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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EXECUTIVE SUMMARY

This report summarizes the results of the third year (2018) of a four-year (2016–19) research project conducted by researchers at Montana State University to assess the effects of livestock grazing management and rangeland conditions on the population and spatial ecology of grassland birds and their predators. The primary objectives of this study are to 1) investigate rest-rotation grazing as a rangeland management technique to improve habitat conditions for sharp-tailed grouse and 2) develop a mechanistic understanding of the effects of grazing management on the occurrence and abundance of grassland passerines and mesopredators.

For objective 1, we examined the effects of grazing management on the ecology of sharp-tailed grouse by comparing demographic rates and habitat selection among properties managed with rest-rotation grazing to those managed with either season-long or summer rotation grazing. Field efforts in 2018 focused on capturing grouse, tracking radio-marked females, monitoring nests, conducting habitat surveys at nest and brood locations as well as random points in the study area. Sharp-tailed grouse were trapped at 8 leks using walk-in funnel traps during 18 March – 3 May 2018. Overall, 125 sharp-tailed grouse (63 males, 62 females) were captured, including 89 new captures (36 males, 53 females) and 36 recaptures from 2016 and 2017 (27 males, 9 females). A total of 70 radio-marked females were monitored ≥ 3 times per week throughout the nesting and brood-rearing period (April – August).

Females initiated 62 nests (53 first nests, 9 renests). Nesting frequency (± SE) was 0.97 ± 0.02, while the probability of renesting after first nest failure was 0.60 ± 0.12. Thirty-eight nests successfully hatched and 24 failed (22 depredated, 1 abandoned, 1 trampled by cattle). The best predictors of nest site selection included visual obstruction (VOR) at the nest bowl, percent residual grass cover and a measure of fragmentation (mean shape complexity). Visual obstruction at the nest bowl had the largest effect and was positively related to the relative probability of selection. Overall nest survival during 2016–2018 varied by year and was 0.48 ± 0.07 in 2018 (ranged from 0.29 ± 0.06 in 2016 to 0.48 ± 0.07 in 2018). The best predictors of nest survival were VOR averaged across a 6 m radius plot, the proportion grassland and the stocking density while the nest was active, which were all positively related to daily nest survival. There was also some evidence for an effect of grazing system, and daily nest survival was lower in rest-rotation pastures compared to season-long pastures. Overall nest survival was 0.48 ± 0.07 in season-long pastures, 0.38 ± 0.06 in summer rotation pastures, and 0.32 ± 0.06 in rest-rotation pastures. We did not find evidence that nest survival differed among nests located within the rest-rotation system (grazed during the growing season, grazed post-growing season, or rested).

We monitored 95 broods to estimate survival and document habitat use (Table 16). Twenty-two broods spent the majority of the time (>70% of brood locations) in rest-rotation pastures, 30 spent the majority of time in summer rotation pastures, 29 spent the majority of time in season-long pastures, and 14 split time between multiple grazing systems. Brood success, calculated as the proportion of broods fledging ≥1 chick to 14-d of age, was 0.59 ± 0.10, 0.80 ± 0.07, 0.66 ± 0.09, and 0.43 ± 0.13 for broods located on the rest-rotation, summer rotation, season-long and multiple systems, respectively. Of broods that survived to fledging, the proportion of chicks that survived was 0.55 ± 0.08, 0.54 ± 0.06, 0.59 ± 0.07, and 0.32 ± 0.09 for broods located on the rest-rotation, summer rotation, season-long and multiple systems, respectively.

Of the 70 radio-marked females, 28 were killed by predators (15 mammalian, 8 avian, 5 unknown predation). An additional 2 females were harvested by hunters. One female was right censored from the study when the transmitter was found with no sign of death. An additional 4 females left the study area within 2 weeks of capture and were right censored after they could not be relocated for more than 2 months. Two females moved onto land to which we do not have access and so were monitored solely for survival.

We collected a total of 2,612 locations from 70 females during April – August in 2018. Mean (± SE) breeding season home range size for all females in 2018 was 455 ± 401 ha, and varied from 57 ha to 2,260 ha. Females showed strong preference for mixed grass prairie over other non-grassland vegetation (e.g., cultivation) and selected against pastures grazed in a summer rotation system when choosing home ranges. Edge density within the home range was the best predictor of home range size and was negatively related to the size of breeding season home ranges for females. We found no evidence for a population-level effect of any habitat variables on habitat selection within the home range, but there was significant selection at an individual level.

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2018 Annual Report

OBJECTIVES

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

Accomplishments

Initial efforts during 2018 focused on securing access to the necessary private lands in the study area, obtaining research materials and equipment, and hiring field technicians. Subsequent efforts focused on capturing and radio-marking female sharp-tailed grouse and intensive monitoring of radio-marked females to locate nests and broods and monitor survival and space use.

Sharp-tailed grouse were trapped using walk-in funnel traps on both the easement and reference areas of the study site. We recorded standard morphometrics including body mass, wing chord, tarsus length, and culmen length, and fitted all birds with a uniquely numbered metal leg band. Birds were sexed and aged by plumage characteristics. Males were fitted with a unique combination of color bands to allow for resighting at leks next year. We fit captured females with 18-g necklace-style radio-transmitters with a 6-8 hour mortality switch and an expected battery life of 12 months (model A4050; Advanced Telemetry Systems, Insanti, MN). Previous work found no impact of necklace-style radio-transmitters on prairie-grouse demography (Hagen et al. 2006).

Radio-marked females were located by triangulation or homing ≥3 times/week using portable radio receivers and handheld Yagi antennas during the nesting and brood-rearing period (April—August). When females localized in an area and their estimated location did not change for 2 successive visits, we assumed that the female was sitting on a nest. For half of the females, we used portable radio receivers and handheld Yagi antennas to locate and flush the female so eggs could be counted and the nest location recorded with a handheld GPS unit. We marked nest locations with natural landmarks at a distance ≥ 25 m to aid in relocation. Nest sites were not visited again until it was determined that the female had departed (i.e., was located away from the nest for ≥ 2 days during incubation and ≥ 1 day after expected hatch date) due to successful hatching of the clutch or failure due to either predation or abandonment. Nesting females were otherwise monitored by triangulation from a distance > 25 m. Thus, nest sites for half of the females were only disturbed by the presence of an observer a maximum of 1 time during the laying and incubation period. The remaining half of the females were never flushed and nest attempts were monitored from a distance of > 25 m to evaluate whether the protocol of flushing females has a negative effect on nest survival. A female was assumed to be incubating if she was located in the same location for 2 consecutive visits and nest sites were only visited after the female was located away from the nest for ≥ 2 days during incubation or ≥ 1 day after expected hatch date.

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 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 predation event occurred, the egg remains were evaluated and the area was searched for predator sign. For successful nests, hatchability was calculated as the proportion of the total clutch that hatched and produced chicks. Eggs that failed to hatch were opened to determine stage of development and possible timing of embryo failure.

Successful broods were relocated ≥3 times/week until failure. Pre-fledging brood survival was estimated by conducting flush counts between 14 and 16 days post hatch. Fledging was considered to occur at 14 days post hatch because at that point chicks are able to thermoregulate and are capable of weak flights (Pitman et al. 2006). Flush counts were conducted at dawn 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 female observed to assess whether chicks were present but undetected. For counts of 0 chicks, the brood female was flushed again the following day to be certain no chicks remained in the brood. Broods were considered successful if ≥ 1 chick survived until fledging at 14-d post-hatch (Pitman et al. 2006). Flush counts were repeated at 14, 30, 45, and 60 days post-hatch or until we were confident that no chicks remained with the female.

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 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 evaluated habitat conditions at each nest and brood flush site within 3 days of hatching or expected hatch date in the case of failure (Figure 1). We recorded visual obstruction readings (VOR) at the nest bowl and at four points 6 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 12 subsampling locations within 6 m of the nest using a 20 × 50 cm sampling frame (Daubenmire 1959). At each subsampling plot, we measured the heights of new grass, residual grass, forbs, and shrubs. We also estimated shrub cover using the line-intercept method, recording the species, height, and length of each shrub intersecting the transect. For nests, we conducted parallel sampling at randomly selected points within a study area defined by a minimum convex polygon placed around the leks of capture and buffered to 2 km. For broods, we conducted parallel sampling at paired points in a randomly determined direction and distance (maximum of 250 m) from each flush location to represent available habitat within the average daily distance traveled by broods (Goddard et al. 2009). Random points that fell within unsuitable habitat (i.e., water, cultivation) or were located on properties to which we did not have access were replaced.

We also measured habitat conditions at the home range scale (500 ha, based on estimated home range sizes of sharp-tailed grouse during the breeding season, see below) under the assumption that the home range contained the resources utilized by a female during the nesting season. The home range area was defined as a circular plot with a 1,300-m radius centered on each nest, brood, and random location. We calculated habitat variables at the home range scale using remotely sensed data and ArcMap 10.4. We included road datasets for both Montana and North Dakota and calculated the distance to paved and gravel roads from the nest bowl (Montana State Library, North Dakota GIS Hub Data Portal). Paved roads, including state highways, had higher traffic volumes and were assumed to represent a different level of disturbance than gravel roads. We also included the locations of oil pads which represented another form of disturbance in the study area and calculated the distance to the nearest oil pad from the center of each home range. Landcover analyses utilized the 30 m resolution LANDFIRE data depicting vegetation type (LANDFIRE 2013). We measured the distance from the center of each home range to the nearest patch of non-grassland habitat. In addition, we used the Patch Analyst Extension in ArcMap to calculate the proportion of grassland, the density of edge habitat, and grassland shape complexity.

We collected stocking information from cattle producers for every pasture in which radio-marked sharp-tailed grouse were located. For each pasture, we recorded the type of animal (cow/calf pairs, heifers, bulls, or horses), number of head, and the dates when animals were in the pasture. We calculated the following grazing management variables: grazing system (rest-rotation, summer rotation, season-long), stocking rate (AUM ha^{-1}), stocking intensity (AU ha^{-1}), stocking duration (in months), and season of stocking (growing season [May—July], post-growing season [August—November], winter [December—April], or rest [no grazing for entire year]).

We used field data to estimate eight demographic parameters related to fecundity for sharp-tailed grouse (Table 1). Some of these parameters, including clutch sizes and chicks per egg laid (CPE), 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 considered to make population-level inferences. To account for imperfect observation, we used the nest survival model in Program MARK to calculate maximum likelihood estimates of daily nest survival (NSURV) following the methods described below.

Nesting rate (NEST) was calculated as the percentage of females that attempted a nest. The probability of renesting (RENEST) 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 or was not relocated after the failure of a first nest attempt. Initial brood size was determined by the number of chicks that were known to hatch based on nest observations. Brood success (BSURV) was calculated as the proportion of broods that successfully fledged ≥1 chick. Fledging success (FPC) was calculated as the proportion of chicks that survived until fledging among successful broods. Broods were included in the easement category if >70% of brood 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.

Fecundity (*F*), or the number of female fledglings produced per female, is expressed as a function of these parameters using the following equation:

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

Bootstrapping procedures were used to calculate 85% confidence intervals for fecundity estimates by randomly drawing from the underlying distributions of input parameters (McNew et al. 2012).

We examined habitat and management variables influencing nest site selection in separate analyses using resource selection functions. Habitat variables were considered for their direct effect on nest site selection, while management variables were considered for potential indirect effects on vegetation structure as mediated through livestock grazing practices. Nests were considered used sites and, as we did not conduct searches for nests of unmarked grouse, random points were considered available following sampling protocol B of Manly et al. (2002). Therefore, we used resource selection functions to compare habitat variables at used sites (1) and available sites (0). For each analysis, we built sets of candidate models in Program R with female ID as a random effect to account for potential autocorrelation among nests. Before fitting models, we examined correlations for each pair of variables ($r \geq 0.5$, $p < 0.05$). Models were compared using AIC_c and model selection was based on minimization of AIC_c and AIC_c weights (w_i). For the habitat-level analysis, we first evaluated underlying variables, variables at the nest-site scale, and variables at the home-range scale independently and built a final candidate model set that included variables supported at each scale. Underlying variables included year, hen age, and nest attempt. Variables at the nest-site scale included VOR at the nest bowl and averaged within the 6 m radius plot, distance to grassland edge, and the percentage of shrubs, new grass, residual grass, forbs, and bare ground. Different functional relationships with VOR were examined, including linear, exponential and natural log models (i.e., pseudo-threshold effects; Dugger et al. 2005, McNew et al. 2014). Variables considered at the home-range scale included the proportion of grassland habitat, density of edge habitat, grassland shape complexity, and distance to oil pad, road, or lek. In the management-level analysis, we evaluated all combinations of the effects of grazing system and stocking rate. We also evaluated additive and interaction models with grazing system and year. Variables were considered significant if 85% confidence intervals did not overlap zero (Arnold 2010). Top variables from both the habitat- and management-level analyses were then combined in a final candidate model set to evaluate relative effects on nest site selection.

Nest success is defined as the probability of a nest producing ≥ 1 chick, whereas nest survival accounts for potential losses of nests before discovery. We constructed nest survival models using the RMARK package in Program R to calculate maximum likelihood estimates of daily nest survival and evaluate the effects of habitat conditions and management variables on daily nest survival during a 77-d nesting period during 28 April – 12 July (White and Burnham 1999, Dinsmore et al. 2002). Before fitting models, we examined correlations for each pair of variables and if a pair was highly correlated ($r \geq 0.5$, $p < 0.05$), we used single-factor models to determine which of the two variables accounted for the largest proportion of variation in daily nest survival. We considered the variable with the lowest model deviance to be the primary variable to consider in subsequent analyses.

Similar to the nest site selection analysis, we evaluated nest survival models at both the habitat and management level and compared model sets using the criteria described above. For the habitat-level analysis, underlying effects included variables of nest attempt, female age, female condition, flushing effect, daily temperature, and three precipitation variables compared to a null

model of constant daily nest survival (Goddard and Dawson 2009). Female condition was calculating by regressing body mass against the length of the wing chord using the reduced major axis method (Green 2001). Precipitation variables included daily precipitation with a 1-day time lag, growing season precipitation from the previous year (total precipitation from previous April to June), and available precipitation from that year (total precipitation from October to May). We then selected the most parsimonious models at each of the different spatial scales (nest- and home range level) and assessed them in the final candidate model set. The management-level analysis included all the models evaluated in the nest site selection analysis (described above), plus a model examining the effect of stocking density while the nest was active. Top variables from both the habitat- and management-level analyses were then combined in a final candidate model set to evaluate relative effects on nest survival.

We also developed a separate set of candidate models to examine the effects of grazing variables on nests within the rest-rotation pastures (*n*=57) and evaluate effects on nest survival of the different treatments within the system (grazed during the growing season, grazed post-growing season, rested entire year).

Finally, we developed a separate candidate set of models to evaluate both the effects of flushing on nest survival and what factors might be mediating effects of flushing. In addition to a flushing variable, covariates considered included female age, female condition, nest attempt, cumulative precipitation during the nest attempt, and dummy variables representing whether a nest was visited on that day or the previous day. Models were compared using the criteria described above.

Overall nest survival for precocial species is the probability that a nest will survive the entire nesting period, defined as the mean laying plus incubation interval for grouse at our study sites (37-d). We calculated the overall nest survival probability with parametric bootstrapping, using the beta estimates and variance-covariance matrix from the top model in the nest survival analysis. Variance of overall nest survival was estimated with the delta approximation (Powell 2007). The average duration of incubation period (27-d) was determined from observations of our sample of successful nests and from previous work (Connelly et al. 1998).

Results.– Eight sharp-tailed grouse leks were monitored during 15 March – 3 May 2018. Sharp-tailed grouse were trapped at 3 easement and 5 reference leks during 18 March – 3 May 2018. Mean overall lek attendance was 11.7 birds (average of 9.5 males and 2.2 females) during this period (Table 2). Attendance declined at all but one lek, with overall attendance at individual leks declining 33-57% compared to previous years, with the most marked declines occurring in male attendance. Female attendance occurred significantly later than in previous years, with the first female observed on 10 April, which was about 2 and 3 weeks later than in 2017 and 2016, respectively. Female attendance also peaked later in the year, with the majority visiting between 24 and 27 April. We captured a total of 125 sharp-tailed grouse (63 males, 62 females), including 89 new captures (36 males, 53 females) and 36 recaptures from 2016 and 2017 (27 males, 9 females) and 57 females were radio-marked (Table 3). An additional 13 females that were radio-marked during the 2017 field season were still present in the study area and therefore monitored for a second year. Overall, 70 radio-marked females were monitored ≥ 3 times per week throughout the nesting and brood-rearing period.

Females initiated 62 nests (53 first nests, 9 renests; Figure 2, Table 4). Nine 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 9 May (5 May for first nests, 4 June for renests; range: 28 April – 12 June). Nesting frequency (± SE) was 0.97 ± 0.02 (nests were not located for two females), while the probability of renesting after first nest failure was 0.60 ± 0.12. Thirty-eight nests successfully hatched and 24 failed (22 depredated, 1 abandoned, 1 trampled by cattle; Table 4). Hatch rate of eggs (± SE) for first nests and renests was 91.4 ± 2.4% and 95.6 ± 2.5%, respectively. Mean clutch size for all nest attempts was 10.2 ± 0.59 eggs. Mean clutch size for first nest and renests was 10.3 ± 0.69 and 9.7 ± 0.60 eggs, respectively.

Eight demographic parameters were estimated using field data (Table 5). Fecundity was calculated as a function of these parameters using the equation described above and was estimated to be 1.14 ± 0.002 female fledglings produced per female.

In the nest site selection analysis, none of the underlying variables, including year, female age and nest attempt, improved model fit over the null model (Table 6). Preliminary analyses suggested that visual obstruction at the nest bowl best predicted nest site selection and that a pseudo-threshold model best represented the relationship between visual obstruction and nest site selection, so only models with the natural log transformation of nest VOR were included in analyses. At the nest-level, nest site selection was best predicted by VOR at the nest bowl and the percentage of new grass, residual grass, and shrubs ($\Delta AIC_c = 0$, $w_i = 0.61$; Table 7). At the home-range level, the model containing a measure of fragmentation (mean shape complexity or MSI) received the most support ($\Delta AIC_c = 0$, $w_i = 0.56$; Table 8). In the final candidate model set, the model that included VOR at the nest bowl, the percentage residual grass, and mean shape complexity received the most support ($\Delta AIC_c = 0$, $w_i = 0.61$; Table 9). Confidence intervals for VOR, MSI, and proportion residual grass and shrubs did not overlap zero, suggesting significant effects (Figure 3). Percent cover of both residual grass ($\beta = 0.48 \pm 0.17$) and shrubs ($\beta = 0.33 \pm 0.20$) had small but positive effects on the relative probability of selection, while selection decreased with increasing fragmentation or MSI ($\beta = -0.50 \pm 0.16$). Visual obstruction at the nest bowl had the largest effect on the relative probability of selection ($\beta = 11.45 \pm 1.31$), with selection increasing up to a threshold (Figure 4).

In the management-level analysis evaluating nest site selection, models containing the effect of stocking rate received the most support ($w_i = 0.68$, Table 9), with 85% confidence intervals that did not overlap zero (Figure 5). The relative probability of selection declined with increasing stocking rates ($\beta = -0.17 \pm 0.10$; Figure 6). However, in the full analysis, the model containing habitat variables ($\Delta AIC_c = 0$, $w_i = 0.58$) outperformed models with management-level variables (Table 9), suggesting that grazing management was not an important predictor of nest site selection after controlling for other factors.

Overall nest survival varied by year and ranged from 0.29 ± 0.06 in 2016 to 0.48 ± 0.07 in 2018. None of the underlying variables improved model fit over the null model (Table 10). Preliminary analyses suggested that visual obstruction averaged across the 6 m radius plot best predicted daily nest survival and that a pseudo-threshold model best represented the relationship between visual obstruction and nest survival, so only models with the natural log transformation of average VOR were included in analyses. At the nest-level, VOR was in the top four models, accounting for 91% of model weight (Table 11). Percentage forb, residual grass, and new grass in combination with VOR each received some support in combination with VOR ($\Delta AIC_c = 0.50 - 1.83$, $w_i = 0.13 - 0.26$; Table 11) and so were examined in the final model set. At the home-range level, distance to road received the most support ($\Delta AIC_c = 0$, $w_i = 0.35$) and proportion grassland marginally improved model fit compared to the null model ($\Delta AIC_c = 1.36$, $w_i = 0.18$),

so both variables were included in the final analysis (Table 12). In the final candidate model set, the model that included VOR, the percentage forbs and the proportion grassland received the most support ($\Delta AIC_c = 0$, $w_i = 0.43$, Table 13). VOR was in all twelve top models, accounting for 100% of model weight, while proportion grassland accounted for 79% of model weight. Confidence intervals for VOR, proportion grassland, and distance to road did not overlap zero, suggesting significant effects (Figure 7). Daily nest survival increased with proportion grassland ($\beta = 0.16 \pm 0.10$), distance to road ($\beta = 0.21 \pm 0.11$), and VOR up to a threshold, as represented by the pseudo-threshold model ($\beta = 0.29 \pm 0.11$; Figure 8), and decreased with the percentage forbs ($\beta = -0.14 \pm 0.11$).

In the management-level analysis evaluating nest survival, stocking density while the nest was active was the best predictor of daily nest survival ($\Delta AIC_c = 0$, $w_i = 0.50$; Table 13), with survival increasing with stocking density ($\beta = 0.30 \pm 0.14$; Figures 9 & 10). There was also some evidence for an effect of year and rest-rotation grazing, with confidence intervals that did not overlap zero (Figure 9). Daily nest survival was higher in both 2017 ($\beta = 0.36 \pm 0.25$) and 2018 ($\beta = 0.73 \pm 0.28$) than in 2016 and was lower in rest-rotation pastures compared to season-long pastures ($\beta = -0.44 \pm 0.27$). Overall nest survival was 0.48 ± 0.07 in season-long pastures, 0.38 ± 0.06 in summer rotation pastures, and 0.32 ± 0.06 in rest-rotation pastures (Figure 11). In the full analysis, the model with the most support included VOR, proportion grassland and stocking density while the nest was active ($\Delta AIC_c = 0$, $w_i = 0.90$, Table 13), with confidence intervals for all three variables not overlapping zero, suggesting significant effects.

Within the rest-rotation system, there was no evidence for an effect of treatment (grazed during the growing season, grazed post-growing season, or rested) on nest survival (Table 14). Estimates of daily nest survival in the three treatments entirely overlapped (Figure 12).

Flushing females from their nests had a negative effect on nest survival, but was mediated by the cumulative precipitation during the nesting period (Table 15). Flushing only had a negative effect during periods with low precipitation (Figure 13).

We monitored 95 broods to estimate survival and document habitat use (Table 16). Twenty-two broods spent the majority of the time (>60% of brood locations) in rest-rotation pastures, 30 spent the majority of time in summer rotation pastures, 29 spent the majority of time in season-long pastures, and 14 split time between multiple grazing systems. Brood success, calculated as the proportion of broods fledging ≥1 chick to 14-d of age, was 0.59 ± 0.10, 0.80 ± 0.07, 0.66 ± 0.09, and 0.43 ± 0.13 for broods located on the rest-rotation, summer rotation, season-long and multiple systems, respectively. Of broods that survived to fledging, the proportion of chicks that survived was 0.55 ± 0.08, 0.54 ± 0.06, 0.59 ± 0.07, and 0.32 ± 0.09 for broods located on the rest-rotation, summer rotation, season-long and multiple systems, respectively.

We determined that 28 females were killed by predators: 15 and 8 by mammalian and avian predators, respectively, and 5 by an unknown predator. An additional 2 females were hunter mortalities. One female was right censored from the study when the transmitters was found with no sign of death. An additional 4 females left the study area within 2 weeks of captured and were right censored after they could not be relocated for more than 2 months. Two females moved onto land to which we do not have access and so were monitored solely for survival.

Goals For Next Quarter:

We will continue to monitor radio-marked females ≥ 1 time/month through the non-breeding season (Sept – March) until death or transmitter failure or loss. We will focus efforts during the next quarter on preparing a manuscript on nesting ecology for publication. Results related to nesting ecology will also be presented at the annual meeting of the American Association for the Advancement of Science in February and the annual meeting of the Montana Chapter of The Wildlife Society in March.

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

Accomplishments

Radio-marked females were located via triangulation or homing ≥ 3 times/week using portable radio receivers and handheld Yagi antennas during the nesting and brood-rearing period (April–August) and ≥ 1 times/month during the rest of the year (September–March).

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 low estimation precision (>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 ≥ 30 locations and ≥ 20 locations not associated with a nest site. 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. We also calculated centroids for each home range by estimating the 1% volume contour of each home range and used the geographic center of that contour as the centroid. We then measured distance from each centroid to the nearest lek, grassland patch edge, road and oil pad. Linear models were used to evaluate the effects of year, nest outcome, density of edge habitat, proportion grassland within the home range, grazing conditions at the home range centroid, and distance to nearest lek, grassland patch edge, road, and oil pad on home range size.

We examined second-order habitat selection, or the selection of habitat for an individual's home range within the larger study area, using the adehabitat package in Program R and conducted composition analysis of used versus available habitat (Johnson 1980, Aebischer et al. 1993). Available habitat was defined as the 95% home range calculated for all locations in a given year and each female's 95% home range represented the used space at an individual level. We used compositional analysis to compare used versus available vegetation types, grazing systems, and ecological site conditions. Habitat classifications utilized the 30-m resolution LANDFIRE data depicting vegetation type (LANDFIRE 2013). Ecological site conditions were measured ocularly in the field and were based on the percent of decreaser grasses present compared to the percentage in the ecological site descriptions published by the Natural Resources Conservation Service (NRCS). Observations were first calibrated using clipped plots and were then estimated for all ecological sites with published descriptions. Conditions were calculated on the scale of a hectare, which based on average daily movements of grouse in this study and the goal was to capture the condition of the area available to a bird on a daily basis. Conditions were based on the percent production of decreaser grasses observed compared to the percent production found

in the climax community and were grouped into five categories: very low (0-20%), low (20-40%), medium (40-60%), high (60-80%), and very high (80-100%).

To evaluate third-order habitat selection, we used resource utilization functions or RUFs (Marzluff et al. 2004). RUFs use utilization distributions to quantify the probability of space use and then relate that space use to habitat variables by quantifying use within a defined area (e.g., the home range) as continuous rather than discrete (used vs. unused) and evaluating the entire distribution of an animal's movements rather than the individual sampling points (Marzluff et al. 2004). In addition, RUFs are recommended for use with VHF telemetry data which is subject to measurement error (Hooten et al. 2013). While home ranges provide information on where an individual was located, RUFs can evaluate why particular areas are used more frequently by linking differential space use to habitat variables. To implement RUFs, we created utilization distributions within 99% fixed kernel home ranges using the adehabitatHR package in Program R. We then evaluated habitat conditions at each grid cell within the polygons. Variables considered included grazing system, density of edge habitat, distance to lek, distance to road, distance to oil pad, and percent grassland, wooded draw or agriculture within 200 m of a cell. A distance of 200 m represents the average daily distance moved by female grouse in this study and thus the distance over which they would be making habitat choices. The height of the utilization distribution represents the relative amount of use of a given cell, which can then be related to habitat conditions using multiple regression (Marzluff et al. 2004). Using multiple regression, we estimated coefficients of relative resource use by relating the cell values from the utilization distribution to the habitat variables using the ruf package in Program R. Coefficients represent the degree to which an individual or population utilize resources within the defined home range (Marzluff et al. 2004). Mean standardized coefficients were used to make population-level inferences about each habitat variable and standardized coefficients with 95% confidence intervals that did not overlap zero were considered significant. While unstandardized coefficients are necessary to predict expected use, standardized coefficients allow for inferences about the relative influence of habitat variables on animal use and can be used to rank the relative importance of each variable (Marzluff et al. 2004).

Results.– During the 2018 breeding season, we collected a total of 2,612 locations from 70 females. During the 2018 breeding season (April – August), 49 females had ≥ 30 locations. Mean breeding season home range size for all females in 2018 was 455 ± 401 ha, but varied from 57 ha to 2,260 ha. Density of edge habitat within the home range was the best predictor of home range size (Table 17) and was negatively related to the size of breeding season home ranges for females (β = -5.26 ± 1.48). There was no evidence for an effect of the grazing system at the centroid of a female's home range on home range size (Figure 14, Table 17).

Breeding season habitat use was ranked as follows: grassland > wooded draws >> other (primarily ruderal grasslands) >> agriculture (Table 18), suggesting that females did not differentiate between grasslands and wooded draws with regards to preference but selected both habitat types over other habitats, including cultivation. Females strongly selected for mixed grass prairie habitats, even though roughly 83% of the entire study area was composed of mixed grass prairie. Breeding season habitat use in relation to grazing system ranked rest-rotation > season-long >> summer rotation (Table 19), suggesting that females were selecting against pastures grazed in a summer rotation system when choosing home ranges, but not differentiating between pastures with rest-rotation and season-long systems. Breeding season habitat use in relation to ecological site conditions was ranked as follows: low >> medium >> very low >> high (Table

20), suggesting that grouse were selecting for intermediate sites over those that were in either high or very low condition compared to the climax community.

We found no evidence for a population-level effect of any habitat variables on habitat selection within the home range, as confidence intervals for all variables overlapped zero (Figure 15). However, there was significant and highly variable selection at an individual level, with between 44–95% of females having significant selection coefficients for each of the variables (Figure 16).

Goals For Next Quarter:

We will focus efforts in the next quarter on reviewing other methods for evaluating habitat selection, particularly at the third order. Resource utilization functions are calculated at an individual level and then coefficients from each individual analysis are combined to make population-level inferences (Marzluff et al. 2004). This means each individual bird included in population-level analyses has to have all relevant variables within its home range, which becomes problematic for a categorical variable such as grazing system, because only a subset of individuals has all three grazing systems within their home ranges. Evaluating a categorical variable in a linear model framework like a resource utilization function also necessitates that one level of the variable (season-long grazing in our analyses) be set as the reference category against which the other levels are compared. To make population-level inferences, all individuals must have the same reference category, which further limits sample sizes to females with a given level of a categorical variable within their home range. As a result, we were only able to use information from 75 of 142 possible individuals in analyses examining third order habitat selection using resource utilization functions. In order to utilize our entire data set and make stronger inferences, we will examine alternative methodologies, including resource selection functions incorporating random effects, to assess third order 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

Project completed. Please see:

Vold, S. T. 2018. Effects of livestock grazing management on the ecology of grassland birds and their predators in a northern mixed-grass prairie ecosystem. Thesis, Montana State University, Bozeman, Montana, USA.

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Table 1. Demographic rates estimated for sharp-tailed grouse.

Demographic Rate	Description
Nesting rate (NEST)	The probability of a female initiating a nest.
Clutch size (CS)	The final clutch size per nest. Estimates generated for both first (CS_1) and renesting (CS_2) attempts.
Nest survival (NSURV)	The probability of a nest producing ≥1 chick.
Renesting rate (RENEST)	The probability of a female initiating a replacement nest after failure of the first attempt
Chicks per egg laid (CPE)	The proportion of eggs laid that produced chicks, or the viability of the eggs; calculated only for successful nests (≥1 egg hatched).
Brood survival (BSURV)	The probability that ≥1 chicks survived to fledging at 14-d post-hatch
Fledglings per chick hatched (FPC)	The proportion of hatched chicks that survived to fledging conditional upon brood survival

Table 2. Average attendance at 8 leks during 15 March – 3 May 2018. The three leks located within the easement are listed first.

Lek	Average Total Attendance	Minimum Total Attendance	Maximum Total Attendance	Average Male Attendance	Average Female Attendance
EasState1	9.7	5	21	7.9	1.8
Prewitt1	9.2	6	14	7.5	1.7
Laumeyer2	14.4	10	21	12.3	2.1
Grassland01	11	6	16	5.8	5.2
Iversen1	17.0	7	28	14.3	2.3
Pennington01	7.2	4	16	5	2.4
Ullman01	9.2	7	12	7.7	1.5
Whited01	8.6	6	13	6.1	2.4
Total	11.7	4	28	9.5	2.2

Table 3. Total number of grouse captured and radio-marked on and off the easement in 2018. The total radio-marked females includes females radio-marked in 2017 but monitored again in 2018.

	Males	Females	New Radio-marked Females	Total Radio-marked Females
Easement	25	28	26	32
Reference	38	34	31	38
Total	63	62	57	70

Table 4. Overview of sharp-tailed grouse nests in pastures managed with different grazing systems in 2018. Egg hatch rate (± SE) is the percentage of eggs that hatched from the initial clutch size. Two nests were in winter-grazed pastures and so were excluded from analysis.

	Median Initiation Date	Clutch Size	First Nests	Renests	Nests Hatched	Median Hatch Date	Egg Hatch Rate
Rest-rotation	10 May	9.3 ± 1.3	12	3	8	15 June	0.98 ± 0.01
Summer rotation	10 May	9.9 ± 0.8	23	6	16	13 June	0.91 ± 0.03
Season-long	5 May	11.4 ± 1.2	16	0	13	13 June	0.89 ± 0.05
Total	9 May	10.2 ± 0.6	51	9	37	3 June	0.92 ± 0.02

Table 5. Estimated demographic rates (± SE) for female sharp-tailed grouse during the 2016–18 breeding seasons.

Demographic Rate	Estimate ± SE
Nesting rate (NEST)	1
Clutch size - first nest (CS1)	11.06 ± 0.57
Clutch size - renests (CS2)	9.57 ± 0.60
Nest survival (NSURV)	0.40 ± 0.04
Renesting rate (RENEST)	0.61 ± 0.10
Chicks per egg laid (CPE)	0.91 ± 0.02
Brood survival (BSURV)	0.69 ± 0.05
Fledglings per chick hatched (FPC)	0.62 ± 0.06

Table 6. Support for candidate models predicting sharp-tailed grouse nest site selection based on underlying variables in 2016–18. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and log-likelihoods are reported.

Model	K	AIC_c	ΔAIC_c	AIC_c w_i	Cum. w_i	LogLik
Null	2	528.04	0.00	0.53	0.53	-262.00
Female Age	3	529.90	1.86	0.21	0.73	-261.92
Nest Attempt	3	530.04	2.00	0.19	0.93	-261.99
Year	4	531.96	3.92	0.07	1.00	-261.92

Table 7. Support for candidate models predicting sharp-tailed grouse nest site selection at the nest site level in 2016–18. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and log-likelihoods are reported.

Model	K	AIC_c	ΔAIC_c	AIC_c w_i	Cum. w_i	LogLik
ln(Nest VOR) + %New Grass + %Residual + %Shrub	6	293.20	0.00	0.61	0.61	-140.49

Model	K	AICc	ΔAICc	wi	Cum.	LogLik
ln(Nest VOR) + %Residual	4	294.22	1.02	0.37	0.98	-143.06
ln(Nest VOR) + %Forb	4	301.41	8.21	0.01	0.99	-146.65
ln(Nest VOR)	3	303.94	10.74	0.00	1.00	-148.94
ln(Nest VOR) + %Shrub	4	304.09	10.89	0.00	1.00	-147.99
ln(Nest VOR) + % New Grass	4	305.88	12.68	0.00	1.00	-148.89
%Bare	3	477.25	184.05	0.00	1.00	-235.59
%New Grass + %Residual + %Shrub	5	483.56	190.36	0.00	1.00	-236.70
%New Grass + %Forb + %Residual + %Shrub	6	485.62	192.42	0.00	1.00	-236.70
%Shrub	3	497.65	204.45	0.00	1.00	-245.79
%Residual	3	521.14	227.94	0.00	1.00	-257.54
Null	2	528.04	234.84	0.00	1.00	-262.00
Dist. to Grassland Edge	3	529.09	235.89	0.00	1.00	-261.51
%Forb	3	529.60	236.40	0.00	1.00	-261.77
%New Grass	3	529.73	236.53	0.00	1.00	-261.83

Table 8. Support for candidate models predicting sharp-tailed grouse nest site selection at the home range level in 2016–18. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and log-likelihoods are reported.

Model	K	AIC_c	ΔAIC_c	AIC_c w_i	Cum. w_i	LogLik
Mean Shape Complexity	3	524.93	0.00	0.56	0.56	-259.43
Null	2	528.04	3.11	0.12	0.67	-262.00
Dist. to Oil Pad	3	528.24	3.32	0.11	0.78	-261.09
Edge Density	3	528.64	3.72	0.09	0.87	-261.29
Dist. to Road	3	529.86	4.93	0.05	0.91	-261.90
Prop. Grassland	3	530.03	5.11	0.04	0.96	-261.99
Dist. to Lek	3	530.04	5.11	0.04	1.00	-261.99

Table 9. Support for final candidate models evaluating sharp-tailed grouse nest site selection in 2016–18 in the habitat- and management-level analyses. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and log-likelihoods are reported.

Model	K	AIC_c	ΔAIC_c	AIC_c w_i	Cum. w_i	LogLik
Habitat Analysis						
ln(VOR) + %Residual + Mean Shape Complexity	5	284.95	0.00	0.61	0.61	-137.40
ln(VOR) + %Grass + %Residual + %Shrub + Mean Shape Complexity	7	285.97	1.02	0.37	0.98	-135.83
ln(VOR) + %Grass + %Residual + %Shrub	6	293.20	8.25	0.01	0.99	-140.49
ln(VOR) + %Residual	4	294.22	9.27	0.01	1.00	-143.06

Mean Shape Complexity	3	524.93	239.97	0.00	1.00	-259.43
Null	2	528.04	243.09	0.00	1.00	-262.00

Management Analysis

Stocking Rate	3	526.45	0.00	0.35	0.35	-260.19
Stocking Rate + Grazing System	5	526.54	0.09	0.33	0.68	-258.19
Null	2	528.04	1.59	0.16	0.84	-262.00
Grazing System	4	528.90	2.45	0.10	0.94	-260.40
Grazing System * Stocking Rate	7	530.34	3.89	0.05	0.99	-258.02
Grazing System + Year	6	533.02	6.57	0.01	1.00	-260.40
Grazing System * Year	10	541.07	14.62	0.00	1.00	-260.24

Full Analysis

ln(VOR) + %Residual + MSI	5	284.95	0.00	0.58	0.58	-137.40
ln(VOR) + %Residual + MSI + Stocking Rate	6	285.57	0.61	0.42	1.00	-136.67
Stocking Rate	3	526.45	241.49	0.00	1.00	-260.19
Null	2	528.04	243.09	0.00	1.00	-262.00

Table 10. Support for candidate models predicting sharp-tailed grouse nest survival in 2016-18 based on underlying variables. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and deviance are reported.

Model	K	AIC_c	ΔAIC_c	$AIC_c\ w_i$	Deviance
Flush Nest	2	757.84	0.00	0.22	753.84
Growing Season Precip.	2	758.20	0.36	0.18	754.19
Null	1	758.94	1.10	0.13	756.94
Available Precip.	2	759.05	1.21	0.12	755.05
Female Condition	2	759.19	1.35	0.11	755.18
Daily Precip.	2	760.36	2.52	0.06	756.35
Nest Attempt	2	760.56	2.72	0.06	756.56
Female Age	2	760.62	2.78	0.05	756.62
Female Condition + Age	3	761.01	3.17	0.04	755.00
Female Age + Nest Attempt	3	762.20	4.36	0.02	756.19

Table 11. Support for candidate models predicting sharp-tailed grouse nest survival in 2016-18 at the nest site scale. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and deviance are reported.

Model	K	AIC_c	ΔAIC_c	$AIC_c\ w_i$	Deviance
ln(VOR)	2	753.59	0.00	0.33	749.59
ln(VOR) + %Forb	3	754.09	0.50	0.26	748.08
ln(VOR) + %Residual	3	755.41	1.82	0.13	749.41

Model	K	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i	Deviance
ln(VOR) + %New Grass	3	755.42	1.83	0.13	749.42
ln(VOR) + %Forb + %New Grass + %Residual	5	757.52	3.93	0.05	747.50
Null	1	758.94	5.35	0.02	756.94
%Forb	2	759.25	5.66	0.02	755.25
%Bare	2	759.58	5.99	0.02	755.58
Dist. to Grassland Edge	2	760.10	6.51	0.01	756.10
%New Grass	2	760.70	7.11	0.01	756.70
%Residual	2	760.94	7.35	0.01	756.94
%Forb + %New Grass + %Residual	4	763.91	10.32	0.00	755.90
%Forb + %New Grass + %Residual + %Shrub	5	764.38	10.79	0.00	754.36

Table 12. Support for candidate models predicting sharp-tailed grouse nest survival in 2016-18 at the home range scale. The number of parameters (K), AIC$_c$ values, ΔAIC$_c$ values, model weights (w_i) and deviance are reported.

Model	K	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i	Deviance
Dist. to Road	2	757.17	0.00	0.35	753.17
Prop. Grassland	2	758.53	1.36	0.18	754.53
Null	1	758.94	1.77	0.14	756.94
Mean Shape Complexity	2	758.99	1.81	0.14	754.98
Edge Density	2	759.23	2.05	0.13	755.22
Dist. to Oil Pad	2	760.60	3.43	0.06	756.60

Table 13. Support for models predicting sharp-tailed grouse nest survival in 2016-18 in the three analyses examining habitat-level variables, management-level analyses and the combined analysis. The number of parameters (K), AIC$_c$ values, ΔAIC$_c$ values, model weights (w_i) and deviance are reported.

Model	K	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i	Deviance
Habitat Analysis					
ln(VOR) + %Forb + Prop. Grassland	4	747.50	0.00	0.43	739.49
ln(VOR) + Prop. Grassland	3	748.94	1.44	0.21	742.94
ln(VOR) + %Residual + Prop. Grassland	4	750.94	3.44	0.08	742.93
ln(VOR) + %New Grass + Prop. Grassland	4	750.94	3.44	0.08	742.93
ln(VOR) + %Forb + Dist. to Road	4	751.64	4.14	0.05	743.63
ln(VOR) + Dist. to Road	3	751.71	4.21	0.05	745.70
ln(VOR)	2	753.59	6.09	0.02	749.59
ln(VOR) + %New Grass + Dist. to Road	4	753.62	6.12	0.02	745.61
ln(VOR) + %Residual + Dist. to Road	4	753.69	6.19	0.02	745.68
ln(VOR) + %Forb	3	754.09	6.59	0.02	748.08
ln(VOR) + %Residual	3	755.41	7.91	0.01	749.41
ln(VOR) + %New Grass	3	755.42	7.92	0.01	749.42

	K	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i	Deviance
Dist. to Road	2	757.17	9.68	0.00	753.17
Prop. Grassland	2	758.53	11.03	0.00	754.53
Null	1	758.94	11.44	0.00	756.94
Management Analysis					
Stocking Density	2	755.05	0.00	0.60	751.05
Grazing System + Year	5	757.17	2.12	0.21	747.15
Null	1	758.94	3.89	0.09	756.94
Grazing System	3	760.18	5.13	0.05	754.17
Stocking Rate	2	760.90	5.85	0.03	756.89
Stocking Rate + Grazing System	4	762.16	7.11	0.02	754.14
Grazing System * Year	9	763.24	8.19	0.01	745.19
Stocking Rate * Grazing System	6	765.84	10.79	0.00	753.82
Full Analysis					
ln(VOR) + Prop. Grassland + Stocking Density	4	743.56	0.00	0.90	735.55
ln(VOR) + Prop. Grassland	3	748.94	5.38	0.06	742.94
ln(VOR) + Prop. Grassland + Grazing System + Year	7	749.82	6.26	0.04	735.79
Stocking Density	2	755.05	11.49	0.00	751.05
Grazing System + Year	5	757.17	13.61	0.00	747.15
Null	1	758.94	15.38	0.00	756.94

Table 14. Support for candidate models predicting sharp-tailed grouse nest survival in 2016-18 within the rest-rotation system. Treatment represents whether the pasture was grazed during the growing season, post-growing season, or rested. The number of parameters (K), AIC$_c$ values, ΔAIC$_c$ values, model weights (w_i) and deviance are reported.

Model	K	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i	Deviance
Null	1	251.86	0.00	0.61	249.85
Stocking Rate	2	253.72	1.86	0.24	249.70
Treatment	3	255.42	3.57	0.10	249.40
Treatment + Stocking Rate	4	257.43	5.58	0.04	249.39
Treatment x Stocking Rate	6	261.46	9.61	0.01	249.39

Table 15: Support for candidate models predicting the effects of flushing on sharp-tailed grouse nest survival in 2016-2018. The number of parameters (K), AIC$_c$ values, ΔAIC$_c$ values, model weights (w_i) and deviance are reported.

Model	K	AIC$_c$	ΔAIC$_c$	AIC$_c$ w_i	Deviance
Flush x Precipitation	4	406.36	0.00	1.00	398.35
Obs. Visit	2	425.67	19.31	0.00	421.67
Obs. Visit + Obs. Visit (1d lag)	3	425.89	19.53	0.00	419.88
Flush x VOR	4	425.89	19.53	0.00	417.88

Null	1	426.95	20.59	0.00	424.95
Flush	2	427.69	21.33	0.00	423.69
Obs. Visit (1d lag)	2	428.23	21.87	0.00	424.22
Flush x Female Age	4	429.01	22.64	0.00	420.99
Flush * Female Condition	4	431.67	25.30	0.00	423.65
Flush * Nest Attempt	4	431.71	25.34	0.00	423.69

Table 16. Sharp-tailed grouse brood survival (± SE) to fledging at 14-d post hatch for broods that spent the majority of time in pastures managed with each grazing system in 2016-2018. Brood success is the proportion of broods that successfully fledged ≥1 chick. Fledging rate is the proportion of chicks within broods that survived to fledging at 14 days.

	Number of Broods	Brood Success	Fledging Rate
Rest-rotation	22	0.59 ± 0.10	0.55 ± 0.08
Summer rotation	30	0.80 ± 0.07	0.54 ± 0.06
Season-long	29	0.66 ± 0.09	0.59± 0.07
Multiple systems	14	0.43 ± 0.13	0.32 ± 0.09
Total	95	0.65 ± 0.05	0.54 ± 0.4

Table 17. Support for candidate models predicting home range size of female sharp-tailed grouse during the breeding seasons of 2016-2018. The number of parameters (K), AIC_c values, ΔAIC_c values, model weights (w_i) and log-likelihoods are reported.

Model	K	AIC_c	ΔAIC_c	AIC_c w_i	Cum. w_i	LogLik
Edge Density	3	2161.89	0.00	0.95	0.95	-1077.86
Dist. to Grassland Edge	3	2169.83	7.95	0.02	0.97	-1081.83
Nest Outcome	3	2170.69	8.80	0.01	0.98	-1082.26
Null	2	2172.04	10.16	0.01	0.99	-1083.98
Year	3	2173.03	11.14	0.00	0.99	-1083.43
Dist. to Lek	3	2173.92	12.03	0.00	0.99	-1083.87
Dist. to Oil Pad	3	2174.01	12.12	0.00	0.99	-1083.92
Dist. to Road	3	2174.10	12.22	0.00	1.00	-1083.96
Prop. Grassland	3	2174.11	12.23	0.00	1.00	-1083.97
Grazing System	5	2175.21	13.32	0.00	1.00	-1082.38

Table 18. Simplified ranking matrix of female sharp-tailed grouse breeding season habitat selection based on vegetation type in 2016-2018. Matrix is based on comparing proportional habitat use within home ranges with proportion of available habitat types. The 'other' habitat is composed primarily of ruderal

grasslands. Habitat types with the same rank suggest that females did not differentiate between the two categories in habitat selection.

	Grassland	Wooded draws	Other	Agriculture	RANK
Grassland	0	+	+++	+++	1
Wooded draws	-	0	+++	+++	1
Other	---	---	0	+++	3
Agriculture	---	---	---	0	4

Table 19. Simplified ranking matrix of female sharp-tailed grouse breeding season habitat selection based on grazing system in 2016-2018. Matrix is based on comparing proportional habitat use within home ranges with proportion of available habitat types. Grazing systems with the same rank suggest that females did not differentiate between the two categories in habitat selection.

	Rest-rotation	Season-long	Summer rotation	RANK
Rest-rotation	0	+	+++	1
Season-long	-	0	+	1
Summer rotation	---	-	0	3

Table 20. Simplified ranking matrix of female sharp-tailed grouse breeding season habitat selection based on ecological site condition in 2016-2018. Matrix is based on comparing proportional habitat use within home ranges with proportion of available habitat types. Conditions are based on the percentage of decreaser grasses compared to the percentage in the climax community of that ecological site. Categories with the same rank suggest that females did not differentiate between the two categories in habitat selection.

	Low	Medium	Very Low	High	RANK
Low	0	+++	+++	+++	1
Medium	---	0	+	+++	2
Very Low	---	-	0	+++	2
High	---	---	---	0	4
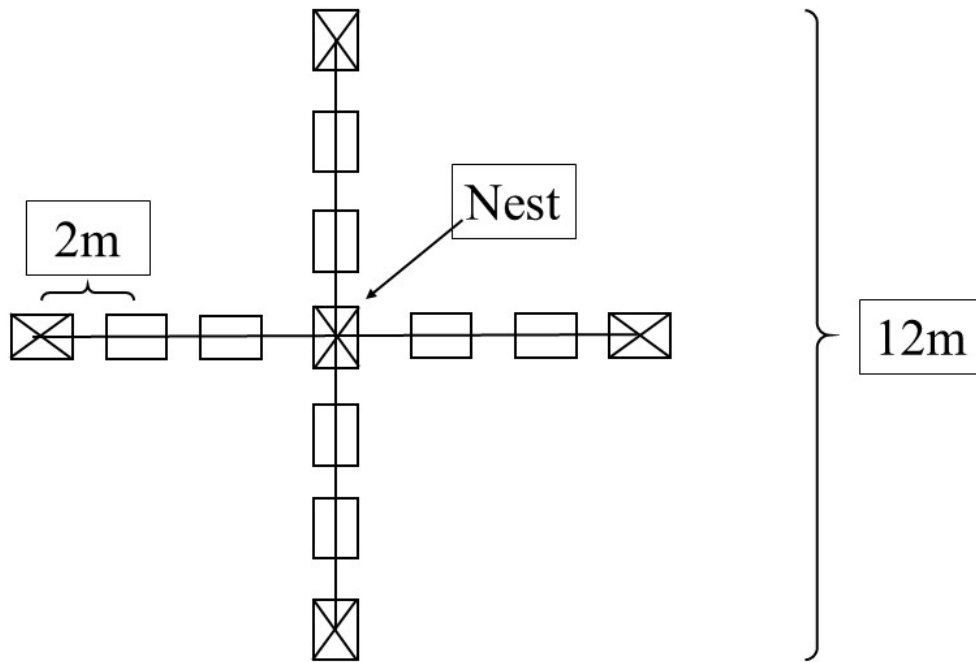
Figure 1. Setup of a vegetation plot. Vegetation cover and height were measured using a Daubenmire frame at each rectangle and visual obstruction with a Robel pole at each X. The lines represent the 12 m transects that were used to estimate shrub cover with the line-intercept method.
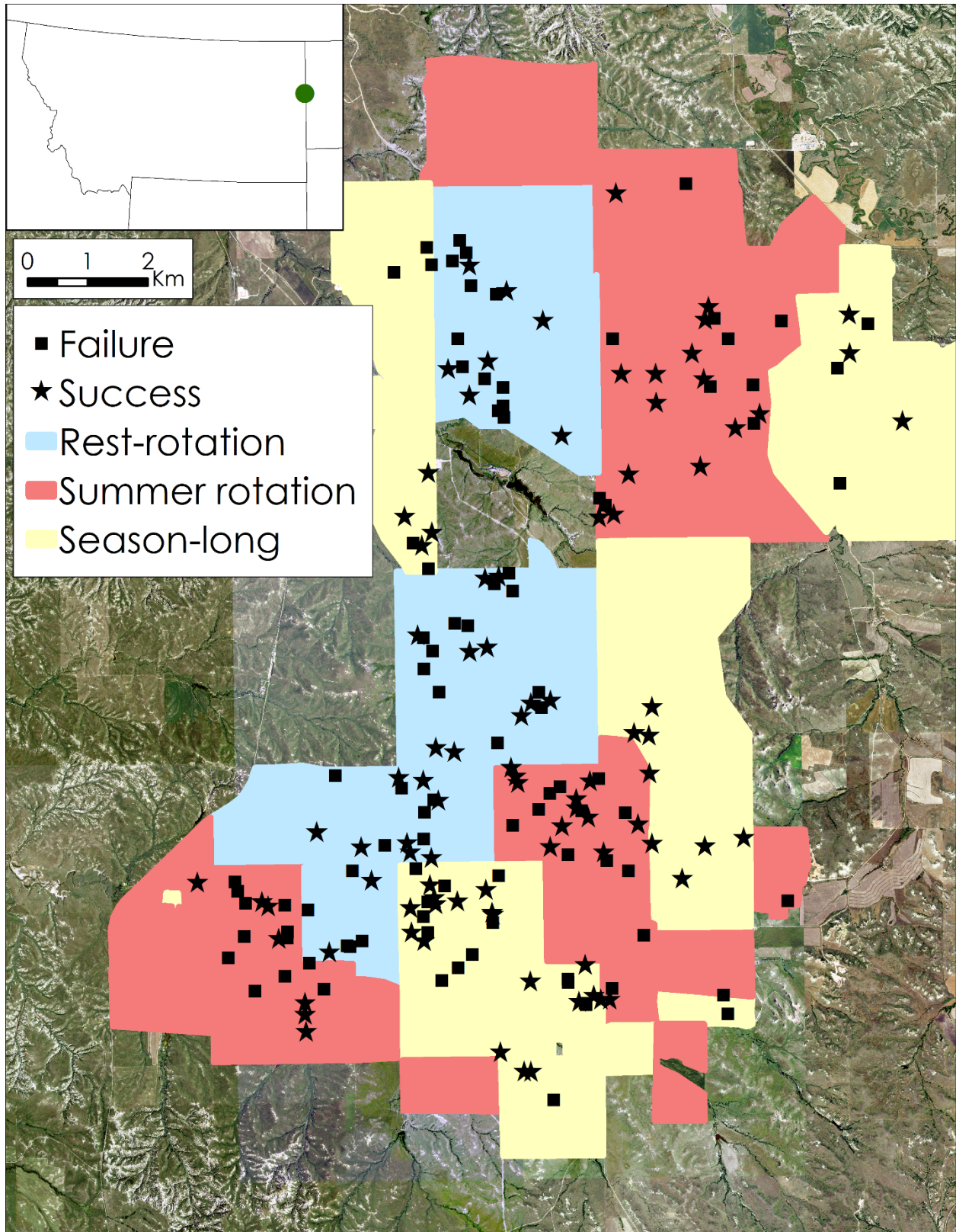
Figure 2. Locations of successful (stars) and failed (squares) sharp-tailed grouse nests in 2016–18 in relation to different grazing treatments.
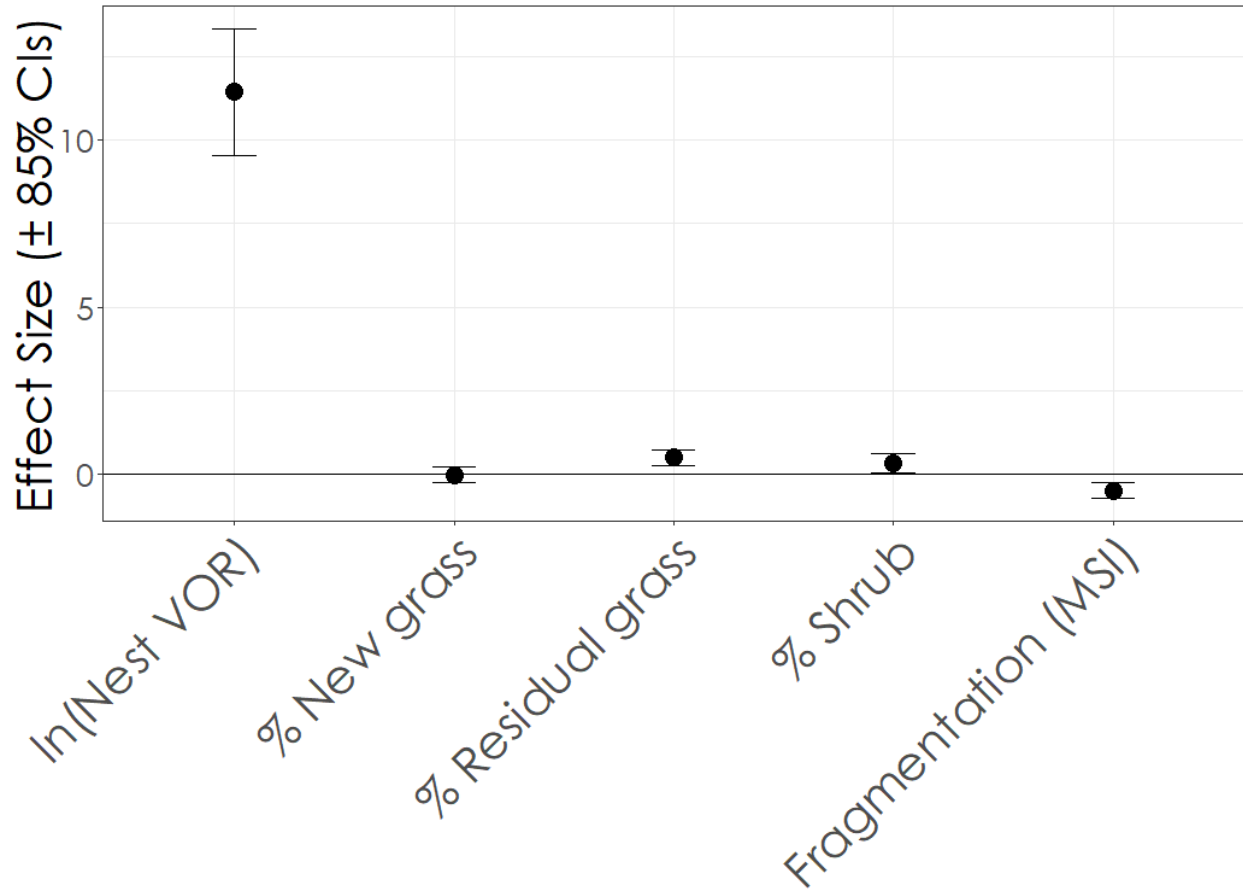
Figure 3. Scaled effect size ($\beta \pm 85\%$ confidence intervals) for each variable in the habitat-level analysis examining sharp-tailed grouse nest site selection in 2016–18.
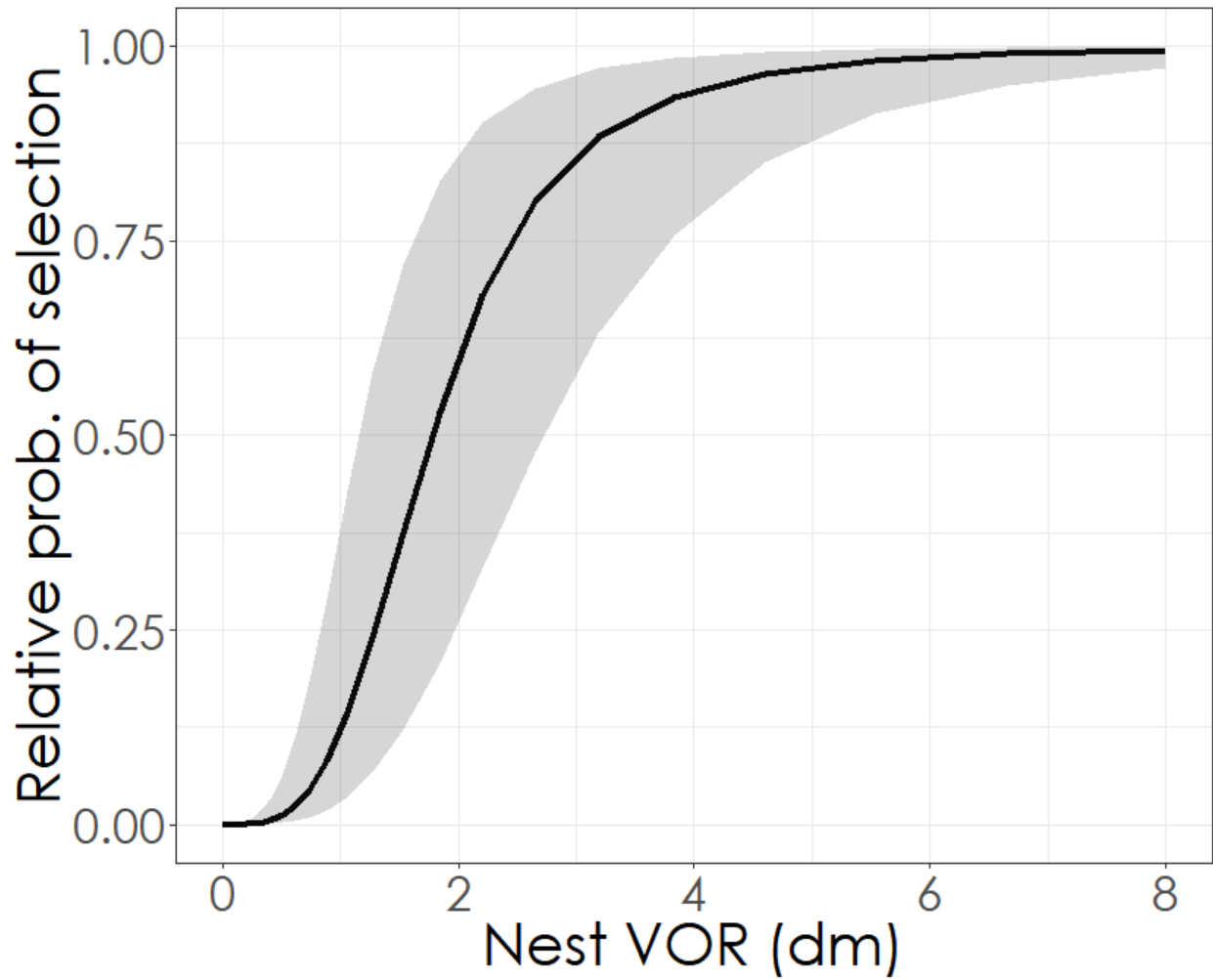
Figure 4. Estimated relative probability of nest site selection in relation to visual obstruction (VOR) at the nest bowl, with 85% confidence intervals shown in grey.
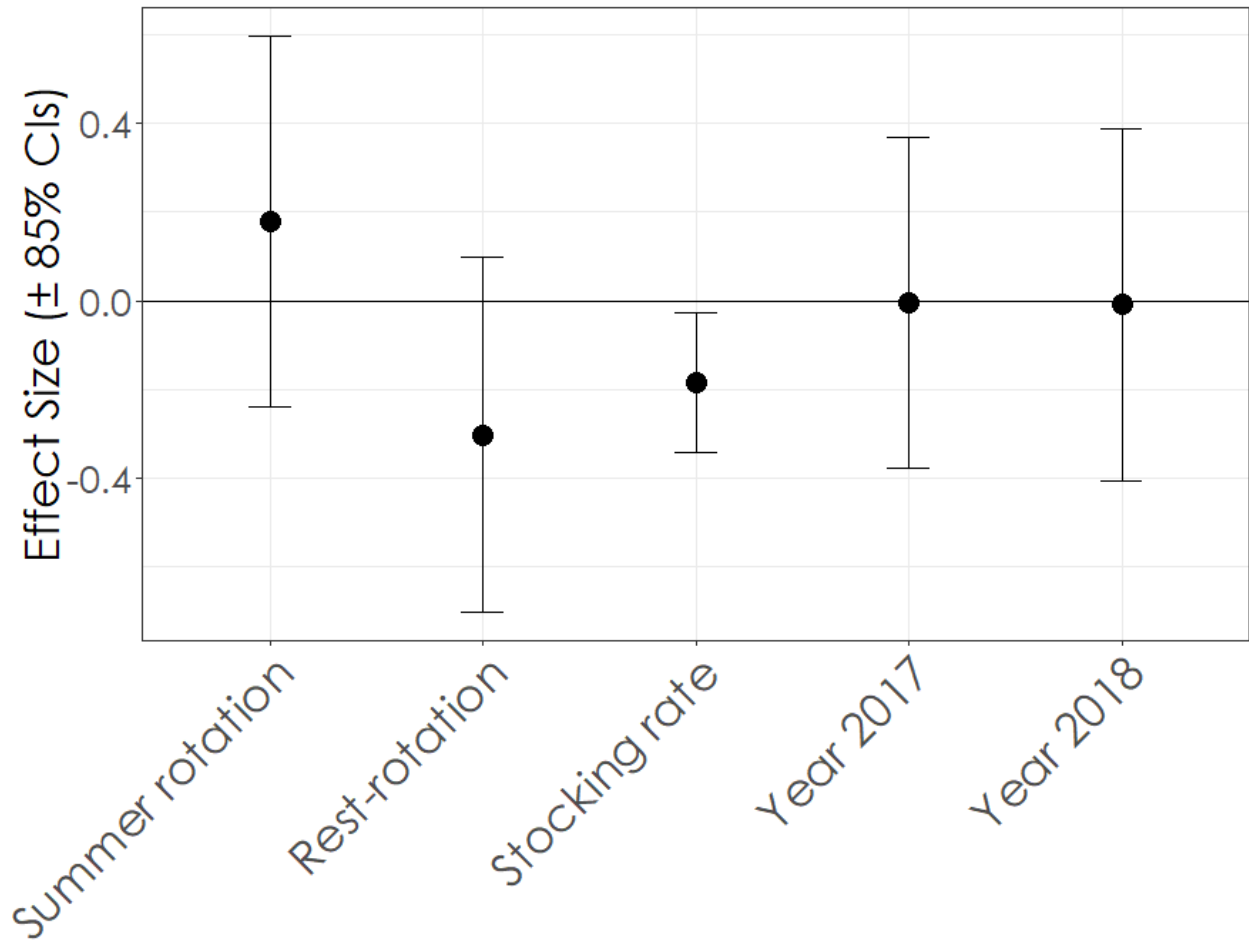
Figure 5. Scaled effect size ($\beta \pm 85\%$ confidence intervals) for each variable in the management-level analysis examining sharp-tailed grouse nest site selection in 2016–18.
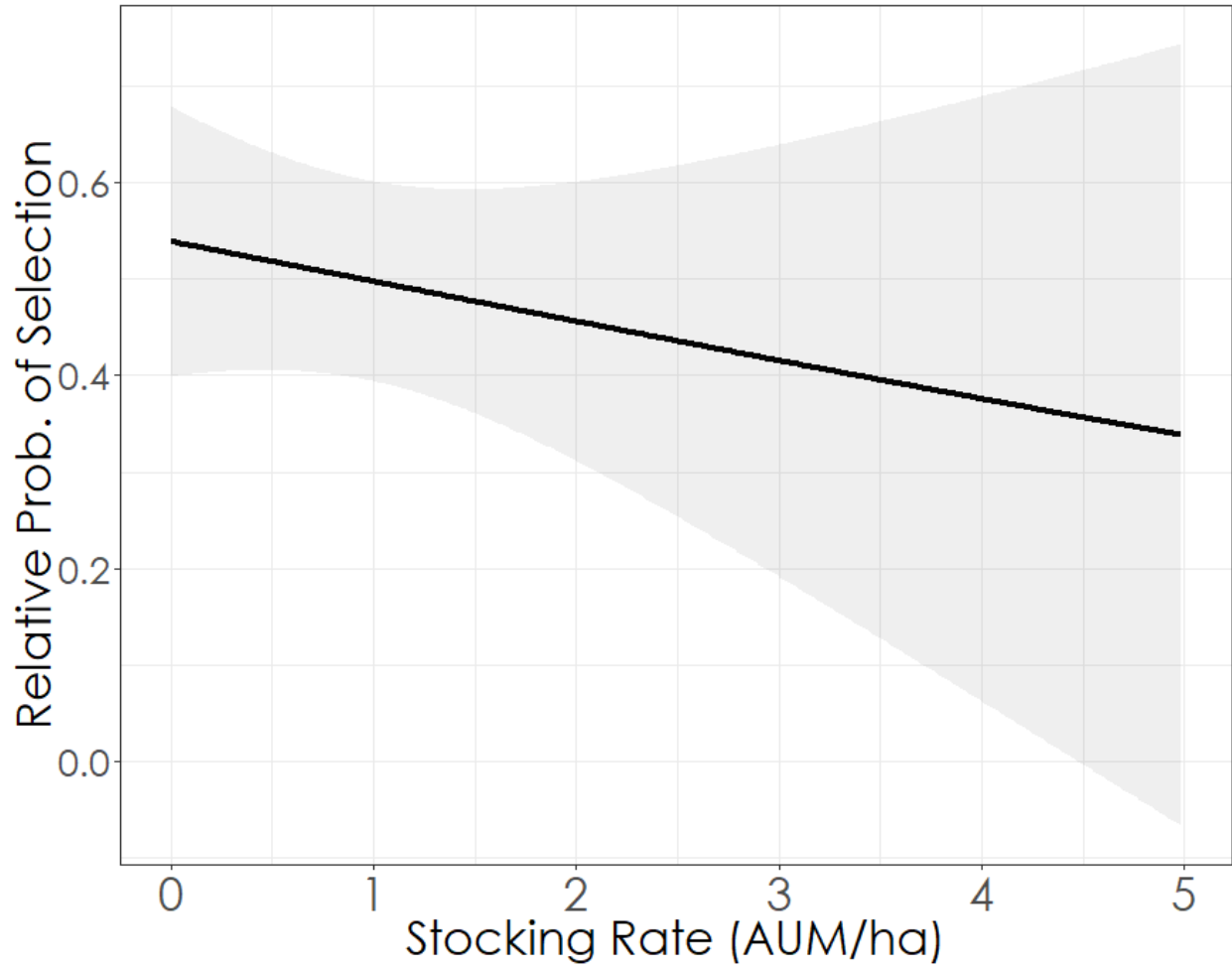
Figure 6. Estimated relative probability of nest site selection in relation to stocking rate, with 85% confidence intervals shown in grey.
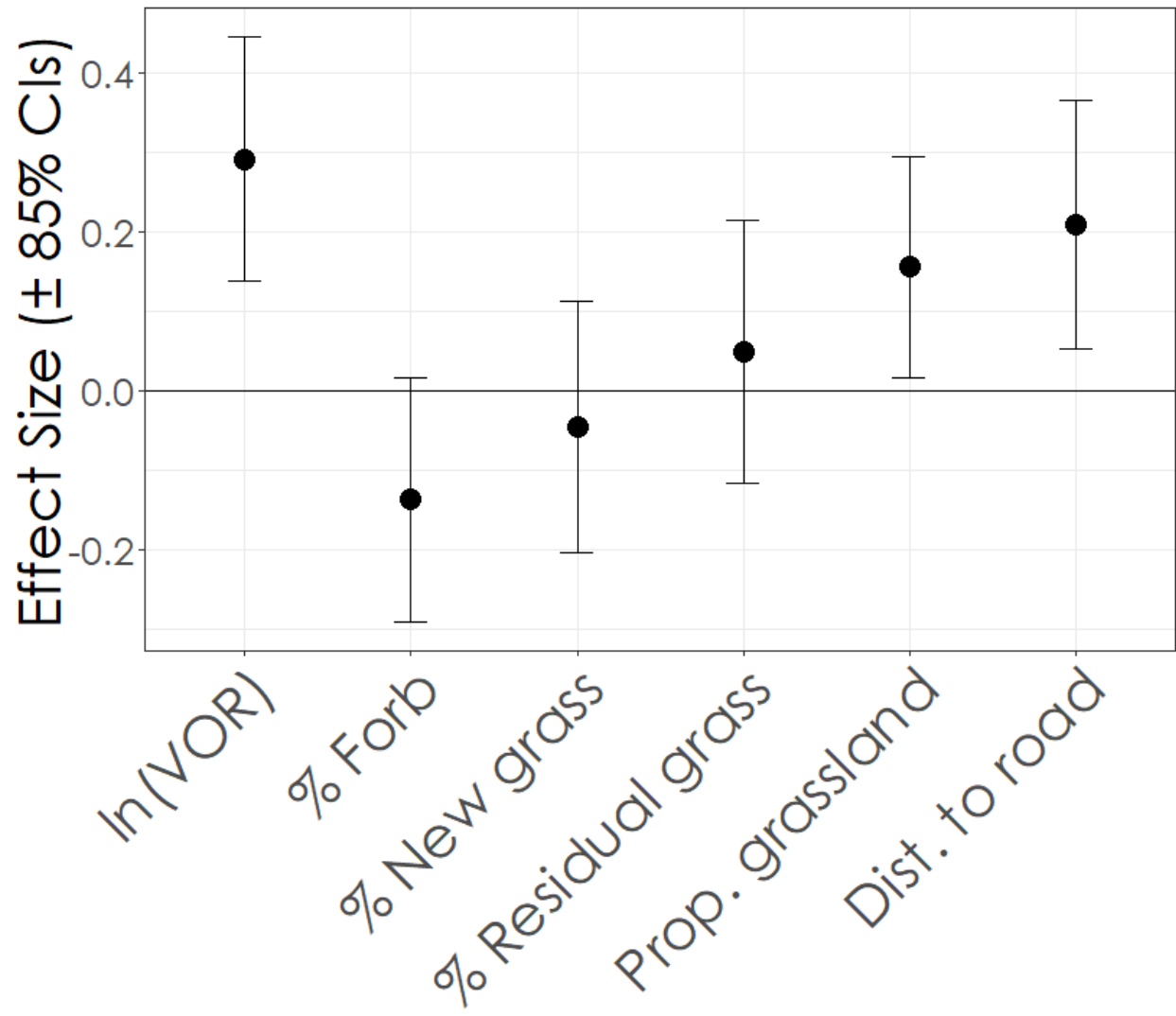
Figure 7. Scaled effect size ($\beta \pm 85\%$ confidence intervals) for each variable in the habitat-level analysis examining sharp-tailed grouse nest survival in 2016–18.
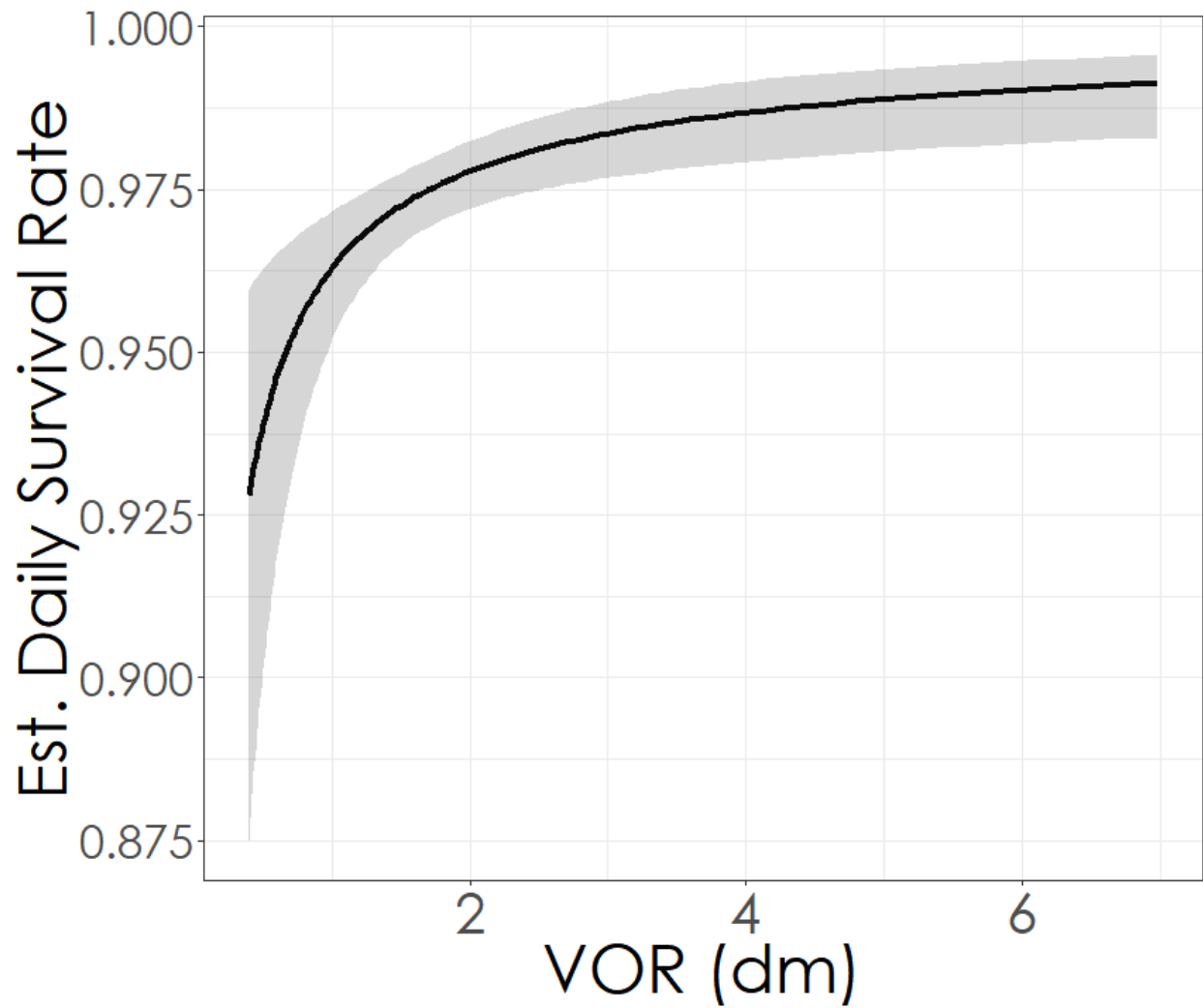
Figure 8. Estimated daily nest survival in relation to average visual obstruction (VOR) within 6 m of the nest bowl, with 85% confidence intervals shown in grey.
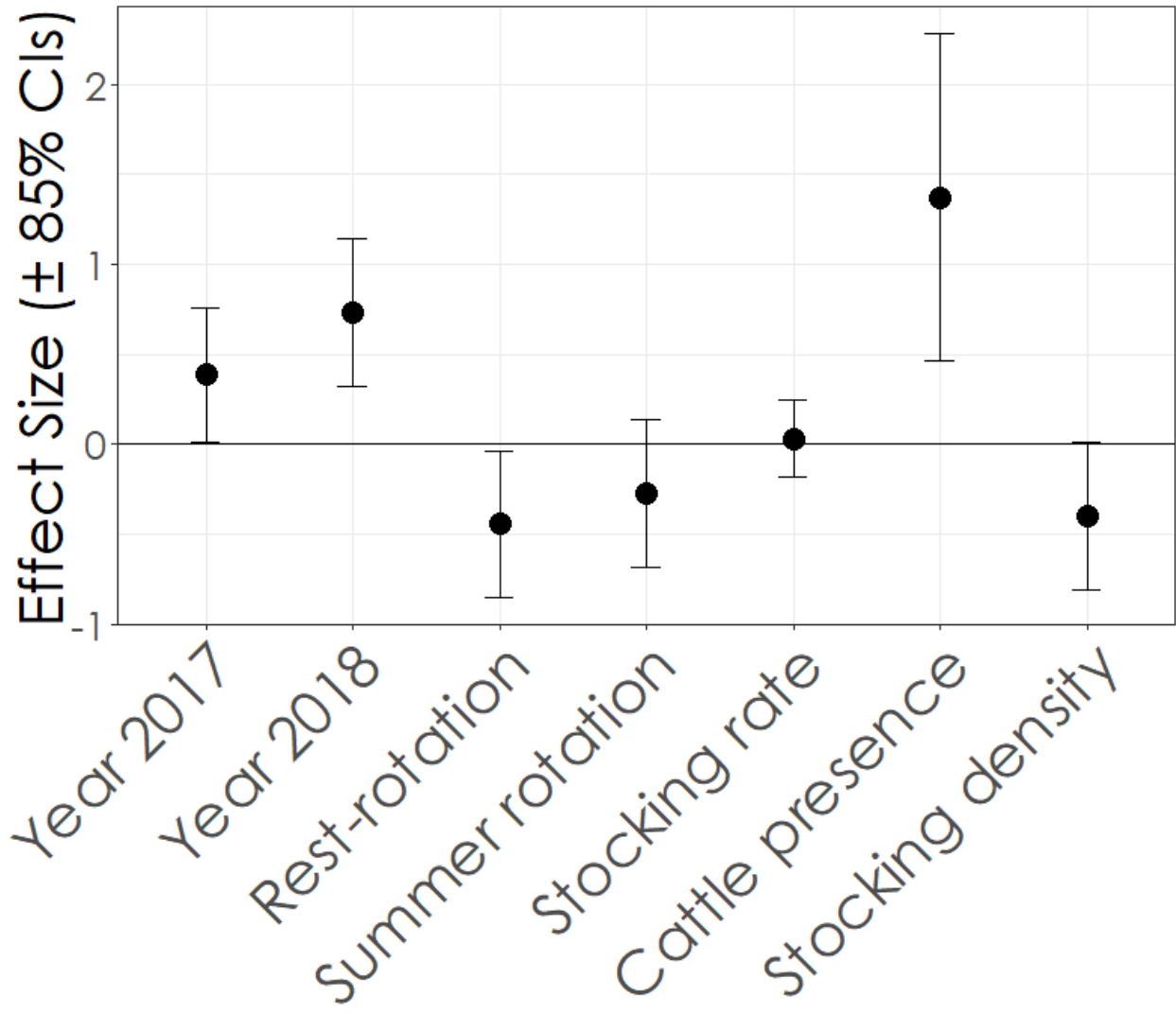
Figure 9. Scaled effect size ($\beta \pm 85\%$ confidence intervals) for each variable in the management-level analysis examining sharp-tailed grouse nest survival in 2016–18.
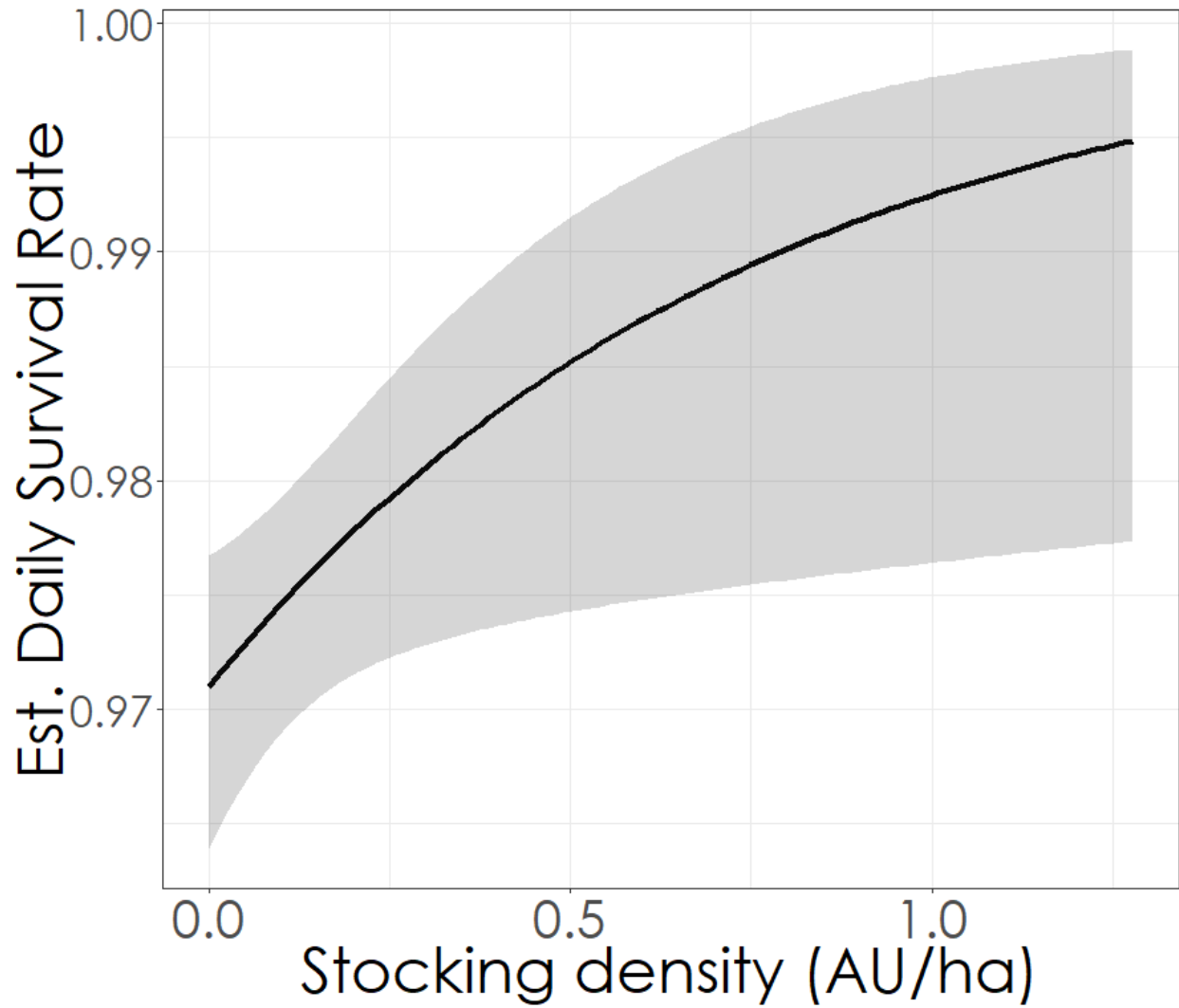
Figure 10. Estimated daily nest survival in relation to stocking density while the nest was active, with 85% confidence intervals shown in grey.
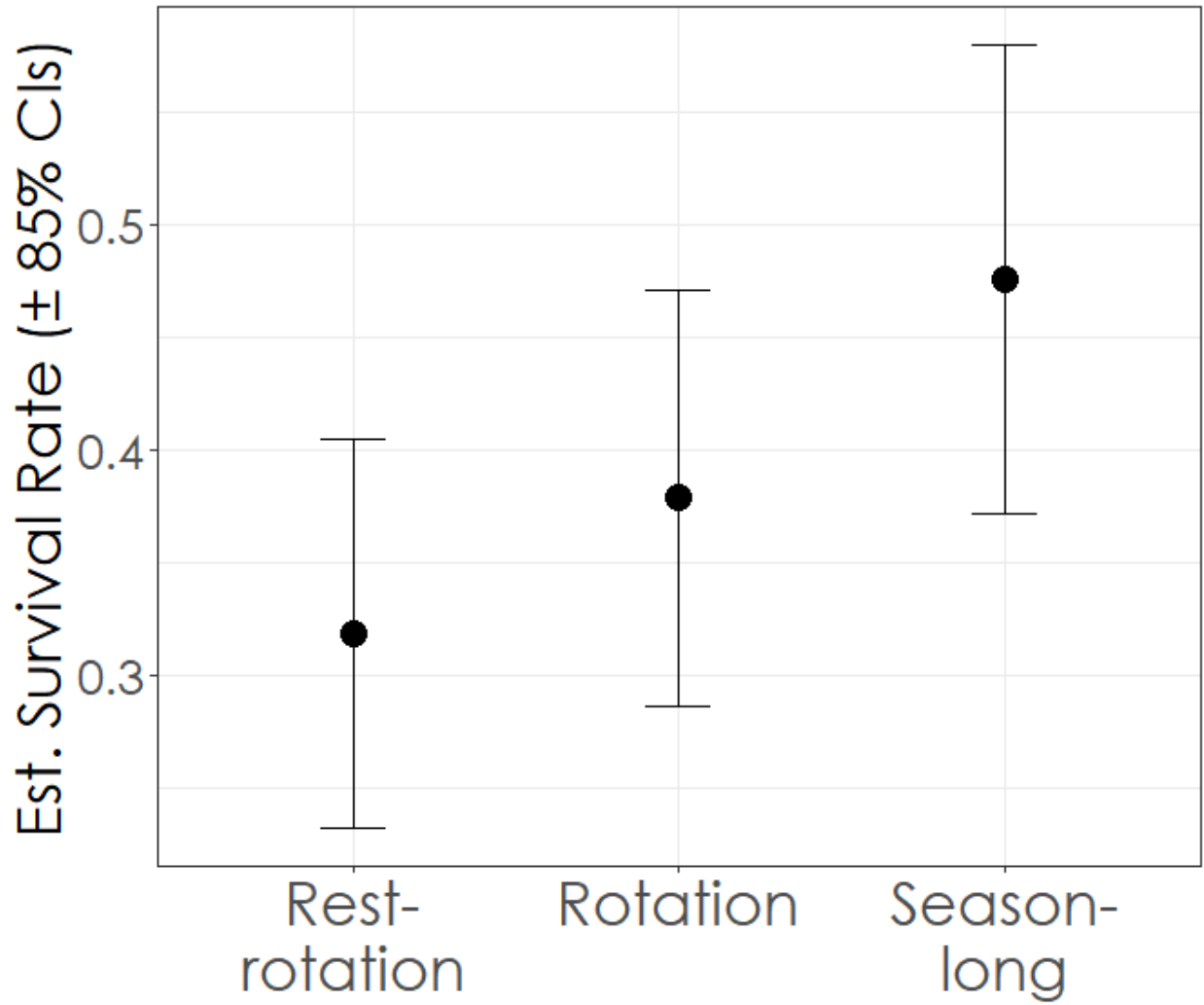
Figure 11. Estimated overall survival (± 85% confidence intervals) of sharp-tailed grouse nests in each of the three grazing treatments in 2016–18.
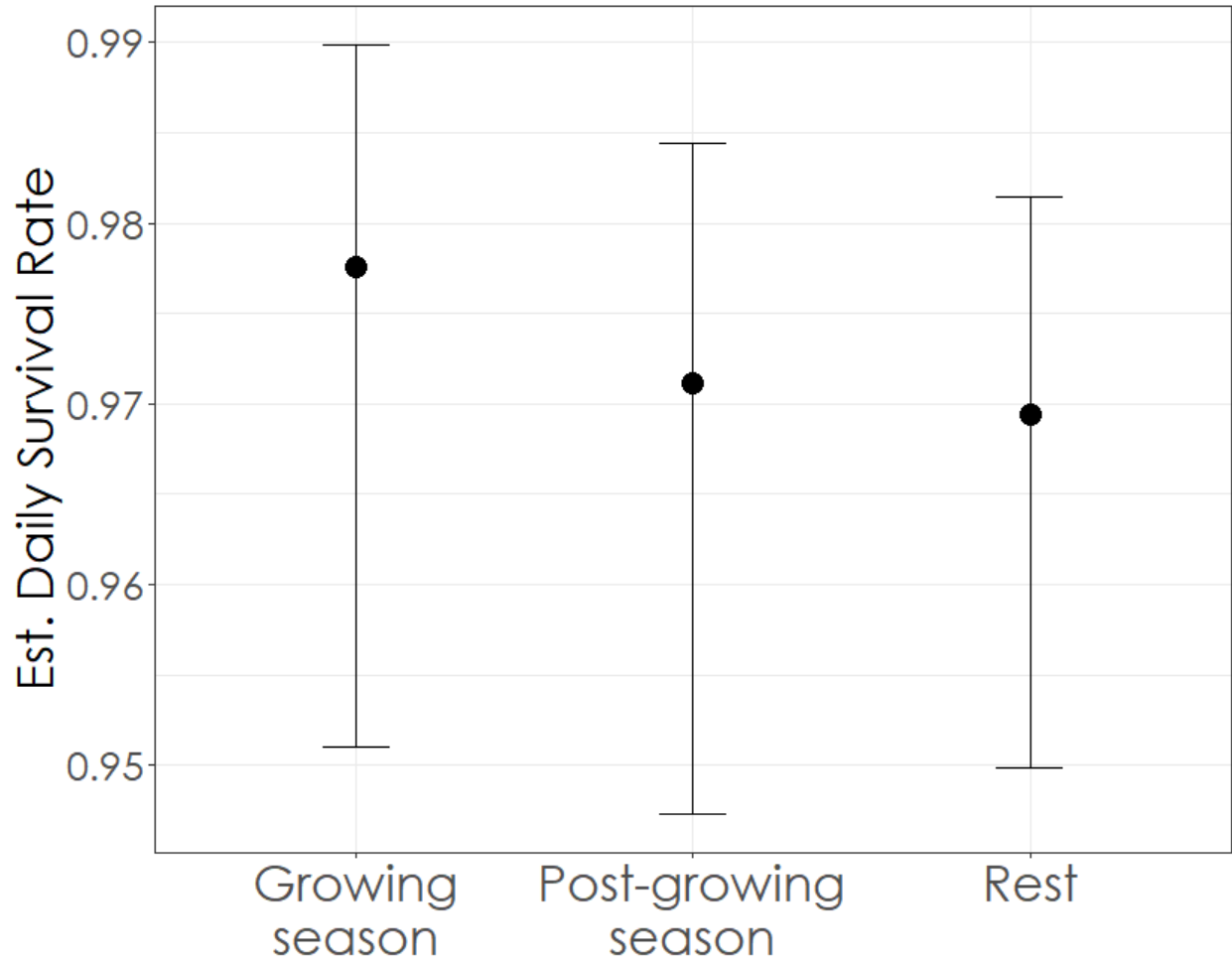
Figure 12. Estimated daily nest survival (± 85% confidence intervals) for sharp-tailed grouse in each of the three treatments within the rest-rotation system in 2016-18.
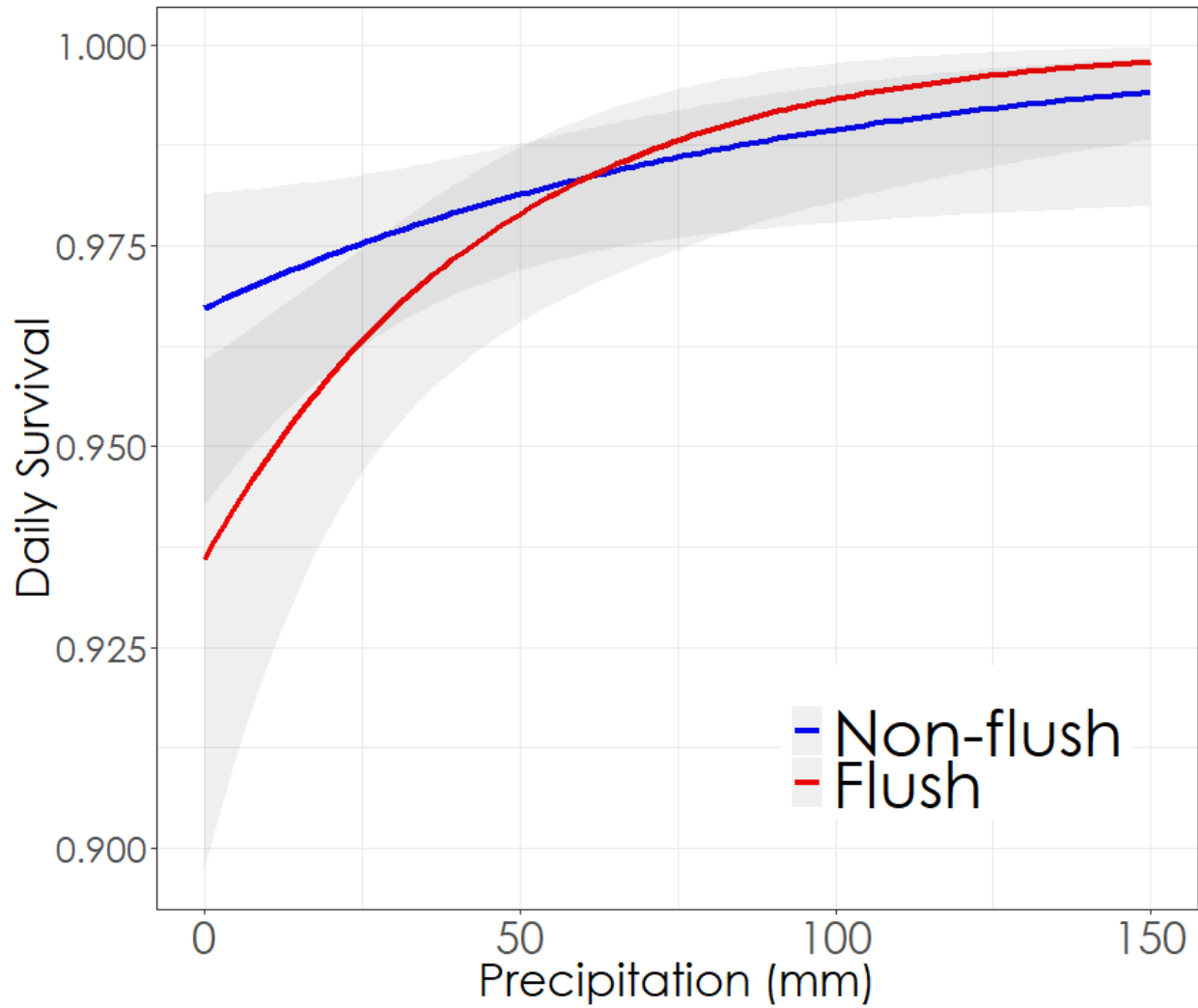
Figure 13. Estimated daily nest survival in relation to cumulative precipitation during the nesting period for birds that were flushed off the nest at least once compared to females that were never flushed off the nest, with 85% confidence intervals shown in grey.
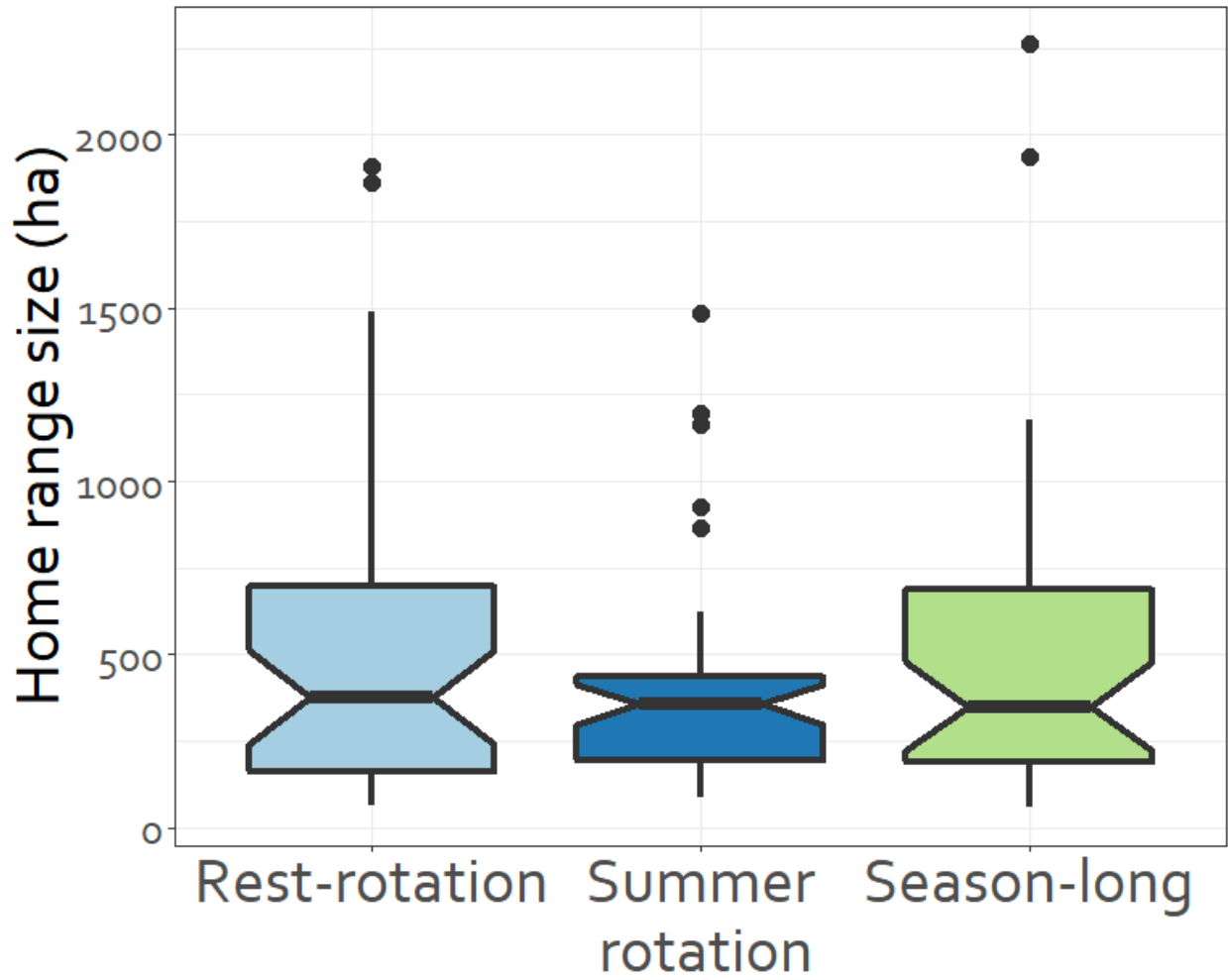
Figure 14. Female sharp-tailed grouse breeding season home range size (± SE) by grazing system. An individual female's home range was assigned to a grazing treatment according to the system at the home range centroid.
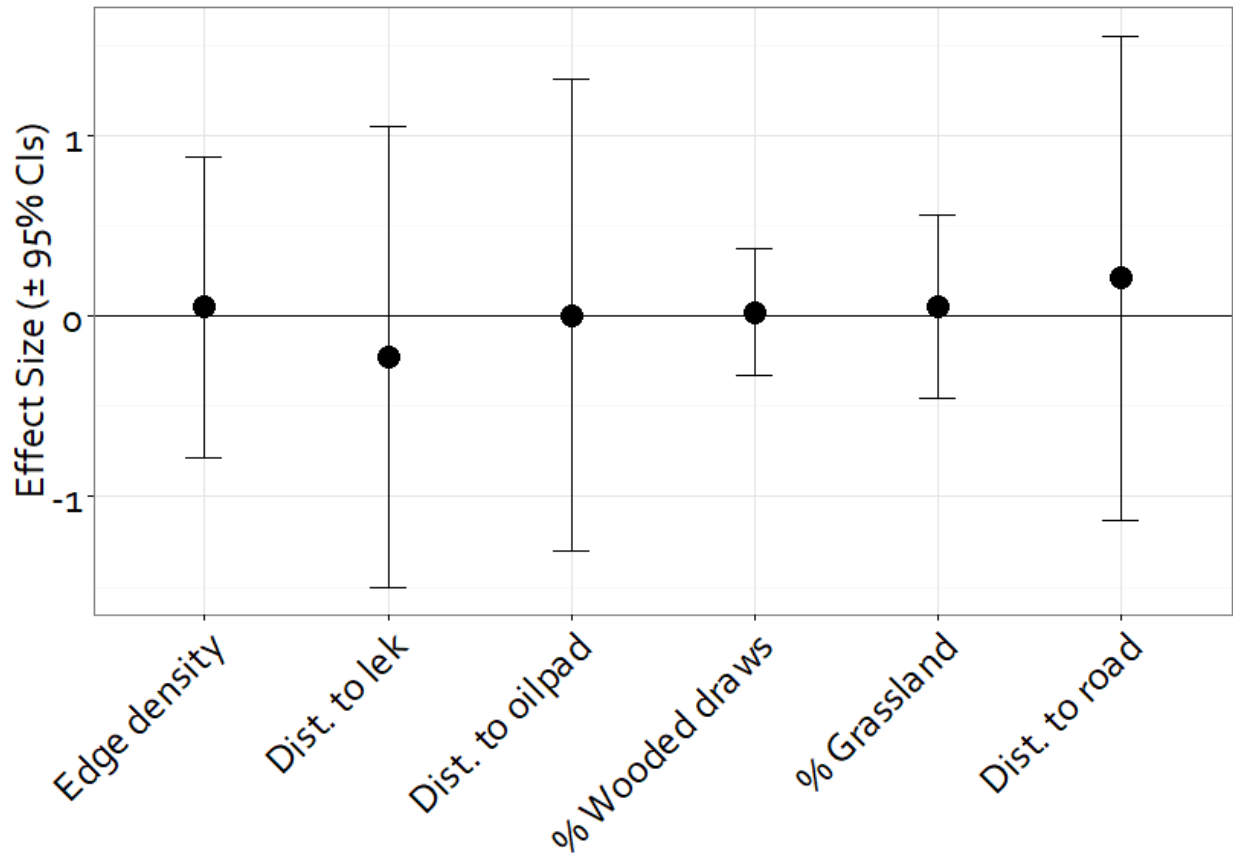
Figure 15. Standardized effect size ($\beta \pm 95\%$ confidence intervals) for each variable in the analysis examining sharp-tailed grouse space use within the home range in 2016–18. Parameters for each grazing system represent effect sizes in relation to the reference category of season-long grazing.
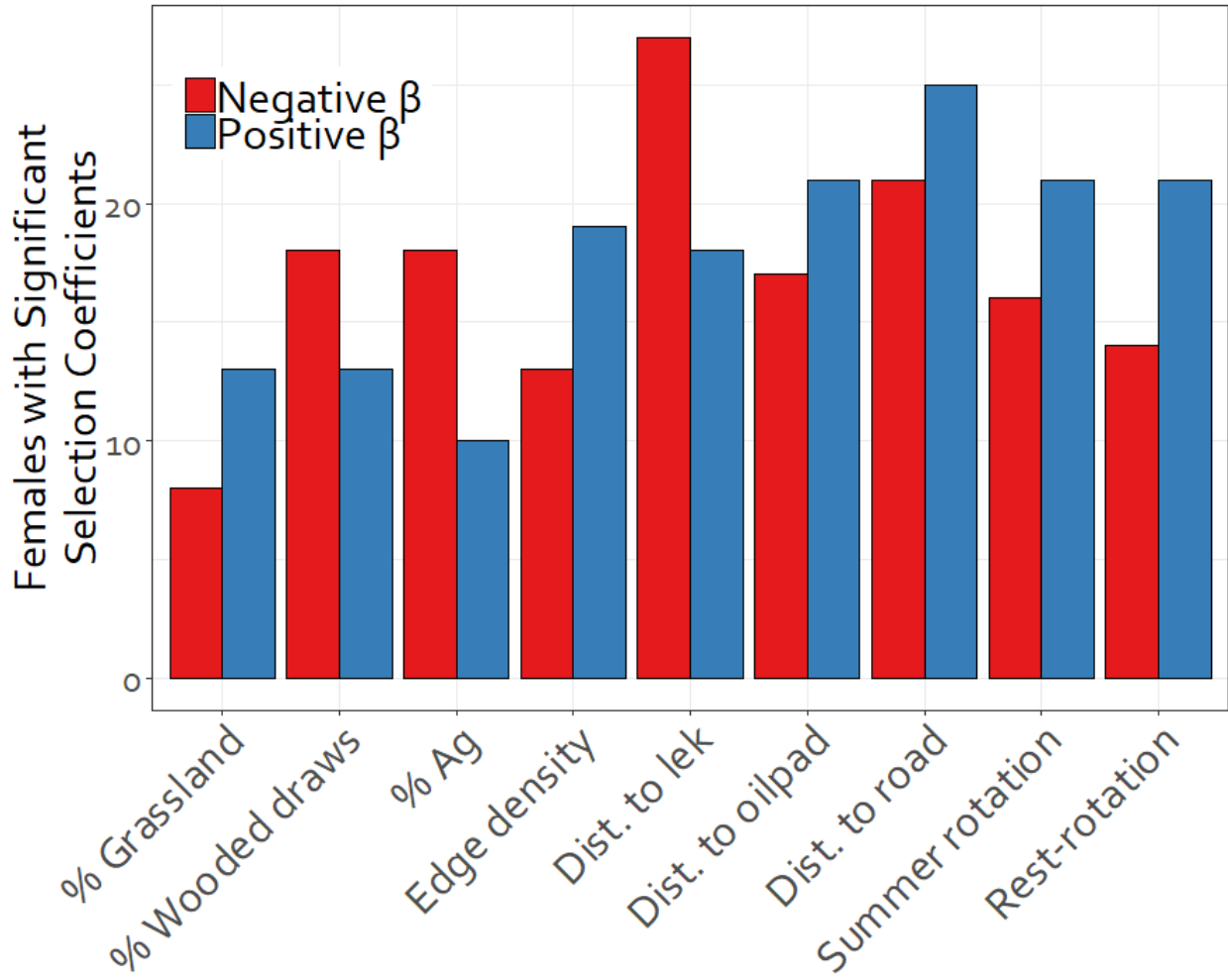
Figure 16. Number of female sharp-tailed grouse with significant positive (blue) or negative (red) selection coefficients for each of the variables examined using resource utilization functions to predict third-order habitat selection.