# EFFECTS OF LIVESTOCK GRAZING MANAGEMENT ON THE ECOLOGY OF SHARP-TAILED GROUSE, GRASSLAND BIRDS, AND THEIR PREDATORS IN NORTHERN MIXED GRASS PRAIRIE HABITATS

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2016 3rd QUARTER REPORT


Submitted by:

Wildlife Habitat Ecology Lab
Department of Animal & Range Sciences
Montana State University


Presented to:

Montana Department of Fish, Wildlife, and Parks


Principal Investigators

Lance McNew
Lorelle Berkeley
Melissa Foster
John Ensign

Graduate Students

Megan Milligan
Skyler Vold

Field Technicians

Kyla Bas, Adam Bradley, Adrian Cain, Drew Howing

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# EFFECTS OF LIVESTOCK GRAZING MANAGEMENT ON THE ECOLOGY OF SHARP-TAILED GROUSE, GRASSLAND BIRDS, AND THEIR PREDATORS IN NORTHERN MIXED GRASS PRAIRIE HABITATS

3rd Quarter Report
Reporting Period: 1 June – 30 September

## EXECUTIVE SUMMARY


Field efforts this quarter focused on tracking radio-marked female grouse, monitoring nests, conducting habitat surveys at nest and brood locations as well as random points in the study area, conducting insect sampling, collecting habitat information at insect sampling locations, and deploying remote cameras to evaluate predator occupancy.

We collected 992 independent locations for 39 radio-marked females during 1 July – 15 August. Reproductive effort was high. Radio-marked females initiated 73 nests (51 first nests, 21 renests, 1 third nest). Nesting frequency was 1 (all females available for monitoring initiated nests), while the probability of renesting (± SE) after first nest failure was 0.733 ± 0.05. Average clutch sizes were 12.16 ± 2.7 and 9.0 ± 2.4 eggs for first and renesting attempts, respectively. Twenty-seven nests successfully hatched and 46 failed (36 depredated, 3 abandoned, 7 hen mortalities). Daily nest survival was 0.968 ± 0.005 and overall nest survival was 0.337 ± 0.065. Preliminary analyses indicated that nest survival was similar between the conservation easement and the reference treatments.

We monitored 27 broods this season. Ten broods spent the majority of the time (>70% of locations) on the easement, 10 spent the majority of time in the reference area, and 7 split time between the two areas. Brood success, calculated as the proportion of broods fledging ≥1 chick to 14-d of age, was 0.40 ± 0.05, 0.60 ± 0.05, and 0.57 ± 0.07 for broods located on the easement, reference, and both areas, respectively.  Of broods that survived to fledging, the proportion of chicks that survived was 0.37 ± 0.14, 0.33 ± 0.09, and 0.86 ± 0.26 for broods located on the easement, reference, and both areas, respectively.

Of the 66 females originally radio-marked, 24 have been depredated (14 mammalian, 8 avian, 2 unknown predation). There was 1 additional mortality for which cause of death could not be determined. Three females were right censored from the study when their transmitters were found with no sign of death and an additional 5 females were right censored after they could not be relocated for more than 2 months.

During the 2016 breeding season (April – August), we located the 62 radio-marked females 2,048 times, including locations of birds at nests; 37 females had at least 25 unique locations and allowed for seasonal home range estimation. Eleven females spent the majority of their time (>70% of locations) on the easement, while 15 spent the majority of their time in the reference area. The remaining 11 females split time between the two areas. Mean breeding season home range size was 543 ± 165 $m^2$, 330 ± 68 $m^2$, and 918 ± 354 $m^2$ for easement females, reference females, and females that split time between the two areas, respectively. Mean distance of the centroid of a female's home range from lek of capture was 840 ± 99 m, 1,801 ± 318 m, and 1,080 ± 150 m for easement females, reference females, and females that split time between the two areas, respectively.

We sampled invertebrates via sweep-netting along two 20-m transects associated with 305 grassland bird survey locations (see July 2016 quarterly report) for a total of 610 invertebrate samples (300 samples on easement pastures, 310 samples on reference pastures). Samples will be processed prior to the beginning of the 2017 field season.

We deployed and monitored camera traps for mesopredators at 90 independent locations within the study area and analyzed all photos from the cameras, identifying predators based on body shape and coloration. Five focal predator species were identified, coyote (*Canis latrans*), badger (*Taxidea taxus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and short-tailed weasel (*Mustela ermine*). Analyses of photos revealed 41 sites had presence of coyote (*Canis latrans*), 16 sites had presence of badger (*Taxidea taxus*), 9 sites had raccoon (*Procyon lotor*), 7 sites had striped skunk (*Mephitis mephitis*), and one site had short-tailed weasel (*Mustela ermine*). We observed predators at 69% of the camera sites within the easement pastures and 66.7% of the camera sites within reference pastures. Four predator species were detected on both the easement and reference pastures.

## OBJECTIVES

### Objective 1: Investigate rest rotation grazing as a rangeland management technique to improve sharp-tailed grouse fecundity and survival.

*Accomplishments Since Last Quarter:*

Efforts this quarter focused on tracking and monitoring nests and broods of radio-marked female sharp-tailed grouse. Sixty-six females were fitted with radio-transmitters in the spring (see previous quarterly report). Three females were never relocated and one died within a week of capture, so 62 females were regularly monitored. Radio-marked females were located by triangulation or homing ≥3 times/week from project trucks, ATV, or on foot. When females localized in an area and their estimated location did not change for 3 successive days, we used portable radio receivers and handheld Yagi antennas to locate and flush the female so eggs could be counted and nest location recorded with a handheld GPS unit. If the nest was first found during egg-laying, nest sites were visited again in <2 weeks to determine final clutch size and nest status. During the second visit, eggs were removed and carried >200 m from the nest and floated in a small container of lukewarm water to assess stage of incubation, estimate hatch date, and estimate the date of clutch initiation by backdating. Nest sites were not visited again until the female was located away from the nest for >2 consecutive days, indicating the female had departed from the nest location.

Once the female departed the nest, we classified nest fate as successful (>1 chick produced), failed, depredated, or abandoned. Nests were considered abandoned if eggs were cold and unattended for >5 days. Nests were considered failed if the eggs were destroyed by flooding, trampling by livestock, or by construction equipment. Nests were considered depredated if the entire clutch disappeared before the expected date of hatching, or if eggshell and nest remains indicated that the eggs were destroyed by a predator. When a depredation event occurred, the egg remains were evaluated and the area was searched for predator sign. For successful nests, hatchability was calculated as the percentage of eggs that hatched and produced chicks. Eggs that failed to hatch were opened to determine stage of development and possible timing of embryo failure.

We evaluated habitat conditions at each nest site within 3 days of hatching or expected hatch date in the case of failure. We recorded visual obstruction reading (VOR) at the nest bowl and at four points 8 m from the nest in each cardinal direction. At each point, VOR was measured in each cardinal direction from a distance of 2 m and a height of 0.5 m using a Robel pole (Robel et al. 1970). We estimated non-overlapping vegetation cover (percent new grass, residual grass, forbs, shrubs, bare ground, and litter) at 16 subsampling locations within 8 m of the nest using a 20 x 50 cm sampling frame (Daubenmire 1959). At each subsampling plot, we measured the heights of new grass, residual grass, forbs, and shrubs. We conducted parallel sampling at randomly selected points (n=71) within a study area defined by a minimum convex polygon placed around the leks of capture and buffered to 2 km. Random points that fell within unsuitable habitat (i.e., water, cultivation, etc.) or were located on properties to which we did not have access were replaced.

Nesting frequency was calculated as the percentage of females that attempted a nest. The probability of renesting was calculated as the number of observed renesting attempts divided by the number of unsuccessful first nests minus the number of females that had first nests but were unavailable to renest. A hen was considered unavailable if she was killed during the first nest attempt.

Nest survival is the proportion of nests that produce ≥1 chick. We constructed nest survival models in Program MARK to calculate maximum likelihood estimates of daily nest survival and evaluate the effects of habitat conditions on daily nest survival during a 70-d nesting period from 28 April to 6 July (White and Burnham 1999, Dinsmore et al. 2002). Variables considered in the preliminary analysis included grazing system (easement or reference), nest attempt (first or renest), visual obstruction at the nest (VOR), and the proportion of new grass, residual grass, forbs and shrubs within 8 m of the nest. We compared covariate models with a null model of constant daily nest survival using Akaike's Information Criterion adjusted for small sample sizes ($AIC_c$). We calculated the overall nest survival probability by raising the daily nest survival estimate from the most parsimonious model to an exponent equal to the mean laying plus incubation interval for grouse at our study sites. Variance of overall nest survival was estimated with the delta approximation (Powell 2007). The average duration of incubation period (23-d) was determined from observations of our sample of successful nests and from previous work (Connelly et al. 1998).

Sixty-two radio-marked females were monitored regularly throughout the season. Females initiated 73 nests (51 first nests, 21 renests, 1 third nest). Eleven females died or were censored from the study before initiating a nest (see below for full mortality results). Median nest initiation date for all nests was 1 May (28 April for first nests, 27 May for renests; range: April 22 – June 9). Twenty-seven nests successfully hatched and 46 failed (36 depredated, 3 abandoned, 7 hen mortalities). Hatch rate of eggs (± SE) for first nests and renests was 95.8 ± 5.7% and 82.6 ± 21.5%, respectively. Mean clutch size for all nest attempts was 11.2 ± 0.35 eggs. Mean clutch size for first nest and renests was 12.16 ± 2.7 and 9.0 ± 2.4 eggs, respectively.

Daily nest survival was 0.968 ± 0.005 and overall nest survival calculated as $DSR^{35}$ was 0.337 ± 0.065. When comparing competing models predicting nest survival, the constant model had the most support relative to other candidates ($w_i = 0.17$; Table 1). However, there was much model uncertainty and all but one model received some support ($\Delta AIC_c < 2$; Table 2). The 95% confidence intervals of the estimated slopes for every variable considered in the analysis overlapped zero (Figure 1). With the exception of the visual obstruction measured at the nest site, vegetation measured at nest sites and random sites in the study area were similar (Figure 2), suggesting random nest placement and survival of nests relative to nest site-scale vegetative conditions in the first year of the study. Future analyses will consider additional habitat metrics collected at nested hierarchical scales.

Pre-fledging brood survival was estimated by conducting flush counts between 14 and 16 days post hatch. Flush counts were conducted at dawn or dusk when chicks were close to radio-marked females to determine the number of surviving chicks in the brood. After females were flushed, the area was systematically searched and the behavior of the hen observed to assess whether chicks were present but undetected. For counts of 0 chicks, the brood hen was flushed again the following day to be certain no chicks remained in the brood. Flush counts were repeated at 14, 30, and 60 days post-hatch or until we were confident that no chicks remained with the hen. We used spotlights and a large net to capture >35 day old chicks by relocating radio-marked females at night. We recorded morphometrics and equipped 1-2 fledglings/brood with radio-transmitters attached with glue and sutures. Radio-marked fledglings were monitored ≥3 times per week until death or transmitter failure or loss.

Initial brood size was determined by the number of chicks that were known to hatch based on nest observations. Brood success was calculated as the proportion of broods that successfully fledged ≥1 chick. Fledging success was calculated as the proportion of chicks that survived until fledging among successful broods. Broods were included in the easement category if >70% of hen locations were within the easement boundaries, in the reference category if >70% of locations were in the reference area, and in the category "both" if they split their time between the two areas.

We monitored 27 broods to estimate survival and document habitat use (Table 3). Ten broods spent the majority of the time (>70% of locations) on the easement, 10 spent the majority of time in the reference area, and 7 split time between the two areas. Brood success, calculated as the proportion of broods fledging ≥1 chick to 14-d of age, was 0.40 ± 0.05, 0.60 ± 0.05, and 0.57 ± 0.07 for broods located on the easement, reference, and both areas, respectively. Of broods that survived to fledging, the proportion of chicks that survived was 0.37 ± 0.14, 0.33 ± 0.09, and 0.86 ± 0.26 for broods located on the easement, reference, and both areas, respectively. We captured 23 fledglings from 7 broods and attached radio-transmitters to 9 fledglings. None of the radio-marked fledglings survived until the 60-d flush count, but 67% of mortalities were due to predation, so it remains to be determined what effect the radio-transmitters had on survival.

We monitored radio-marked females ≥3 times per week to estimate survival. Transmitters were equipped with a mortality switch that activated after 6–8 hours of inactivity. Once the mortality switch activated, transmitters were located and the area searched to determine probable cause of death. Mortality events were classified as either predation, hunter, other, or unknown. Predation mortalities were further identified as either mammal, avian, or unknown predator. A mortality event was classified as mammalian predation if bite marks, chewed feathers, or mammalian tracks were present. Mortality was determined to be avian predation if the carcass had been decapitated and/or cleaned of the breast muscle with no bite marks, or if the feathers had been plucked. If none of these signs were present or if there were conflicting signs of mortality, the event was classified as unknown predation. Females were censored from the study if their collars were found with no sign of death or if they could not be located for ≥2 months.

We determined that 24 females were killed by predators: 14 and 8 by mammalian and avian predators, respectively, and 2 by an unknown predator. There was 1 additional mortality for which cause of death could not be determined. Three females were right censored from the study when their transmitters were found with no sign of death. An additional 5 females were right censored after they could not be relocated for more than 2 months.

*Goals For Next Quarter:*

We will continue to monitor radio-marked females ≥2 times/week through the non-breeding season (Sept – March) until death or transmitter failure/loss. In the next quarter, we will focus on estimating fecundity. Estimates of fecundity, or the number of female fledglings produced per adult female, are calculated using 7 demographic parameters that we will estimate directly from nest and brood data. These parameters include:

1) Nesting rate (NEST); the probability of a female initiating a nest.
2) Clutch size (CS): the final clutch size per nest.
3) Nest survival (NSURV); the probability of a nest producing ≥1 chick.
4) Renesting rate (RENEST): the probability of a female initiating a replacement nest after failure of the first attempt.
5) Chicks per egg laid (CPE): the proportion or eggs laid that produced chicks, or the hatchability of the eggs.
6) Brood survival (BSURV); the probability that ≥1 chick survived to fledging at 14-d post-hatch.
7) Fledgings per chick hatched (FPC); the proportion of hatched chicks that survived to fledging conditional upon brood survival.

Fecundity is expressed as a function of these parameters using the following equation:

$$F = \big[(NEST * CS_1 * NSURV_1) + [(1 - NSURV_1) * RENEST * CS_2 * NSURV_2]\big] * CPE * BSURV * FPC * 0.5$$

Some of these parameters, including nesting rate, clutch size, renesting rate, and chicks per egg laid, can be estimated directly from field data. However, other parameters are observed imperfectly. Nests are not observed from the initiation date and nests that fail before discovery must be taken into account. In addition, broods are not observed daily, resulting in ragged observation data. To account for imperfect observation, we will use the nest survival model in Program MARK to calculate maximum likelihood estimates of both daily nest and daily brood survival. Multiple model selection and inference will be used to evaluate the importance of multiple sources of variation, including grazing system, on daily survival rates.

**Objective 2: Investigate impacts of rest-rotation grazing on sharp-tailed grouse home ranges, movements and habitat selection.**

*Accomplishments Since Last Quarter:*

Efforts this quarter focused on monitoring female sharp-tailed grouse. Radio-marked females were located via triangulation or homing ≥3 times/week using portable radio receivers and handheld Yagi antennas. Females with broods were located ≥4 times/week, including one nighttime roosting location per week.

Coordinates for triangulated locations were calculated using Location of a Signal software (LOAS; Ecological Software Solutions LLC, Hegymagas, Hungary) and examined for spatial error. All locations with excessive error (>200 m error ellipse) were discarded for initial analysis, but the level of acceptable error will be examined on a case-by-case basis in the future. Previous studies have found that small sample sizes can bias home range estimates (Seaman et al. 1999), so analyses were restricted to birds with ≥25 unique locations after excluding multiple relocations of a female at the same nest. We used the fixed kernel method (Worton 1989) with the default smoothing parameter to calculate 95% home ranges for the breeding season (April – August) using the adehabitatHR package in Program R (R Core Team 2014, Vienna, Austria). We also calculated centroids for each home range using the rgeos package in Program R and calculated the distance each female traveled from lek of capture to the home range centroid in ArcGIS 10.4 (Environmental Systems Research Institute, Redlands, CA). Females were included in the easement category if >70% of their locations were within the easement boundaries, in the reference category if >70% of locations were in the reference area, and in the category "both" if they split their time between the two areas. We compared home range sizes and movement distances between easement females, reference females, and those that split time between the two areas using a Kruskal-Wallis rank sum test and considered groups to be significantly different at $p < 0.05$. If either home range size or movement distances differed significantly between the three groups, we performed a Wilcoxon rank-sum test to determine if there was a significant difference between either variable for easement and reference females.

During this quarter, we collected a total of 992 locations from 39 females, including 922 unique locations that excluded duplicate nest locations (Figure 3). Twenty females died during the second quarter and so were no longer available for locations. Three females were not located this quarter and four additional females were located irregularly due to the loss of field access. During the 2016 breeding season (April – August), 37 females had ≥25 unique locations. Eleven females spent the majority of their time (>70% of locations) on the easement, while 15 spent the majority of their time in the reference area. The remaining 11 females split time between the two areas. Mean breeding season home range size for all 37 females was 569 ± 122 $m^2$, but varied from 77 $m^2$ to 4,077 $m^2$. Mean breeding season home range size (Table 4) did not differ significantly between the three groups ($H = 3.52$, df=2, $p = 0.17$). However, the distance traveled by a female from the lek of capture (Table 4) did differ between the three groups ($H = 11.33$, df=2, $p = 0.003$) and was significantly higher for reference females compared to easement females ($W = 19$, $p = 0.0005$). The minimum distance from home range centroid to lek of capture for all females was 168 m, while the maximum was 5446 m.

*Goals For Next Quarter:*

We will continue to track radio-marked females ≥2 times/week during the non-breeding season (September – March) until death or transmitter failure or loss. Coordinates for triangulated locations will be calculated using LOAS software and all locations will be examined for spatial error. We will focus efforts in the next quarter on exploring different methods, such as resource utilization functions and resource selection functions, for estimating space use and habitat selection.

**Objective 3. Develop a mechanistic understanding of the ecological effects of various grazing treatments with a focus on rest rotation grazing by examining abundance and space use of the grassland bird and mesopredator communities**

*Accomplishments since the last quarter*

Efforts in the field this quarter were focused on sampling invertebrates, surveying vegetation, and deploying and monitoring camera traps for predators. We randomly generated points across gradients of habitat conditions to survey for grassland birds, invertebrates, and meso-predators within the easement and on adjacent private and federal lands managed with alternative grazing methods. One-hundred and fifty points were generated on the easement with 50 points in each of the three rotational pasture types; 155 points were randomly selected in pastures adjacent to the easement, with 60 points located on season-long grazing systems and 95 points on summer rotational grazing systems, where cattle are turned out at the end of May and moved between pastures after 6–8 weeks. Within 100-m of each bird survey point, we sampled two 20-m sweep-net transects for invertebrates, each at a random bearing and distance (0-80m) from the survey point. We recorded survey conditions at each point, including the time of day, temperature, wind speed, and precipitation. We did not sample invertebrates if the vegetation was wet from morning dew or precipitation or if the average wind speed exceeded 10 mph.

To evaluate relationships between vegetation conditions and invertebrate abundance and diversity, we measured 5 subplots of vegetation along each 20-m sweep-net transects. At each subplot, visual obstruction was measured from the north at a distance of 2 m and a height of 0.5 m (Robel et al. 1970), and non-overlapping vegetation coverages were measured using methods of Daubenmire (1959). Percent coverage of new growth grass, residual grass, litter, shrub, forb, tree, bare ground, rock, and cowpie were measured in percentage classes (0-5, 5-25, 25-50, 50-75, 75-95, and 95-100%). Heights (cm) of the nearest plant were measured for each new growth grass, residual grass, litter, shrub, forb, and tree. We estimated shrub cover using line intercept surveys, where the species of each shrub intersecting the transect was recorded, as well as the height and length of the shrub as it crossed the transect. With the addition of two insect habitat transects to our original three habitat transects surveyed during point counts, each established bird survey point includes five 20-m transects consisting of 25 vegetation subplots that correspond to the breeding and nesting seasons for grassland birds.

Ninety predator survey points were randomly selected within the study site at the beginning of the field season, with 45 points in rest-rotation pasture treatments (easement) and 45 in season-long and summer rotation grazing pasture treatments (reference areas). During this quarter, we deployed 29 remote field cameras for our final sampling period (1 July – 22 July) to survey the meso-predator community within the study site. Cameras were spaced ≥ 600 m apart to ensure independence and set in the most optimal location within 200m of the randomly selected point to maximize detections. For this last sampling period, we baited all the camera traps with difference trapping lure than previous sampling periods (Gusto; Minnesota Trapline Products, Inc.), in an attempt to increase detection frequencies of predators.

Following the field season, we analyzed all photos from the remote camera traps and identified predators based on body shape and coloration. Of the 87 sites surveyed, coyote (*Canis latrans*), were present at 41 sites, badger (*Taxidea taxus*) were present at 16 sites, raccoon (*Procyon lotor*) were present at 9 sites, striped skunk (*Mephitis mephitis*) were present 7 sites, and short-tailed weasel (*Mustela ermine*) were present at one site. We observed predators at 69% of the camera sites within the easement pastures and 66.7% of the camera sites within reference pastures (Table 5). The raw counts of predators detected on the easement compared to predators detected off the easement were similar, as well as the number of sites that were used by predators within the 3 week timeframe at each site (Table 5). The mean number of predators per site was also very similar across easement and reference pastures (Figure 4).

We interviewed landowners to acquire stocking information for pastures in the study. In 2015, pastures A1, B1, and C1 were grazed from mid-May through seed ripe, pastures A2, B2, and C2 were grazed from seed ripe (~Aug 1) through mid-November, and pastures A3, B3, and C3 were rested from grazing during the entire year (Table 7). In 2016, A1, B1, and C1 pastures will be grazed from seed ripe to mid-November; A2, B2, and C2 pastures are being rested from grazing the entire year, and A3, B3, and C3 pastures were grazed from mid-May through seed ripe. Stocking rates within easement pastures ranged from 0 (rested pastures) to 3.73 AU ha $^{-1}$ (Table 7); however, stocking rates may change throughout the year and final stocking information will be finalized at the end of the grazing season.

We conducted preliminary analyses of our bird point count data. The mean totals for all birds detected per point were very similar across all easement and reference pastures (Figures 5, 6). Within the easement, pastures deferred from grazing in 2015 had slightly more birds per point on average than pastures grazed during the 2015 growing season and pastures grazed post seed-ripe (Table 6). Within the reference pastures, the second and third pastures managed with intensive summer rotational grazing had slightly more birds per point than the first rotational grazed pasture and the pastures grazed season-long, although confidence intervals overlapped. Of the 57 total species detected, 21 were obligate grassland birds (Table 6). Raw species counts were similar across easement and reference pastures (Figure 7). Easement pastures had 12.0 ± 0.3 bird species per point, rotational pastures had 11.5 ± 0.5 species per point, and season-long pastures had 12.3 ± 0.4 species per point.

Following spring point count surveys last quarter, we identified three grassland birds as focal species: the grasshopper sparrow (*Ammodramus savannarum*), Baird's sparrow (*A. bairdii*), and vesper sparrow (*Pooecetes gramineus*). These three species have specific habitat and life history requirements of native grasslands for breeding activities throughout the season. These species also have adequate sample sizes for further analysis after the first year of data collection.

The mean number of grasshopper sparrows detected per point was similar between pasture types (Figure 8). Pastures deferred from grazing in 2015 had the highest abundance of grasshopper sparrows relative to all other pasture and system types (Figure 8). Pastures with season-long grazing, and two rotationally grazed pastures had slightly lower mean abundance of grasshopper sparrows than pastures deferred from grazing in 2015 (Figure 8). The mean totals for Baird's sparrow detected per point were similar (Figure 9). Of the focal species, Baird's sparrow had the fewest total detections. The mean number of Baird's sparrow per point ranged from 1 to 3 for all easement and reference pastures. The mean totals for vesper sparrow detected per point were also similar between easement and reference grazing systems and across pasture types within a system (Figure 10). The mean number of vesper sparrow per point ranged from 2 to 4, with the highest mean within the second rotationally grazed pasture.

Additional efforts this quarter were focused on data entry, including both grassland bird habitat sampling data and invertebrate sampling habitat data.

*Goals for Next Quarter:*

There will be no efforts in the field next quarter. We will focus on finishing data entry for both the grassland bird habitat and the invertebrate habitat surveys. Further analyses of the grassland bird point counts can then be conducted, relating bird abundances to vegetation measurements. Preliminary associations with habitat conditions, grazing intensity, and grassland bird presence may then be evaluated.

We will complete further analysis of the predator data through occupancy modeling, accounting for variable detection probabilities, and resulting in a more accurate estimate of predator occupancy throughout the study site.

We will also begin sorting through invertebrate samples and identifying invertebrates to the family level. This will be a large undertaking and will not be accomplished by the end of next quarter, but preliminary results may be reported.

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Table 1. Overview of nests in the easement and reference sections of the study area. Egg hatch rate is the percentage of eggs that hatched from the initial clutch size.

| | Median Initiation Date | Clutch Size | First Nests | Renests | Nests Hatched | Median Hatch Date | Egg Hatch Rate |
|---|---|---|---|---|---|---|---|
| Easement | 30-Apr | 11.5 ± 0.50 | 26 | 8 | 11 | 10-Jun | 0.88 ± 0.04 |
| Reference | 6-May | 10.9 ± 0.49 | 24 | 14 | 15 | 23-Jun | 0.92 ± 0.04 |
| **Total** | 1-May | 11.2 ± 0.35 | 50 | 22 | 26 | 15-Jun | 0.90 ± 0.03 |

Table 2. Support for candidate models predicting nest survival for the 2016 breeding season. The number of parameters (K), AICc values, ΔAICc values, model weights ($w_i$) and deviance are reported. The parameter S(.) represents the null model with a constant daily survival rate.

| Model | K | AICc | ΔAICc | AICc $w_i$ | Deviance |
|---|---|---|---|---|---|
| S(.) | 1 | 252.18 | 0.00 | 0.17 | 250.18 |
| Prop. Grass | 2 | 252.39 | 0.20 | 0.16 | 248.37 |
| VOR | 2 | 253.18 | 0.99 | 0.11 | 249.16 |
| VOR + VOR$^2$ | 2 | 253.18 | 0.99 | 0.11 | 249.16 |
| Prop. Shrub | 2 | 253.19 | 1.01 | 0.11 | 249.18 |
| Prop. Residual | 2 | 253.31 | 1.13 | 0.10 | 249.30 |
| Prop. Grass + VOR | 3 | 253.36 | 1.17 | 0.10 | 247.33 |
| Prop. Forb | 2 | 253.96 | 1.77 | 0.07 | 249.94 |
| Grazing treatment | 2 | 254.01 | 1.83 | 0.07 | 250.00 |
| Prop. Grass + Prop. Residual + Prop. Forb + Prop. Shrub | 5 | 257.91 | 5.73 | 0.01 | 247.85 |

Table 3. Brood survival and fledging rate (± SE) of grouse located in the easement, reference, and both sections of the study area. Brood survival is the proportion of broods that survived to fledging at 14 days. Fledging rate is the proportion of chicks that initially hatched that survived to fledging at 14 days.

| | Brood Survival | Fledging Rate |
|---|---|---|
| Easement | 0.55 ± 0.07 | 0.41 ± 0.18 |
| Reference | 0.57 ± 0.05 | 0.35 ± 0.09 |
| Both | 0.50 ± 0.08 | 0.90 ± 0.25 |
| **Total** | 0.52 ± 0.10 | 0.50 ± 0.11 |

Table 4. Mean breeding season home range size (±SE) and mean distance of the centroid of a female's home range from lek of capture for females in the easement, reference and both sections of the study area.

| Group | Home range size ($m^2$) | Distance traveled from capture lek (m) |
|---|---|---|
| Easement | 543 ± 165 | 840 ± 99 |
| Reference | 330 ± 68 | 1,801 ± 318 |
| Both | 918 ± 354 | 1,080 ± 150 |
| **Total** | 569 ± 122 | 1,301 ± 154 |

Table 5. Predator abundance and species diversity detected from remote camera trap surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016.

| | Buxbaum Conservation Easement[a] | | | | Reference Pastures[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Growing-season 2015 | Post Seed-ripe 2015 | Rested 2015 | **Easement** | **Season-long** | Rotation1 | Rotation2 | Rotation3 | **Rotation** | **Total** |
| Number sites w/Cameras | 11 | 14 | 17 | **42** | **22** | 13 | 4 | 6 | **23** | 87 |
| Number sites occupied | 9 | 10 | 10 | **29** | **16** | 7 | 3 | 4 | **14** | 59 |
| Number Species Detected | 4 | 3 | 3 | **4**[c] | **4**[d] | 4 | 2 | 3 | **4**[e] | 5 |
| Total encounters[f] | 18 | 28 | 16 | **52** | **33** | 9 | 5 | 13 | **27** | 112 |

[a] Easement pasture designations: In 2015, the pastures in each system grazed during the growing season, post-seed ripe, and rested.
[b] Reference pastures include 2 pastures that are grazed annually during the growing season (season-long), and three pastures managed with intensive summer rotational grazing.
[c] Easement pastures predator species detected include coyote, badger, striped skunk, and raccoon
[d] Season-long pastures predator species detected include coyote, badger, raccoon, and short-tailed weasel
[e] Rotational pastures predator species detected include coyote, badger, raccoon, and striped skunk
[f] Total encounters include all predators that were detected by cameras, excluding predators of the same species detected within an hour of initial detection

Table 6. Total bird species detected on 305 point count surveys on the Buxbaum conservation easement and adjacent reference properties and number of each species in each pasture.

| | Buxbaum Conservation Easement[a] | | | | Reference Pastures[b] | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| | Growing-season 2015 | Post Seed-ripe 2015 | Rested 2015 | **Easement** | **Season-long** | Rotation1 | Rotation2 | Rotation3 | **Rotation** | |
| AMCR | 0 | 0 | 0 | **0** | 0 | 2 | 0 | 0 | **2** | 2 |
| AMGO | 30 | 8 | 13 | **51** | 2 | 10 | 7 | 2 | **21** | 72 |
| AMRO | 8 | 7 | 0 | **15** | 0 | 3 | 0 | 2 | **5** | 20 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| AMWI | 0 | 0 | 0 | **0** | 0 | 0 | 2 | 0 | **2** | 2 |
| BAIS* | 8 | 29 | 21 | **58** | 50 | 53 | 1 | 11 | **115** | 173 |
| BANS | 3 | 2 | 28 | **33** | 0 | 1 | 0 | 0 | **1** | 34 |
| BARS | 0 | 1 | 1 | **2** | 0 | 3 | 0 | 0 | **3** | 5 |
| BBMA | 3 | 1 | 0 | **4** | 0 | 1 | 0 | 0 | **1** | 5 |
| BEKI | 1 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | **0** | 1 |
| BHCO | 152 | 78 | 65 | **295** | 76 | 53 | 69 | 33 | **231** | 526 |
| BHGR | 1 | 1 | 0 | **2** | 0 | 0 | 0 | 0 | **0** | 2 |
| BOBO* | 0 | 1 | 17 | **18** | 9 | 0 | 0 | 8 | **17** | 35 |
| BRBL | 4 | 10 | 6 | **20** | 30 | 6 | 0 | 2 | **38** | 58 |
| BRTH | 6 | 3 | 11 | **20** | 8 | 8 | 8 | 5 | **29** | 49 |
| BUOR | 3 | 3 | 0 | **6** | 1 | 1 | 0 | 1 | **3** | 9 |
| CAGO | 2 | 0 | 0 | **2** | 0 | 0 | 0 | 0 | **0** | 2 |
| CCSP* | 43 | 6 | 6 | **55** | 10 | 32 | 0 | 7 | **49** | 104 |
| CEDW | 10 | 0 | 52 | **62** | 0 | 0 | 10 | 4 | **14** | 76 |
| CLSW | 0 | 0 | 0 | **0** | 0 | 2 | 0 | 0 | **2** | 2 |
| COGR | 4 | 2 | 2 | **8** | 0 | 2 | 0 | 1 | **3** | 11 |
| CONI | 13 | 7 | 4 | **24** | 4 | 3 | 0 | 0 | **7** | 31 |
| EABL* | 0 | 1 | 0 | **1** | 0 | 0 | 1 | 0 | **1** | 2 |
| EAKI* | 43 | 46 | 40 | **129** | 32 | 48 | 34 | 16 | **130** | 259 |
| EUST | 2 | 0 | 3 | **5** | 1 | 1 | 4 | 0 | **6** | 11 |
| FISP* | 45 | 20 | 54 | **119** | 11 | 46 | 18 | 5 | **80** | 199 |
| GRCA | 2 | 0 | 2 | **4** | 1 | 3 | 5 | 1 | **10** | 14 |
| GRSP* | 111 | 244 | 273 | **628** | 354 | 368 | 26 | 91 | **839** | 1467 |
| HOLA* | 4 | 11 | 13 | **28** | 30 | 1 | 2 | 0 | **33** | 61 |
| HOWR | 44 | 20 | 19 | **83** | 7 | 26 | 6 | 11 | **50** | 133 |
| KILL | 0 | 0 | 1 | **1** | 1 | 13 | 0 | 0 | **14** | 15 |
| LARB* | 11 | 2 | 0 | **13** | 0 | 1 | 0 | 0 | **1** | 14 |
| LASP* | 9 | 1 | 2 | **12** | 0 | 12 | 5 | 0 | **17** | 29 |
| LEFL | 3 | 3 | 2 | **8** | 0 | 3 | 6 | 3 | **12** | 20 |
| LOSH* | 1 | 0 | 5 | **6** | 20 | 1 | 0 | 1 | **22** | 28 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MALL | 3 | 0 | 0 | **3** | 2 | 4 | 1 | 0 | **7** | 10 |
| MOBL* | 6 | 0 | 5 | **11** | 0 | 3 | 0 | 0 | **3** | 14 |
| MODO* | 25 | 38 | 30 | **93** | 23 | 23 | 18 | 13 | **77** | 170 |
| NOFL | 16 | 8 | 7 | **31** | 17 | 8 | 7 | 7 | **39** | 70 |
| NOHA* | 0 | 0 | 2 | **2** | 1 | 0 | 1 | 1 | **3** | 5 |
| Oriole spp. | 0 | 0 | 2 | **2** | 0 | 1 | 0 | 0 | **1** | 3 |
| OROR | 0 | 1 | 3 | **4** | 3 | 1 | 2 | 2 | **8** | 12 |
| RHPH | 0 | 0 | 0 | **0** | 1 | 0 | 0 | 1 | **2** | 2 |
| ROPI | 0 | 0 | 0 | **0** | 2 | 0 | 0 | 0 | **2** | 2 |
| ROWR | 0 | 0 | 2 | **2** | 0 | 0 | 0 | 0 | **0** | 2 |
| RTHA | 6 | 0 | 0 | **6** | 0 | 3 | 0 | 0 | **3** | 9 |
| RWBL* | 4 | 1 | 0 | **5** | 25 | 0 | 0 | 2 | **27** | 32 |
| SAPH | 9 | 0 | 1 | **10** | 0 | 1 | 0 | 0 | **1** | 11 |
| SPPI* | 0 | 2 | 0 | **2** | 0 | 0 | 0 | 0 | **0** | 2 |
| SPTO | 58 | 19 | 43 | **120** | 13 | 18 | 27 | 6 | **64** | 184 |
| STGR* | 0 | 0 | 3 | **3** | 1 | 2 | 0 | 2 | **5** | 8 |
| Swallow spp. | 0 | 0 | 0 | **0** | 0 | 3 | 0 | 0 | **3** | 3 |
| TRES | 0 | 1 | 6 | **7** | 0 | 0 | 0 | 0 | **0** | 7 |
| UNSP | 6 | 2 | 5 | **13** | 2 | 12 | 6 | 1 | **21** | 34 |
| UPSA* | 0 | 6 | 2 | **8** | 9 | 13 | 2 | 4 | **28** | 36 |
| VESP* | 57 | 92 | 87 | **236** | 86 | 106 | 41 | 15 | **248** | 484 |
| WEKI* | 17 | 3 | 11 | **31** | 8 | 8 | 6 | 7 | **29** | 60 |
| WEME* | 114 | 220 | 230 | **564** | 211 | 164 | 71 | 75 | **521** | 1085 |
| YBCH | 7 | 0 | 0 | **7** | 0 | 6 | 0 | 0 | **6** | 13 |
| YHBL* | 0 | 0 | 1 | **1** | 0 | 0 | 0 | 0 | **0** | 1 |
| YWAR | 76 | 25 | 26 | **127** | 17 | 42 | 27 | 11 | **97** | 224 |

*Designates grassland obligate species.

[a] Easement pasture designations: In 2015, the pastures in each system grazed during the growing season, post-seed ripe, and rested.

[b] Reference pastures include 2 annually grazed during the growing season (season-long), and three pastures managed with intensive summer rotational grazing.

Table 7. Stocking information for the pastures in the study site, along with area (ha). Stocking rates are based on animal unit months (AUMs) per hectare.

| | | 2015 | | | | 2016 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pasture | Area (ha) | Head | Turn-in Date | Turn-out Date | Stocking rate (AUM/ha) | Head | Turn-in Date | Turn-out Date | Stocking rate (AUM/ha) |
| A1[a] | 211 | NA | NA | NA | NA | 150 | 8/1 | 11/15 | 2.51 |
| A2[a] | 256 | NA | NA | NA | NA | 0 | ungrazed | | 0.00 |
| A3[a] | 263 | NA | NA | NA | NA | 150 | 6/15 | 8/1 | 0.89 |
| B1 | 364 | 150 | 6/15; 10/5 | 8/15; 11/25 | 3.73 | 170 | 8/1 | 11/15 | 1.65 |
| B2 | 434 | 150 | 8/15 | 10/5/2015 | 0.59 | 0 | ungrazed | | 0.00 |
| B3 | 310 | 0 | ungrazed | | 0.00 | 170 | 6/14 | 8/1 | 0.88 |
| C1 | 453 | 170 | 6/15; 10/5 | 8/15; 11/25 | 1.40 | 150 | 8/1 | 11/15 | 1.17 |
| C2 | 346 | 170 | 8/15 | 10/5 | 0.84 | 0 | ungrazed | | 0.00 |
| C3 | 371 | 0 | ungrazed | | 0.00 | 150 | 6/14 | 8/1 | 0.65 |
| Rotation1a | 547 | 240 | 6/1 | 7/15 | 0.64 | 280 | 6/1 | 7/15 | 0.75 |
| Rotation1b | 1375 | 240 | 7/15 | 12/1 | 0.81 | 280 | 7/15 | 11/15 | 0.83 |
| Rotation2a | 252 | 85 | 5/25; 10/25 | 7/15; 12/1 | 0.99 | 155 | 6/1 | 7/15 | 0.90 |
| Rotation2b | 298 | 85 | 7/15; 10/25 | 9/30; 12/1 | 1.08 | 155 | 6/1 | 7/15 | 0.76 |
| Rotation3a | 128 | 58 | 7/16 | 9/13 | 0.89 | 42 | 7/16 | NA | NA |
| Rotation3b | 150 | 58 | 6/2 | 7/16 | 0.57 | 7 | 6/7 | NA | NA |
| Rotation4a | 110 | 60 | 6/1; 10/10 | 7/1; 11/1 | 0.95 | 65 | 6/1; 10/10 | 7/1; 11/1 | 1.02 |
| Rotation4b | 220 | 60 | 7/1 | 10/10 | 0.92 | 65 | 7/1 | 10/10 | 0.99 |
| Rotation5a | 58 | 6 | 2/1 | 6/15 | 0.65 | 6 | 2/1 | 6/15 | 0.47 |
| Rotation5b | 30 | 28 | 10/1 | 11/15 | 1.12 | 0 | ungrazed | | 0.00 |
| Rotation5c | 132 | 65 | 6/1 | 10/1 | 2.00 | 0 | ungrazed | | 0.00 |
| Rotation6a | 92 | 50 | 9/15 | 10/31 | 0.83 | 60 | 7/1 | 8/5 | 0.76 |
| Rotation6b | 90 | 0 | ungrazed | | 0.00 | 60 | 8/5 | 10/31 | 1.93 |
| Rotation6c | 102 | 50 | 6/1 | 9/15 | 1.73 | 0 | ungrazed | | 0.00 |
| Rotation7 | 120 | 160 | 4/15 | 5/30 | 2.00 | 160 | 10/1 | 10/31 | 1.33 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Season-long1 | 413 | 70; 42; 80 | 5/1; 6/1; 10/20 | 6/1; 10/20; 1/1/16 | 1.24 | 40 | 5/15 | 11/15 | 0.59 |
| Season-long2 | 857 | 180 | 6/1 | 10/28 | 1.04 | 180 | 6/1 | 11/1 | 1.07 |
| Season-long3 | 36 | 2 | 1/1 | 12/31 | 0.84 | 2 | 1/1 | 12/31 | 0.84 |
| Season-long4 | | 0 | ungrazed | | 0.00 | 0 | ungrazed | | 0.00 |
| Season-long5[a] | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Season-long6[a] | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Season-long7[a] | NA | NA | NA | NA | NA | NA | NA | NA | NA |

[a] NAs represent pastures for which stocking information is still being collected.

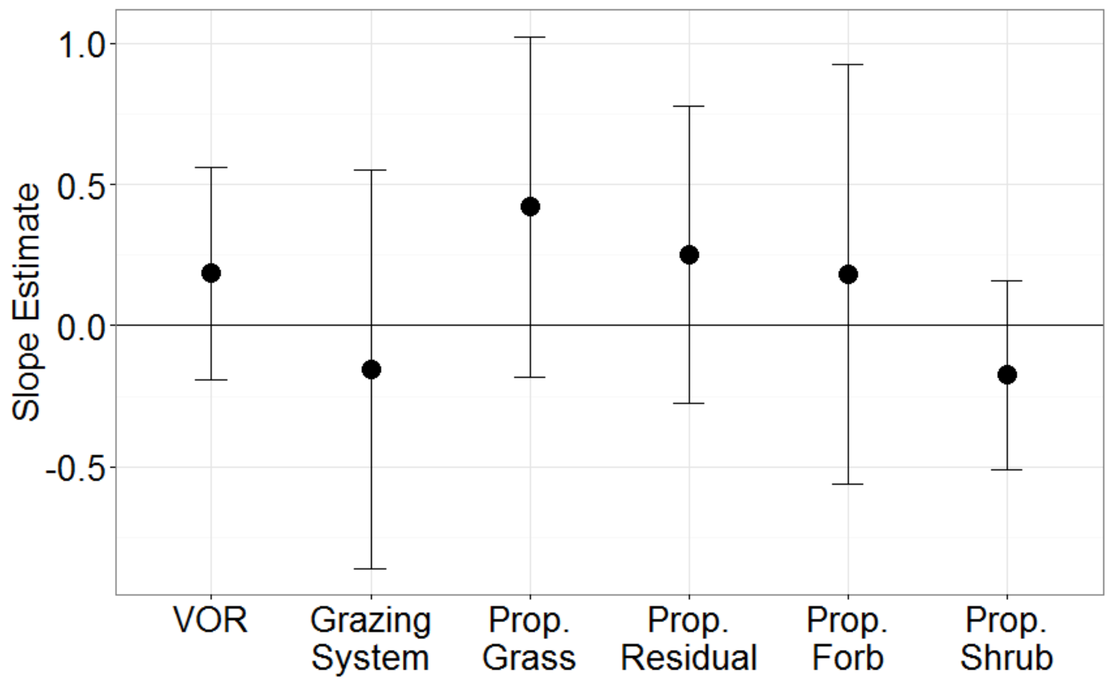


Figure 1. Effect size ($\beta$ ±95% confidence intervals) for each variable in the nest survival analysis.

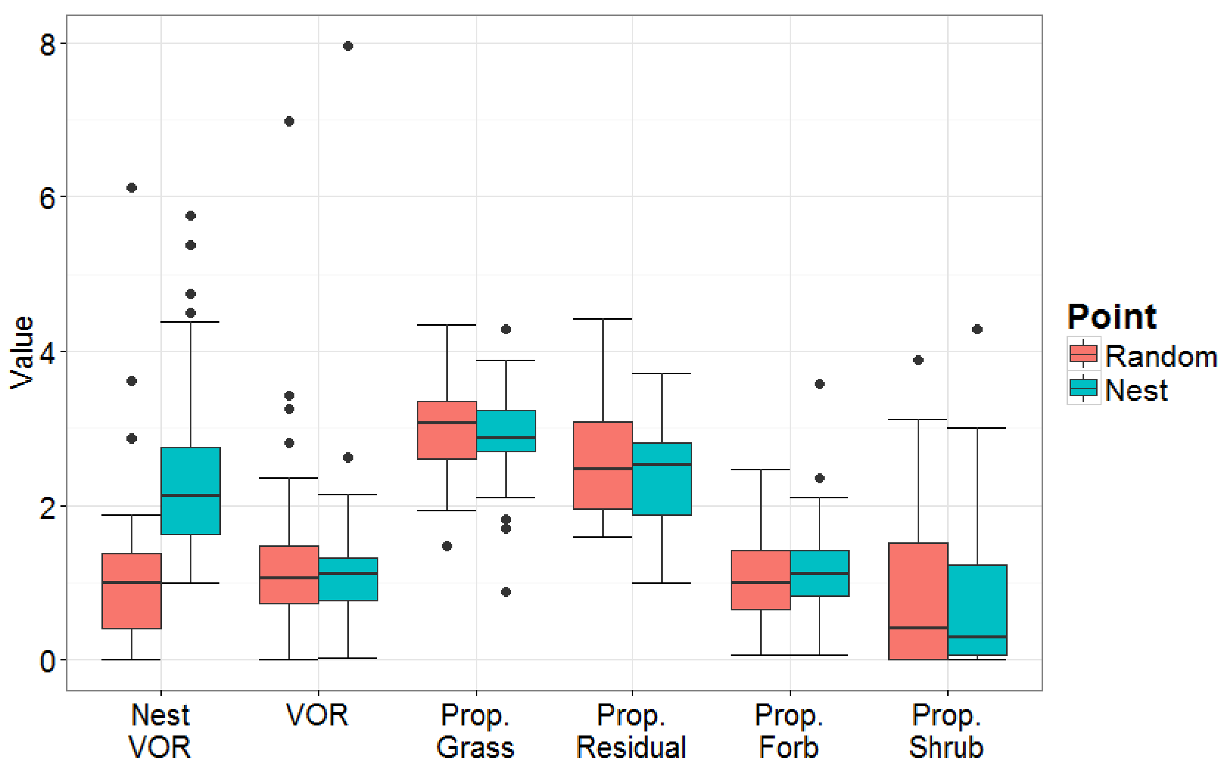


Figure 2. Vegetation measurements at nest sites and random locations in the study area.

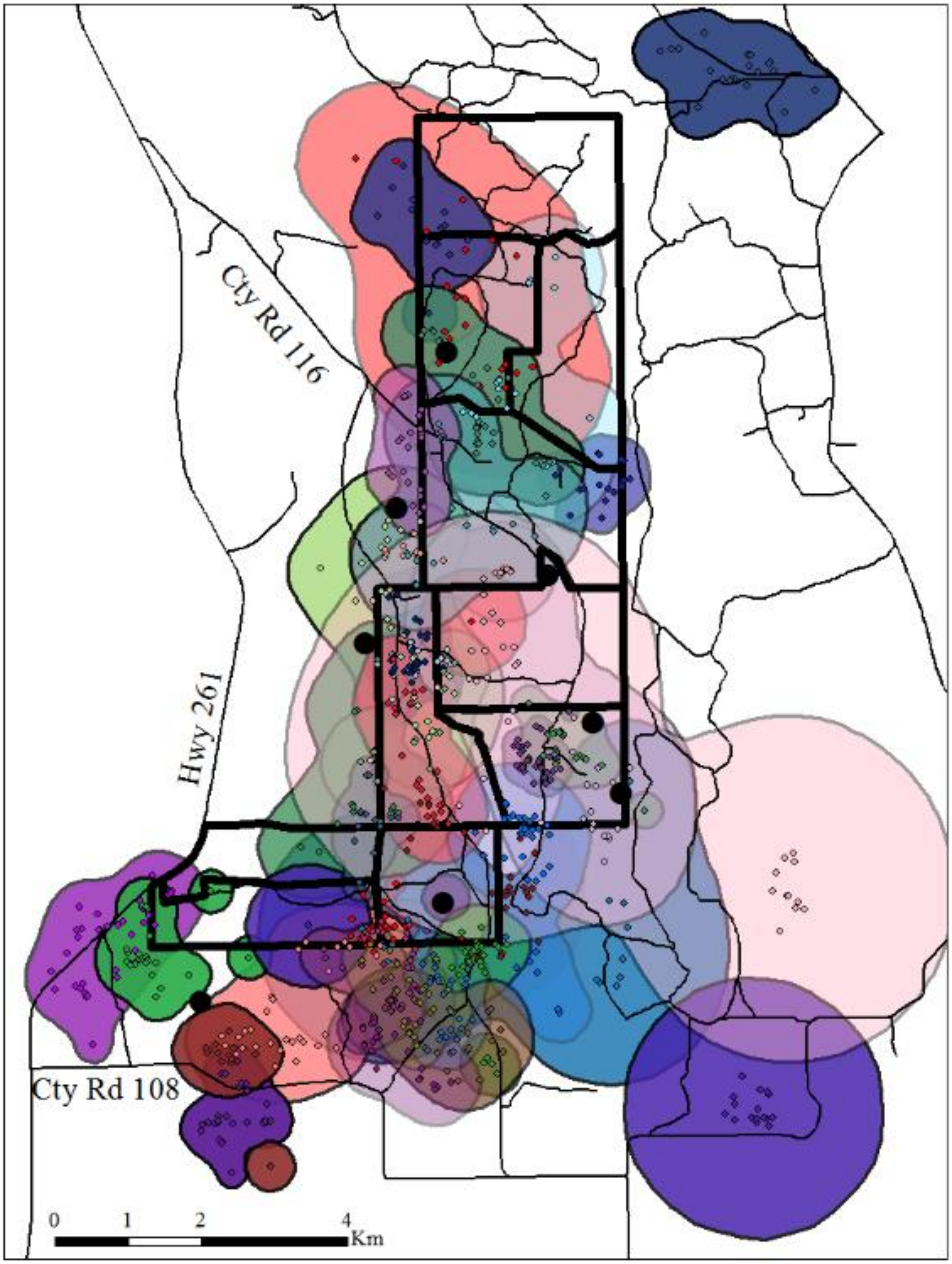


Figure 3. Breeding season home ranges of 37 sharp-tailed grouse. Points used to construct the home ranges are overlaid in the same color as the home ranges to which they correspond. The boundaries of the easement are represented by dark black lines and leks of capture are shown as large black circles.

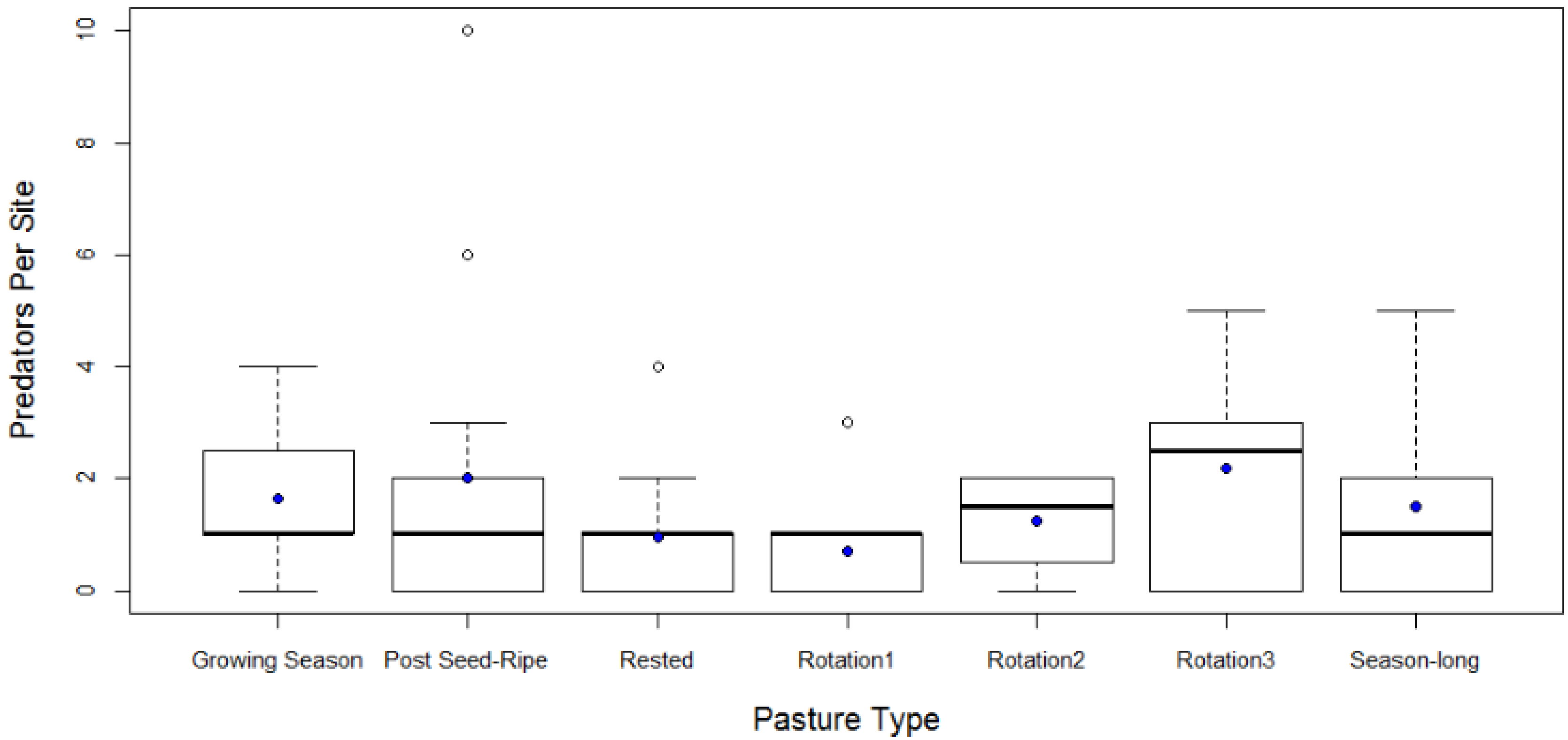


Figure 4. Mean and median number of predators detected from remote camera trap surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, grazed from seed ripe through the end of the grazing season, and rested from grazing for the year. Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.

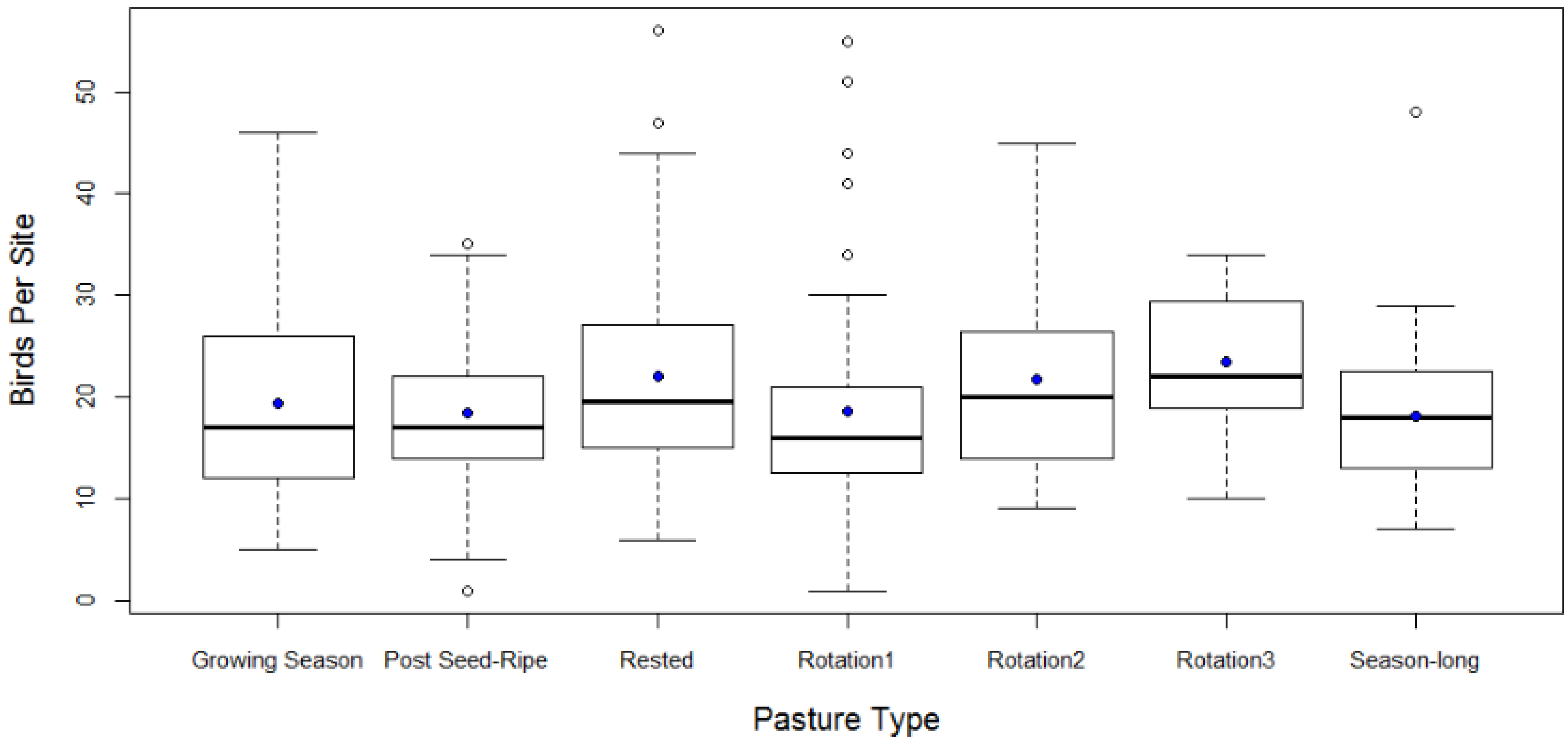


Figure 5. Mean and median number of birds detected per point over three visits during late spring point count surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, from seed ripe through the end of the grazing season, and rested from grazing for the year. Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.

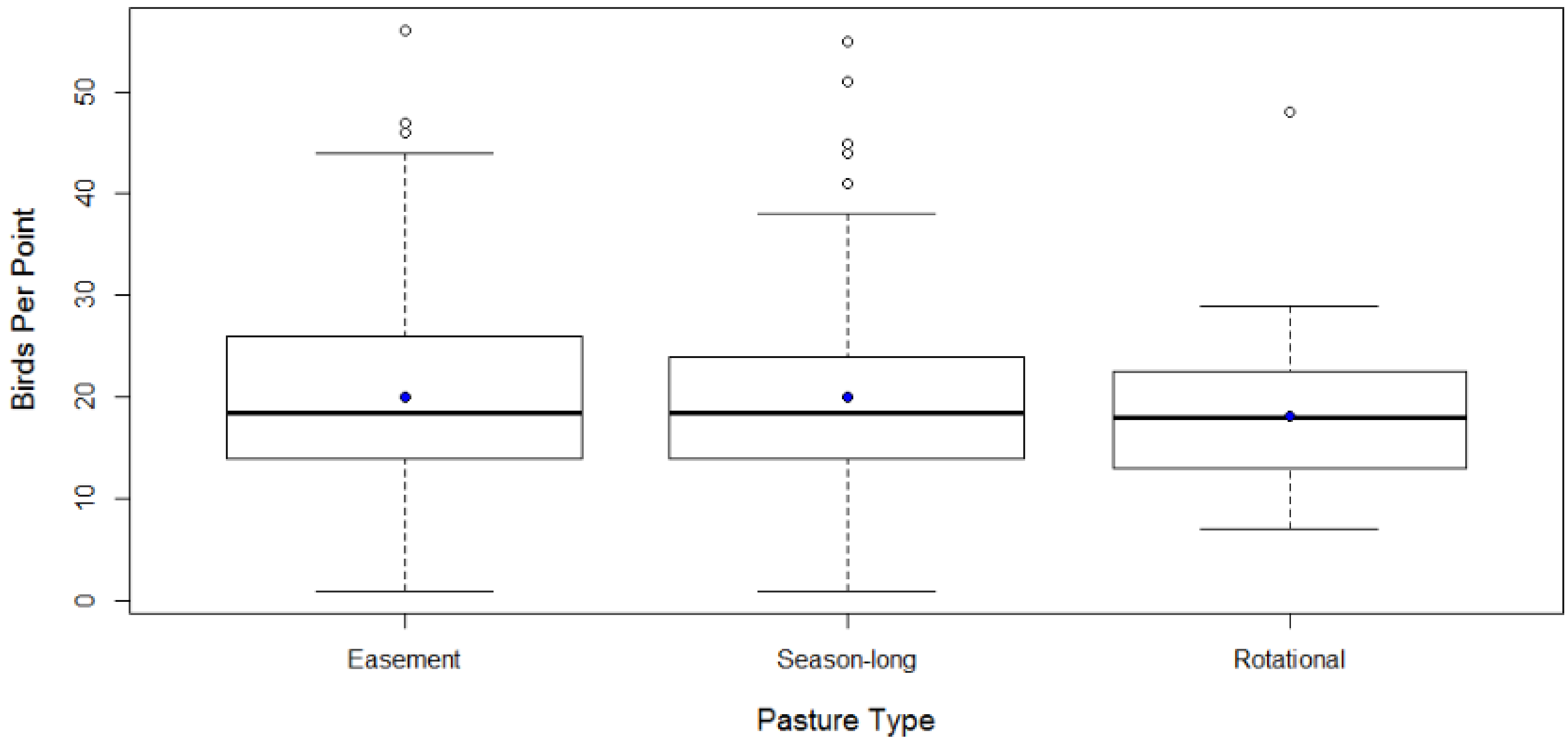


Figure 6. Mean and median number of birds detected per point over three visits during late spring point count surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, grazed from seed ripe through the end of the grazing season, and rested from grazing for the year. Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.

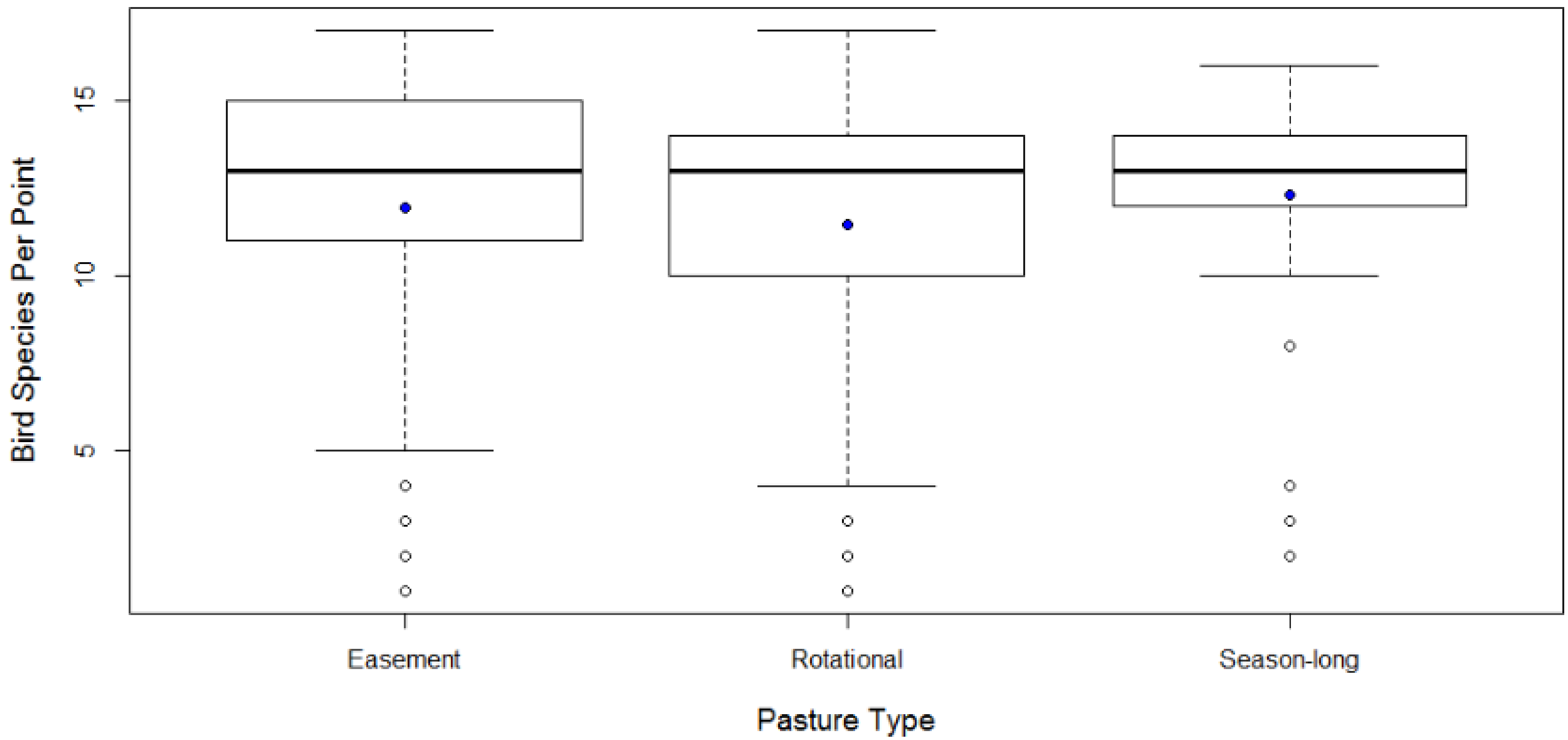


Figure 7. Mean and median number of bird species detected per point over three visits during late spring point count surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, grazed from seed ripe through the end of the grazing season, and rested from grazing for the year. Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.

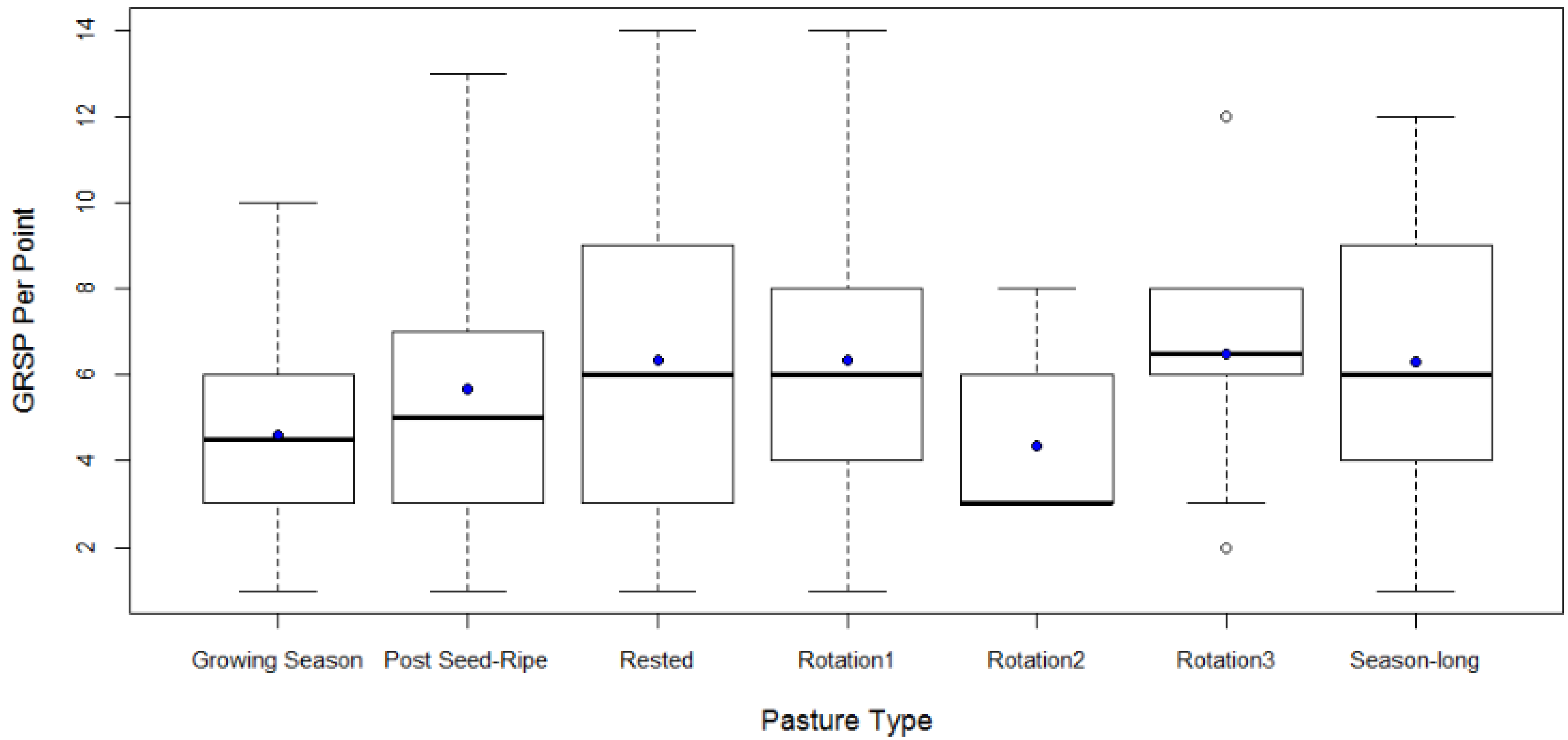


Figure 8. Mean and median number of grasshopper sparrows (*Ammodramus savannarum*) detected per point over three visits during late spring point count surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, from seed ripe through the end of the grazing season, and rested from grazing for the year. Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.

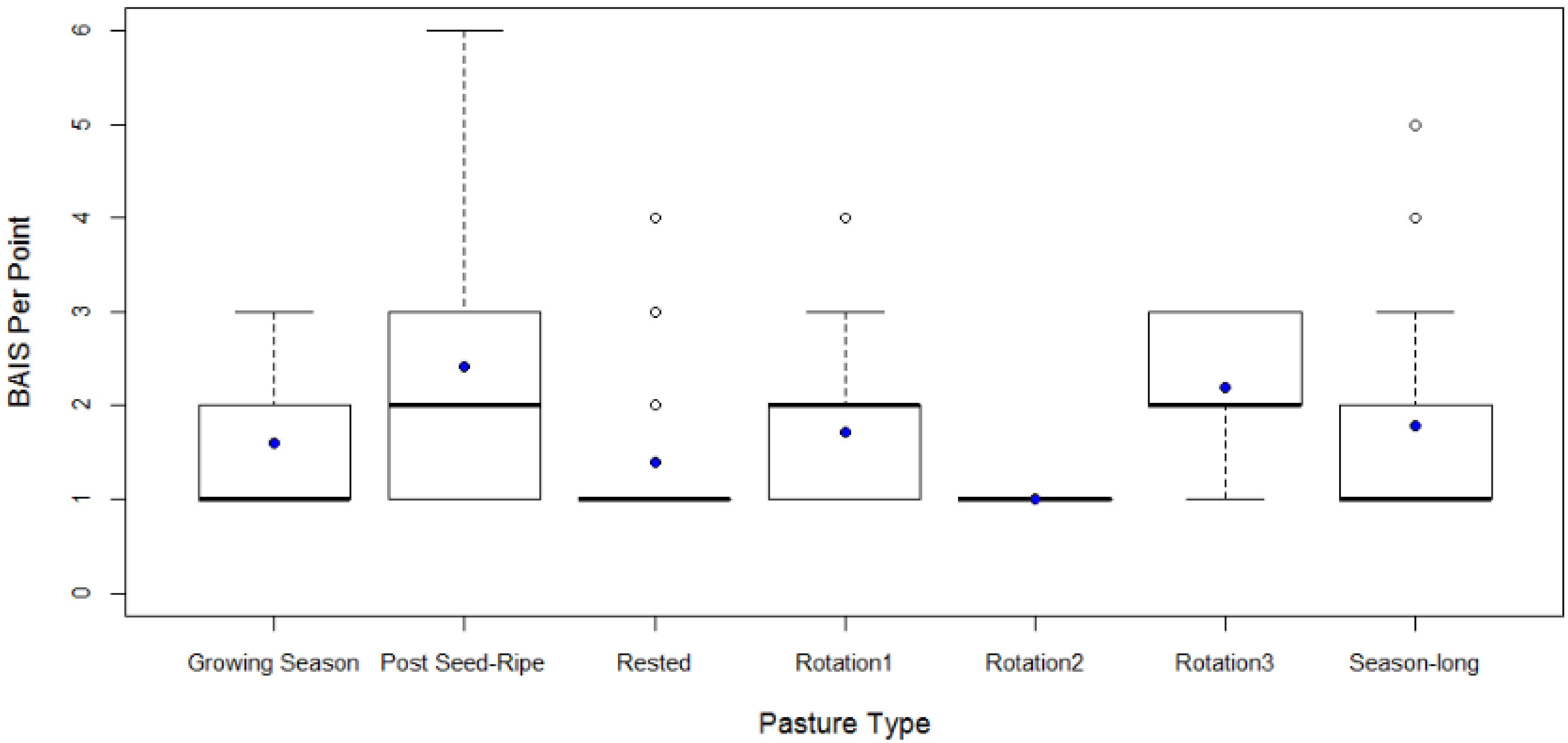


Figure 9. Mean and median number of Baird's sparrows (*A. bairdii*) detected per point over three visits during late spring point count surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, from seed ripe through the end of the grazing season, and rested from grazing for the year. Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.

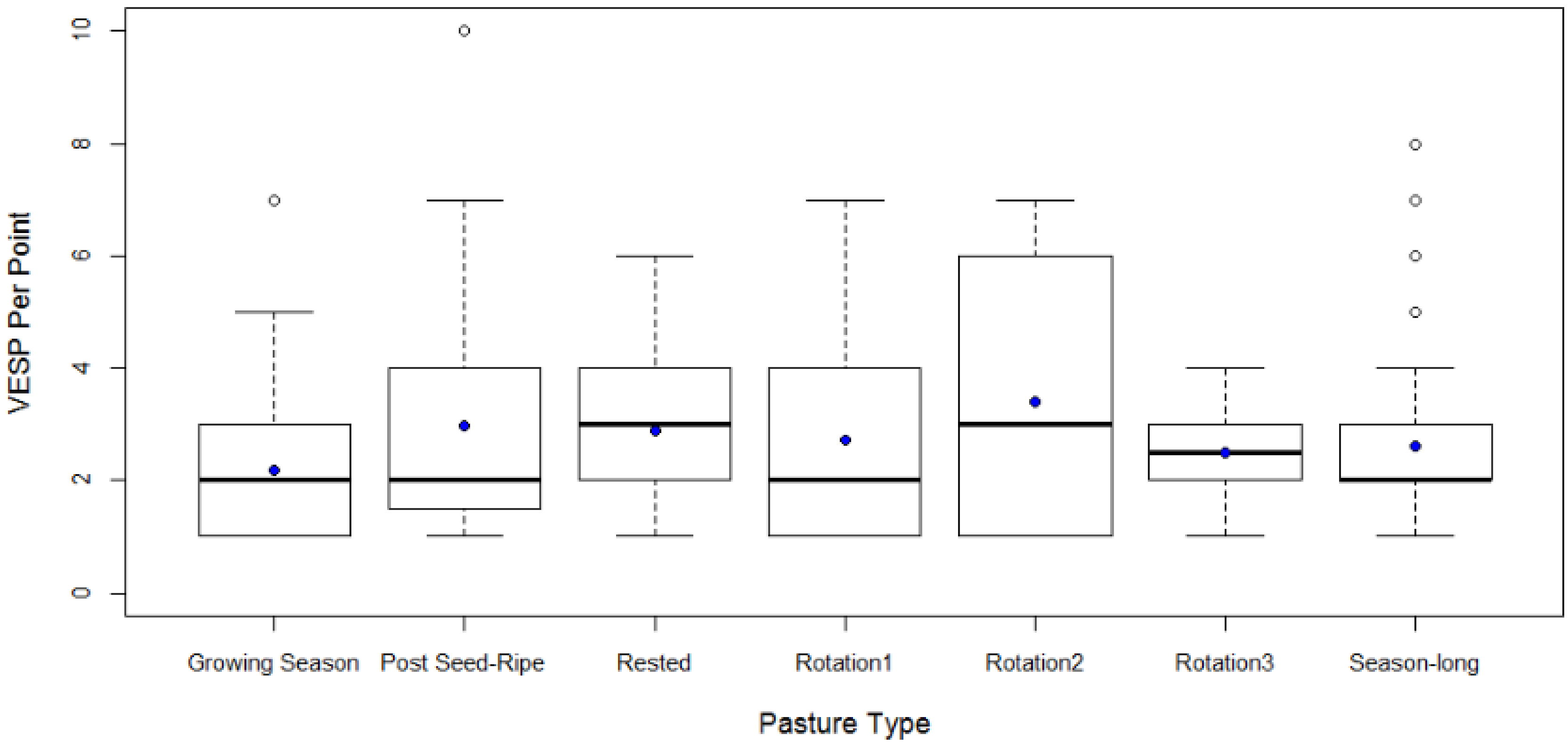


Figure 10. Mean and median number of vesper sparrows (*Pooecetes gramineus*) detected per point over three visits during late spring point count surveys on the Buxbaum conservation easement and adjacent reference properties in eastern Richland County, Montana in 2016. Easement pastures are grazed from the beginning of the growing season through seed ripe, grazed from seed ripe through the end of the grazing season, and rested from grazing for the year Reference pastures include 2 pastures that are grazed annually during the growing season, and three pastures managed under intensive summer rotational grazing.