SURVIVAL, NEST SUCCESS, AND HABITAT SELECTION OF SHARP-TAILED GROUSE IN EAST-CENTRAL MINNESOTA – FINAL PROJECT REPORT

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SUMMARY OF FINDINGS

Across 3 years of study, 39 female and 20 male sharp-tailed grouse (*Tympanuchus phasianellus*) were radiocollared at 7 leks in East-Central Minnesota. Lek attendance (average number of grouse observed per lek) was affected by wind speed, and female attendance occurred later than expected, peaking in early May, which was thought to be driven by late snow cover. Annual survival of radiocollared grouse was 0.41 ± 0.07 for females and 0.24 ± 0.10 for males. Monthly survival rates indicated that female grouse mortality was greatest during the breeding season with the highest mortality rate occurring in June. A total of 44 nests were located and monitored during the study, including 4 known re-nests. Nest sites included a wide variety of cover types and vegetation structure, but had greater overhead cover, shrubs present at the nest, lower vegetation density at 0.5-1.0 m from 15 m, lower soil moisture, greater vegetation density at 0-0.5 m from 2m, and fewer perches than non-nest sites. Nest survival rate (≥1 egg hatched) was 0.42 ± 0.09. Vegetation metrics were not significantly related to nest success, however successful nests tended to have more overhead cover and higher vegetation density than unsuccessful nests. Broods were followed for 26 hatched nests over 3 years of study. Brood survival (≥ 1 chick at 50 days post hatch) for hatched nests was 42%. The average number of surviving chicks per nesting hen was 1.15. Hens used brushland, open upland, agriculture, and hayfield in greater proportion than their availability. Brooding hens showed similar use of cover types, with a notable increase in the use of hayfields. Lek complexes ranged in size from 40 – 1,460 ha and grouse locations were within 4.1 km of lek sites. Habitat management for sharp-tailed grouse should focus within 4 km of leks and provide nesting and brood rearing habitat in close association on both public and private lands.

INTRODUCTION

Sharp-tailed grouse ranged across much of the state of Minnesota prior to European settlement (Berg 1997). The open and brushland cover they inhabited was maintained by natural disturbances, particularly wildfire. Since that time, sharp-tailed grouse have been experiencing a long-term decline throughout their range (Gregg and Niemuth 2000; Silvy and Hagen 2004), and in recent decades have suffered marked population declines (Connelly et al. 1998) due to poor management and habitat loss (Riley 2004). In Minnesota, sharp-tailed grouse populations have declined sharply because the open brushland habitat they inhabit is vulnerable to destruction, senescence, conversion to incompatible cover, and succession to forest (Berg 1997). Estimated annual harvest rates for sharp-tailed grouse have fluctuated over time, with a high of 154,000 in 1949 (Berg 1997). Today, harvest rates have decreased to a 10-year average (2006-2015) of approximately 11,100 (Dexter 2015, Figure 1). Annual spring surveys of dancing grounds in Minnesota indicate that the mean number of sharp-tailed grouse per dancing ground has fluctuated since 1980 and remains within the observed range, however the number of leks surveyed in East-Central Minnesota had declined markedly (Roy 2016). Though it is unclear how this decline is affected by survey effort, observations of historical leks becoming inactive are common in the East-Central (MNDNR, unpublished data).

Because of population decline, and subsequent lower harvest, MNDNR set a long-term goal to raise the annual sharp-tailed grouse harvest to 40,000 (MNDNR 2007). To attain this goal, forest planning efforts have identified priority open landscapes for brushland management (MNDNR 2007) with an objective of increasing the quantity and quality of habitat throughout the sharp-tailed grouse range in Minnesota. Brushland management, however, is expensive and comprises a considerable portion of the MNDNR Wildlife Operations budget. Open-brushland management expenditures on public lands exceeded $700,000 annually from FY2012-FY2014 (MNDNR, unpublished data). Despite the amount of resources allocated to open-brushland management, significant information gaps exist in relation to sharp-tailed grouse habitat use in Minnesota.

Research on sharp-tailed grouse habitat specific to Minnesota has been limited, though some studies have been conducted in the northwestern (Artmann 1971; Schiller 1973; Wells 1981) and east-central (Hanowski et al. 2000) sharp-tailed grouse ranges. In addition, Berg (1997) summarized results from unpublished investigations to determine specific recommendations for habitat, such as size, composition, height, and density. The MNDNR and Minnesota Natural Resources Conservation Service (MN NRCS) provide detailed management guidance for sharp-tailed grouse habitat based on these studies, however it is unclear whether areas currently used by sharp-tailed grouse reflect the recommended characteristics or if managing for these features benefit sharp-tailed grouse populations. Annual dancing ground surveys and harvest estimates may provide some insight into the population level response to management (Connelly et al. 1998), however linking survival and fitness of sharp-tailed grouse to vegetation characteristics and associated management would better direct management resources (Martin 1992).

OBJECTIVES

1. Quantify adult and brood survival and identify causes of mortality.
2. Identify vegetation characteristics that influence nest site selection and nest success.
3. Evaluate breeding season habitat use by sharp-tailed grouse hens and broods.

METHODS

Study Area

Study sites were within the east-central Minnesota sharp-tailed grouse range. The east-central sharp-tailed grouse range is within the forested region of Minnesota. Sharp-tailed grouse habitat in this region consists mainly of open and brush lowlands and hayfields on both public and private lands. Grouse were captured at 7 leks in 2 concentrated areas in Aitkin County and St. Louis County. Leks selected for trapping occurred on public and private lands with known habitat management histories.

Field Methods

Sharp-tailed grouse were captured and radiocollared at active leks (dancing grounds) during the lekking period (from late March through early May) in 3 years (2013-2015). Grouse were captured using walk-in funnel traps and drift fences placed across the center of the lek (Toepfer et al. 1987). Staff and volunteers monitored trap sets daily from nearby ground blinds and recorded weather conditions and daily attendance of male and female grouse. Captured grouse were fitted with a necklace style radio transmitter (ATS Model A3960) equipped with a 12-hour mortality sensor. Date of capture, location, transmitter frequency, sex, age class (juvenile or adult), and weight (only in 2015) were recorded for each grouse.

Radiocollared grouse were located using truck mounted omni-directional antennas and hand-held 2-element antennas (Telonics RA-23K) in combination with portable receivers (ATS R2000). Location was determined either by searching on foot using homing techniques and circling or visually confirming location or from a distance using triangulation with a minimum of 3 directional azimuths. Bird ID (frequency), date, time, coordinates at the site, and azimuth to source of greatest signal (if using triangulation) was recorded. All GPS locations were recorded using the UTM Zone 15 North (NAD 1983) coordinate system.

Grouse were located every 2-3 days (minimum of 2 observations per week) to determine breeding status, habitat selection, and survival over the course of the breeding season (May-August). All observations were made during daylight hours, and the order of observations was interchanged to obtain a sample that accounts for differing time of day and associated activities (e.g. feeding, loafing, and roosting). For hens, once sedentary behavior was initiated (found repeatedly at the same location), the nest was confirmed by flushing the hen. Actual location, clutch size, and overhead cover (see methods below) were recorded. The average incubation time for sharp-tailed grouse is 23 days, during which hens usually remain on or within close distance of the nest. If nesting hens were found to be off of the nest, the nest was located to determine fate. In cases of depredation, the nest site was searched and any predator signs noted. After hatch, nests were observed to confirm clutch size and determine the number of successfully hatched eggs. Egg shells were collected, air-dried and stored for future projects using genetic analysis. In cases of mortality, location, condition, and cause of mortality (e.g., mammalian predation, avian predation, exposure/weather, hunting) were recorded and any predator or scavenger signs noted.

Following hatch, hens and broods were located every 2-3 days (minimum of 2 observations per week) to monitor habitat use and survival. Chicks are generally able to fly 10 days after hatch, though they may not flush when approached. Hen location was recorded at or near the site where the hen and/or brood was flushed or by circling within 5 m of the hen without flushing. To determine brood survival, hen behavior and visual confirmation of chicks was used. When possible, the number of chicks present was determined, however young broods were not purposefully flushed. After 30 days from hatch, hens were flushed and the immediate area searched to flush any chicks to determine brood survival and size. Brood counts continued through August or until approximately 50 days post-hatch, as the likelihood of chick dispersal increases at this point. During the fall and winter season, grouse were located monthly to check for mortality and to determine over-winter survival rates. In cases of mortality, grouse were located and probable cause of mortality was determined.

After hatch and movement away from the nest, vegetation metrics at the nest site were assessed. In addition, for each nest 2 non-nest points were assessed using the same methods. Non-nest points were chosen by randomly selecting a bearing and distance (from 100 to 200 m). Non-nest points were searched to ensure that no other sharp-tailed grouse nests occurred in the immediate area. Brood sites were also assessed using the same vegetation assessment methods, once the hen had moved away from the site.

At each nest, non-nest, and brood site the existing vegetation was measured. Height of the residual cover, understory, and mid-story (shrub) vegetation, if present, was measured to the nearest cm or m at the plot center (the nest), at 2 m, and at 15 m from plot center in each cardinal direction. Overhead cover at plot center (within the nest bowl) was estimated using a 20 cm disc with 9 evenly spaced squares (Roersma 2001; Manzer 2004). The number of squares at least 50% visible (not obscured by vegetation) when viewed from 1 m directly overhead was recorded. Vegetation density was measured using a 2 m tall density pole divided into four 0.50 m sections (adapted from Nudds 1977). Percent obscured (in 10% increments) was determined from a height of 1 m (kneeling) for each section from 2 m and 15 m away in each cardinal direction. The number of potential avian predator perch sites (stems > 3 m in height) within 30 m of the nest was recorded (Manzer and Hannon 2005). If the nest or point occurred under a shrub patch, the species was identified and the patch height, length, and width were measured to the nearest m. For large patches, patch height was determined by measuring the tallest stem in each cardinal direction and averaging. Patch area and volume were calculated from these values. Soil moisture level was classified as well-drained, saturated, or standing water using a scale from 1-3.

Analysis

Factors affecting lek attendance were assessed using univariate linear regression. Annual and monthly adult survival were estimated by sex using known-fate models in Program MARK (White and Burnham 1999). Monthly survival probabilities were estimated using the Kaplan-Meier product limit estimator (Kaplan and Meier 1958) with a staggered entry design (Pollock et al. 1989). Cases of mortality within 1 week of capture were removed from the survival analysis.

Nest success was evaluated using the nest-survival module in Program MARK (Dinsmore and Dinsmore 2007). Daily survival rate (DSR) was calculated and used to estimate overall nest success. Vegetation characteristics affecting nest success were assessed in MARK and R using logistic regression. Nest site selection was assessed in R using case-control conditional logistic regression using matched nest and non-nest sites. Akaike's Information Criteria corrected for small sample sizes (AICc) and likelihood values were used to compare candidate models and the top model is presented. Brood survival was not statistically analyzed due to the low sample size of broods, however apparent brood survival, brood size, and the ratio of hatch-year birds to nesting hens are reported by year. Vegetation at brood sites were characterized by comparing brood sites to nest and non-nest sites in pairwise comparisons using Tukey's Honest Significant Difference in R.

Breeding season (May-August) habitat use was assessed using compositional analysis of cover types (Aebischer et al. 1993) for all hen locations and for locations of hens with broods. Individual hen locations were compared to cover type availability surrounding the lek, or lek complex when leks overlapped. Six leks/complexes were identified and delineated using a convex hull incorporating hen locations. Cover type was classified into 6 categories: agriculture, brushland, forest, hayfield, open lowland, and open upland based on field assessment, aerial imagery, and ground-truthing at the study sites. Digitized cover type was converted to a 10m resolution grid for analysis. Developed land and open water were classified as covering <1% of the land, but were excluded from the analysis because of non-use. Use was defined as the proportion of locations in each cover type, excluding successive locations of hens on lekking grounds and nests. Availability was defined as the proportion of the lek or lek complex in each cover type.

RESULTS

Sharp-tailed grouse lek attendance was monitored at each trap site for a total of 202 observations with dates ranging from March 13 to May 16. Daily maximum attendance of females and males at leks were significantly related to each other ($P < 0.001$). Wind speed and temperature were significantly related to date ($P < 0.01$, $P < 0.001$). Wind speed was significantly related to both female ($P < 0.01$) and male ($P < 0.001$) lek attendance (Figure 2), however temperature was not related to either female or male lek attendance ($P = 0.23$, $P = 0.71$, Figure 3). Date was significantly related to female grouse attendance ($P < 0.001$, Figure 4), but not to male attendance ($P = 0.50$, Figure 5). Timing of female attendance at leks varied year to year. The first hen was observed on April 16 in 2013, April 3 in 2014, and March 27 in 2015. Spring snow melt varied year to year with 2013 being a late spring and 2015 being an early spring, however snow pack was not tracked at trapping sites.

A total of 39 female and 20 male sharp-tailed grouse were radiocollared at seven leks over the three years of the study. Average annual survival rate of radiocollared grouse was 0.41 ± 0.07 for females and 0.24 ± 0.10 for males; however survival rates differed by year (Figure 6). Monthly survival rates differed by month and between females and males (Table 1, Figure 7). The lowest monthly survival rate for females was in July, while the lowest monthly survival for males was in November. Over-winter survival from December to February was also low for males but was relatively high for females. Causes of mortality for adult grouse were difficult to determine in many cases (n = 15). Avian predation was the most common identifiable cause of mortality (n = 12). Also observed were cases of mammalian predation (n = 6), hunter harvest (n = 2), and un-depredated deaths potentially due to health or exposure (n = 7).

Across all years of the study, a total of 44 nests were located and monitored. This included 4 known re-nests initiated after nest loss. Following nest depredation or loss, 27% of hens re-nested. Average clutch size from nests that reached the incubation stage (n = 35) was 11 and ranged from 7 to 14 eggs. On average, nests were 1.2 km from the lek where trapped, but distances ranged from 60 m to 3.8 km from the lek. No nest site fidelity was observed year to year or for re-nesting hens. The top model for nest site selection, using nest sites and non-nest sites, included overhead cover, presence of shrub at the nest, vegetation density 0.5-1.0 m from 15 m, soil moisture level, vegetation density 0-0.5 m from 2m, and number of perches ($P < 0.001$, AICc = 54.77, Table 2).

Apparent nest success ($\geq$ 1 egg hatched) was 59%. Adjusted rate of nest survival was 0.42 ± 0.09, based on a daily survival rate of 0.976 ± 0.006, however nest survival differed by year (Table 3). For successful nests, the rate of egg hatch was 88%, with unhatched eggs being found in a variety of stages of development. The average hatch date for first nests was 24 June. The most common reason for nest loss was depredation (n = 14). Also observed were cases of hen mortality (n = 3), prescribed fire (n = 1), and unknown loss (n = 1). The influence of vegetation metrics on nest success was modeled using 42 nests (2 nests were unable to be relocated for sampling), however vegetation variables were not able to sufficiently explain nest success despite some indication of relationships (see discussion).

Broods were followed for 26 hatched nests over 3 years of study. Seven broods were assumed to be lost following hen mortality during the brooding period. Eleven broods (42% of hatched nests, 25% of all nests) had at least one surviving chick at approximately 50 days post-hatch, with a total of 47 surviving chicks counted among the 3 years. The average number of surviving chicks per nesting hen was 1.15, and the average number of chicks per successfully nesting hen was 1.81 but varied greatly by year (Table 4). Brood sites were more similar to random non-nest sites than nest sites (Table 5). However, brood sites were similar to nest sites in that the height of shrubs at 15m was shorter than non-nest sites. Brood sites differed from both nest and non-nest sites in that they had shorter residual vegetation at the center, 2m, and 15 m, and lower density of vegetation at 15 m from 0.5-1.0m, 1.0-1.5m, and 1.5-2.0m (Table 5).

Compositional analysis was conducted using proportional cover type use of 43 hens. Results indicated that habitat selection by hens differed from random ($\lambda = 0.28$, $P < 0.01$). Cover types ranked by magnitude of selection based on use and availability were brushland, open upland, agriculture, hayfield, open lowland, and forest (Table 6). Brushland, open upland, agriculture, and hayfield were used at a greater proportion than their availability (Figure 8). Compositional analysis of cover type use by hens with broods also indicated that brood use differed from random ($\lambda = 0.18$, $P < 0.01$) with the same ranking of cover types. However, overall, hayfields were used at a noticeably higher rate by brooding hens (Figure 9).

Grouse locations (male and female, n=1,087) ranged from 0–4.1 km from the lek, with an average distance of 0.9 ± 0.03 km. Of these locations 36% were on public lands, and 24% were on lands with known habitat management occurring within 10 years. Using all locations at each lek or lek complex, area of a convex hull ranged from 40–1460 ha, however avoidance of forest cover within some areas was apparent.

DISCUSSION

As expected, grouse attendance on leks was influenced by wind speed and date, consistent with other studies of lek attendance (Drummer et al. 2011). In Minnesota, annual lek surveys are to be conducted when the wind speed is <16 km/hr (Roy 2016). In this study, wind speeds as low as 5 km/hr reduced the average number of grouse present. Female grouse attendance on leks peaked later than expected. Traditionally annual lek surveys are to be conducted from April 1 to April 25, to capture the peak of lek activity (Roy, unpublished instructions). In 2013, snow remained on the ground into mid-April, and the first hen was not observed until April 16, with hen attendance peaking during the first week of May. Anecdotally, across years snow depth seemed to influence hen attendance on leks, however was not measured directly. Across all years, hen attendance was greatest from mid-April through early May. Male lek attendance peaked from early April through early May, corresponding to the survey period. Because annual lek surveys in Minnesota rely on an index of males per dancing ground they are likely not impacted by the later arrival of hens, however the finding that male and female attendance are significantly related suggests that in years when hen attendance peaks later, potentially because of late snow melt, male counts could be lower.

Average annual survival rates of 41% for females and 24% for males, were similar to the annual survival rates found in other studies across the range of sharptails. In hunted populations, survival rates ranged from 17 to 42% (Robel et al. 1972, Moyles and Boag 1981, Giesen 1987), and in an un-hunted population survival was 53% (Schroeder 1994). Hunter harvest accounted for <5% of mortality observed. For hens, a drop in survival in July corresponds with the time period when hens are caring for young broods and may be more vulnerable to predation. Similarly, Manzer and Hannon (2007) found that hen survival was lowest during the reproductive period, reporting 53% survival from May to mid-August. Hen survival during the breeding season may be an important component in understanding population trends.

Cover type and vegetation varied greatly among nest sites selected. There was no indication that hens were selecting for specific nest site characteristics, however modeling results suggested that overhead cover and shrub presence were important drivers. Similarly, a study in northeast British Columbia found that sharp-tailed grouse hens selected nest sites with greater shrub, grass, and residual cover and taller vegetation (Goddard et al. 2009). In this study, cover types and vegetation metrics at nest sites had high variability, making it difficult to detect drivers of nest success and nest site selection. Despite vegetation metrics not being strongly related to nest success, successful nests tended to have more overhead cover and higher vegetation density than unsuccessful nests. Sharp-tailed grouse in east-central MN may be showing some adaption to a less frequent disturbance regime by using a variety of nesting sites that are not typical of sharp-tailed grouse in the prairie habitats of NW Minnesota and other states.

Nest survival of 42% ± 9% in this study was on the lower end of nest success rates of 47 to 72% found in other studies (Sisson 1976, Marks and Marks 1987, Meints 1991, Manzer and Hannon 2005). Manzer and Hannon (2005) found that nests were more likely to succeed with taller concealment cover, and that nest success was related to corvid density, which was not measured in this study. Brood survival was low with only 25% of nests having $\geq$1 chick survive to 50 days post-hatch and an average of 1.81 chicks per successfully nesting hen. Another study reporting on reproduction found 67% of broods had $\geq$1 chick survive 35 days post-hatch, with an average of 3.59 chicks per successfully nesting hen (Goddard and Dawson 2009). Goddard and Dawson (2009) found that increased travel distances were related to chick mortality, suggesting the importance of having nesting and brood-rearing habitat in close association. Further analysis of data in this study could explore the spatial arrangement of habitat and its relationship to brood survival.

Hens with broods used hayfields more often and in greater proportion than their availability. Goddard et al. (2009) also found that brood-rearing hens primarily used hayfields and cereal crops during the brood-rearing period. A survey of hayfield mowing practices in counties associated with our study sites indicated that on average sites are first mowed early-mid June and are mowed 2-3 times per year with > 5 weeks between mowing (Corace et al. 2009). These activities overlap with the time when sharp-tailed grouse hens are raising broods. Mowing practices and an affinity for hayfields by brooding hens could be a conservation concern for the species. In this study, when brooding hens were located in hayfields, they were always in un-mowed hayfields. Freshly mowed hayfields likely do not provide sufficient cover for broods. In addition 2 mortalities were discovered in recently mowed sites, however the cause of mortality was not clear.

Berg (1997) reported that in Minnesota sharp-tailed grouse require blocks of contiguous habitat at least 5 km^2 (500 ha). Similarly, Sjogren (1996) reported that the home range size of grouse in the Upper Peninsula of Michigan was 641 ha. Based on locations of male and female grouse, lek complexes in this study ranged in size from 40–1460 ha. Grouse locations were as far as 4.1 km from the lek, however 94% of locations were within 2.5 km of the lek. These results suggest that habitat management efforts can be focused on lands within 4 km of the lek, with a greater priority given to lands within 2.5 km. Only 36% of locations were on public lands and 24% on lands with habitat management conducted by the MNDNR. Surrounding private lands play an important role in sharp-tailed grouse habitat.

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Table 1. Monthly and over-winter (December to February) survival rates by sex for radiocollared sharp-tailed grouse in East-Central Minnesota from 2013-2015.

Time period	Female	Male
March	$1.00 \pm 0.13 \times 10^{-4}$	$1.00 \pm 0.65 \times 10^{-7}$
April	$1.00 \pm 0.13 \times 10^{-7}$	$1.00 \pm 0.30 \times 10^{-9}$
May	0.91 ± 0.04	0.87 ± 0.07
June	0.88 ± 0.05	0.85 ± 0.08
July	0.67 ± 0.08	0.94 ± 0.06
August	0.87 ± 0.07	0.94 ± 0.06
September	0.95 ± 0.05	0.93 ± 0.07
October	$1.00 \pm 0.20 \times 10^{-4}$	0.83 ± 0.11
November	$1.00 \pm 0.11 \times 10^{-4}$	0.71 ± 0.17
Over-winter	0.94 ± 0.06	0.67 ± 0.19

Table 2**.** Conditional logistic regression results for the top model explaining radiocollared sharp-tailed grouse nest site selection in East-Central Minnesota from 2013-2015.

Variable	Coefficient	P-value
Overhead cover	0.57	<0.001
Presence of shrub	3.41	0.004
15m density 0.5-1.0m	-0.05	0.006
Soil moisture	-1.48	0.01
2m density 0-0.5m	0.03	0.03
Number of perches	-0.16	0.19

Table 3. Number of nests, apparent nest success, daily nest survival rate, and nest survival rate by year for radiocollared sharp-tailed grouse hens in East-Central Minnesota from 2013-2015.

Year	Total nests	Apparent nest success	Daily nest survival rate	Nest survival rate
2013	19	0.74	0.985 ± 0.003	0.60 ± 0.07

Year	Total nests	Apparent nest success	Daily nest survival rate	Nest survival rate
2014	14	0.57	0.974 ± 0.005	0.40 ± 0.09
2015	11	0.36	0.955 ± 0.01	0.20 ± 0.08

Table 4**.** Brood survival statistics by year for radiocollared sharp-tailed grouse hens in East-Central Minnesota from 2013-2015.

Year	Hatched broods	Hen mortality while brooding	Broods surviving	Chicks surviving	Chicks per nesting hen	Chicks per successfully nesting hen
2013	14	6	3	13	0.72	0.93
2014	8	1	5	16	1.23	2.00
2015	4	0	3	18	1.80	4.50

Table 5. Pairwise comparison (Tukey HSD) results showing the observed means and P-values comparing radiocollared sharp-tailed grouse brood sites to nest and non-nest sites in East-Central Minnesota from 2013-2015.

Variable	Brood	Nest	Non-nest	P-value brood/nest	P-value brood/non
Overhead cover	3.14	5.76	2.64	<0.001	0.4
Residual height (cm)	6.52	22.12	14.10	<0.001	<0.001
Understory height (cm)	53.86	62.64	50.92	0.08	0.63
Shrub height (m)	0.21	0.58	0.20	0.01	0.99
2m residual height	8.51	15.43	13.74	<0.001	<0.001
2m understory height	54.76	56.23	52.40	0.92	0.70
2m shrub height	0.13	0.23	0.25	0.28	0.06
2m density 0-0.5m	61.91	78.20	62.16	<0.01	1.00
2m density 0.5-1.0m	13.29	25.57	18.38	<0.01	0.17
2m density 1.0-1.5m	2.93	10.21	5.90	<0.001	0.13
2m density 1.5-2.0m	2.02	7.41	4.08	0.01	0.34
15m residual height	8.21	14.85	13.96	<0.001	<0.001
15m understory height	57.40	55.91	55.36	0.92	0.78
15m shrub height	0.22	0.40	0.44	0.10	0.01
15m density 0-0.5m	91.73	96.42	88.00	0.33	0.33
15m density 0.5-1.0m	46.20	61.03	58.31	0.05	0.04
15m density 1.0-1.5m	21.08	41.93	40.31	<0.001	<0.001
15m density 1.5-2.0m	14.92	30.54	31.57	0.01	<0.001
Number of perches	8.42	2.93	5.93	0.10	0.46
Shrub presence	0.09	0.33	0.08	<0.001	0.97
Road distance	536.37	368.62	373.74	0.16	0.07

Table 6**.** Compositional analysis results for radiocollared sharp-tailed grouse hen use of six cover types in East-Central Minnesota from 2013-2015. Symbols in the table indicate if the cover type in the row is used significantly more (+++), more (+), significantly less (---), or less (-) than the cover type in the column. Cover types are ordered from most to least selected for.

	Brushland	Open upland	Agriculture	Hayfield	Open lowland	Forest
Brushland		+	+	+++	+++	+++
Open upland	-		+	+++	+++	+++
Agriculture	-	-		+	+++	+++
Hayfield	---	---	-		+	+
Open lowland	---	---	---	-		+++
Forest	---	---	---	-	---	

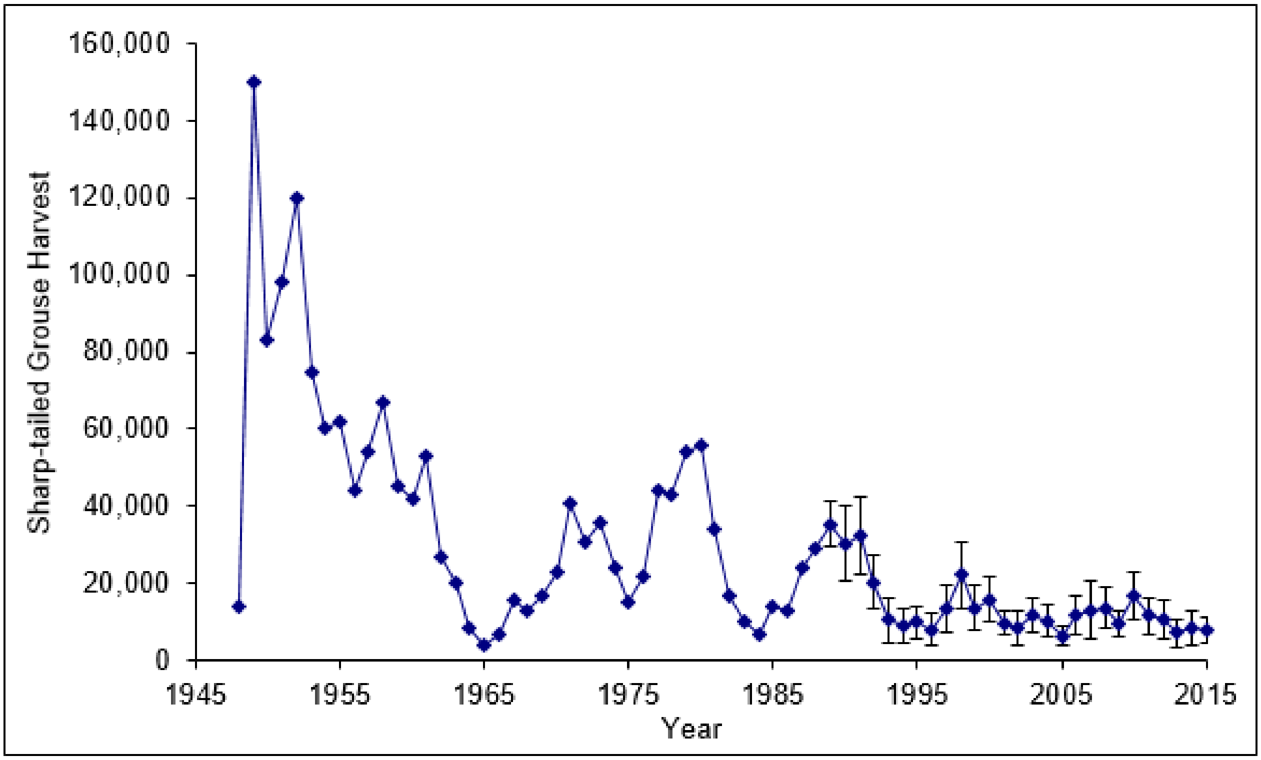

Figure 1**.** Sharp-tailed grouse harvest estimates for Minnesota from 1948 to 2015 from the Small Game Hunter Harvest Survey (Dexter 2015). Estimates from 1989 on show the 95% confidence interval.

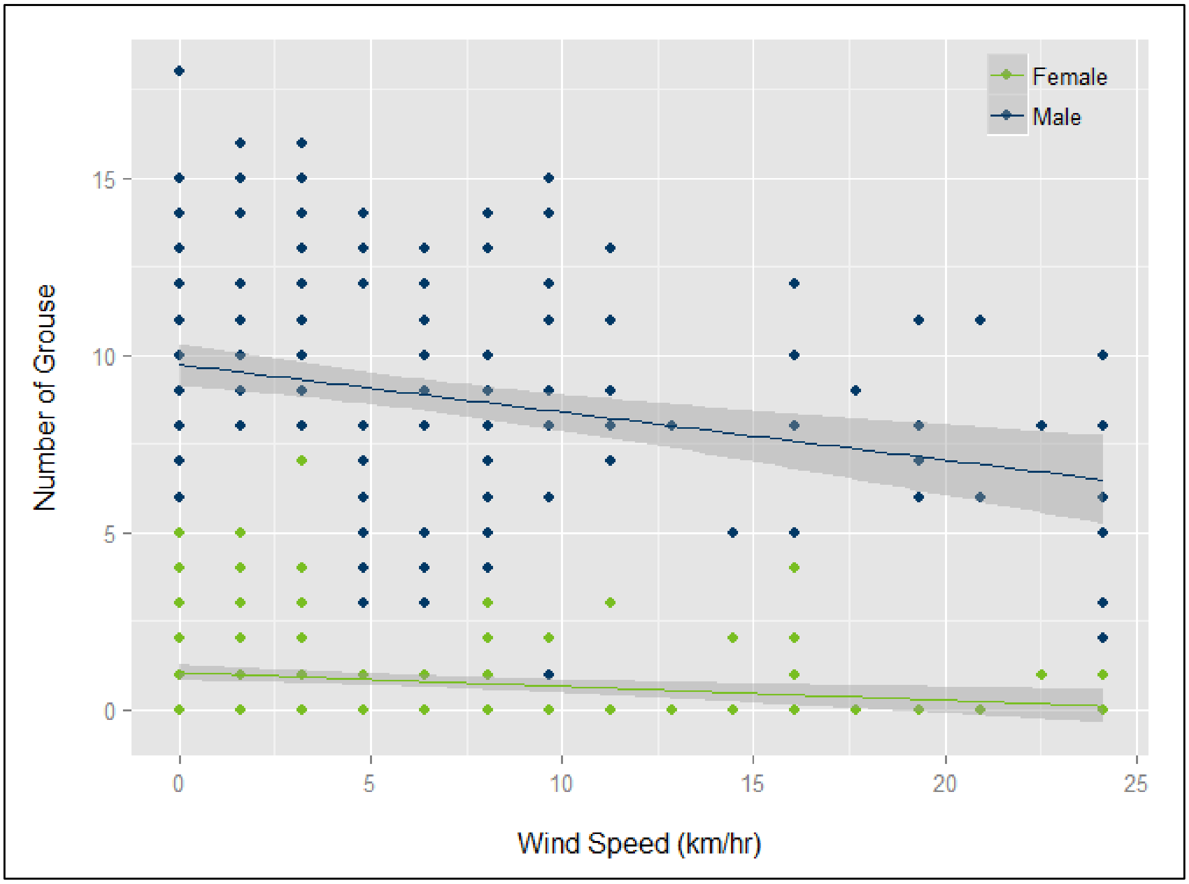

Figure 2**.** Sharp-tailed grouse lek attendance (number of grouse) by sex in relation to wind speed (km/hr) at trapping sites in East-Central Minnesota from 2013-2015. Linear regression (lines) and standard error (shading) are shown.

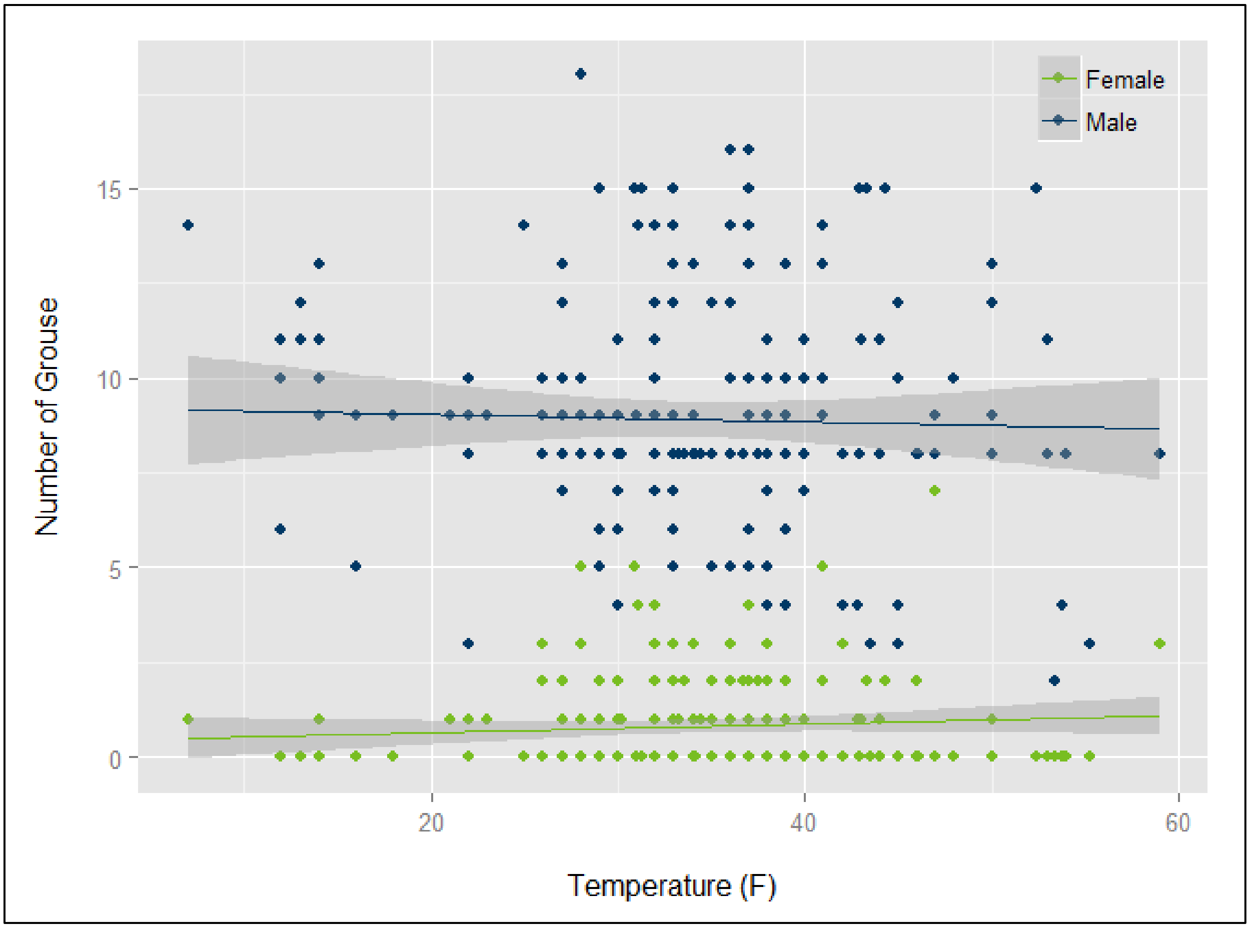

Figure 3. Sharp-tailed grouse lek attendance (number of grouse) by sex in relation to temperature (F) at trapping sites in East-Central Minnesota from 2013-2015. Linear regression (lines) and standard error (shading) are shown.

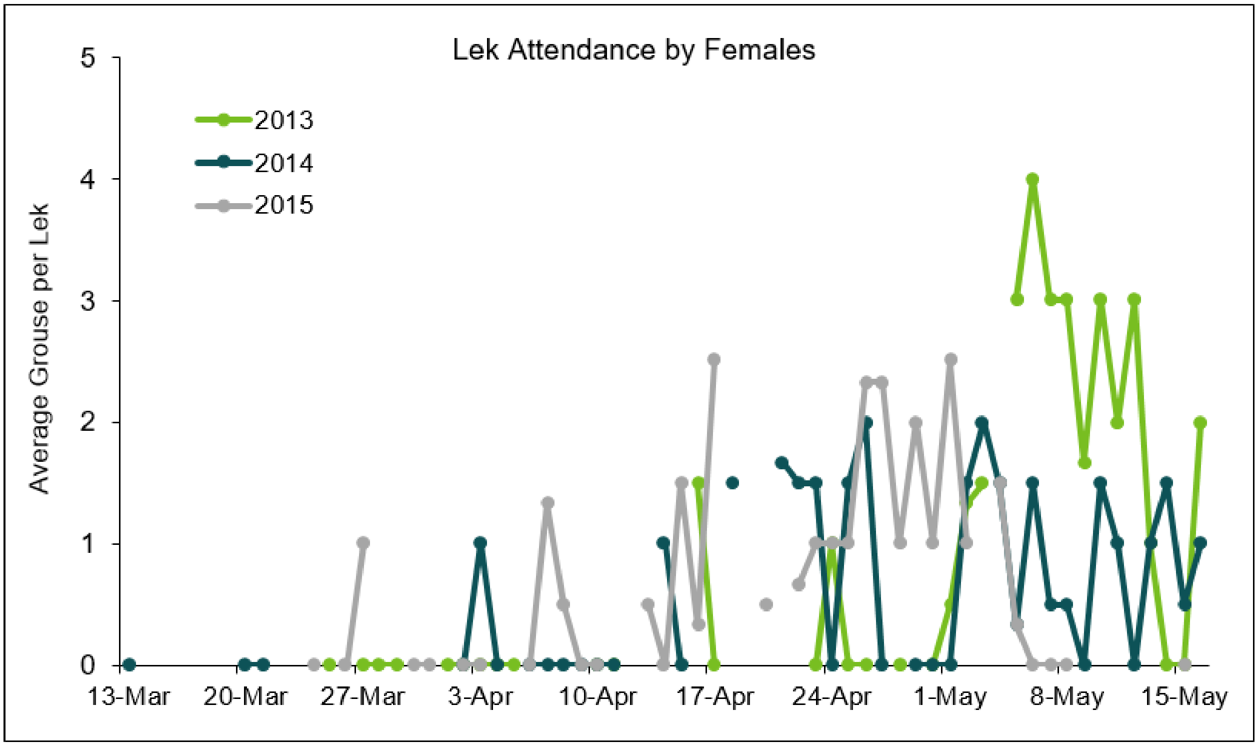

Figure 4. Female sharp-tailed grouse lek attendance (average number of grouse per lek sampled) by date at trapping sites in East-Central Minnesota from 2013-2015.

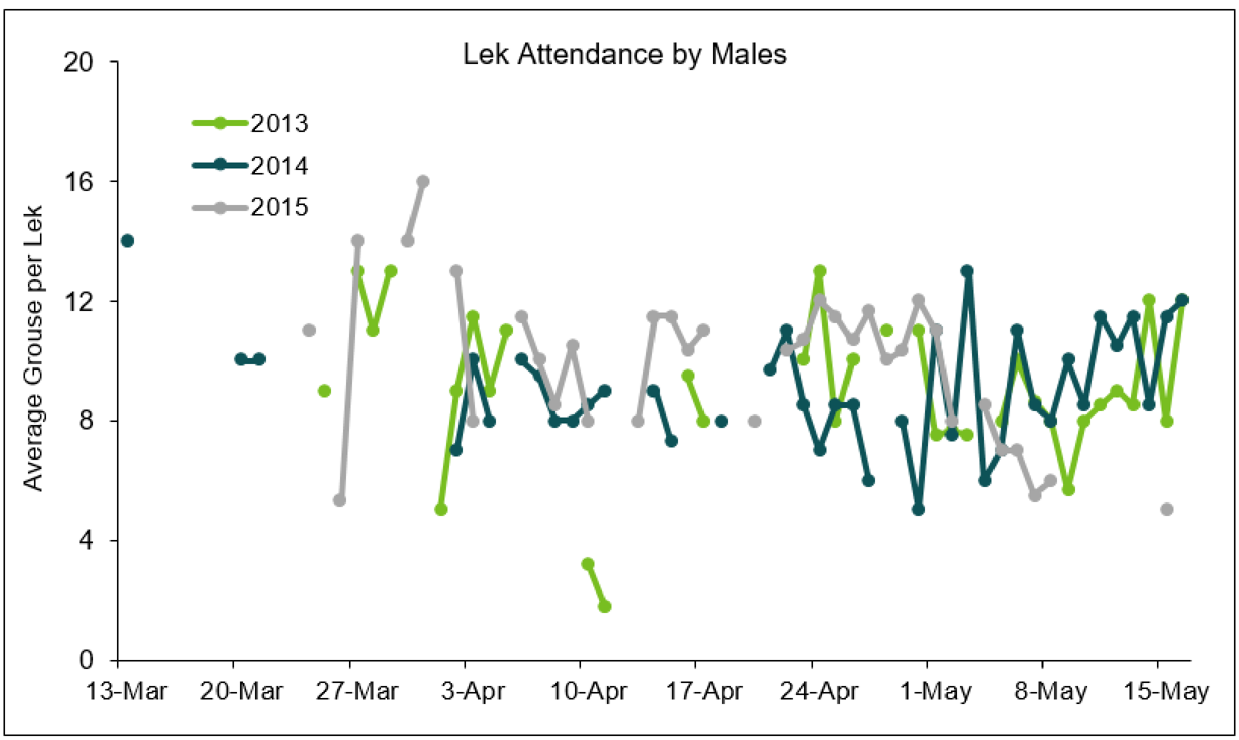

Figure 5. Male sharp-tailed grouse lek attendance (average number of grouse per lek sampled) by date at trapping sites in East-Central Minnesota from 2013-2015.

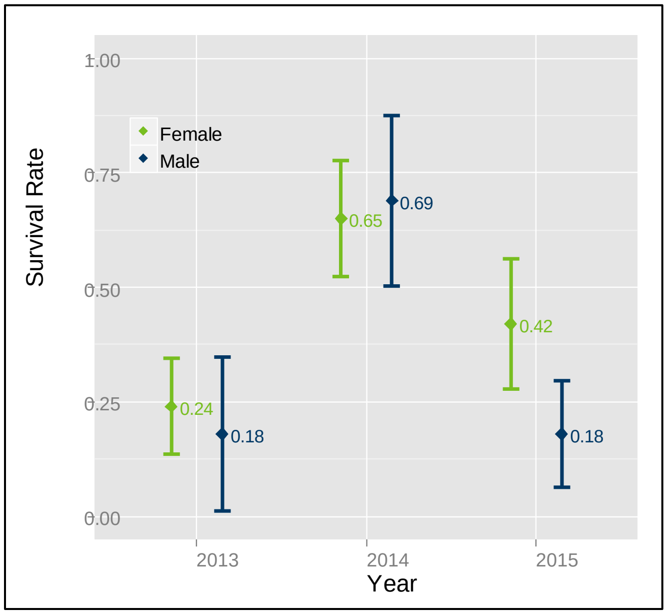

Figure 6. Annual survival rates and standard error by sex for radiocollared sharp-tailed grouse in East-Central Minnesota from 2013-2015.

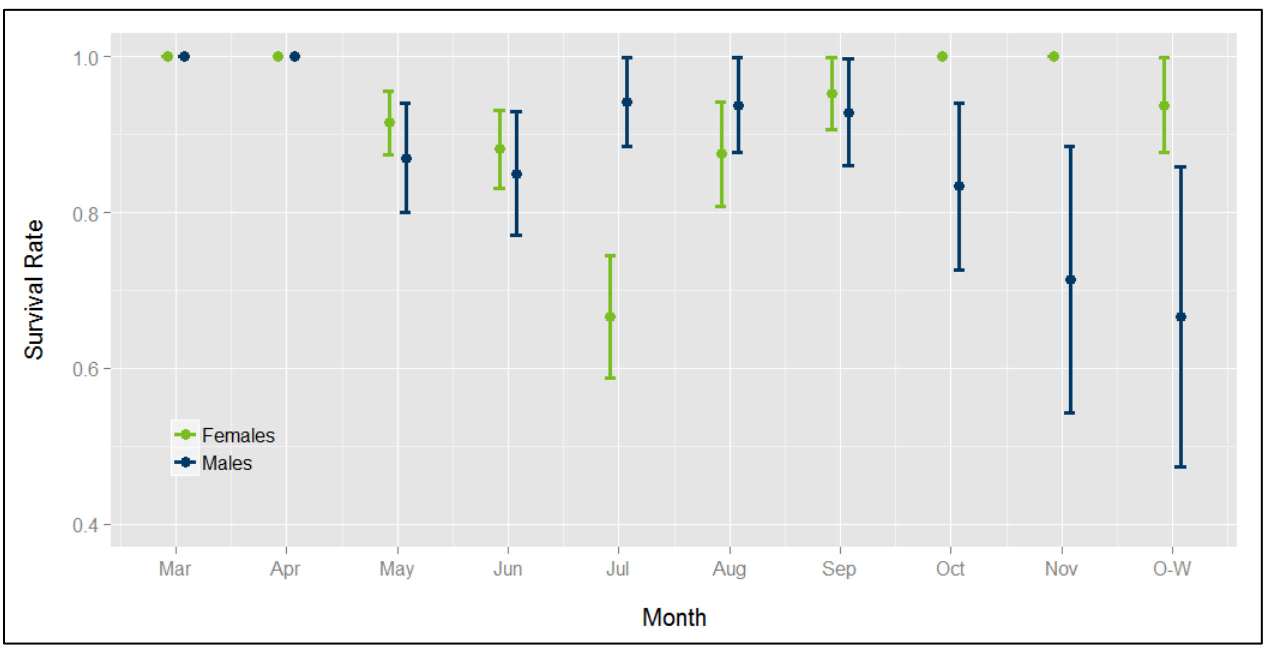

Figure 7. Monthly survival rates and standard error by sex for radiocollared sharp-tailed grouse in East-Central Minnesota from 2013-2015. O-W represents the over-winter period from December through February.

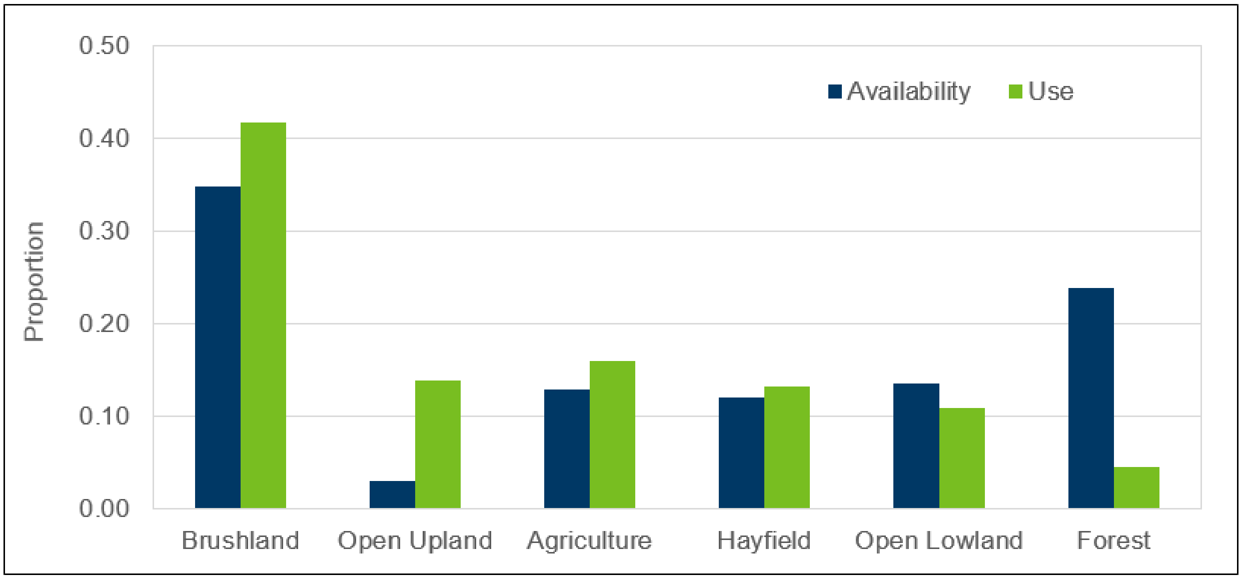

Figure 8**.** Availability and use of six cover types, ordered from greatest to least selected for, by radiocollared sharp-tailed grouse hens in East-Central Minnesota from 2013-2015.

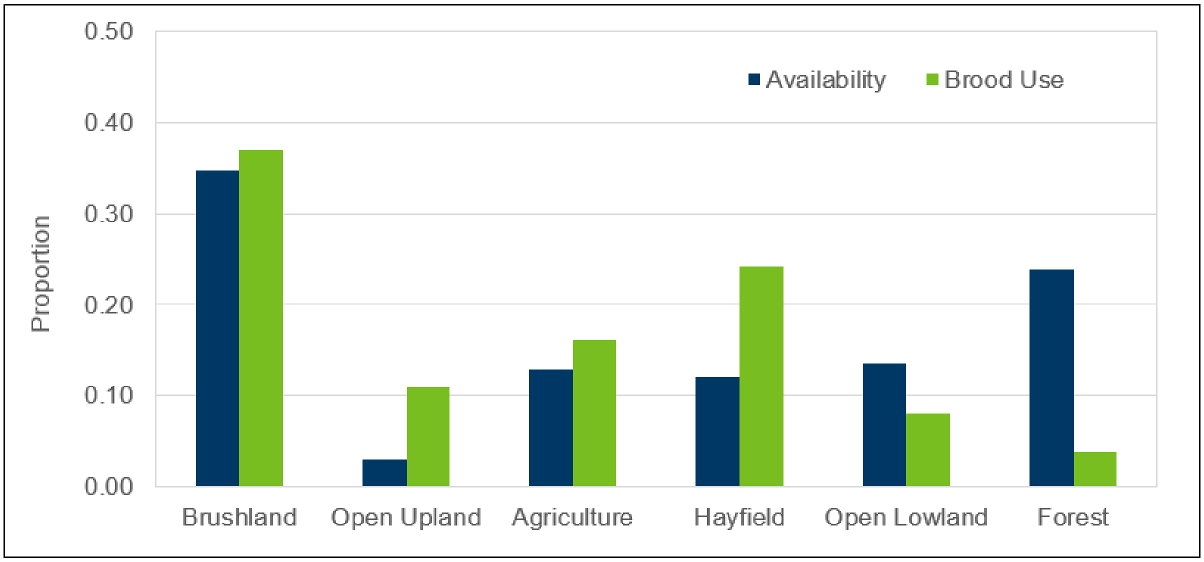

Figure 9. Availability and use of six cover types, ordered from greatest to least selected for, by radiocollared sharp-tailed grouse hens with broods in East-Central Minnesota from 2013-2015.