
-	Ruderal Upland-Old Field
-	Great Lakes Alvar
-	North-Central Interior Sand and Gravel Tallgrass Prairie
-	Northern Tallgrass Prairie
-	Central Tallgrass Prairie
-	Northwestern Great Plains Shrubland
Water	Open Water
Wetlands	Woody Wetlands
-	Emergent Herbaceuous Wetlands
-	Western Great Plains Floodplain Systems
-	Eastern Boreal Floodplain
-	Eastern Great Plains Floodplain Systems
-	Central Interior and Appalachian Floodplain Systems
-	Laurentian-Acadian Floodplain Systems
-	Boreal Acidic Peatland Systems
-	Central Interior and Appalachian Swamp Systems
-	Laurentian-Acadian Alkaline Conifer-Hardwood Swamp
-	Great Plains Prairie Pothole
-	Eastern Great Plains Wet Meadow-Prairie-Marsh
-	Great Lakes Coastal Marsh Systems
-	Central Interior and Appalachian Shrub-Herbaceous Wetland Systems
-	Laurentian-Acadian Shrub-Herbaceous Wetland Systems
-	Western Great Plains Depressional Wetland Systems
-	Introduced Wetland Vegetation-Herbaceous

LANDFIRE data is available at http://gisdata.usgs.net/website/landfire

Appendix B. Continued

Reclassified Land-cover Type	**LANDFIRE Land-cover Types**
Mature Forest	Deciduous Forest (Height >5 m)
-	Evergreen Forest (Height >5 m)
-	Mixed Forest (Height >5 m)
-	Boreal Aspen-Birch Forest (Height >5 m)
-	Laurentian-Acadian Northern Hardwoods Forest (Height >5 m)
-	North-Central Interior Dry-Mesic Oak Forest and Woodland (Height >5 m)
-	North-Central Interior Dry Oak Forest and Woodland (Height >5 m)
-	North-Central Interior Beech-Maple Forest (Height >5 m)
-	North-Central Interior Maple-Basswood Forest (Height >5 m)
-	Eastern Great Plains Tallgrass Aspen Parkland (Height >5 m)
-	Boreal Jack Pine-Black Spruce Forest (Height >5 m)
-	Laurentian-Acadian Northern Pine(-Oak) Forest (Height >5 m)
-	Boreal White Spruce-Fir-Hardwood Forest (Height >5 m)
-	Laurentian-Acadian Pine-Hemlock-Hardwood Forest (Height >5 m)
-	Western Great Plains Wooded Draw and Ravine (Height >5 m)
-	North-Central Interior Oak Savanna (Height >5 m)
-	North-Central Oak Barrens (Height >5 m)
-	Laurentian Pine-Oak Barrens (Height >5 m)
-	Ruderal Forest-Northern and Central Hardwood and Conifer (Height >5 m)
-	Managed Tree Plantation-Northern and Central Hardwood and Conifer Plantation Group (Height >5 m)
-	Western Great Plains Dry Bur Oak Forest and Woodland (Height >5 m)

LANDFIRE data is available at http://gisdata.usgs.net/website/landfire

Appendix B. Continued

Reclassified Land-cover Type	LANDFIRE Land-cover Types
Early Successional Forest	Deciduous Forest (Height <5 m)
-	Evergreen Forest (Height <5 m)
-	Mixed Forest (Height <5 m)
-	Recently Logged-Herb and Grass Cover (Height <5 m)
-	Boreal Aspen-Birch Forest (Height <5 m)
-	Laurentian-Acadian Northern Hardwoods Forest (Height <5 m)
-	North-Central Interior Dry-Mesic Oak Forest and Woodland (Height <5 m)
-	North-Central Interior Dry Oak Forest and Woodland (Height <5 m)
-	North-Central Interior Beech-Maple Forest (Height <5 m)
-	North-Central Interior Maple-Basswood Forest (Height <5 m)
-	Eastern Great Plains Tallgrass Aspen Parkland (Height <5 m)
-	Boreal Jack Pine-Black Spruce Forest (Height <5 m)
-	Laurentian-Acadian Northern Pine(-Oak) Forest (Height <5 m)
-	Boreal White Spruce-Fir-Hardwood Forest (Height <5 m)
-	Laurentian-Acadian Pine-Hemlock-Hardwood Forest (Height <5 m)
-	Western Great Plains Wooded Draw and Ravine (Height <5 m)
-	North-Central Interior Oak Savanna (Height <5 m)
-	North-Central Oak Barrens (Height <5 m)
-	Laurentian Pine-Oak Barrens (Height <5 m)
-	Western Great Plains Dry Bur Oak Forest and Woodland (Height <5 m)
-	Ruderal Forest-Northern and Central Hardwood and Conifer (Height <5 m)
-	Managed Tree Plantation-Northern and Central Hardwood and Conifer Plantation Group (Height <5 m)

LANDFIRE data is available at http://gisdata.usgs.net/website/landfire