ECOLOGY OF GREATER SAGE-GROUSE IN THE UPPER BIG HOLE VALLEY, MONTANA 2018–2022

Final Report, December 2023

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EXECUTIVE SUMMARY

We used greater sage-grouse (GSG) movement and survival data generated from 38 GPS-marked hens (21 yearlings, 16 adults) from April 2018 – March 2022 to increase our understanding of GSG ecology within the Upper Big Hole Valley (UBHV), define seasonal habitat use within the UBHV and identify seasonal use outside the UBHV, identify migration corridors and stop-over locations, characterize the UBHV population's contribution to genetic connectivity across the wider GSG population in southwestern MT and Idaho, and characterize GSG nesting habitat in the UBHV. Of the 38 marked hens, 19 were on the air for ≥1 year. Hen ages at the time of mortality ranged from 1 to 5+ years. Most hen mortalities occurred during the spring breeding, nesting and early brood rearing periods. We estimated the probability of adult hens surviving one year post-capture was 0.58, the probability of surviving the first breeding/early brood rearing season post-capture to be 0.73, and the probability of surviving the first winter post-capture to be 0.95. Of 26 mortalities that were investigated, evidence suggested that 15 were caused by predation. No mortalities were hunter related.

We used movement data from marked hens to define seasons that represent biologically meaningful separations. We calculated the mean net displacement of all individuals from their point of capture over the entire calendar year, simultaneously considering all individuals over all calendar years, such that data from individuals across years were considered independent. We then determined seven consolidated changepoints in net displacement, i.e. breaks between periods of relative movement consistency, suggesting the following seasons and dates specific to the UBHV GSG population:

(1) 2/13–4/13 = spring staging & migration (~61 days)
(2) 4/14–7/05 = breeding/nesting/early brood rearing (~83 days)
(3) 7/05–10/29 = late brood rearing & fall staging (~117 days)
(4) 10/29–11/14 = fall migration (~17 days)
(5) 11/14–02/12 = winter [11/14–12/20 early winter & 12/20–02/12 late winter] (~91 days)

We used these seasonal dates for subsequent analyses in our study. By basing seasonal delineation on movement data from within the study area, we harnessed a more nuanced understanding of habitat use during each biologically significant season for the GSG year. To estimate seasonal utilization of the landscape, we calculated a cumulative utilization distribution (UD) for all individuals for each season then summarized seasonal use of both cover and land ownership underlying UDs. We found that across all seasons, sagebrush and herbaceous cover types were used most frequently (spring staging & migration 39% and 43%, nesting/early brood rearing 53% and 42%, late brood rearing & fall staging 52% and 44%, fall migration 52% and 46%, and winter 58% and 39%, respectively). Across all seasons, GSG in the UBHV used

private land 2–4 times as often as all public lands combined [DNRC, USFS, BLM] (spring staging & migration 67%, nesting/early brood rearing 80%, late brood rearing & fall staging 80%, fall migration 70%, and winter 71%). DNRC land was the public land used most often (nesting/early brood rearing 16%, late brood rearing & fall staging 17%, fall migration 27%, and winter 26%) except during spring staging & migration when USFS land was the public land that received the most use (19%).

We found 20–46.5% of marked GSG hens exhibited migratory patterns depending on season, with the greatest percentage of migration patterns occurring during the spring staging & migration and the late brood rearing & fall staging seasons.

We found that hens in the UBHV displayed strong lek fidelity and that female attendance on leks increased after mid-April. We found 95% of nests from marked GSG hens occurred within 7.75 km of known leks, the average distance between a hen's nest and the nearest lek was 3.51 km, and between a hen's nest and her lek of capture was 2.18 km. We did not find an age effect to these distances. We detected the start of incubation from April 29 through May 27 for first nest attempts and May 21 through June 12 for renest attempts. We did not detect either a year effect or an age effect on the start of incubation.

We found clutch size to average 7 eggs, but with variation by age and nesting attempt. We found the likelihood of nesting (1^{st} nest attempt) was 94%, with variation by age, and the likelihood of renesting when the first nest attempt failed was 28%, with no age variation. Nest success for the UBHV GSG population averaged 32% regardless of whether it was a 1^{st} or 2^{nd}attempt; however, we did find an age effect. Mammalian predators were the main cause of nest failure. We found annual reproductive success to be 31% in the first nest attempt and 37% when renest attempts were considered.

We found that hens whose nest failed in Year 1 moved further between consecutive nests the following year than hens who successfully nested in Year 1 and that greater distance between consecutive nests appeared to increase the likelihood of nesting success. We also found that the average distance between nests decreased with increasing number of years an individual hen nested, suggesting that fidelity to nest site increases as the number of years nesting increases. We found that within years, consecutive nests were closer together for adult than for yearling hens, suggesting an age-related period of establishment.

We characterized both nesting site and nest shrub characteristics for marked GSG hens in the UBHV. Nesting site vegetation was sampled using the 4^{th} Order Habitat Assessment Framework (HAF) protocol outlined by Stiver et. al. (2015). Our results suggest that nesting sites in the UBHV provide suitable habitat overall and that morphological features of nest shrubs align with other studies, accounting for regional land cover differences.

Lastly, we examined the genetics of the GSG population in the UBHV relative to within the study area and across SW Montana. The leks in the UBHV are part of the Southwestern-North subpopulation identified by Cross et al. (2017) and the greater Central Rockies subpopulation identified by Oyler-McCance et al. (2022). Per-locus and overall genetic diversity within the UBHV population compared to these greater subpopulations indicates genetic diversity has been maintained despite the UBHV's peripheral location relative to the overall species range and the consequent expectation of isolation. Within the UBHV we found fine-scale spatio-genetic structure reflective of the geographic proximity of leks, and indicative of lek philopatry and higher within-lek kinship.

The purpose of this study has always been to utilize knowledge gained from the birds to direct our conservation efforts on their behalf. Our results are directly relatable to local management actions and habitat characteristics in the UBHV. They can be and currently are being applied by both public and private land management and conservation agencies to inform conservation practices and projects across sagebrush-steppe habitat on a landscape scale. Ensuring key seasonal habitat remains intact for Greater sage-grouse will not only benefit the birds but all the other many wildlife species that use it as well.

BACKGROUND and STUDY AREA

Montana supports approximately 18 percent of the range-wide greater sage-grouse (GSG) population (Doherty et al. 2008). The largest populations are in northern Montana, the Yellowstone watershed, and southwestern (SW) Montana. There are three Montana Core Areas located in SW Montana along with dispersed general habitat (Figure 1). The Upper Big Hole Valley (UBHV) is north of the SW Montana core areas and located in general habitat. The primary threats to GSG in SW Montana are conifer expansion, sagebrush elimination, and improper livestock grazing (USFWS 2013).

The UBHV is 1,785,600 acres and includes a mix of valley bottom, sagebrush steppe and mountain forest ecotypes. Landownership includes private, federal (National Forest Service, Bureau of Land Management, National Park Service) and state lands (Department of Natural Resources and Conservation). Sagebrush habitat is primarily located on private and DNRC lands.

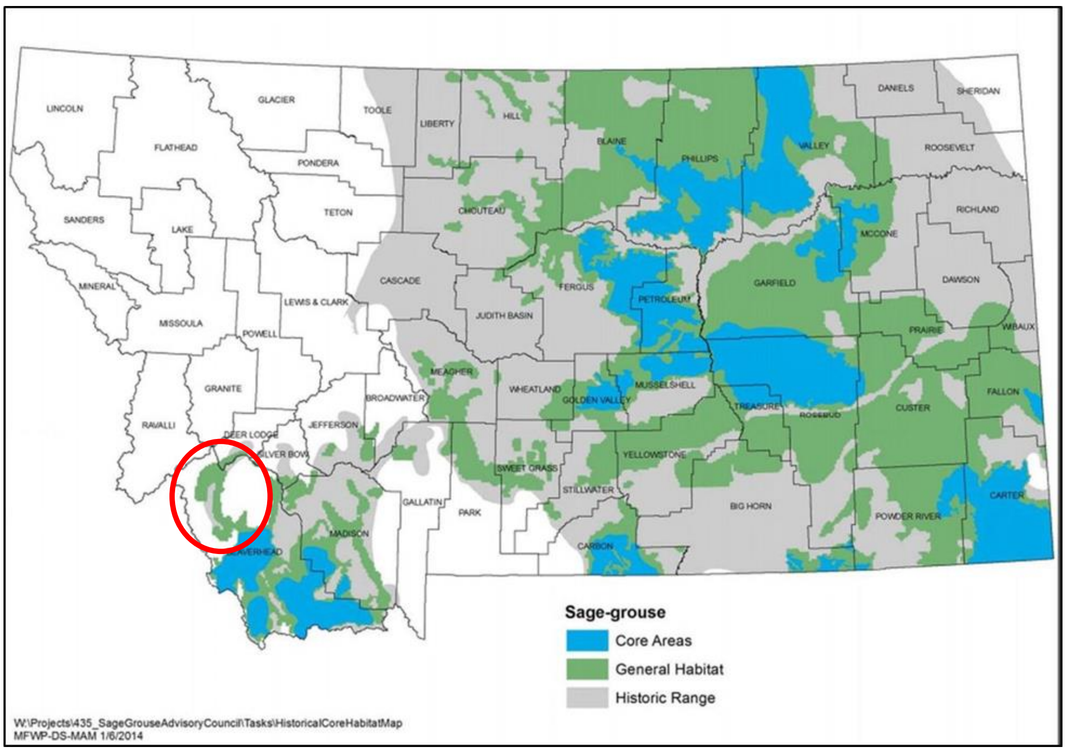

Figure 1. Montana Greater sage-grouse core areas (blue), general habitat (green) and historic range (gray). Southwest Montana has three core areas. The Upper Big Hole Valley GSG population, circled in red, is located in general habitat.

The UBHV supports a viable GSG population. Five leks have been monitored annually since the early 1990's. Survey efforts in 2016 and 2017 identified five additional leks, bringing the total number of known active leks in the UBHV to ten (Boccadori 2017, pers. comm.). The cumulative high count for males across these ten leks was at least 209 in 2017 (Figure 2).

There has been little information about seasonal habitat use and movements of GSG in the UBHV beyond the lekking season. To better manage and conserve GSG and sagebrush habitat across landownerships, managers and conservation partners need to better understand where, when and how GSG are using the area, the limiting factors and threats for this GSG population, and the importance and connectivity of this population to the broader population in southwestern Montana and Idaho.

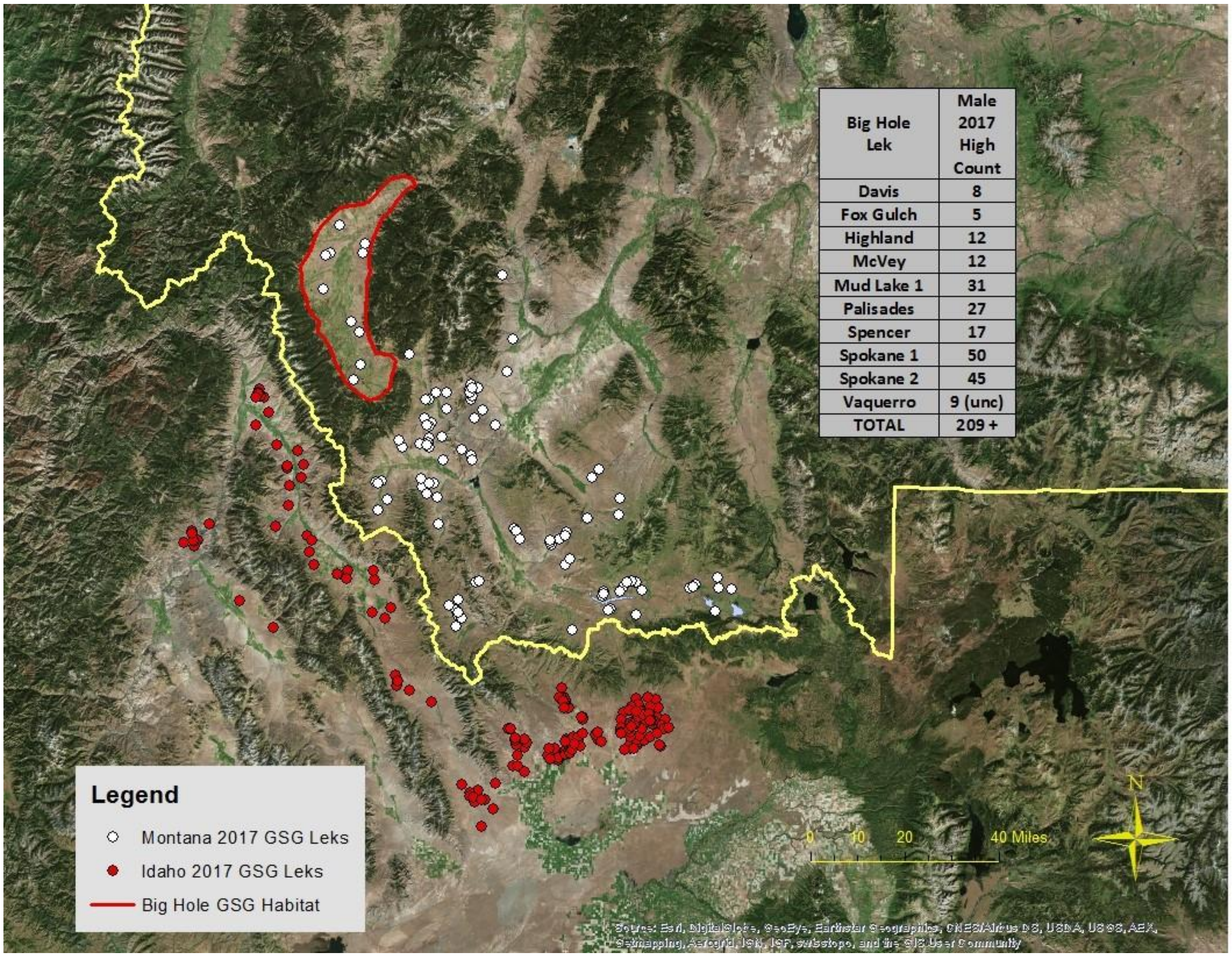

Figure 2. Upper Big Hole Valley greater sage-grouse habitat with current active leks and proximity to leks in southwest Montana and southeast Idaho. Table insert shows highest number of males counted at each Big Hole lek in April 2017.

Concern for the GSG and sagebrush-steppe habitat in the UBHV and a desire to be proactive led to the formation of the greater sage-grouse workgroup of the Big Hole Watershed Committee. Members of this collaborative group include Montana Department of Fish, Wildlife & Parks (FWP), USFWS Partners for Fish and Wildlife Program (USFWS), Bureau of Land Management (BLM), Beaverhead-Deerlodge National Forest (USFS), Montana Department of Natural Resources and Conservation (DNRC), The Nature Conservancy (TNC), Vigilante Electric Cooperative, and several area ranchers. The workgroup was supported by the Beaverhead County Commissioners. The workgroup mission was to develop a proactive GSG and sagebrush conservation approach compatible with and sustained by a working landscape. The workgroup sought to develop a conservation strategy that would address GSG threats by conserving and enhancing habitats across landownership boundaries while promoting sustainable economies and ranching lifestyles. While this study has specified GSG life-history knowledge gaps in the UBHV, it is understood that the larger goal is to conserve and enhance the sagebrush-steppe habitat that is equally important for a broad host of wildlife species, ranching, recreation and aesthetics.

Results from this study have already helped to define land management actions in the UBHV and across SW Montana. In 2018, a Montana statewide GSG Candidate Conservation Agreement with Assurances was released that assists private landowners with conservation of GSG and their habitat on their properties. The NRCS Sage Grouse Initiative has taken a proactive approach to conserve sagebrush habitat with landowners in SW Montana since 2012. In addition, the SW MT Sagebrush Partnership made up of state and federal agencies, conservation and watershed groups has been formed to implement sagebrush conservation projects across landowner boundaries in SW Montana. The Beaverhead-Deerlodge NF has initiated a landscape-level habitat project in the UBHV that aims to improve sagebrush, riparian, and forested habitats across 20,000 acres. Knowledge about GSG habitat use in the UBHV will help guide these efforts and make them more effective at meeting their objectives of GSG and sagebrush habitat conservation.

PROJECT OBJECTIVES

1. Characterization of Greater sage-grouse ecology in the UBHV.
2. Definition of Greater sage-grouse seasonal habitat use in the UBHV and identification of seasonal use outside the UBHV.
3. Identification of potential migration corridors and stop-over locations between the UBHV and the surrounding area in southwestern Montana and Idaho.
4. Characterization of the UBHV population contribution to genetic connectivity across the wider Greater sage-grouse population in southwestern Montana and Idaho.
5. Characterization of Greater sage-grouse nesting site habitats in the UBHV.

CAPTURE

We used spotlights, all-terrain vehicles (ATVs), and large rubber mesh nets to capture GSG hens on or near leks in April. Captures occurred at night while birds were roosting. In 2018 we captured on Spokane 1, Spokane 2 and Mud Lake leks. In 2019–2021 we expanded our captures to include Spencer, Highlands and Palisades leks in addition to the ones we captured on in 2018. The main capture crew consisted of Jim Magee (USFWS), Adam Braddock (USFWS) and Vanna Boccadori (FWP) with help from Kyle Cutting and his crew (USFWS), James Wax and Ericka Nunlist, and several volunteers.

Captured hens were fitted with a 22g solar Argos/GPS PTT-100 satellite transmitter (PTT) from Microwave Telemetry, Inc. using Teflon tape harnesses. Each hen was weighed, aged as yearling or adult using primary wing feathers, and had 3–5 feathers collected for genetic sampling.

Thirty-eight hens were captured (15 in 2018, 15 in 2019, 2 in 2020, 6 in 2021; Figure 3). Captures occurred between April 15–May 1. Twenty-one total hens were captured on the Spokane 1 and Spokane 2 leks, 7 hens were captured on the Mud Lake lek, 8 hens on the Spencer lek and 1 hen each on the Highlands lek and Palisades lek (Figure 3). Hens were aged as 22 yearlings and 16 adults. The average weight for yearling and adult hens was 139.3g and 149.5g, respectively. Feathers were collected from all 38 hens to be used for genetic sampling.

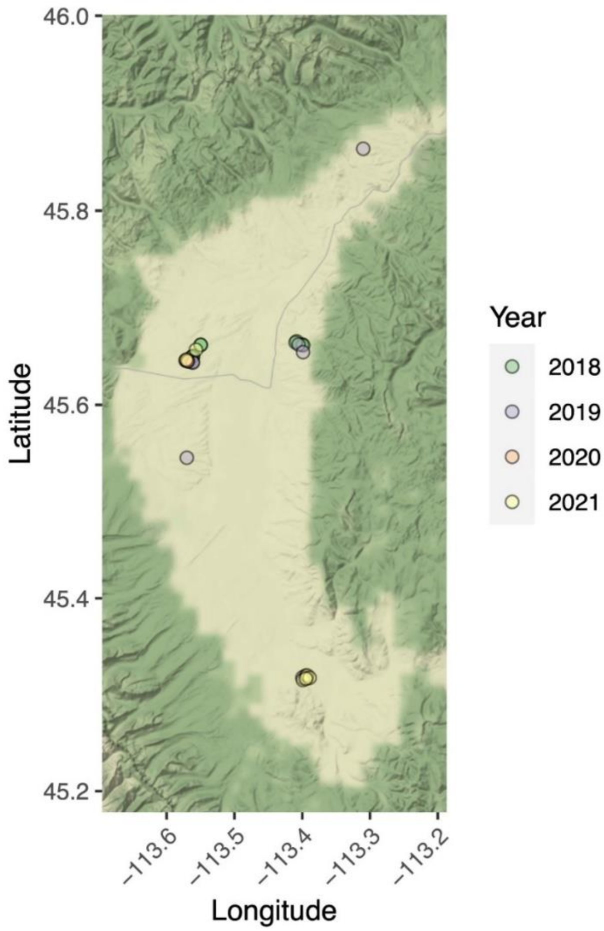

Figure 3. Map of greater sage-grouse capture locations 2018–2022, color coded by year.

HEN SURVIVAL and MORTALITY

Marked GSG hens were monitored regularly by downloading GPS locations every 4–7 days post capture and during nesting period, then every 20 days after that. PTTs were programmed to fix a GPS location six times during every 24-hour period annually and transmit to the Argos satellite every two days during the breeding and nesting period (March 2–Aug 15). After this period, from August 16 – March 1, the PTTs were programmed to transmit location data to the satellite every five days until the start of the next breeding season. The shorter transmission period during breeding, nesting and brood-rearing allowed us to monitor hen- and nest fate at a finer scale during the time when birds are most vulnerable while the longer transmission period for the remainder of the year reduced project costs (charges are incurred for each transmission) yet still allowed us to monitor hen fates and movement. Because we opted not to have ground-tracking components added to PTT units due to the extra weight and antenna that comes with adding a VHF component, we used the most recent location data to ground-locate marked birds. Some studies have shown a possible correlation between hen mortality and PTTs fitted with VHF components (Severson et al, 2019).

Of the 38 hens that were marked between 2018–2022, there were 29 mortalities, one PTT failure, two slipped PTTs, and six hens that were still alive at the end of this reporting period (March 31, 2022). Half of the marked birds were on the air less than one year before mortality occurred (Figure 4). There were three hens that have been on the air for three or more years.

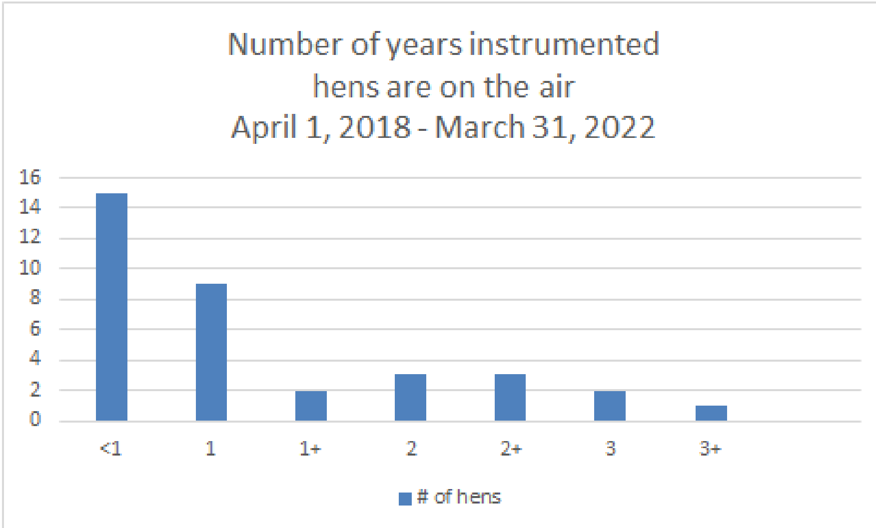

Figure 4. Number of years that marked GSG hens remained on-air during the study, 2018–2022. Hens that were still alive and on-air at the end of this reporting period are represented in the "year +" categories.

Hen ages at the time of mortality ranged from 1 to 5+ years across the 29 mortalities (Figure 5). Age at mortality was calculated from age at time of capture, capture date, and mortality date, rounded to the nearest half year. For yearlings, birth date was assumed to be June of the year prior to capture. For adults, birth date was assumed to be at least June two years prior to capture. For example, if a yearling bird was captured in April 2018 then died in December 2019, it was estimated to be 2.5 years old at the time of mortality (assumed birth date June 2017). If an adult bird was captured in April 2018 then died in December 2019, it was estimated to be 3.5+ years old (assumed *minimum* birth date June 2016).

Of the six marked hens still alive at the end of the reporting period, one was 3 years old, two were 3+ years old, two were 4 years old and one was 5+ years old.

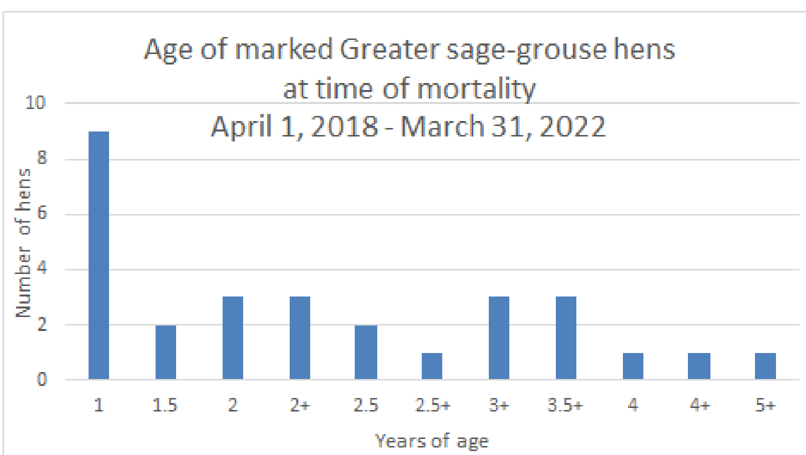

Figure 5. Age of GSG hens at time of mortality or at the end of the study if still alive, based on age at capture.

Timing of marked hen mortality suggests that hens are most vulnerable during the spring mating, nesting, and early brood rearing period April through June, regardless of year (Figure 6). A study of wild turkeys (*Maleagris gallopavo)* in the Black Hills, South Dakota found that increased time spent incubating was associated with reduced female survival (Yarnall et al. 2020). Additionally, they found that daily precipitation was associated with reduced survival of incubating females. Hens appear to be less vulnerable during the late brood rearing & fall staging time frame that includes the sage-grouse hunting season (September 1–30) and during the winter months (December through March) and least vulnerable during mid-summer when food resources both for them and their predators are abundant (Figure 7). Of the mortalities that occurred during this reporting period, 64% (*n*=18) occurred during the spring mating, nesting and early brood rearing period; 14% (*n*=4) occurred during the September sage-grouse hunting season (Sept 1–30); and 22% (*n*=6) occurred during the winter. None of the September mortalities were hunter-harvest. This pattern of GSG mortality is consistent with findings from other studies (Connelly et al. 2000a, Wik 2002, Hausleitner 2003).

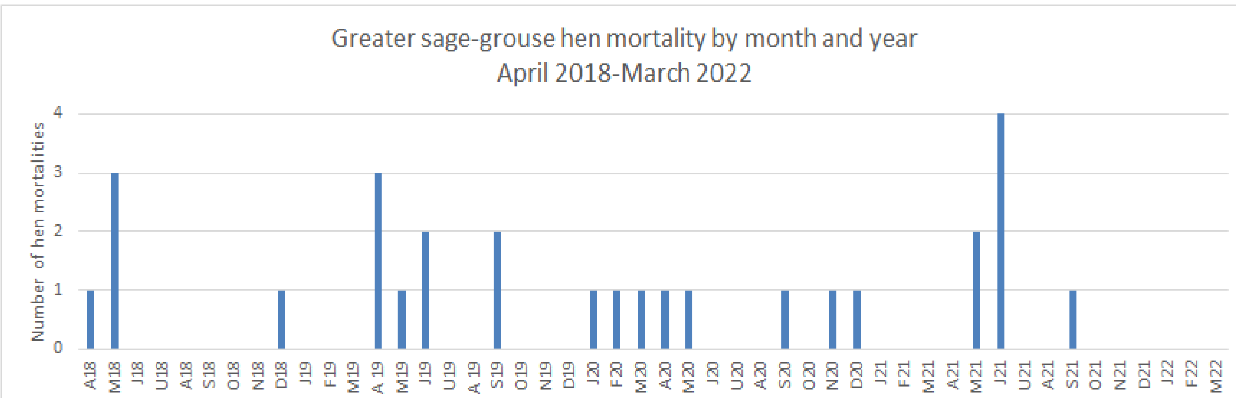

Figure 6. Month and year in which marked GSG hen mortalities occurred, 2018–2022.

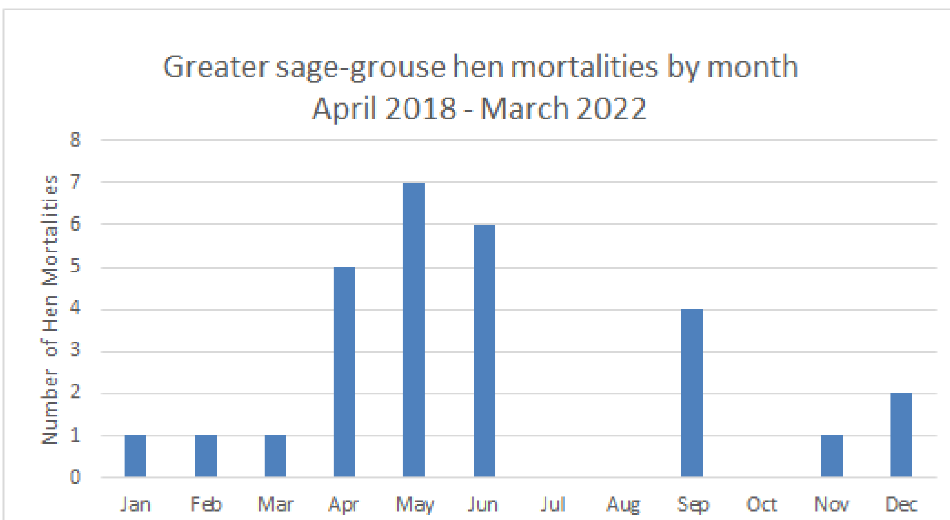

Figure 7. Month in which marked GSG hen mortalities occurred, pooled across years.

We used the Kaplan-Meier method for known fates (Cooch and White 2021) to estimate survival at different time intervals for adult female Greater sage-grouse in the UBHV. The probability of surviving year one post-capture, independent of year, was 0.58 (*n* = 33). Other studies estimated annual female survival rates to be 0.48–0.78 in Wyoming (June 1963, Halloran 1999, 2005), 0.48–

0.75 in Idaho (Connelly et al. 1994, Wik 2002), 0.57 in Alberta (Aldridge and Brigham 2001), 0.61 in Colorado (Hausleitner 2003), 0.37 in Utah (Brunnel 2000) and 0.42–0.82 in central Montana (Berkeley et al. 2020).

The probability of surviving the first breeding/early brood rearing season post-capture, independent of year, for adult female birds in the study area was 0.73 (n = 33). In contrast, the probability of surviving the first winter post-capture, independent of year, was 0.95 (n = 21). Winter survival rates from other studies ranged from 0.82 to 1.00 (Hausleitner 2003) in Colorado and from 0.85 to 1.00 in southwestern Idaho (Wik 2002). All estimates from other studies except June (1963) were based on known-fate analyses from telemetry data.

When possible, we conducted field investigations of each mortality by going to the last GPS location for that hen to determine cause of death and retrieve the PTT. Of the 26 mortalities that we were able to investigate, evidence suggested that 1 mortality was capture related, 2 mortalities were caused by avian predators, 2 were caused by mammalian predators, 11 were caused by predation but the type of predator could not be determined, and the cause of mortality for 10 hens could not be determined. No mortalities appeared to be hunter related. Likely predators of Greater sage-grouse in the UBHV study area include red fox *(Vulpes vulpes),* coyote *(Canis latrans),* American badger *(Taxidea taxus)*, bobcat (*Lynx rufus)* and a variety of raptor species. Other causes of mortality for sage-grouse include collisions with vehicle, fences, and powerlines; and hunter harvest although none of those were found to be the cause in this study.

MOVEMENTS and SEASONAL USE

Seasonal Movement

We monitored GSG hen movement via GPS data downloaded from Argos satellites every 2–20 days. PTTs were programmed to fix locations and transmit to Argos satellites at times and cycles that accounted for daily and seasonal behavior of the birds while also being economical with the project budget and life expectancy of the PTT battery (Table 1).

Table 1. 2019–2022 schedule for GPS fixes and transmission to Argos satellites for PTTs put on GSG hens in the Upper Big Hole Valley study. The 2018 schedule was similar but offset by a few hours and days for each category. Adjustments were made after that first year to better address project objectives.

Annual Start Date	**Annual End Date**	**GPS Receiver Fix (local military time)**	**Duty Cycle (uploads data every "x" days)**
03/02	05/31	06, 10, 13, 16, 19, 22	2
06/01	08/15	05, 08, 12, 16, 19, 23	2
08/16	10/31	00, 05, 09, 12, 15, 19	5
11/01	03/01	00, 06, 09, 12, 15, 18	5

We used movement data from marked hens to define seasons that represent biologically meaningful separations. We calculated the mean net displacement of all individuals from their point of capture over the entire calendar year, simultaneously considering all individuals over all calendar years, such that individuals on air in more than one year were considered independent. To calculate the changepoints in net displacement we used the cpt.mean function in the "*changepoint"* package in R. This function calculates the optimal positioning of changepoints for data. We constrained the number of changepoints to range from 4–7, setting a manual penalty value of 2*log(n) and used the binary segmentation method (Scott et al. 1974). To eliminate the arbitrary breakpoint in the data corresponding to the start and end of a calendar year, we set the start date of the "grouse year" to be the first changepoint detected after January 1st. After we adjusted to this new start date, we re-ran the analysis to determine the remaining changepoints, unaffected by the non-biological start/end date of the calendar year and determined that seven changepoints best fit the data, i.e. breaks between periods of relative movement consistency (Figure 8). While the timing of these periods of relative movements were stable across years, the magnitude varied somewhat between years (Figure 9). Given the ecology and behavior of greater sage-grouse, we expected to see minimal collective movement during winter, larger pulses of movements during spring and fall migrations, and moderate movements during summer, especially of females that successfully hatched nests and were assumed to have broods.

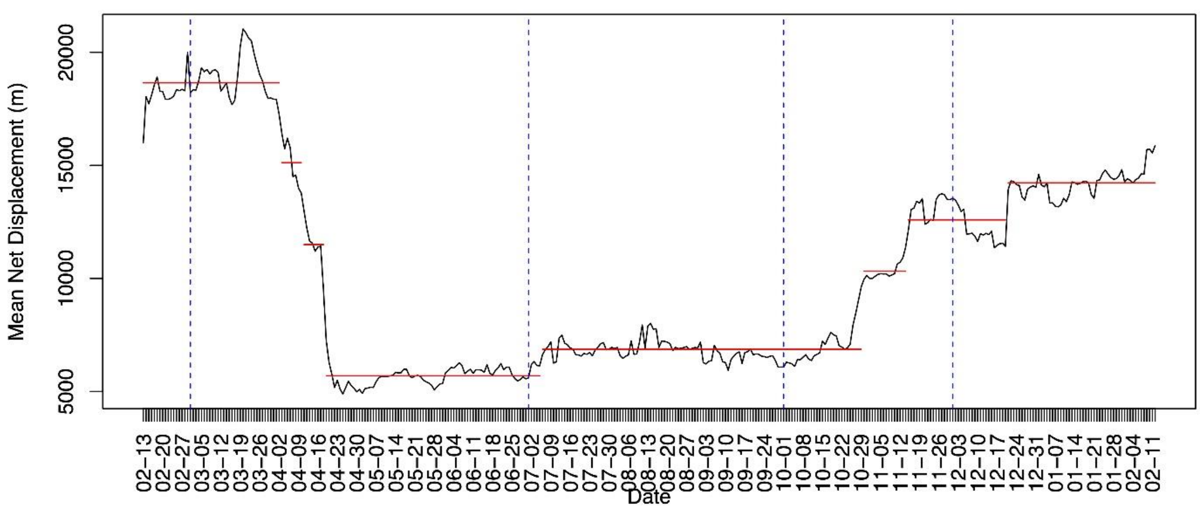

Figure 8. Mean net displacement (m) of all daily movements for all GPS-marked GSG hens, over the duration of this study 2018-2022, collapsed into one year and plotted by calendar date. Horizontal bars represent the periods between changepoints detected using the "changepoint" R package. Vertical dotted lines indicate the seasonal breakpoints posited by Connelly et al.

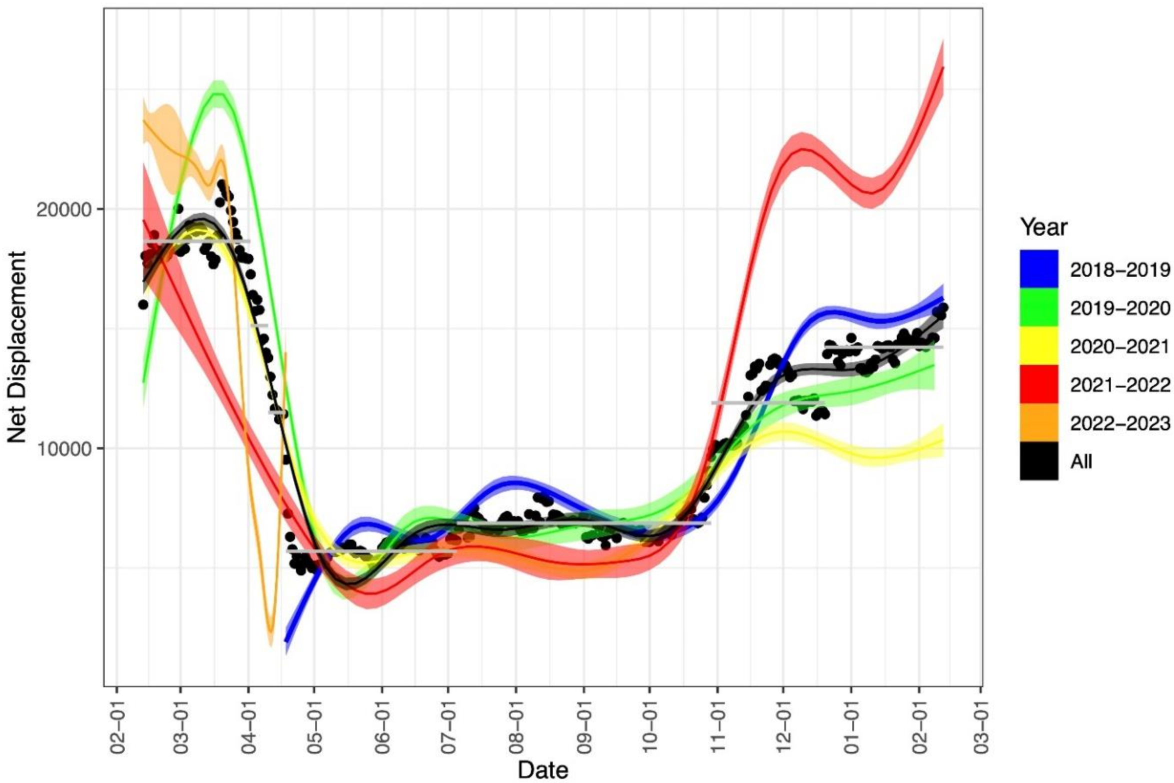

Figure 9. Mean individual-based net displacement between daily movements for all GPS-marked GSG hens 2018–2023. Net displacement is measured as meters from capture. Individual years models are shown as colored lines/ribbons, while all years are shown in black. Points indicate the mean daily net displacement across all years (similar to the line in Figure 8). Season dates suggested by hen movement are denoted by horizontal gray bars.

Results of this movement analyses suggested five biologically significant seasons for greater sage-grouse in the UBHV (Figure 10):

(1) 2/13–4/13 = spring staging & migration (~61 days)
(2) 4/14–7/05 = breeding/nesting/early brood rearing (~83 days)
(3) 7/05–10/29 = late brood rearing & fall staging (~117 days)
(4) 10/29–11/14 = fall migration (~17 days)
(5) 11/14–02/12 = winter [11/14–12/20 early winter & 12/20–02/12 late winter] (~91 days)

We used these seasonal dates for subsequent analyses in our study.

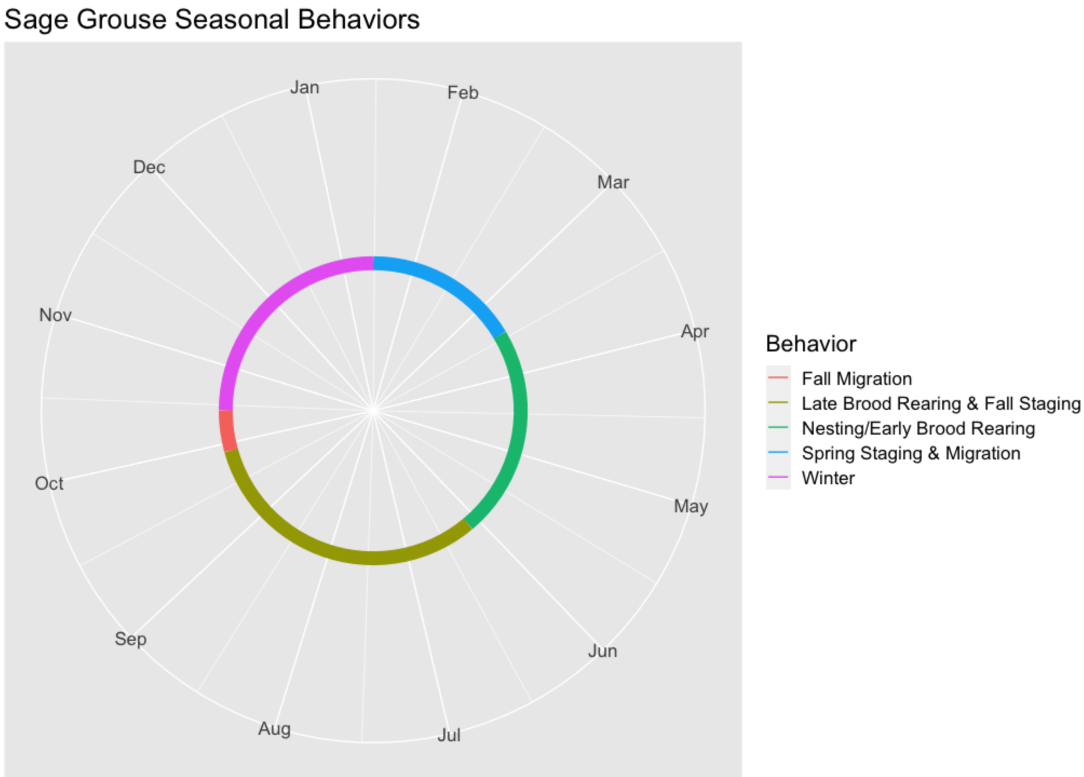

Figure 10. Calendar of primary seasonal behaviors of Greater sage-grouse in the Upper Big Hole Valley, based on hen movement data, 2018-2023.

Other studies (e.g., Connelly et al. 2000b, Schroeder et al. 1999) typically have used conventional seasons/dates:

(1) March 1–June 30 = breeding/nesting/early brood-rearing
(2) July 1–September 30 = summer/late brood-rearing
(3) October 1 – November 30 = fall
(4) December 1 – Feb 28/29 = winter

Our findings for fall migration and the onset of spring staging/migration are somewhat consistent with other studies. However, greater sage-grouse in the UBHV appear to take longer to arrive on leks than what has been found in Washington (Schroeder et al. 1999) and other locations. By basing seasonal delineation on movement data from within the study area, we harnessed a more nuanced understanding of seasonal use within the UBHV resulting in a better understanding of habitat use during each biologically significant time of the GSG year.

Seasonal Use of Cover Types and Land Ownership

To estimate greater sage-grouse seasonal utilization of the landscape, we calculated a cumulative usage distribution (UD) for all individuals for each of the seasons. First, we segregated GPS movement data into each of the seasons as described above, then estimated the utilization distribution (UD)—the bivariate function giving the probability density that an animal is found at a point according to its geographical coordinates—for each individual grouse, for each season, and for each year an individual was on-air. We estimated UDs using the kernelUD function in the adehabitatHR package in R, where we used the ad hoc method for the smoothing parameter (h), a grid size of 2000m, an extent of 1, and using the same grid for all animals. Second, we calculated individual UD weights as the proportion of total season days a given individual was on-air. Third, we multiplied each UD by its respective weight then summed all UDs for each season (across all years). The volume UD (VUD) was estimated from the cumulative UD using the getvolumeUD, then we delineated the 55%, 75%, and 95% home ranges therefrom. Within the VUD, the pixel values of the resulting raster are equal to the percentage of the smallest home range containing this pixel, such that a cell value of 100 would indicate all cells in the study area are included.

Seasonal Use of Cover Types

Land cover data was sourced from the National Land Cover Database (Dewitz and USGS 2021) at a 30 m resolution. For our purposes, we first reclassified the three classes of "developed" (High, Medium, and Low), into a single Developed class. Due to their rarity across the study area, we reclassified to "Other" the following NLCD land cover classes: Barren Land, Cultivated Crops, Deciduous Forest, Mixed Forest, Perennial Snow/Ice, and Unclassified. Finally, we reclassified Shrub/Scrub to Sagebrush. The final cover classes mapped were open water, developed, evergreen forest, sagebrush, herbaceous, woody wetlands, emergent herbaceous wetlands, and other.

Seasonal Use of Land Ownership

Land ownership data was sourced from the Montana Natural Heritage Program (MTNHP 2011). We simplified the ownership categories (from the data attribute "OWNERLABEL") to BLM, FWP, State Trust, NPS, USFS, and combined into "Other" the categories "MT DOT" & "Unknown" given their scarcity and presence outside the usage distribution of sage grouse. In this data, private lands are represented by all remaining unclassified lands.

Summary of Seasonal Use of Cover and Ownership

We summarized land cover and land ownership within greater sage-grouse seasonal ranges by first mapping the weighted cumulative usage distribution across all GPS marked individuals as an overlay, then calculating the 55%, 75%, and 95% home range from the weighted cumulative usage distribution. We then mapped the overlay of cumulative usage (cover: Figures *11*, *13*, *15*, *17*, *19*; ownership: Figures *22*, *24*, *26*, *30*), percent home range (cover: Figs *12*, *14*, *16*, *18*, *20*; ownership: Figures *23*, *25*, *27*, *29*, *31*), tabulated the results (cover: Tables *2*, *3*, *4*, *5*, *6*; ownership: Tables *7*, *8*, *9*, *10*, *11*), and plotted a comparative histogram of the 95% home range land composition (cover: *Figure 21*; ownership: *Figure 32*).

Home ranges were largest during Spring Staging & Migration (only slightly less than all other seasons combined: 55% HRs = 108, 25, 35, 29, 17, & 24, respectively) due to the concerted push composed of greater movement and variability in movement as individuals find their way back to Nesting & Brood Rearing home ranges. Nesting & Brood Rearing home ranges were second smallest only after Fall Migration (likely the smallest due to the gradual and resource-constrained movement back to Early & Late Winter home ranges.

UBHV GSG home ranges encompassed near equal amounts of sagebrush and herbaceous (Tables 2–6; *Figure 21*). However, during Nesting & Early Brood Rearing, Fall Migration, and Early & Late Winter, sagebrush composed the vast majority of landcover across home ranges (Figures *14*, *18*, and *20*, Tables *3*, *5*, and *6*). During both migration seasons, evergreen forest increased within home ranges, likely due to individual movement over/past these areas (Figure *12* and *Figure 18*).

UBHV GSG home ranges are composed nearly entirely of private lands (67–80% of 9% HRs, Tables *7–11*), with State Trust and USFS distant second and thirds (*Figure 32*). During Spring Staging & Migration, USFS lands follow private lands as the second greatest ownership category, which corresponds to the increased evergreen forest landcover noted above. An increase in State Lands home range composition during Fall Migration, and Early & Late Winter is notable when comparing to Nesting & Early Brood Rearing and Late Brood Rearing & Fall Staging(*Figure 32*).

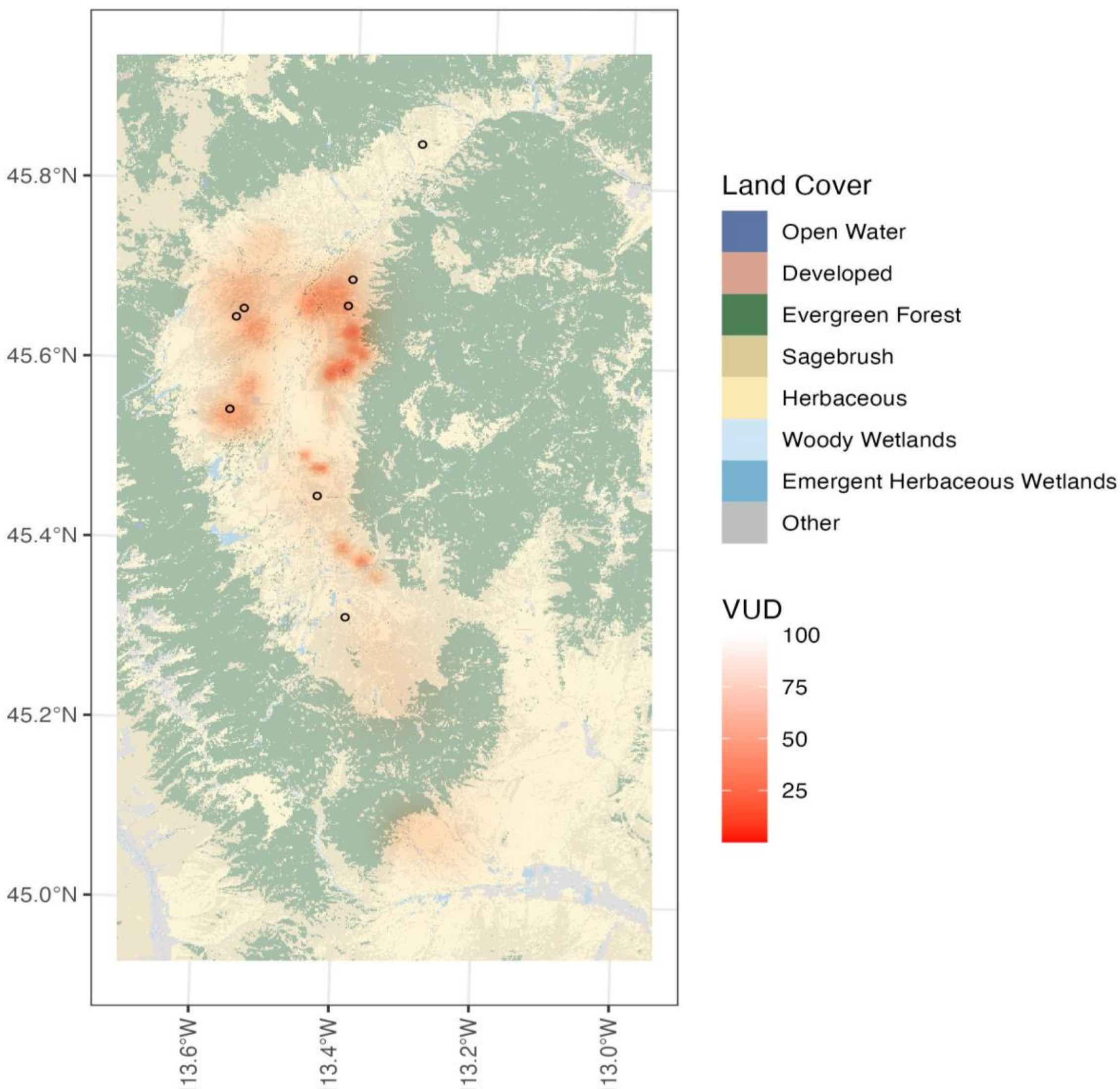

Figure 11. Spring Staging & Migration weighted cumulative usage distribution across all GPS marked GSG, 2018–2022, overlaid on land cover. Volume usage distribution (VUD) was standardized from each seasonal kernel usage distribution (KUD) and scales from 1 (encompassing most concentrated usage) to 100 (encompassing all usage).

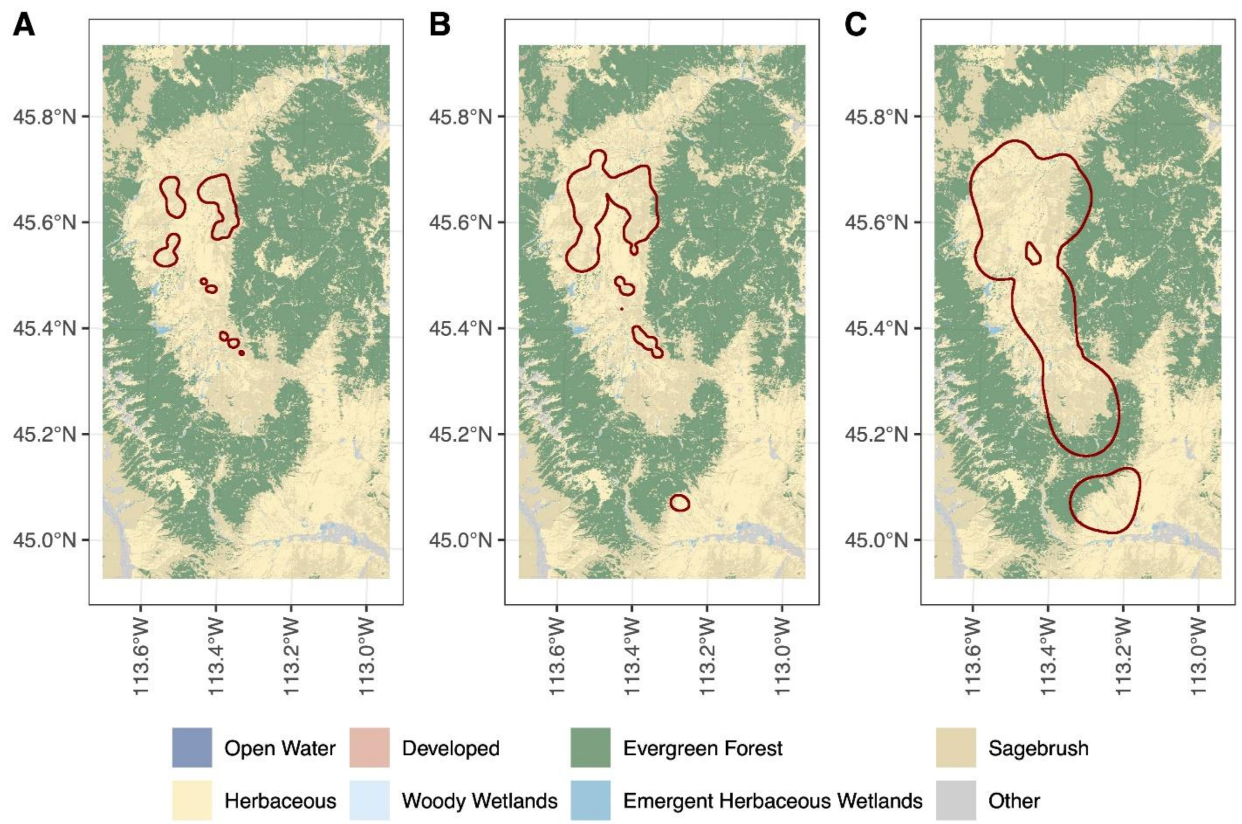

Figure 12. Spring Staging & Migration 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS collared GSG, 2018–2022, overlaid on land cover.

Table 2. Land cover (Dewitz and USGS 2021) by area and percentage composing Spring Staging & Migration 55%, 75%, and 95% cumulative home ranges across all GPS marked GSG hens, 2018–2022.

	55%		75%		95%	
NLCD Class	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
Developed	0.96	0.9	2.69	1.0	9.38	0.9
Emergent Herbaceous Wetlands	0.17	0.2	0.77	0.3	5.92	0.6
Evergreen Forest	1.52	1.4	6.74	2.5	164.37	15.7
Herbaceous	43.03	39.7	126.70	47.7	452.31	43.1
Open Water	0.17	0.2	0.20	0.1	0.62	0.6
Other	0.03	0.0	0.95	0.4	0.94	0.3
Sagebrush	62.40	57.6	127.26	47.9	412.56	39.3
Woody Wetlands	0.01	0.0	0.26	0.1	1.99	0.2
Total	108.30	100.0	265.56	100.0	1050.25	100.0

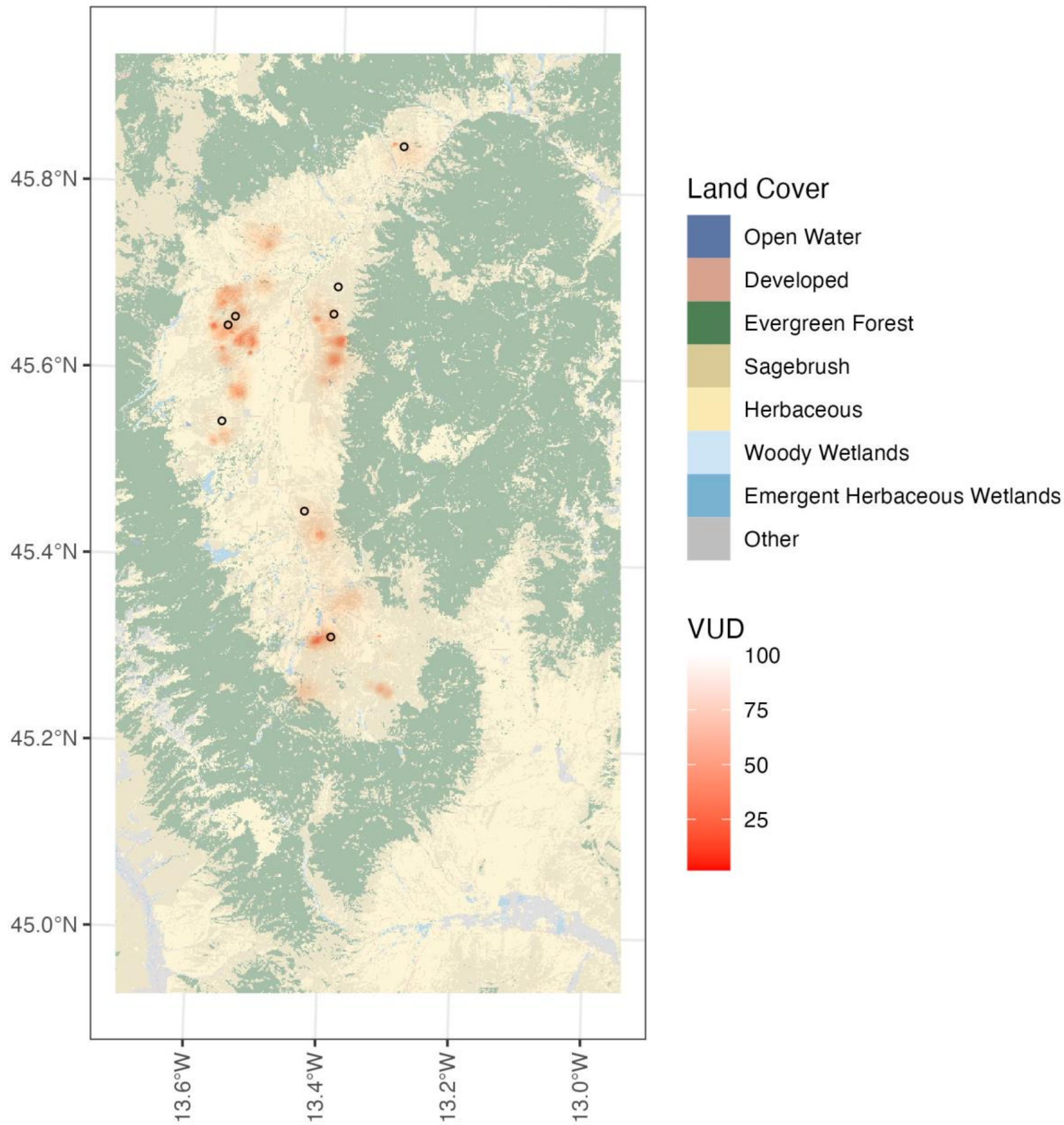

Figure 13. Nesting & Early Brood Rearing weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

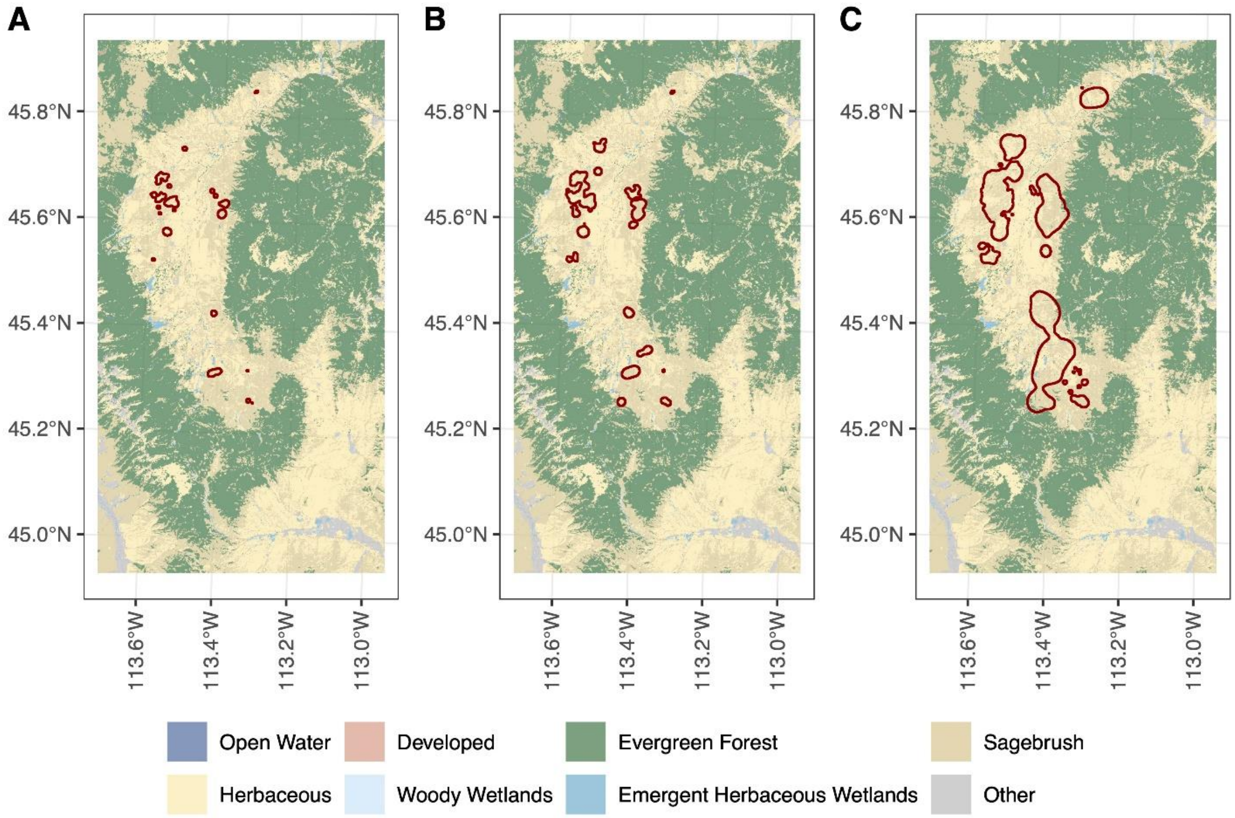

Figure 14. Nesting & Early Brood Rearing 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

Table 3. Land cover (Dewitz and USGS 2021) by area and percentage composing Nesting & Early Brood Rearing 55%, 75%, and 95% cumulative home ranges across all GPS marked GSG hens, 2018–2022.

	55%		75%		95%	
NLCD Class	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
Developed	0.20	0.8	0.57	0.8	3.02	1.0
Emergent Herbaceous Wetlands	0.03	0.1	0.24	0.3	2.83	1.0
Evergreen Forest	0.04	0.2	0.46	0.6	8.08	2.7
Herbaceous	9.50	37.8	27.62	38.7	125.25	42.2
Open Water	0.00	0.0	0.04	0.1	0.30	0.1
Other	0.01	0.1	0.03	0.0	0.37	0.1
Sagebrush	15.35	61.1	42.30	59.3	156.55	52.7
Woody Wetlands	0.01	0.0	0.04	0.1	0.49	0.2
Total	25.15	100.0	71.30	100.0	296.89	100.0

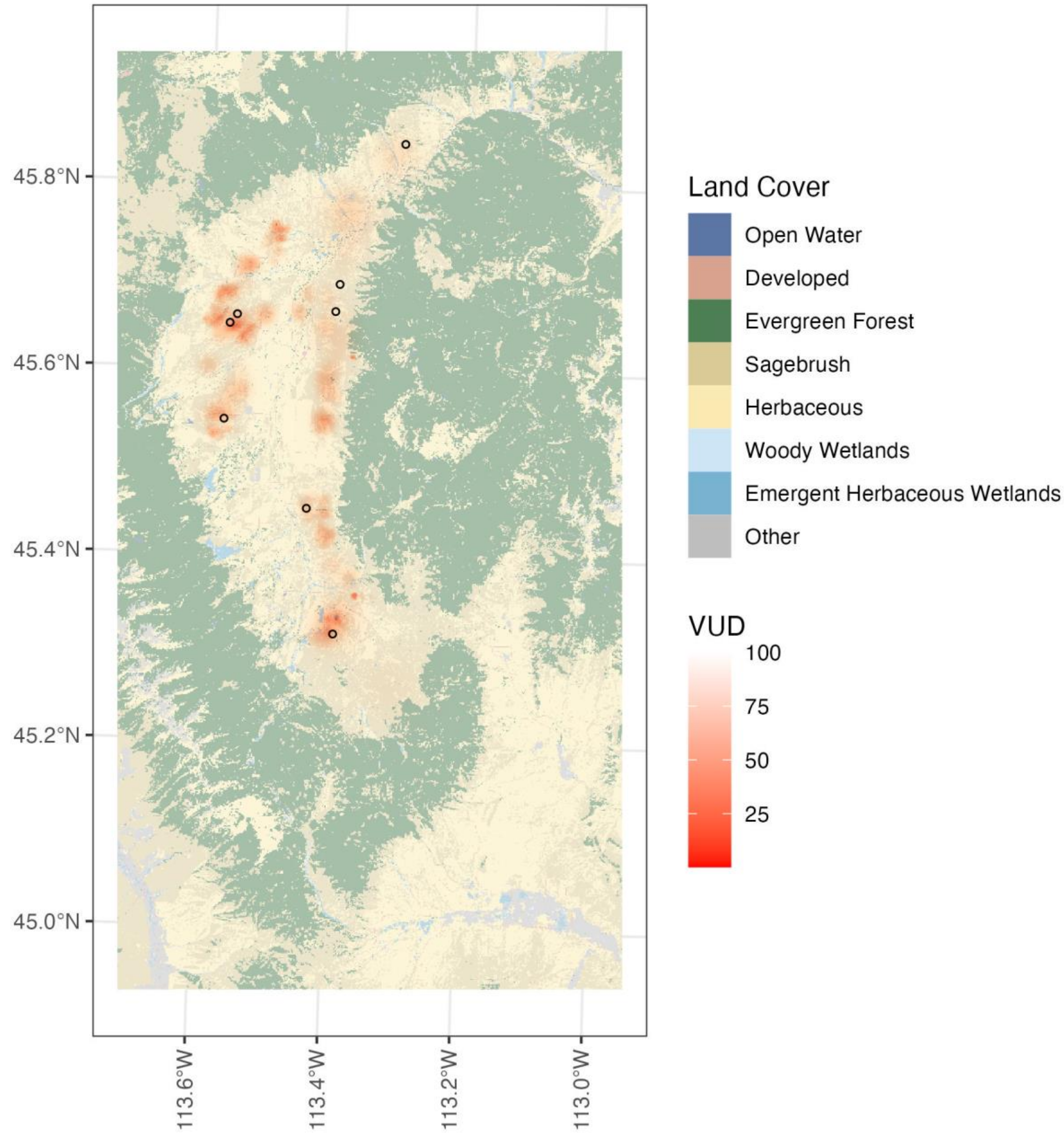

Figure 15. Late Brood Rearing & Fall Staging weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

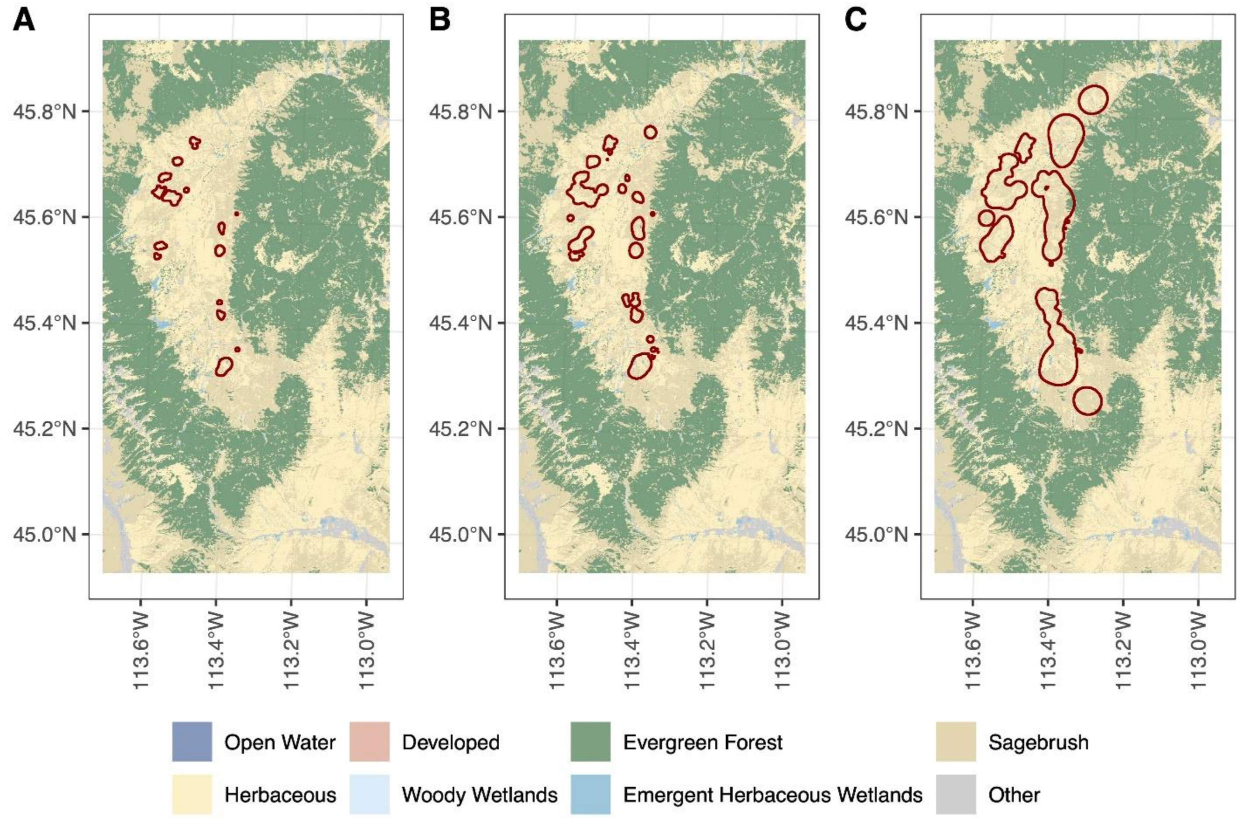

Figure 16. Late Brood Rearing & Fall Staging 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

Table 4. Land cover (Dewitz and USGS 2021) by area and percentage composing Late Brood Rearing & Fall Staging 55%, 75%, and 95% cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%		75%		95%	
NLCD Class	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
Developed	0.26	0.7	0.55	0.5	3.92	1.0
Emergent Herbaceous Wetlands	0.39	1.0	1.34	1.2	3.71	0.9
Evergreen Forest	0.17	0.4	0.58	0.5	8.77	2.2
Herbaceous	19.01	48.9	53.29	48.2	171.49	43.8
Open Water	0.02	0.0	0.09	0.1	0.73	0.2
Other	0.02	0.0	0.07	0.1	0.42	0.1
Sagebrush	19.06	48.9	54.63	49.4	202.47	51.7
Woody Wetlands	0.01	0.0	0.06	0.1	0.29	0.1
Total	39.00	100.0	110.60	100.0	391.80	100.0

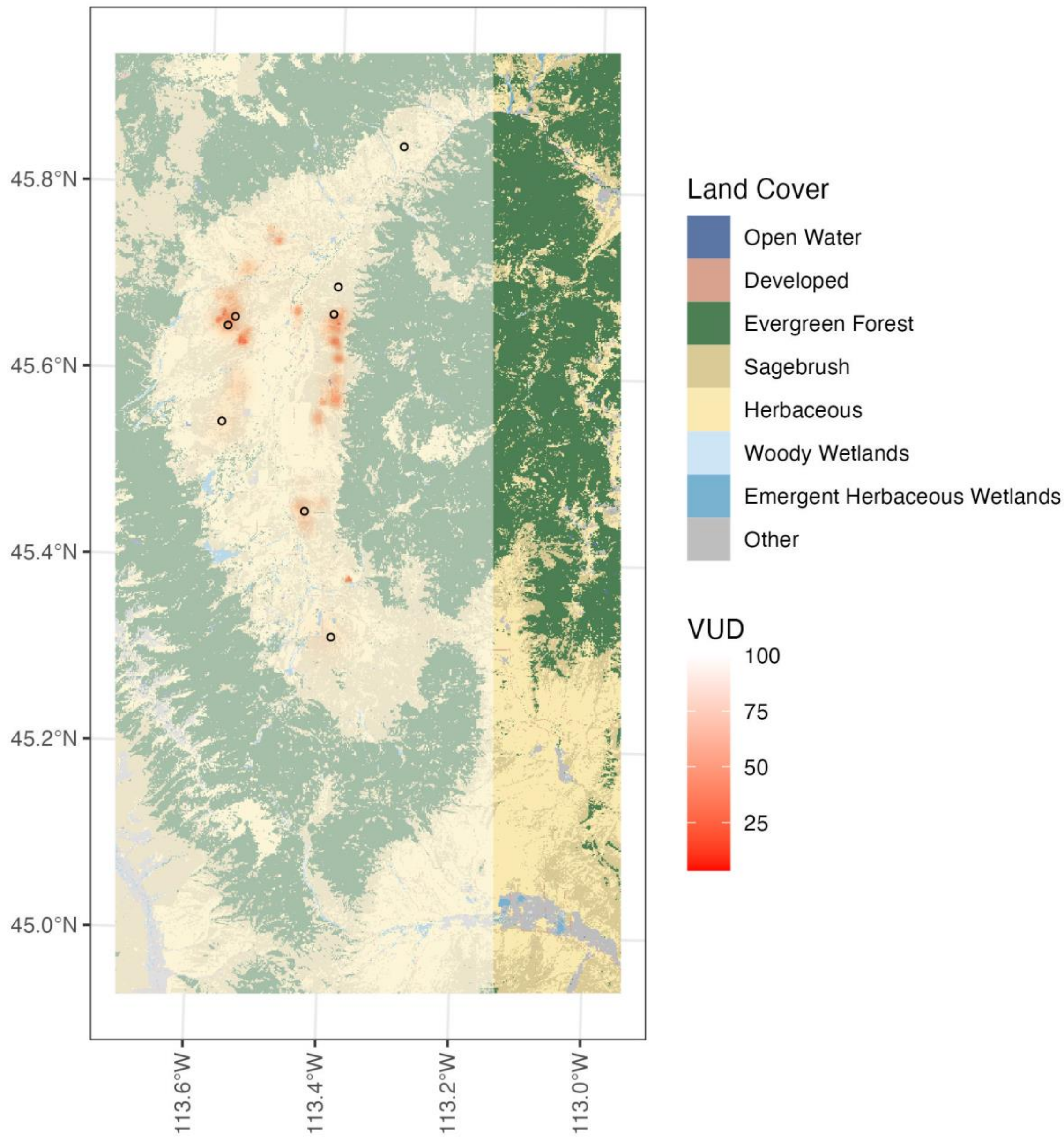

Figure 17. Fall Migration weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land cover. The Fall Migration cumulative usage distribution extent was more limited than other seasons, due to a concentration of usage within the Big Hole Valley, so the overlay appears incomplete.

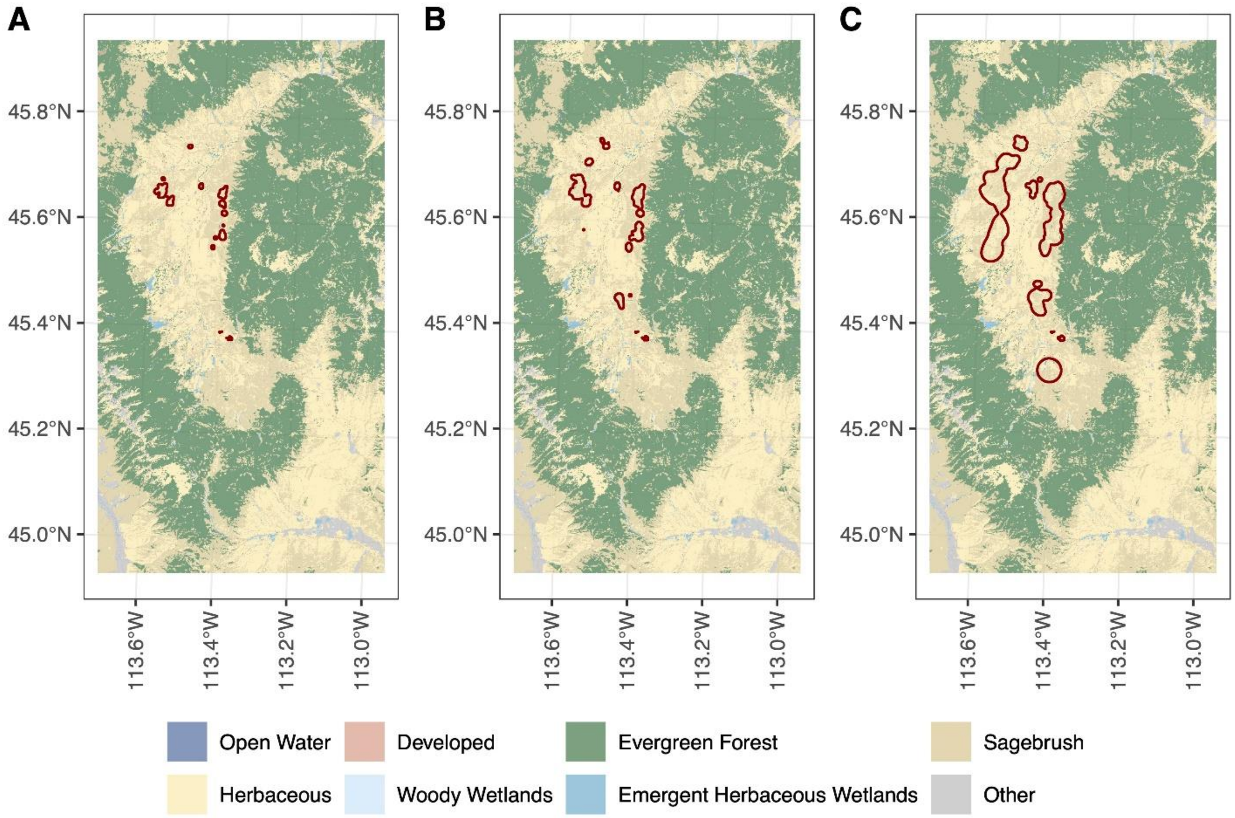

Figure 18. Fall Migration 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

Table 5. Land cover (Dewitz and USGS 2021) by area and percentage composing Fall Migration 55%, 75%, and 95% cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%		**75%**		**95%**	
NLCD Class	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
Developed	0.06	0.4	0.10	0.2	1.12	0.7
Emergent Herbaceous Wetlands	0.00	0.0	0.13	0.3	1.15	0.7
Evergreen Forest	0.06	0.4	0.14	0.3	2.04	1.2
Herbaceous	5.64	33.9	15.79	38.0	76.67	45.7
Open Water	0.07	0.4	0.13	0.3	0.17	0.1
Other	0.00	0.0	0.01	0.0	0.15	0.1
Sagebrush	10.82	64.9	25.23	60.7	86.37	51.5
Woody Wetlands	0.00	0.0	0.00	0.0	0.17	0.1
Total	16.66	100.0	41.53	100.0	167.84	100.0

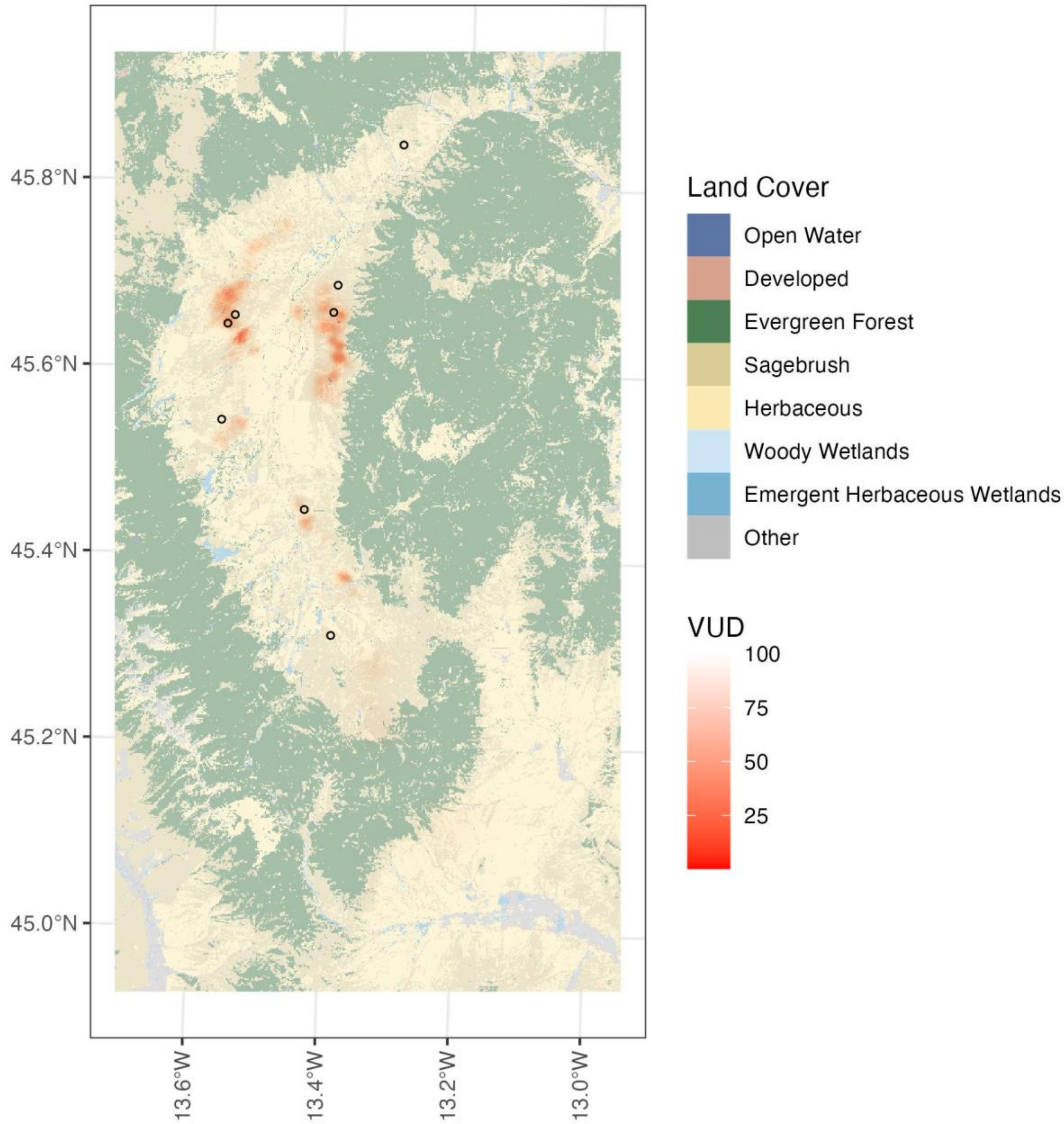

Figure 19. Early & Late Winter weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

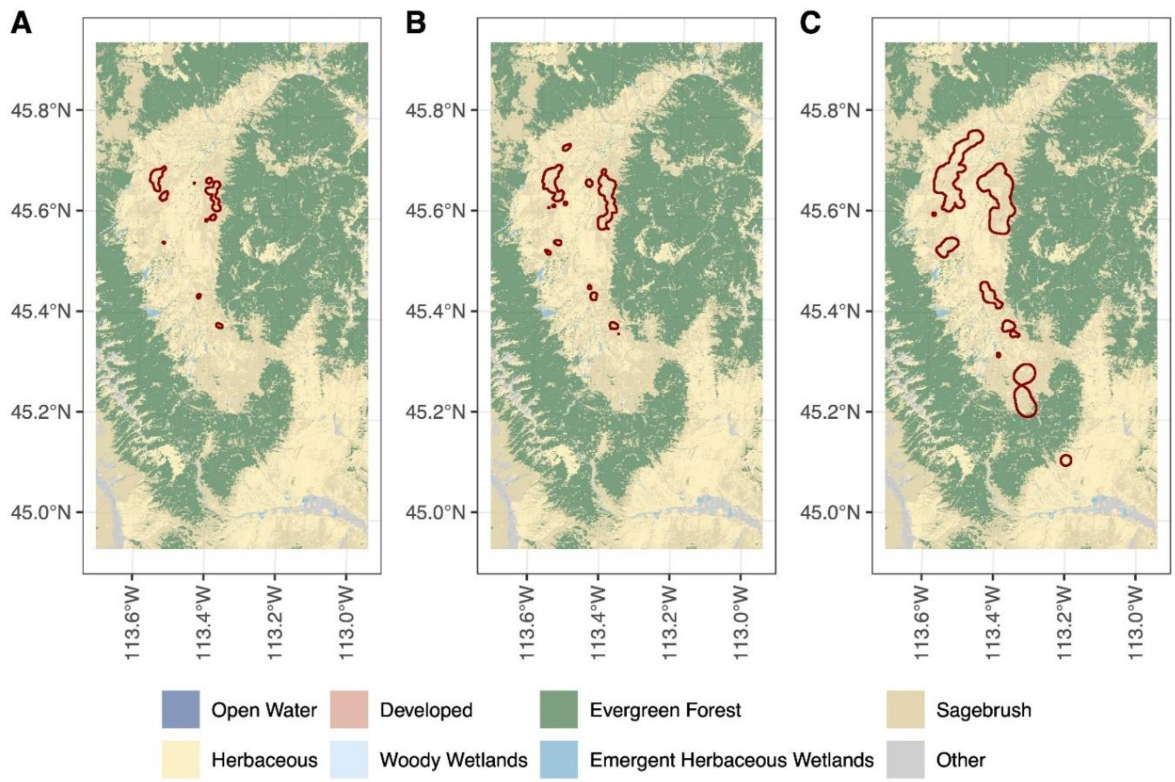

Figure 20. Early & Late Winter 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land cover.

Table 6. Land cover (Dewitz and USGS 2021) by area and percentage composing Early & Late Winter 55%, 75%, and 95% cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%		75%		95%	
NLCD Class	**Area (km²)**	**% HR**	**Area (km²)**	**% HR**	**Area (km²)**	**% HR**
Developed	0.05	0.2	0.19	0.4	1.67	0.8
Emergent Herbaceous Wetlands	0.00	0.0	0.06	0.1	1.06	0.5
Evergreen Forest	0.08	0.3	0.16	0.3	4.27	2.2
Herbaceous	7.84	33.0	19.15	35.8	76.41	38.6
Open Water	0.13	0.5	0.16	0.3	0.22	0.1
Other	0.00	0.0	0.01	0.0	0.19	0.1
Sagebrush	15.69	66.0	33.79	63.1	113.99	57.5
Woody Wetlands	0.00	0.0	0.00	0.0	0.36	0.2
Total	23.79	100.0	53.52	100.0	198.17	100.0

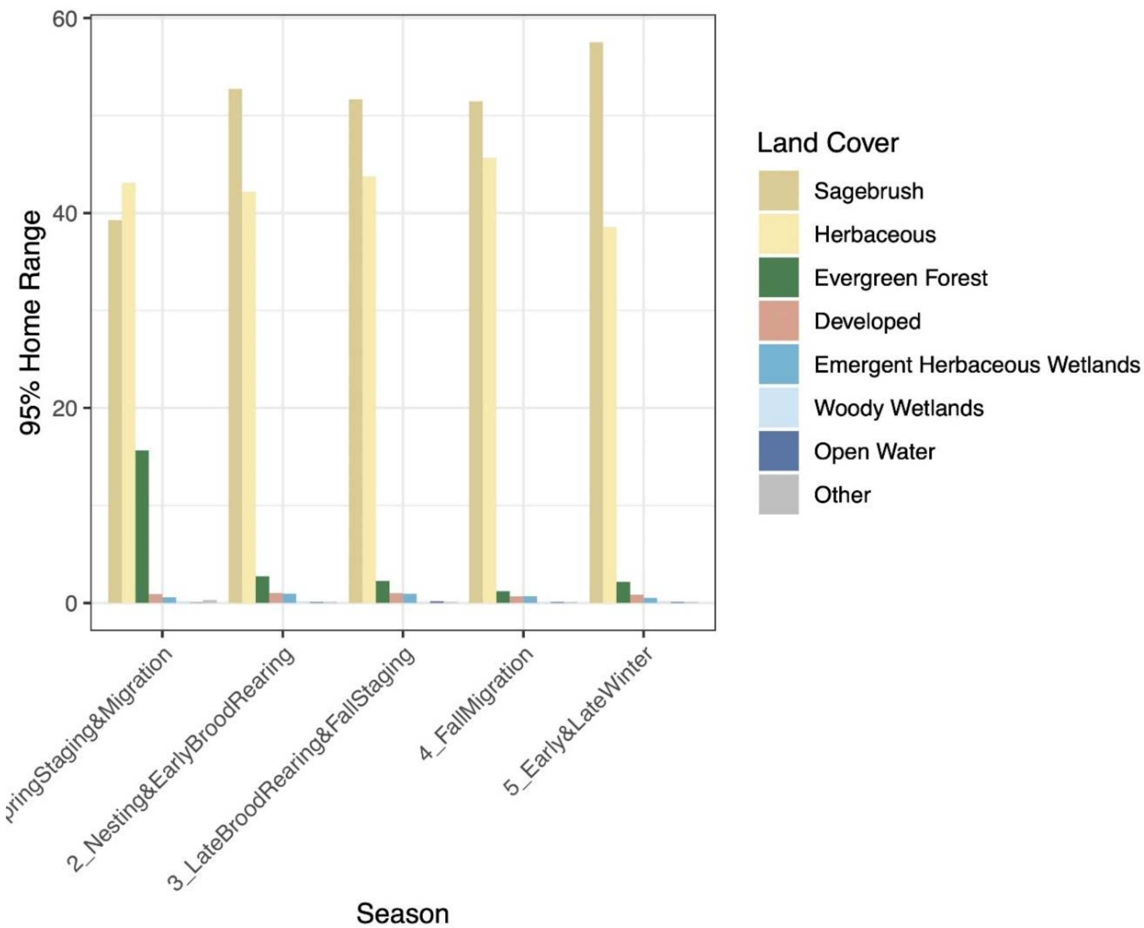

Figure 21. Land cover (Dewitz and USGS 2021) within seasonal 95% cumulative home ranges across all GPS marked GSG hens, 2018–2022.

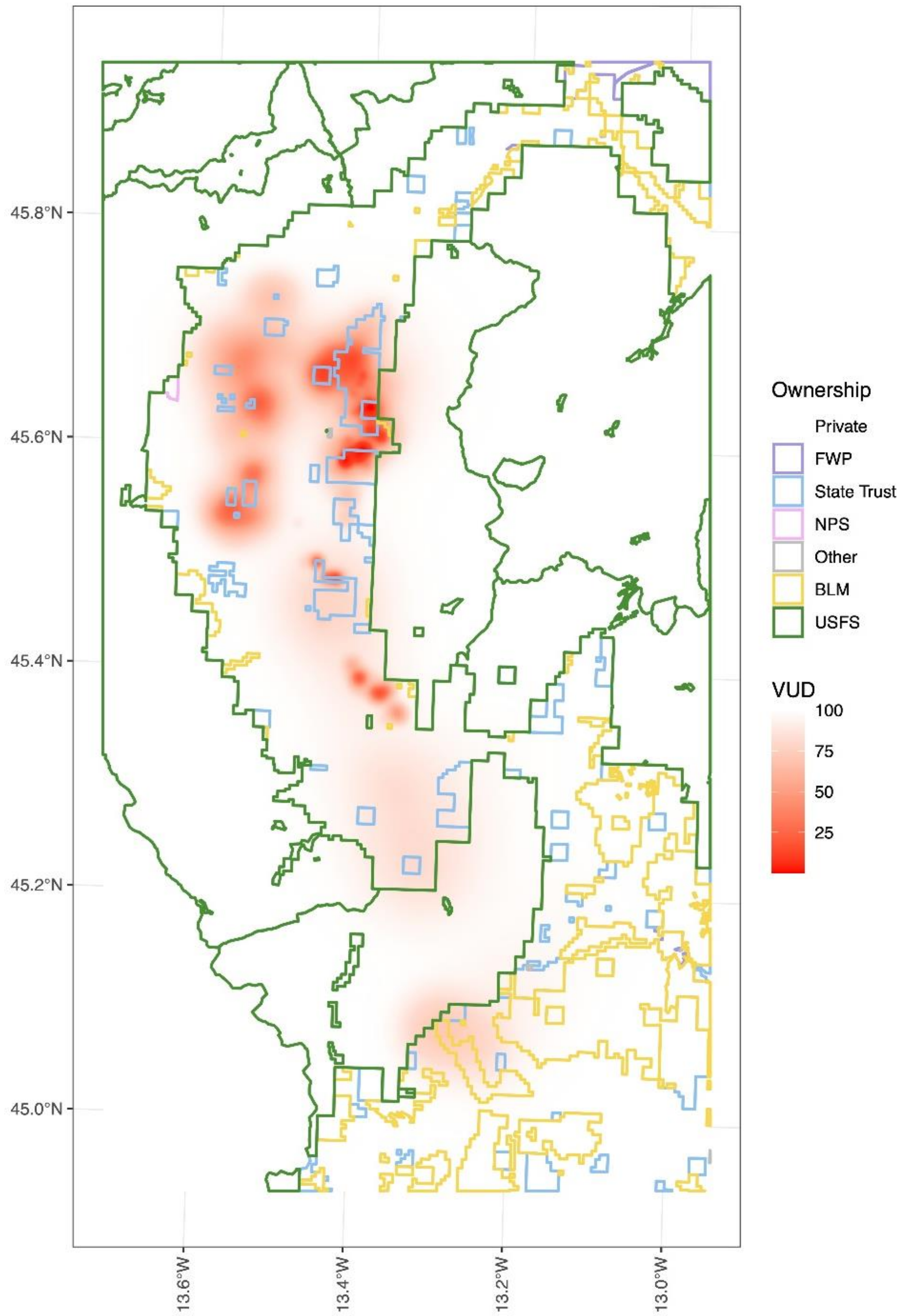

Figure 22. Spring Staging & Migration weighted cumulative usage distribution across all GPS collared greater sage-grouse, 2018–2022, overlaid on land ownership (MTNHP 2011). The volume usage distribution (VUD) was standardized from each seasonal kernel usage distribution (KUD) and scales from 1 (encompassing the most concentrated usage) to 100 (encompassing all usage).

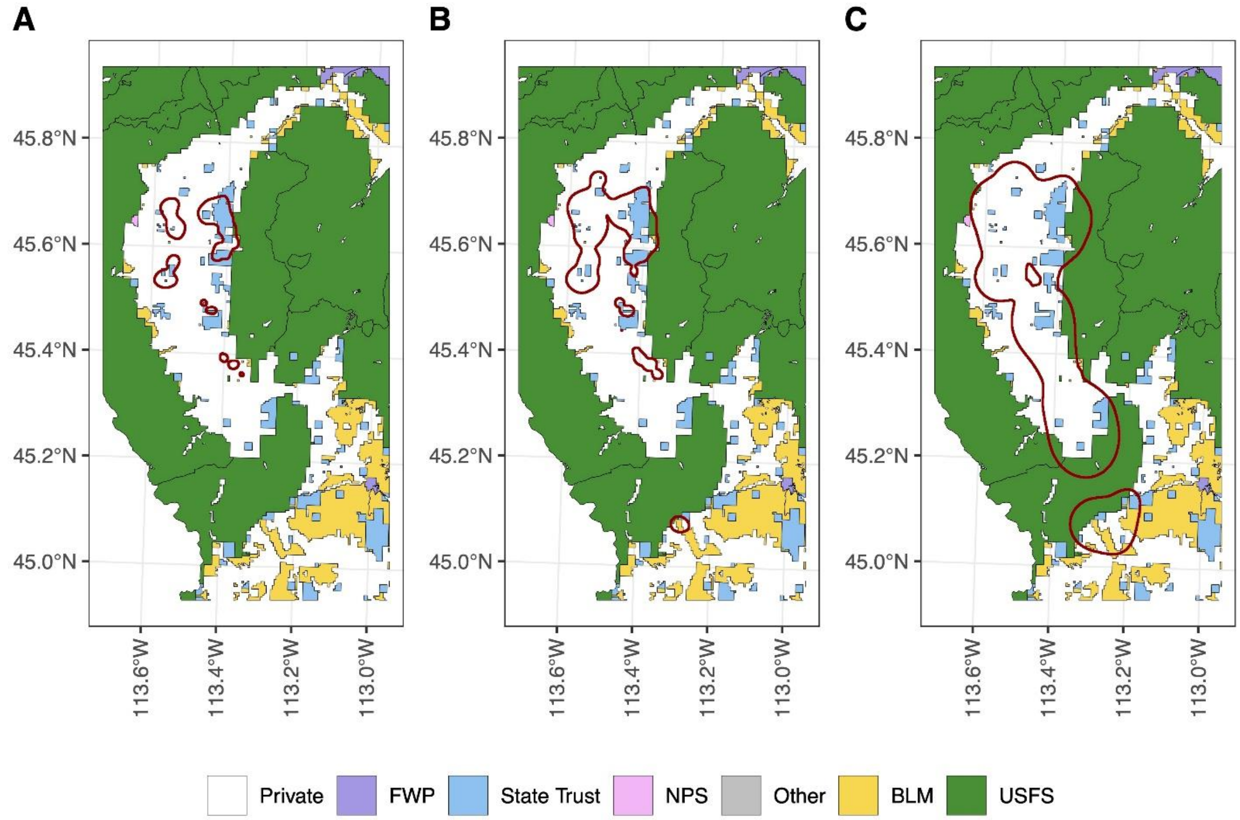

Figure 23. Spring Staging & Migration 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

Table 7. Land ownership (MTNHP 2011) by area and percentage composing Spring Staging & Migration 55%, 75%, and 95% volume utility distribution cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%		75%		95%	
Owner	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
BLM	0.54	0.5	4.68	1.6	37.17	3.2
USFS	1.72	1.4	10.40	3.5	217.24	18.7
State Trust	41.25	34.5	63.96	21.8	125.46	10.8
Private	76.09	63.6	214.10	73.0	779.12	67.2
Total	119.60	100.0	293.15	100.0	1159.40	100.0

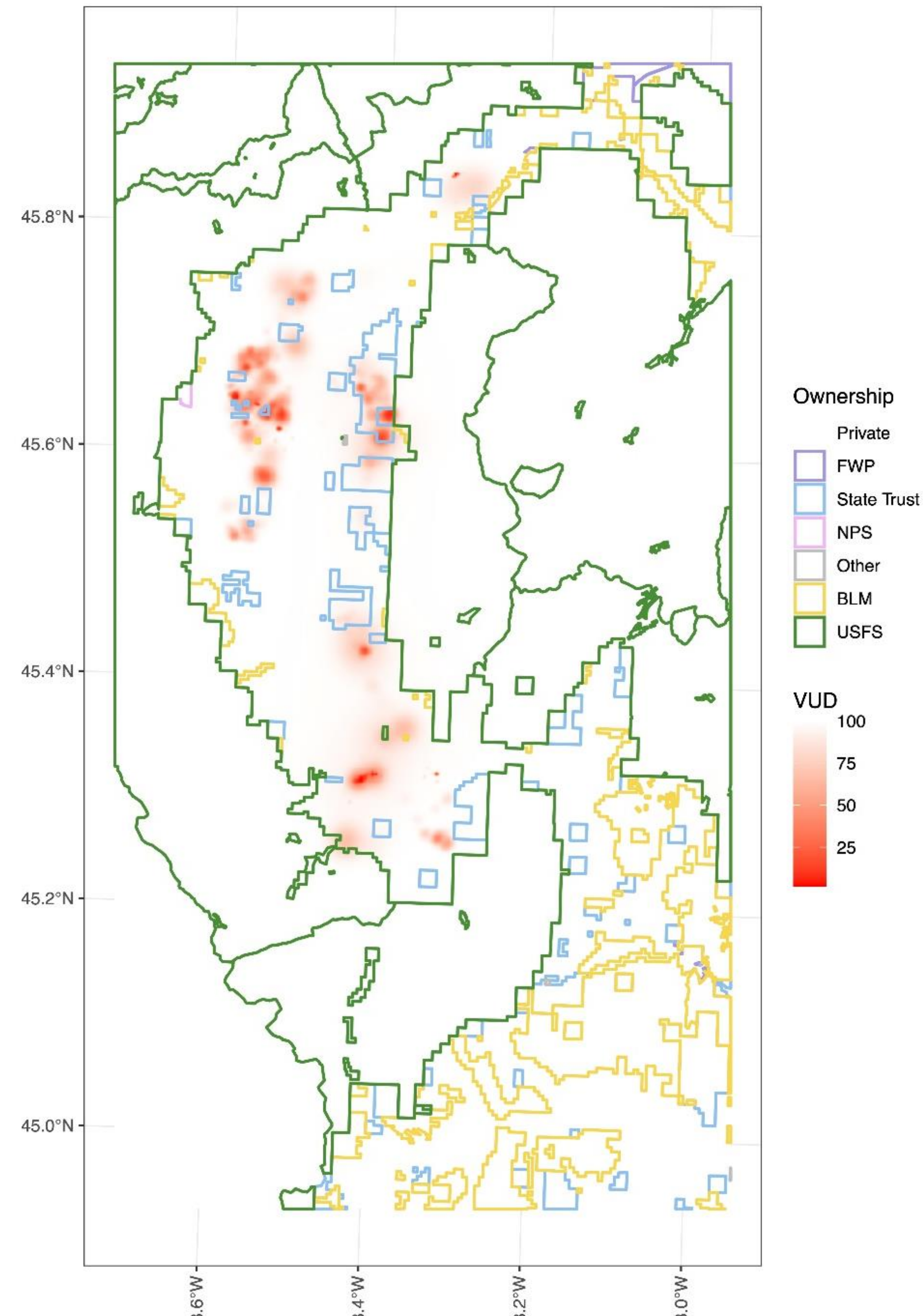

Figure 24. Nesting & Early Brood Rearing weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

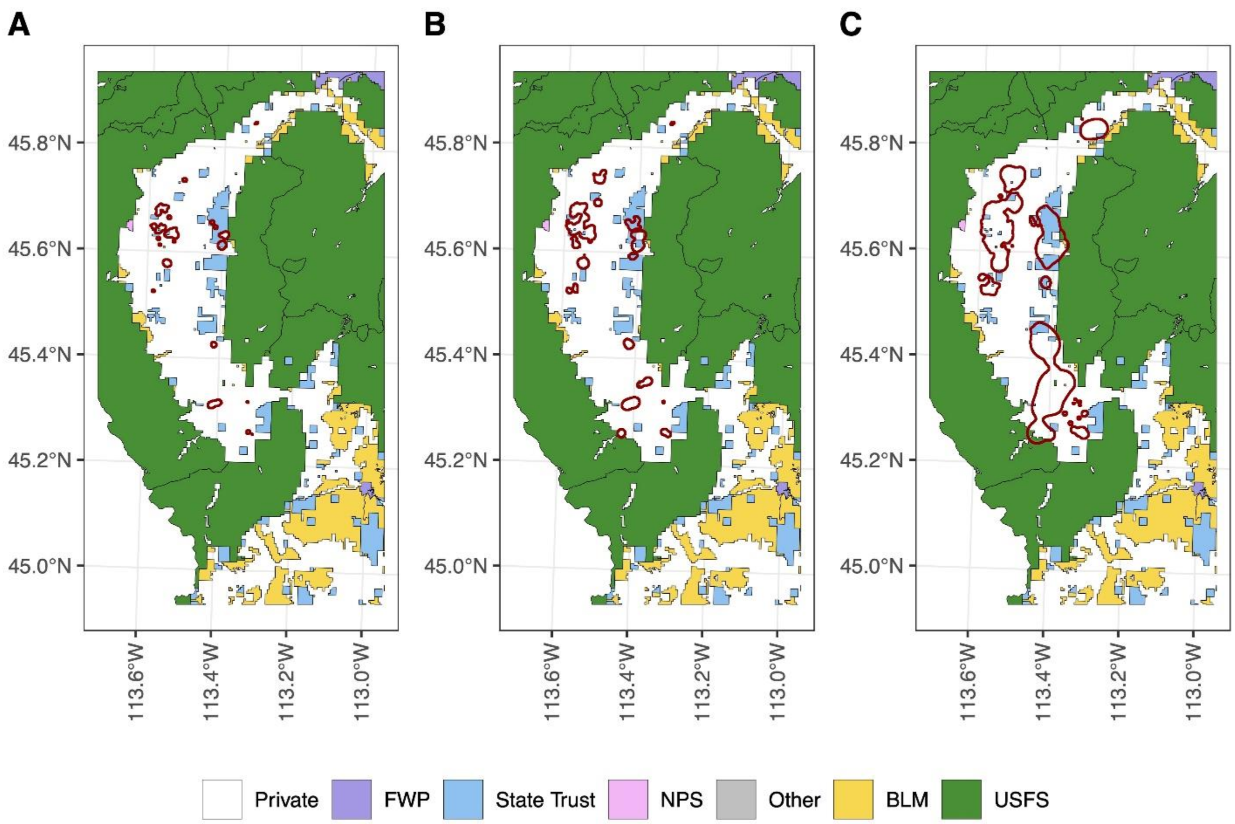

Figure 25. Nesting & Early Brood Rearing 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

Table 8. Land ownership (MTNHP 2011) by area and percentage composing Nesting & Early Brood Rearing 55%, 75%, and 95% cumulative home ranges across all GPS marked GSG hens, 2018–2022.

	55%		**75%**		**95%**	
Owner	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
BLM	0.00	0.0	0.060	0.1	1.83	0.6
USFS	0.22	0.8	0.99	1.3	8.97	02.7
State Trust	3.64	13.1	13.26	16.9	52.44	16.0
Private	23.88	86.1	64.36	81.8	264.12	80.6
Other	0.00	0.0	0.00	0.0	0.24	0.1
Total	27.75	100.0	78.67	100.0	327.60	100.0

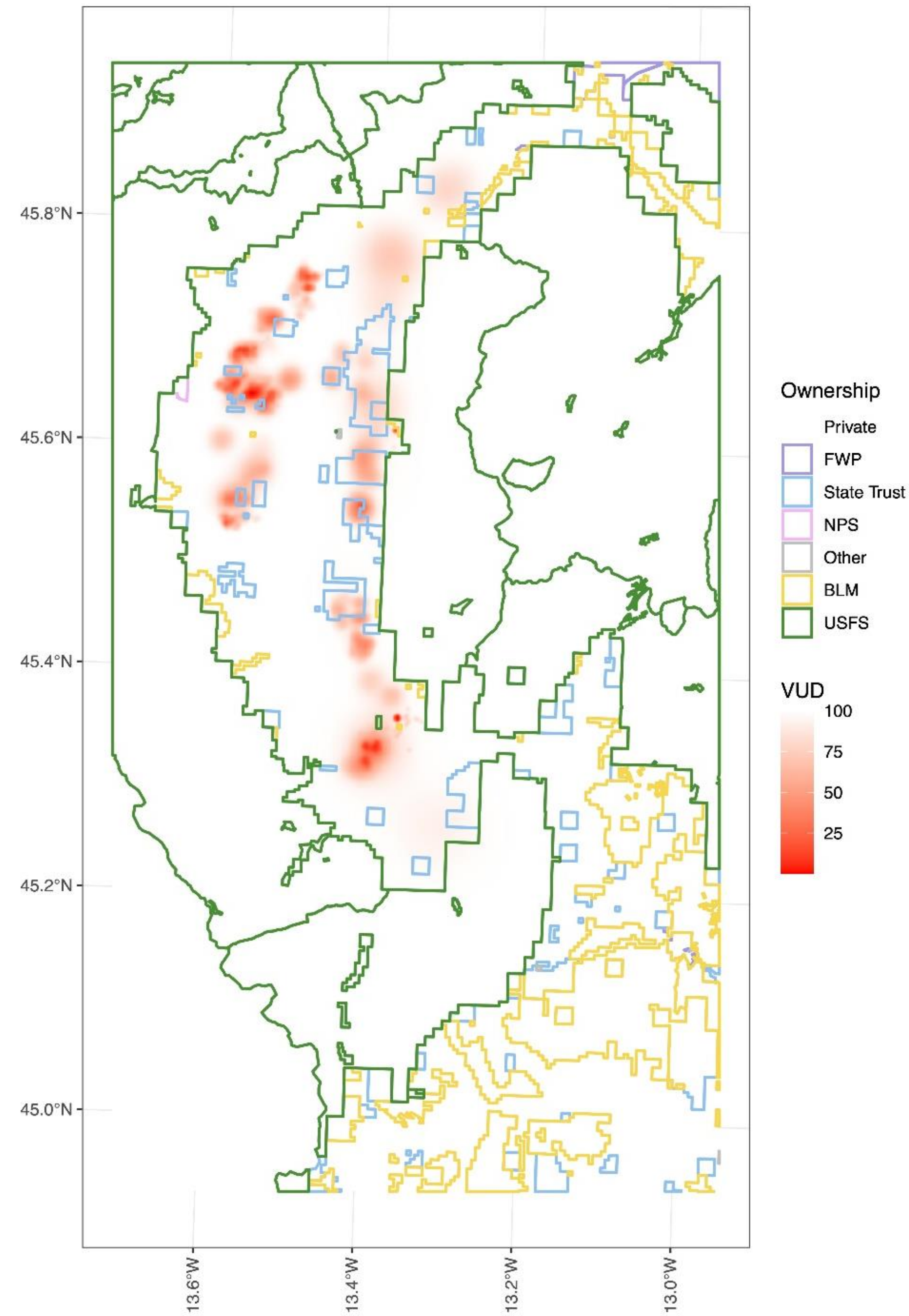

Figure 26. Late Brood Rearing & Fall Staging weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

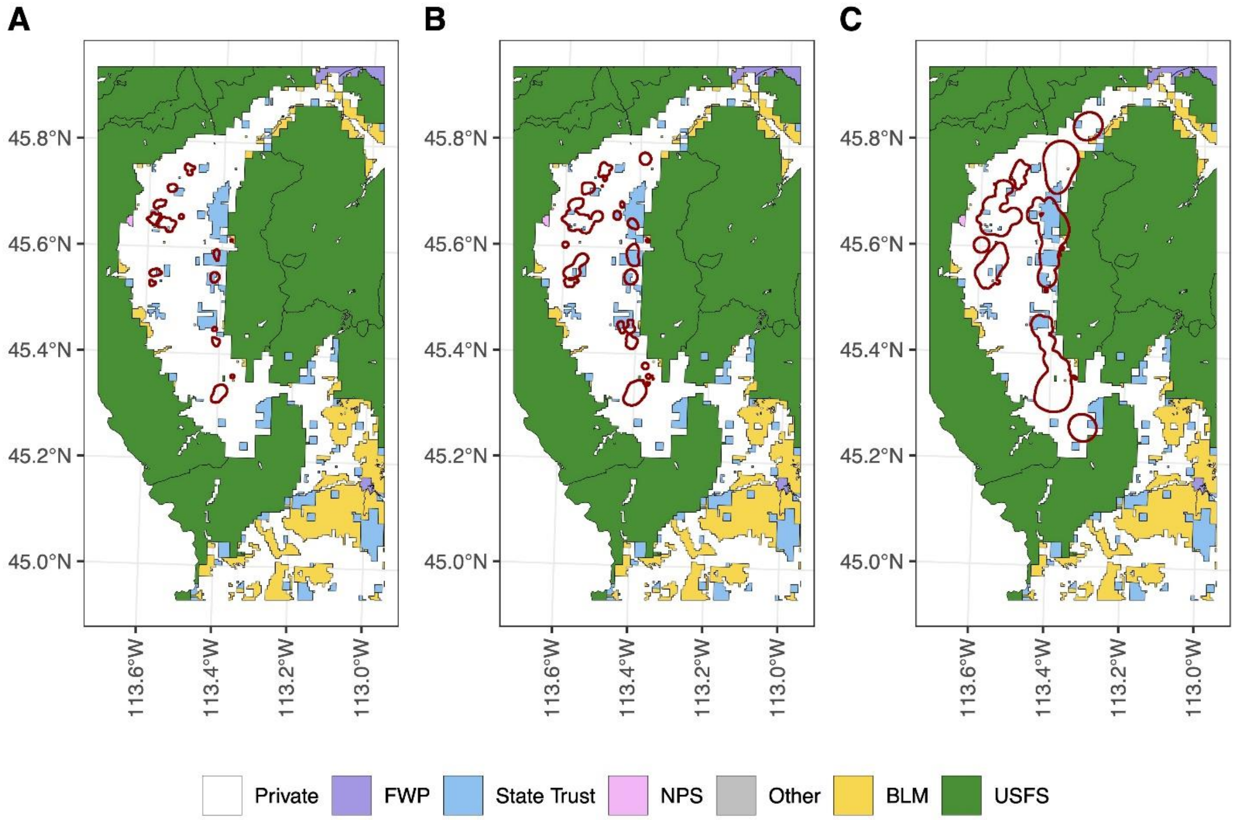

Figure 27. Late Brood Rearing & Fall Staging 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

Table 9. Land ownership (MTNHP 2011) by area and percentage composing Late Brood Rearing & Fall Staging 55%, 75%, and 95% cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%		75%		95%	
Owner	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
BLM	0.00	0.0	0.03	0.0	2.72	0.6
USFS	0.00	0.0	0.09	0.1	10.06	2.3
State Trust	6.17	14.3	24.59	20.1	75.05	17.4
Private	36.91	85.7	97.32	79.8	344.62	79.7
Total	43.09	100.0	122.03	100.0	432.46	100.0

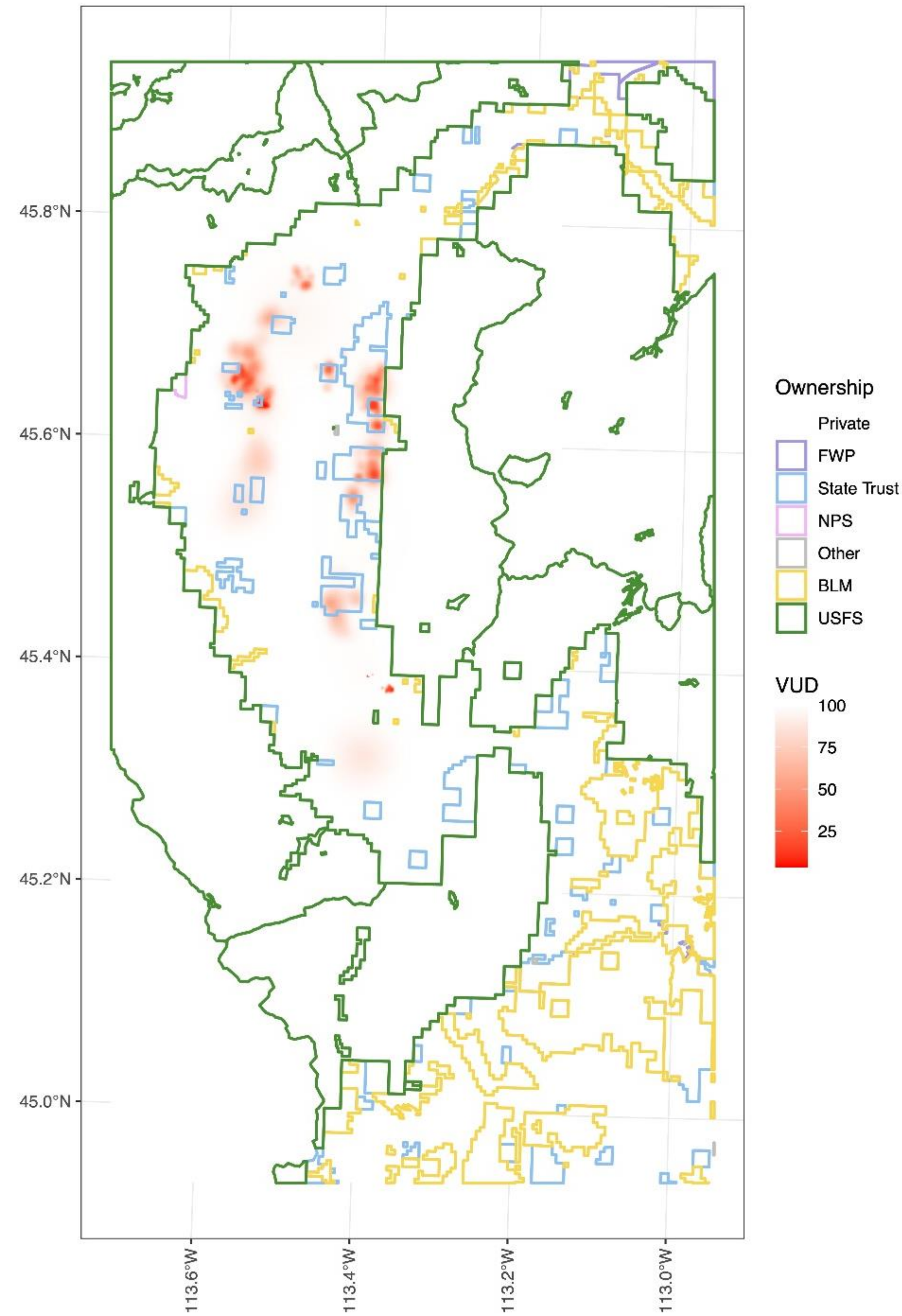

Figure 28. Fall Migration weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

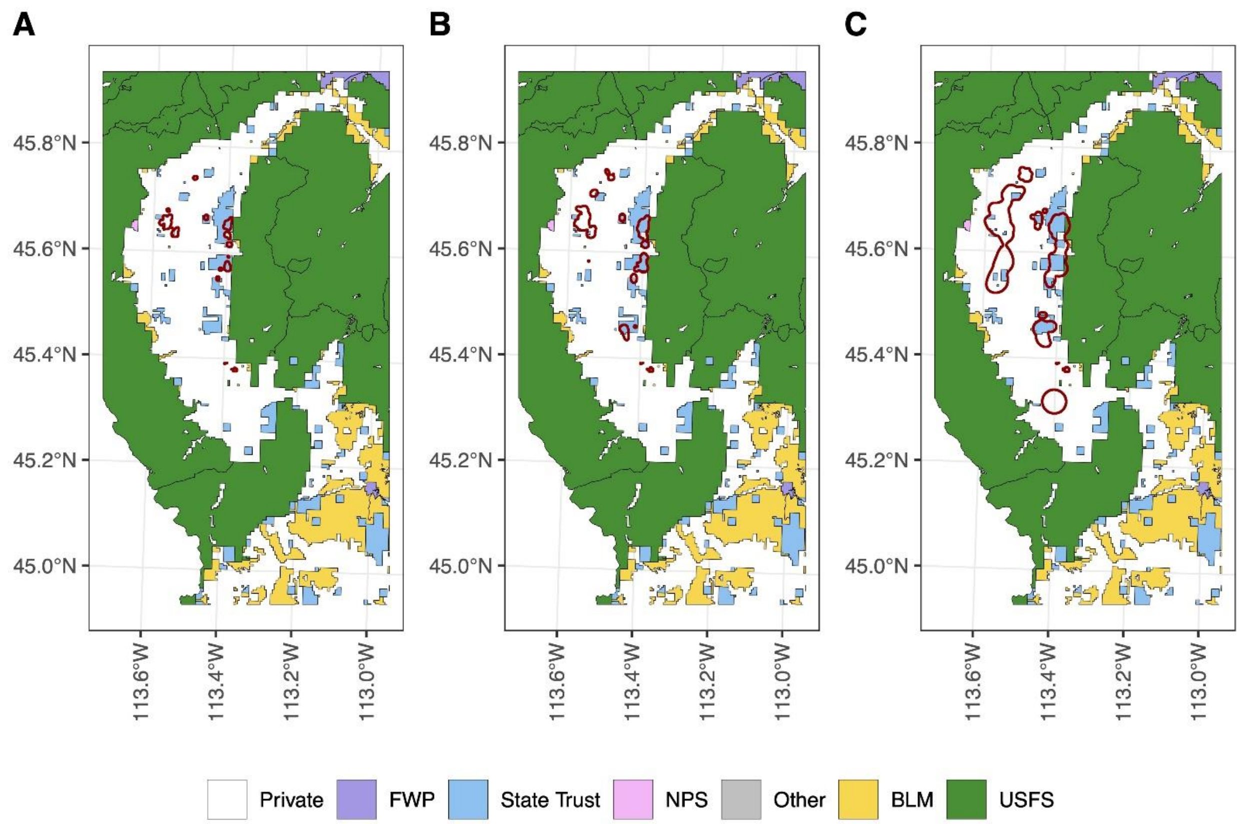

Figure 29. Fall Migration 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

Table 10. Land ownership (MTNHP 2011) by area and percentage composing Fall Migration 55%, 75%, and 95% cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%		75%		95%	
Owner	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
BLM	0.00	0.0	0.00	0.0	0.18	0.1
USFS	0.00	0.0	0.10	0.2	4.93	2.7
State Trust	8.13	44.3	21.00	45.8	50.78	27.4
Private	10.22	55.7	24.77	54.0	129.38	69.8
Total	18.35	100.0	45.87	100.0	185.27	100.0

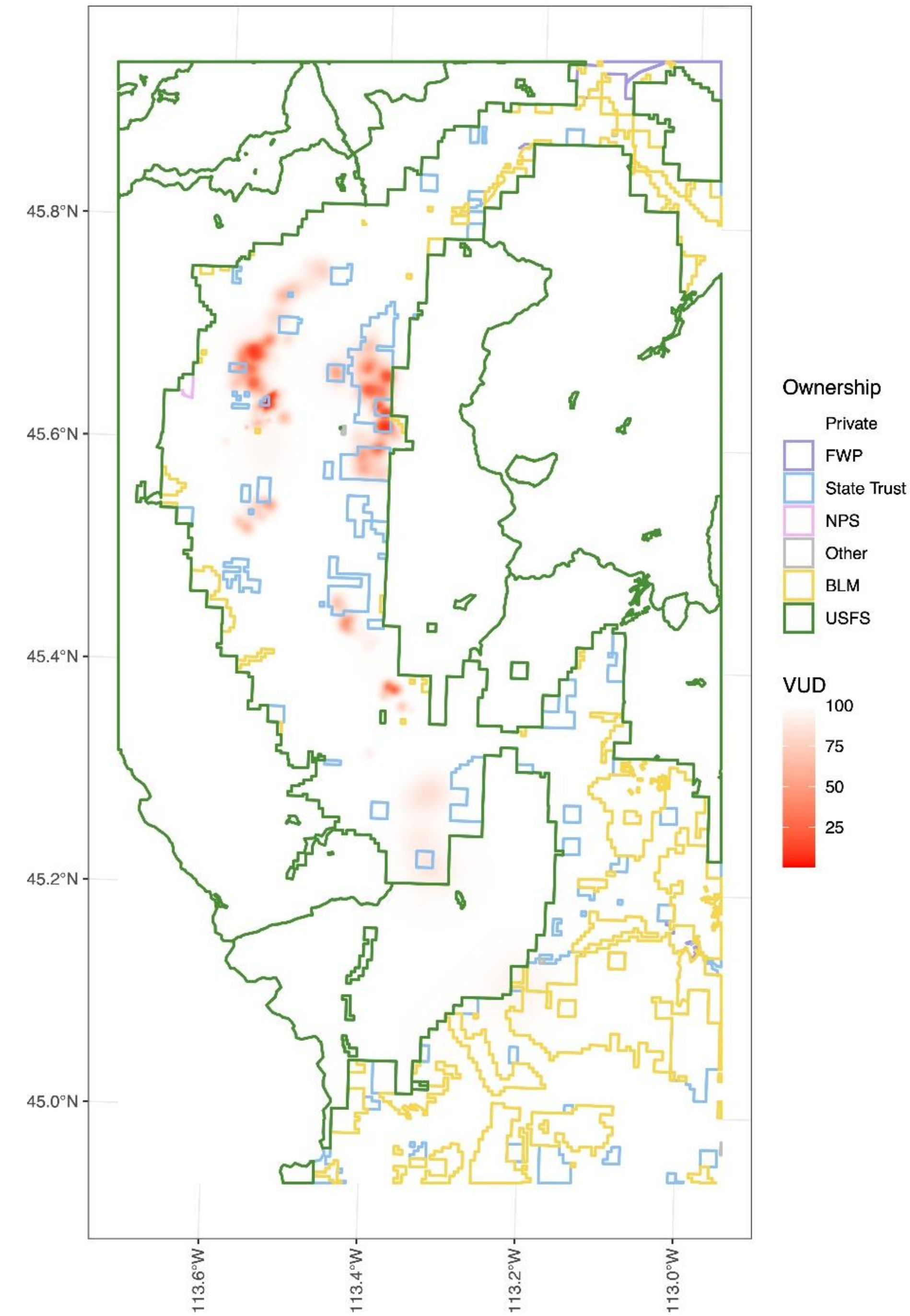

Figure 30. Early & Late Winter weighted cumulative usage distribution across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

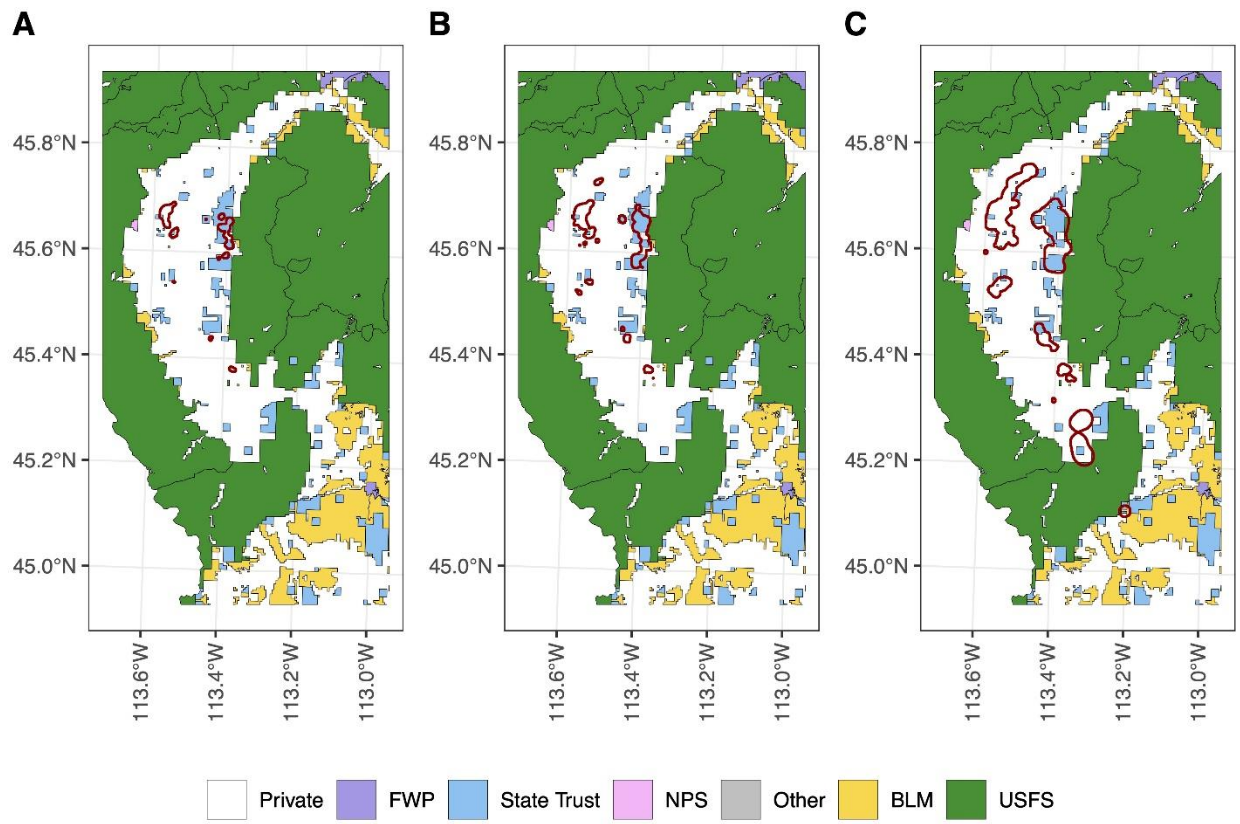

Figure 31. Early & Late Winter 55% (A), 75% (B), and 95% (C) cumulative home ranges across all GPS marked GSG hens, 2018–2022, overlaid on land ownership (MTNHP 2011).

Table 11. Land ownership (MTNHP 2011) by area and percentage composing Early & Late Winter 55%, 75%, and 95% cumulative home ranges across all GPS collared greater sage-grouse, 2018–2022.

	55%			75%		95%	
Owner	**Area (km^2)**	**% HR**		**Area (km^2)**	**% HR**	**Area (km^2)**	**% HR**
BLM	0.00	0.0		0.02	0.0	2.00	0.9
USFS	0.08	0.3		0.46	0.8	5.87	2.7
State Trust	10.95	41.6		26.36	44.6	56.20	25.7
Private	15.26	58.1		32.28	54.6	154.73	70.7
Total	26.29	100.0		59.12	100.0	218.80	100.0

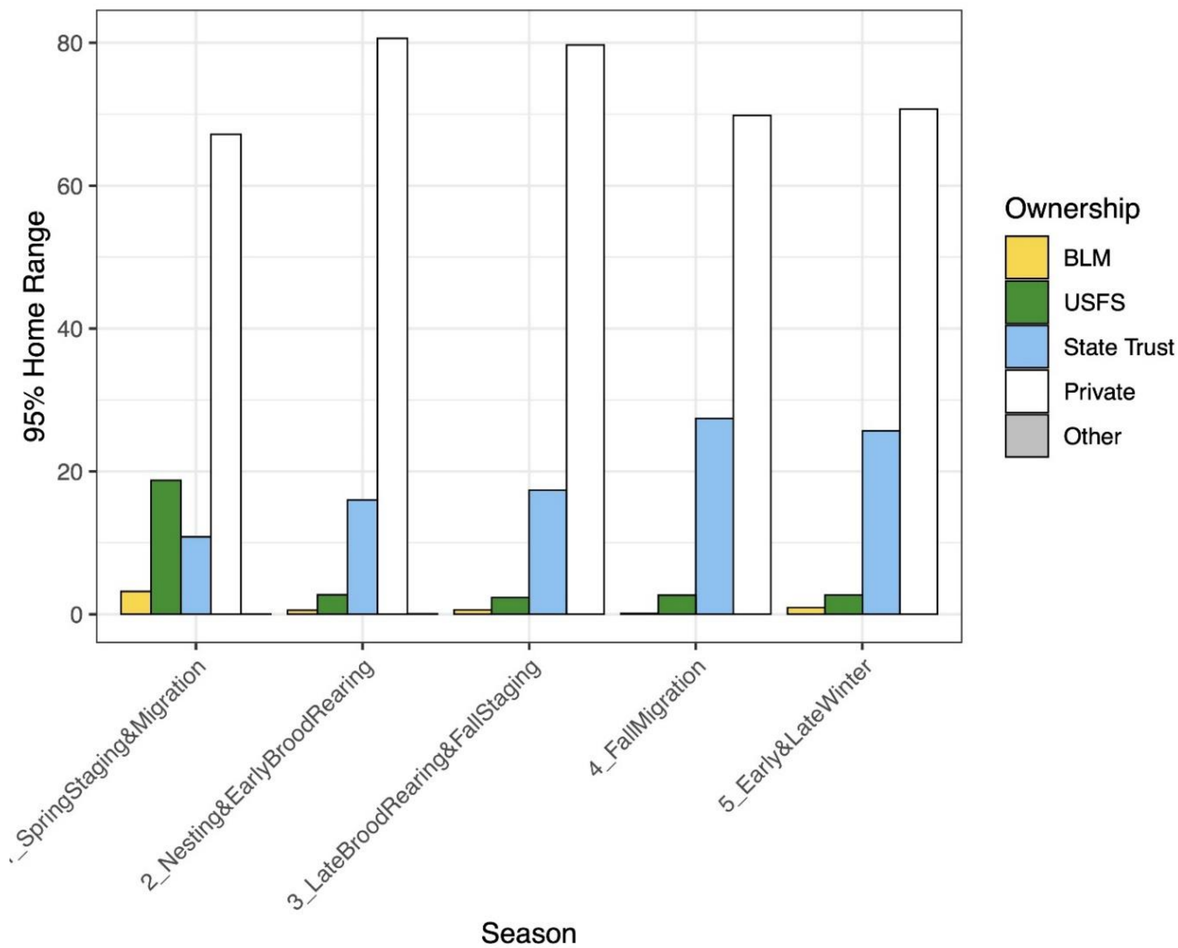

Figure 32. Land ownership (MTNHP 2011) within seasonal 95% cumulative home ranges across all GPS marked GSG hens, 2018–2022.

Categorization of Movement patterns

Connelly et al. (2000b) define three categories of sage grouse movement patterns:

(1) Nonmigratory (sage-grouse make 1-way movements <10 km between or among seasonal ranges)

(2) 1-stage migration (sage-grouse move ≥10 km between two distinct seasonal ranges)

(3) 2-stage migration (grouse move ≥10 km among three distinct seasonal ranges)

We used movement data from GPS marked GSG hens that were on the air for at least 75% of one full grouse year (i.e., beginning 0:00 Feb 13th and ending at 11:59 Feb 12th of the following year) to assess migration status using Connelly et al.'s (2000b) definitions (

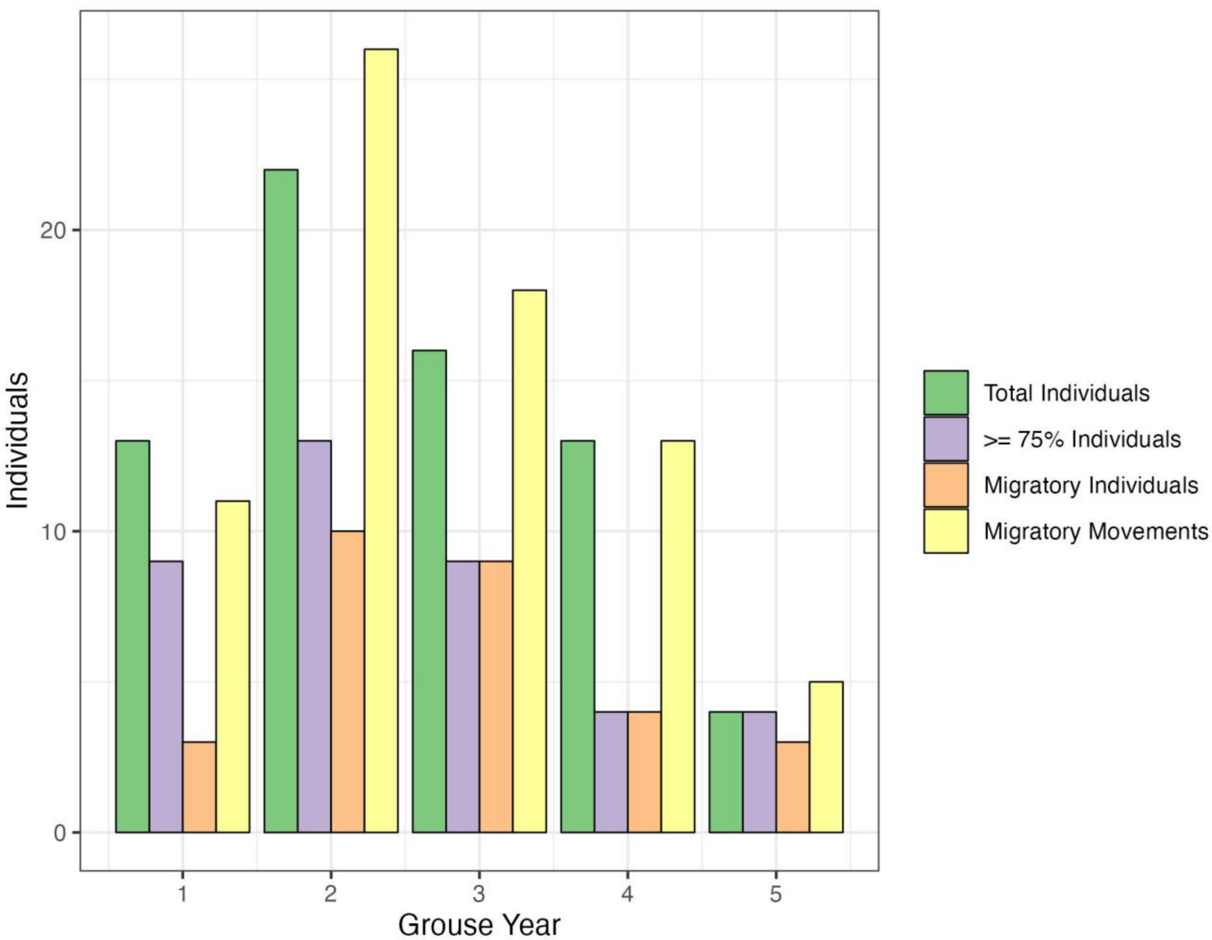

Figure 33). Because individuals were captured in April, birds captured and marked within a grouse year could still potentially transmit for 10 out of 12 months (83.3% of the year). Applying this to the UBHV study, it appears that greater sage-grouse employ all three migration strategies with the majority of the female segment of the population being nonmigratory (Table 12, Figures 34 and 35). The smallest number of movements ≥10 km was made during Nesting & Early Brood Rearing, while the greatest number of movements ≥10 km was made during Spring Staging & Migration and Late Brood Rearing & Fall Staging (Figure 35). We suspect the reason that "migratory" movements occurred outside of migratory seasons (those detected using changepoint analysis of mean net displacement) is due to two things: (1) the definition of a single date as the end point of a season, when in reality there is more variation in individual movement with individuals migrating or continuing to migrate after a season end date, and (2) the occurrence of smaller movements that just clear the 10 km threshold but that are not truly migratory. The plot of migratory individual net displacement (Figure 33) seems to confirm these conclusions.

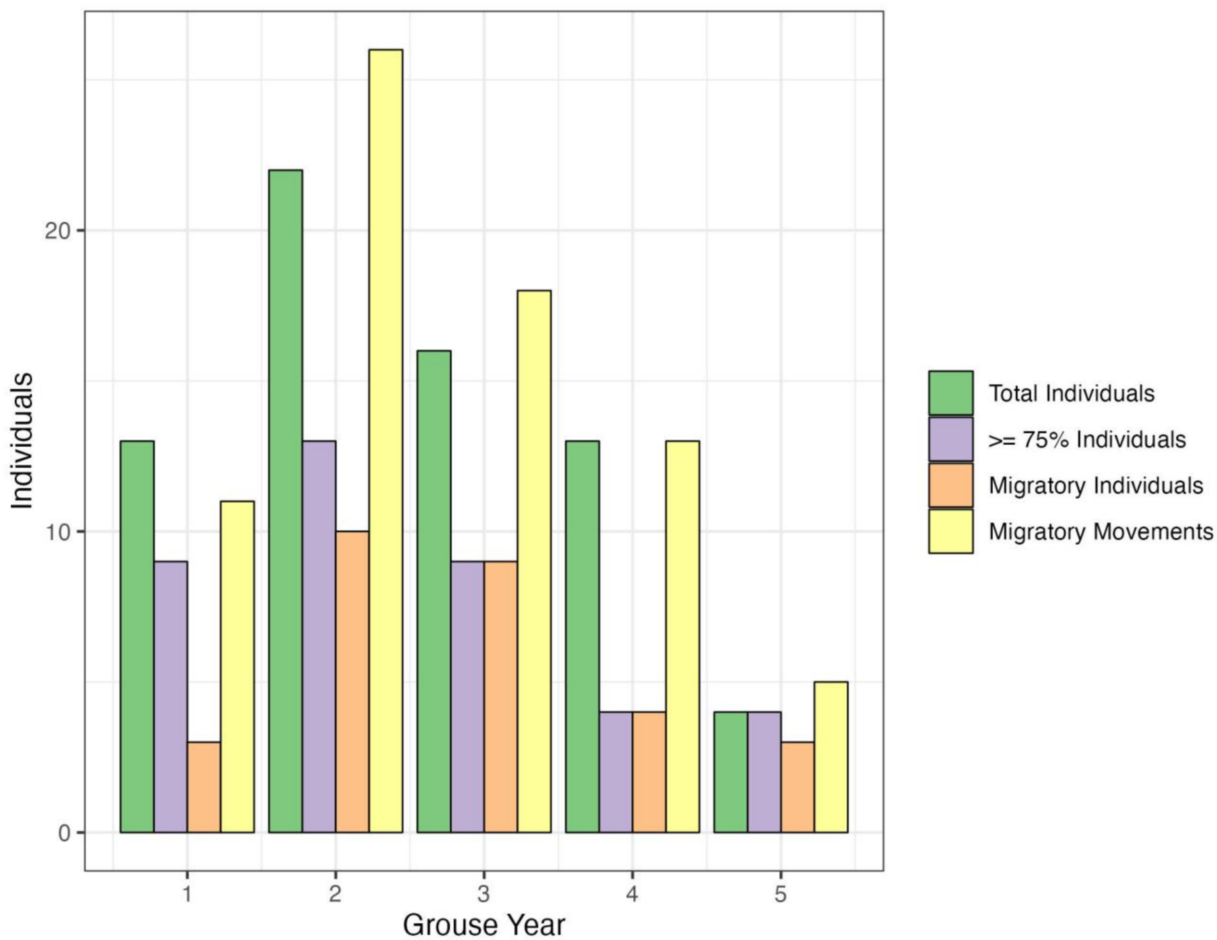

Figure 33: The total number of individuals, number of individuals on air >= 75% of the year, the number of individuals that moved >= 10 km at least once in the year, and the total number of movements >= 10 km.

Table 12. For each grouse year of this study, individual GSG hens that moved ≥10 km during a season and the seasons that the movement occurred. Many individuals made multiple "migratory" movements within a grouse year.

Grouse Year	Grouse ID (PTT [ID])	Season w/ >10 km
1	174160 [2018-13]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	174161 [2018-12]	3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	174166 [2018-04]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
2	174158 [2018-03]	1: Spring Staging & Migration
	174160 [2018-13]	1: Spring Staging & Migration
		2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	174162 [2019-06]	3: Late Brood Rearing & Fall Staging
		5: Early & Late Winter
	174163 [2018-11]	1: Spring Staging & Migration
	174166 [2018-04]	1: Spring Staging & Migration
		2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	174167 [2019-02]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
	174169 [2019-04]	4: Fall Migration
		5: Early & Late Winter
	177753 [2019-15]	3: Late Brood Rearing & Fall Staging
		4: Fall Migration

		5: Early & Late Winter
	177755 [2019-11]	3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	180302 [2019-07]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
3	143451 [2019-13]	1: Spring Staging & Migration
	174158 [2018-03]	1: Spring Staging & Migration
	174161 [2018-12]	1: Spring Staging & Migration
	174162 [2019-06]	1: Spring Staging & Migration
		3: Late Brood Rearing & Fall Staging
	174167 [2019-02]	1: Spring Staging & Migration
		3: Late Brood Rearing & Fall Staging
	177752 [2020-01]	3: Late Brood Rearing & Fall Staging
	177753 [2019-15]	1: Spring Staging & Migration
		2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	177754 [2020-02]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		5: Early & Late Winter
	177755 [2019-11]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
4	174162 [2019-06]	3: Late Brood Rearing & Fall Staging
	174167 [2019-02]	1: Spring Staging & Migration
		2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
	177746 [2021-03]	3: Late Brood Rearing & Fall Staging

		4: Fall Migration
		5: Early & Late Winter
	177753 [2019-15]	2: Nesting & Early Brood Rearing
		3: Late Brood Rearing & Fall Staging
		4: Fall Migration
		5: Early & Late Winter
5	174167 [2019-02]	1: Spring Staging & Migration
	177746 [2021-03]	1: Spring Staging & Migration
		2: Nesting & Early Brood Rearing
	177753 [2019-15]	1: Spring Staging & Migration
		2: Nesting & Early Brood Rearing

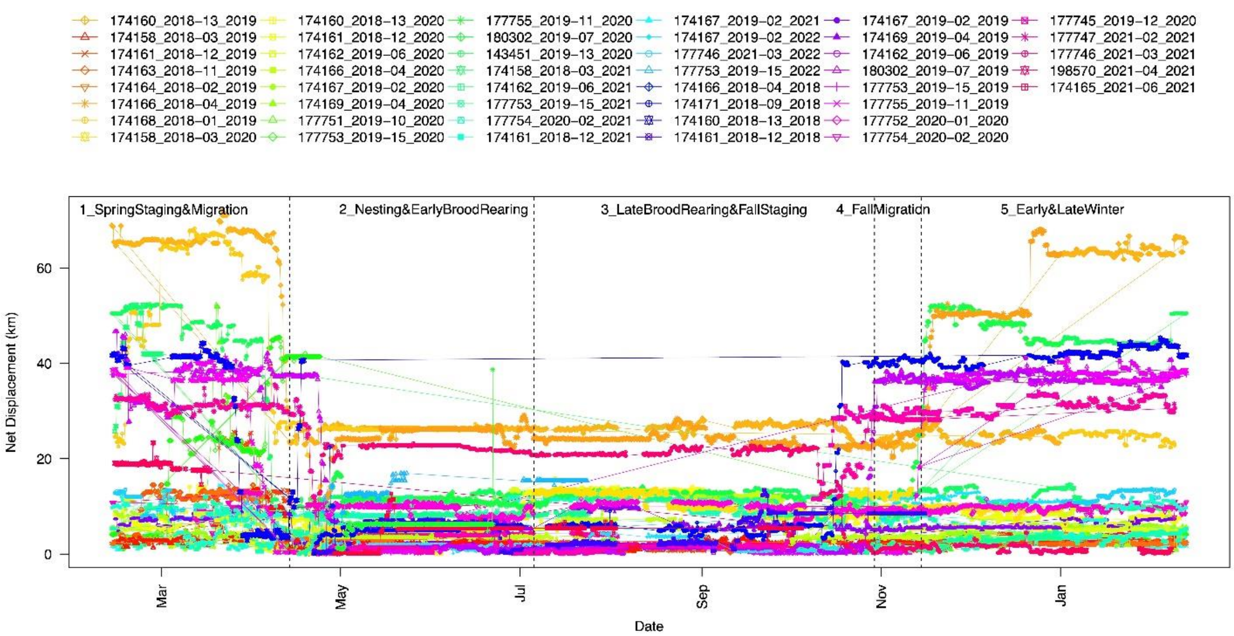

Figure 34. Net displacement of individual GSG hens classified as migratory (moving >10 km within each season) and across all years. IDs in legend are listed as PTT_ID, unique ID, year. Vertical dotted lines represent the seasonal delineation identified using the movement data herein and changepoint analysis.

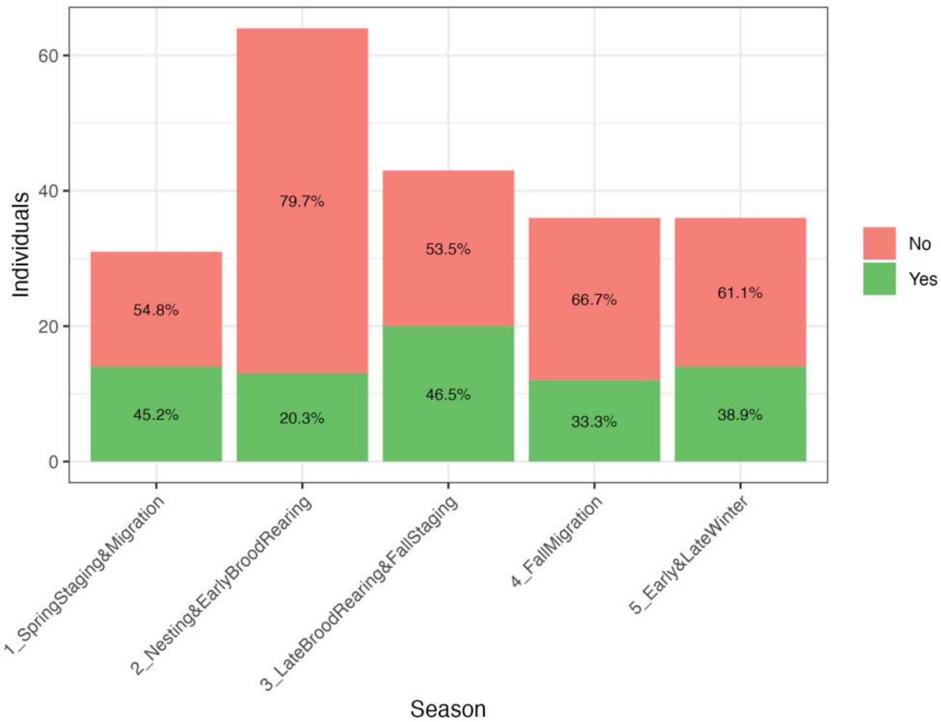

Figure 35. Seasonal (across all years) count and percent of individual GSG hens classified as migratory by Connelly et al. (2000b) standards (moving >10 km within each season). Bar height indicates the total number of individuals "on air" ≥ 75% of a particular season.

Lek Fidelity

We assessed fidelity to leks by examining movements of hens marked during two or more consecutive lekking periods (last week in March to 2nd week in May, n=8). Data suggests that hens in the UBHV displayed strong lek fidelity, attending no more than two lek/s consistently across years, and these leks being the same ones each year. Fidelity to lek sites as been well documented in greater sage-grouse populations (Dalke et al. 1963, Wallestad and Schladweiler 1974, Emmons and Braun 1984, Dunn and Braun 1985). Data from our study does not suggest an age-effect in lek fidelity, i.e. hens displayed lek fidelity regardless of age at Lek Season 1, although samples sizes were small for both yearlings (n=4) and adults (n=4) in Lek Season 1.

Fidelity to Nesting Areas

We assessed fidelity to nesting areas of GPS marked GSG hens in the UBHV (Table 13). The distance between a hen's nest in consecutive years averaged 0.64 km (SD = 1.05 km, n = 19) across all hens regardless of age or nest success at Year 1. Other studies found this distance to average 3.0 km (SD = 6.8 km) in Washington (Schroeder and Robb 2003), 2.0 km (SD = 5.5 km) in Montana (Moynahan et al. 2007), 0.7 km in Wyoming (Holloran and Anderson 2005), 2.4 km (SD = 0.1 km) in North Dakota (Herman-Brunson 2007) and 1.1 km (SD = 0.4 km) in South Dakota (Kaczor 2008). The smaller distance between consecutive nests found in this study can likely be attributed to the large extant of intact sagebrush communities in the UBHV, making it unnecessary for a hen to travel far to find a suitable nesting area.

When age in Year 1 is taken into consideration, the distance between nests in consecutive years for hens that were adults in Year 1 averaged 0.67 km (SD = 1.13 km, n = 14) while that for hens that were in their first breeding season ("yearlings") in Year 1 averaged 0.57 km (SD = 0.78 km, n = 5). This suggests that there does not seem to be an age-related period of establishment of nesting areas.

On average, hens whose nest failed in Year 1 moved further between consecutive nests than hens who successfully nested in Year 1 (0.92 km, SD = 1.38, n = 10 versus 0.32 km, SD = 0.19 km, n = 6, respectively). Studies in Colorado, Washington and Wyoming also found this to be the case (Hausleitner 2003, Schroeder and Robb 2003, Holoran and Anderson 2005), but not in the Dakotas (Herman-Brunson 2007, Kaczor 2008).

Greater distance between consecutive nests appeared to increase the likelihood of nesting success when a hen's nest failed in Year 1. The average distance between a nest that failed in Year 1 and that hen's successful nest in Year 2 was 1.2 km (SD =1.56, n = 7) while the average distance between a hen's failed nests in consecutive years was 0.27 km (SD = 0.16 km, n = 3).

The average distance between nests decreased with increasing number of years an individual hen nested during the study. The average distance between nests for hens that nested only 2 consecutive years was 1.06 km (n = 5), for hens that nested 3 consecutive years it was 0.70 km (n = 4), and for hens that nested 4 consecutive years it was 0.28 km (n = 2). This suggests that fidelity to nest site increases as the number of years nesting increases.

Table 13. Age at nesting, nest fate, and distance between nests in consecutive years for marked Greater sage-grouse hens in the Upper Big Hole Valley, April 2018–July 2021. Y=Yearling, A=Adult

ID	Unique ID	**Year 1**	**Year 2**	**Age @ Nest 1, Year 1**	**Age @ Nest 1, Year 2**	**Fate Nest 1, Year 1**	**Fate Nest 1, Year 2**	**Distance (km)**
174158	2018-03	2018	2019	Y	A	Fail	Success	0.181
174160	2018-13	2018	2019	A	A	Fail	Success	0.868
174161	2018-12	2018	2019	A	A	Success	Not Determined	0.374
174163	2018-11	2018	2019	A	A	Fail	Success	0.142
174158	2018-03	2018	2020	Y	A	Fail	Fail	0.225
174160	2018-13	2018	2020	A	A	Fail	Mortality	0.572
174161	2018-12	2018	2020	A	A	Success	Success	0.528
174158	2018-03	2018	2021	Y	A	Fail	Mortality	0.296
174161	2018-12	2018	2021	A	A	Success	Mortality	0.058
143451	2019-13	2019	2020	A	A	Success	Success	0.025
174158	2018-03	2019	2020	A	A	Success	Fail	0.089
174160	2018-13	2019	2020	A	A	Success	Mortality	0.491
174161	2018-12	2019	2020	A	A	Not Determined	Success	0.568

174162	2019-06	2019	2020	Y	A	Not Determined	Not Determined	0.114
174167	2019-02	2019	2020	Y	A	Fail	Success	2.098
177751	2019-10	2019	2020	Y	A	Fail	Success	0.027
177753	2019-15	2019	2020	A	A	Fail	Fail	0.223
177755	2019-11	2019	2020	A	A	Fail	Success	4.678
174158	2018-03	2019	2021	A	A	Success	Mortality	0.115
174161	2018-12	2019	2021	A	A	Not Determined	Mortality	0.393
174162	2019-06	2019	2021	Y	A	Not Determined	Fail	0.265
174167	2019-02	2019	2021	Y	A	Fail	Fail	2.216
177753	2019-15	2019	2021	A	A	Fail	Fail	0.274
174158	2018-03	2020	2021	A	A	Fail	Mortality	0.122
174161	2018-12	2020	2021	A	A	Success	Mortality	0.477
174162	2019-06	2020	2021	A	A	Not Determined	Fail	0.376
174167	2019-02	2020	2021	A	A	Success	Fail	0.457
177753	2019-15	2020	2021	A	A	Fail	Fail	0.482
177754	2020-02	2020	2021	Y	A	Fail	Success	0.421
Average distance between nests in consecutive years for all hens regardless of age or nest success at Year 1.						N=19	SD=1.05	0.64
Average distance between nests in consecutive years for hens that were yearlings in Year 1						N=5	SD=0.78	0.57
Average distance between nests in consecutive years for hens that were adults in Year 1						N=14	SD=1.13	0.67
Average distance between consecutive nests for hens who successfully nested in Year 1						N=6	SD=0.19	0.32
Average distance between consecutive nests for hens whose nest failed in Year 1						N=10	SD=1.38	0.92
Average distance between a nest that failed in Year 1 and that hen's successful nest in Year 2						N=7	SD=1.56	1.20
Average distance between a hen's failed nest in two consecutive years						N=3	SD=0.16	0.27
Average distance between nests for hens that nested only 2 consecutive years						N=5		1.06
Average distance between nests for hens that nested only 3 consecutive years						N=4		0.70
Average distance between nests for hens that nested only 4 consecutive years						N=2		0.28
Average distance for consecutive nests within years for adult hens.						N=5	SD=1.74	1.55

Average distance for consecutive nests within years for yearling hens.	N=4	SD=1.5 6	2.38

Within years, consecutive nests were closer together for adult than for yearling hens (1.55 km (SD = 1.74 km, n = 5 versus 2.38 km, SD = 1.56, n = 4, respectively) (Table 14). This suggests an age-related period of establishment. This behavior was also observed in Washington (Schroeder and Robb 2003).

Rotenberry and Wiens (2009) found that GSG hens continue to display nest fidelity even when the habitat has been substantially altered since the hen began nesting there. This suggests that the abundance of nests in an area may reflect previous rather than current habitat conditions (Rotenberry and Wiens 2009). Consequently, greater sage-grouse may not respond quickly to habitat changes. Knick and Rottenbery (2000) showed that several shrub-steppe avian species including Brewer's sparrow (*Spizella breweri*), horned lark (*Eremophila alpestris*), and sage sparrow (*Amphispiza belli*) seem to exhibit this "habitat memory" up to 10 years. Thus, population vital rates should be assessed over long intervals in order to make more effective management decisions (Taylor et al. 2012).

Table 14. Age at nesting, nest fate, and distance between nests within the same year for marked Greater sage-grouse hens in the Upper Big Hole Valley, April 2018–July 2021. Y=Year-ling, A=Adult

PTT ID	Unique ID	Year	Age @ Nest 1	Age @ Nest 2	Fate Nest 1	Fate Nest 2	Distance (km)
174159	2018-05	2018	A	A	Depre-dated	No Nest Found	2.19
174161	2018-12	2019	A	A	Not De-termined	Success	0.23
174163	2018-11	2018	A	A	Depre-dated	Depre-dated	0.22
174167	2019-02	2019	Y	Y	Depre-dated	Success	2.33
174168	2018-01	2018	Y	Y	Depre-dated	Depre-dated	2.12
177752	2020-01	2020	Y	Y	Not De-termined	Depre-dated	3.03
177753	2019-15	2020	A	A	Depre-dated	Depre-dated	3.79
177755	2019-11	2019	A	A	Depre-dated	Depre-dated	4.74
198570	2021-04	2021	Y	Y	Depre-dated	Depre-dated (+ Mortal-ity)?	4.71

BREEDING BIOLOGY

Breeding Period

Female attendance on leks in the UBHV appeared to be relatively synchronous, peaking during the 3rd week of April, with the exception of the Palisades lek at the far north end of the valley (Figure 36). Marked hens did not arrive at this lek until the 4th week of April, although samples size was low. Other studies found female lek attendance peaking in mid- to late March in Washington (Schroeder 1997); late March to early April in California (Bradbury et al. 1989) and Oregon (Hanf et al. 1994); and early to mid-April in Alberta (Aldridge and Brigham 2001), Colorado (Peterson 1980, Walsh 2002, Hausleitner 2003), Montana (Jenni and Hartzler 1978), and Wyoming (Patterson 1952). Eng (1963) found females irregularly visiting leks later in the breeding season due to renesting efforts.

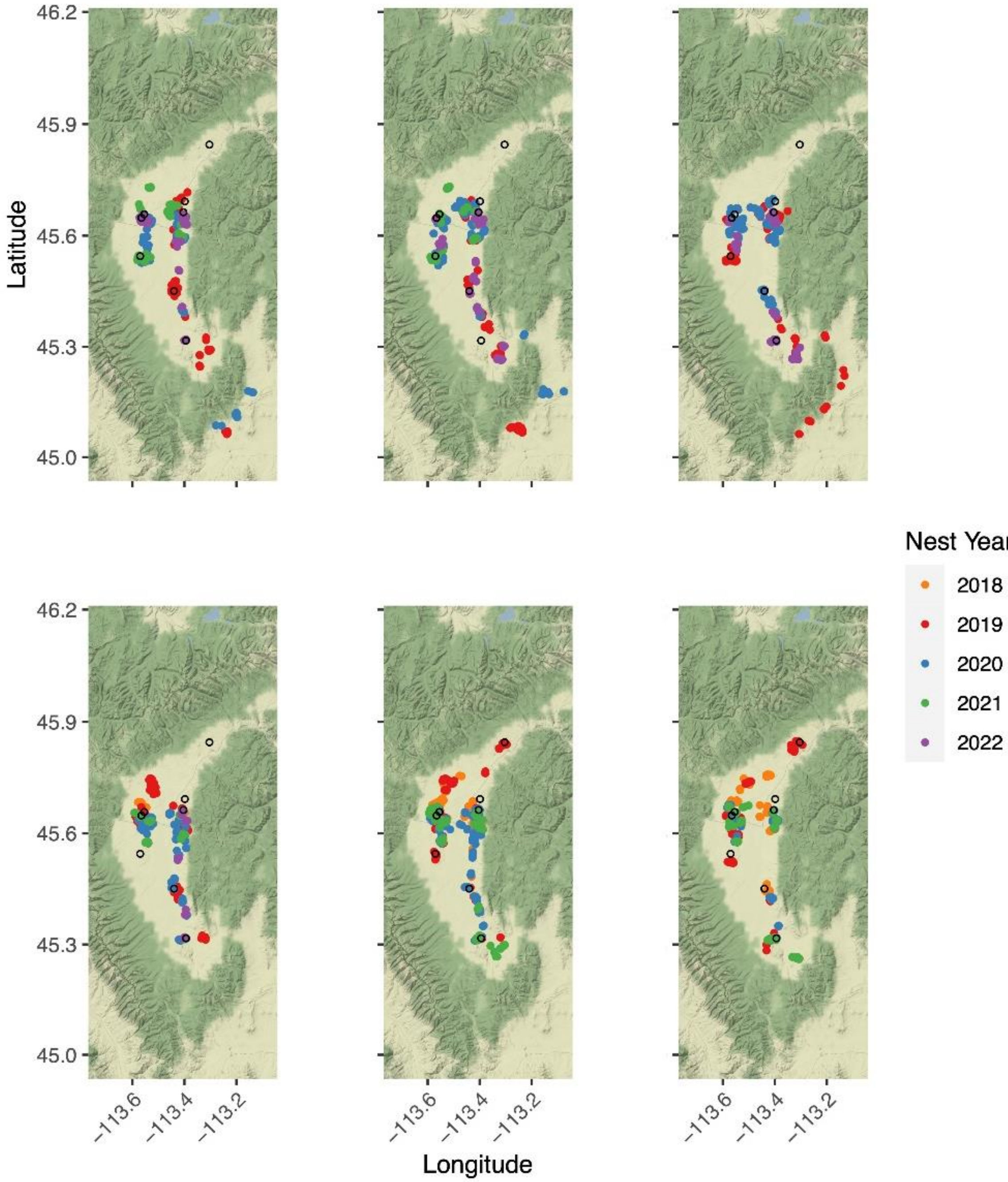

Figure 36. GSG hen locations (colored by year) and known active leks (black open circles) for each week of the lekking season (left to right, top to bottom) in the Big Hole Valley, MT. The weeks are as follows: (1) 3/24–30, (2) 4/1–7, (3) 4/8–14, (4) 4/15–21, (5) 4/22–28, (6) 4/29–5/4.

Nest Location

We used movement data from marked hens to determine nest locations by identifying where GPS points were tightly clustered in space and time during the nesting/early brood-rearing season. Sixty nests from 31 marked hens were identified (Figure 37). Of these, 95% of the nests occurred within 7.75 km of known leks and the average distance between a female's nest and the nearest lek was 3.51 km (Figures 38, 39, 40). Early synthesis of sage-grouse biology and management guidelines indicated that most females nest within 3.2 km of a lek (Braun et al. 1977). Other studies have found the average distance between a female's nest and the nearest lek to be 1.3–1.5 km in Idaho (Wakkinen et al. 1992, Fischer 1994), 2.7 km in North Dakota (Herman-Brunson 2007), 2.8 km in Colorado (Petersen 1980), 4.9 km in Alberta (Aldridge 2005) and 5.1 km in Washington (Schroeder et al. 1999).

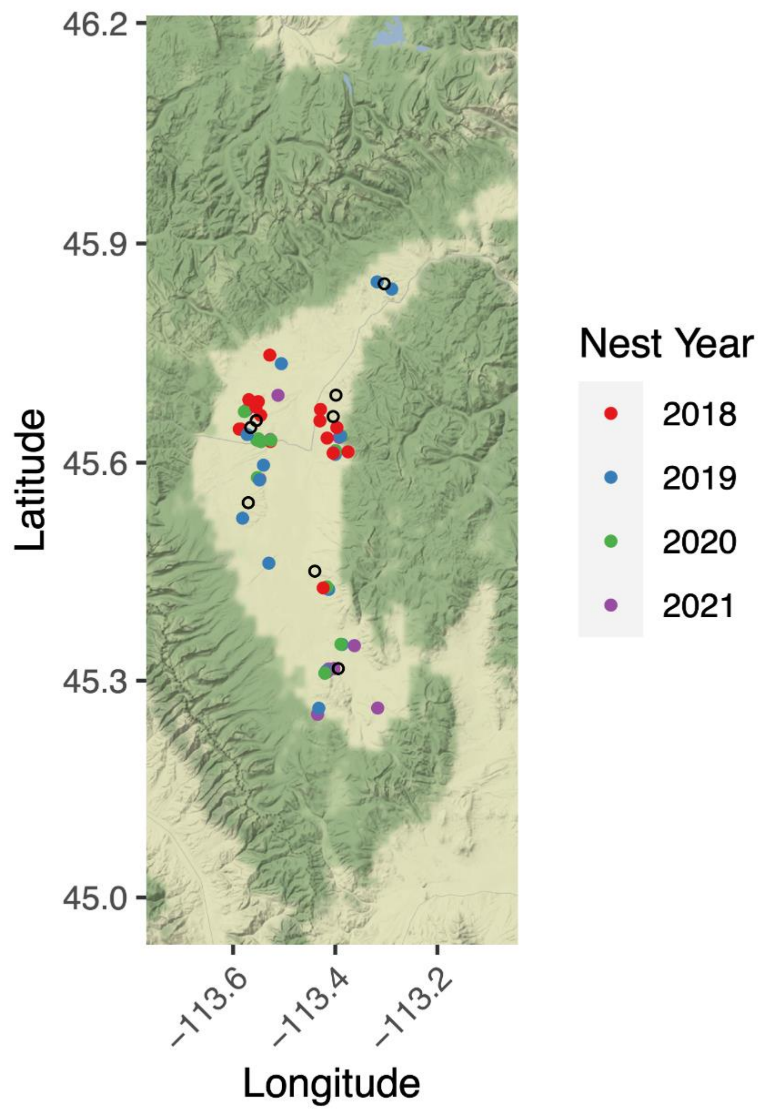

Figure 37. Greater sage-grouse nest locations (colored by year) and all known active leks (black open circles) in the Big Hole Valley of Montana.

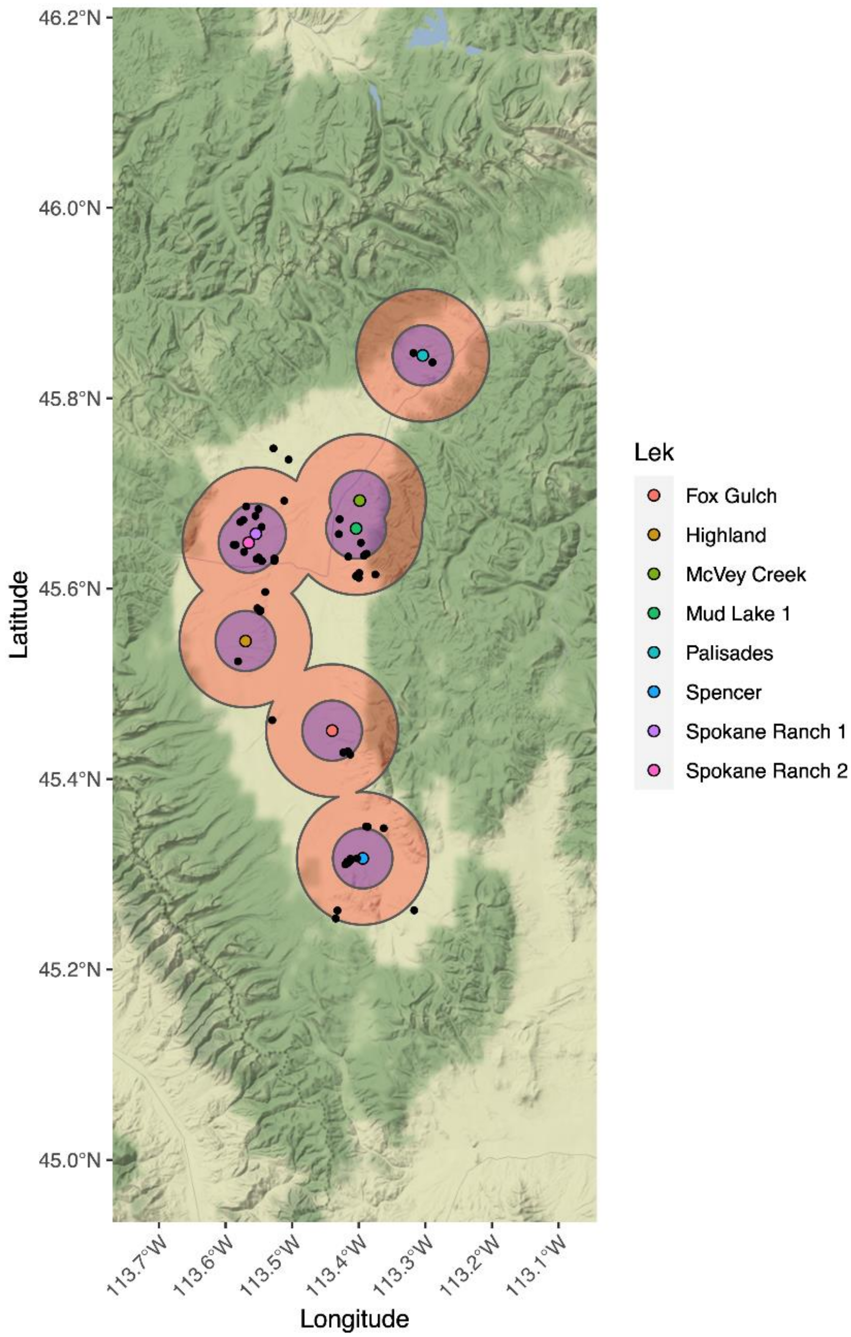

Figure 38. Greater sage-grouse nest locations in the Big Hole Valley (black points) with colored polygons showing the mean (3.51 km, purple) and 95th percentile (7.75 km, red) distances from nest to nearest known lek (colored points).

Mean distance between a female's nest and her lek of capture was 2.18 km greater than the distance to the nearest lek which averaged 3.51 km (Figures *39* and *40*), although 5 individuals travelled > 10 km between lek of capture and nest site, and one individual (2018-13) never nested closer over three years 2018–2020. For most of the hens this distance was <10 km. Other studies found this mean distance between nest and lek of capture to be 8.6 km in west-central Wyoming (Lyon 2000), 2.7 km in central Montana (Wallestad and Pyrah 1974), and 4.0 km in Colorado (Hausleitner 2003). The larger distances between a hen's nest and lek of capture could be attributed to the fact that hens may not have been captured at the lek nearest their nest (Peterson 1980, Wakkinen et al. 1992, Fischer 1994, Schroeder et al. 1999).

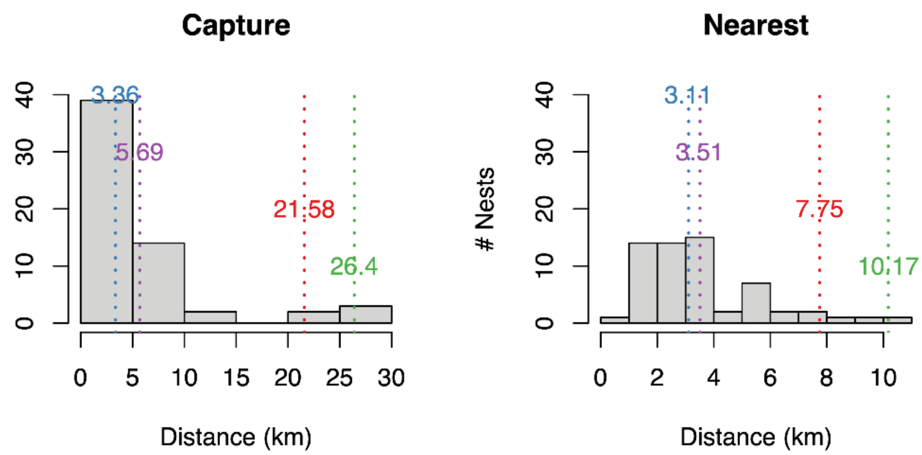

Figure 39. Distribution of distances from nest to lek of capture (left) and to nearest active lek (right) also showing median (blue), mean (purple), 95th percentile (red) and max (green). Note the different scales on the X-axes.

We hypothesized that yearling hens would nest closer to their lek of capture compared to adults. However, there was no statistical support for this hypothesis (*Mann-Whitney* **U**: W = 460, p = 0.7838; Figure 38), nor was there support for yearlings nesting closer to the nearest lek when compared to adults (*Mann-Whitney* **U**: W = 403, p = 0.4633). All nesting attempts of all hens were included in these analyses.

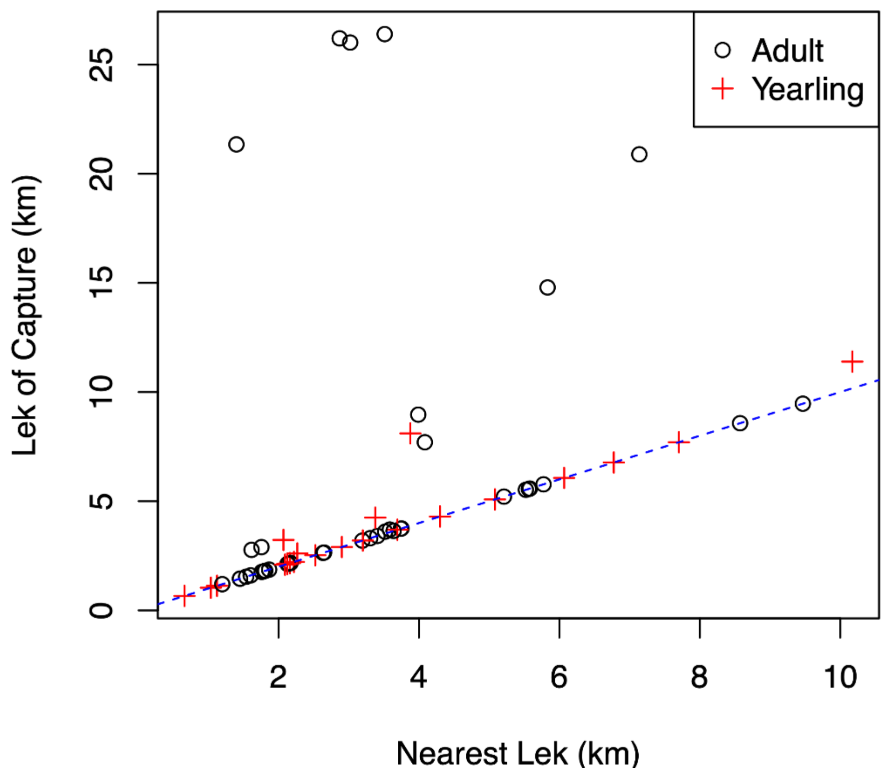

Figure 40. Distance from nest to nearest active lek and lek of capture. Points along dotted line represent hens that nested near their lek of capture while points above the line represent hens that nested closer to a lek other than their lek of capture. Open black circles represent adults while red plus signs represent yearlings.

Juxtaposition of habitats, disturbance and extent of habitat fragmentation may influence location of nests with respect to leks (Lyon and Anderson 2003, Connelly et al. 2004, Schroeder and Robb 2003). Females in highly fragmented habitats of Washington moved almost twice as far to nest (Schroeder et al. 1999) as females in relatively intact habitats of southeastern Idaho (Wakkinen et al. 1992, Fischer 1994). Similarly, females from undisturbed leks in southwestern Wyoming moved an average of 2.1 km to nests, while females from disturbed leks moved 4.1 km (Lyon and Anderson 2003). The fact that hens in the UBHV move a relatively short distance from lek to nest suggests healthy, intact sagebrush communities with little to no disturbance at leks.

Timing of Nesting

Prior to incubation, movement data suggested that hens made routine visits to the nest to lay eggs but otherwise moved about the nest area. Once incubation began, it appeared that the hen rarely left the nest, as suggested by tightly clustered GPS locations over multiple days. Given this behavior pattern, we estimated the start of incubation as the day the hen stopped making regular movements around the nest area and the end of incubation when the hen started to move away from the nest. We did not visit the nest during this time to minimize disturbance. If a hen moved away from the nest prior to the expected hatch date and didn't return, this suggested a failed nest and we conducted a field investigation as soon as possible to determine cause of failure. If a nest survived to hatch date, we would conduct a field investigation as soon as movement data suggested that the hen moved off the nest with her brood.

During the period of this study, we observed a total of 60 nest attempts from 31 marked hens (15 attempts in 2018, 20 in 2019, 13 in 2020 and 12 in 2021). We detected the start of incubation from April 29 through May 27 for first nest attempts (n=51, Figure 41) and May 21 through June 12 for renest attempts (n=9). Other studies found renesting stretching into early July (Schroeder et al. 1999, Gregg 2006).

We converted calendar dates to Julian dates to calculate average start of incubation by year. This yielded incubation start dates of May 16, May 13, May 16 and May 14 for 2018, 2019, 2020 and 2021, respectively, suggesting no year effect on the start of incubation. Doing the same for age at time of nesting, we calculated incubation start dates of May 16 and May 14 for yearling (n=17) and adult (n=34) hens, respectively, suggesting no age effect on the start of incubation. In north-central Washington adults started incubation on average nine days earlier than yearlings (Schroeder 1997). We found the incubation period to average 27 days (n=17). This is consistent with findings from other studies (Schroeder et at. 1999).

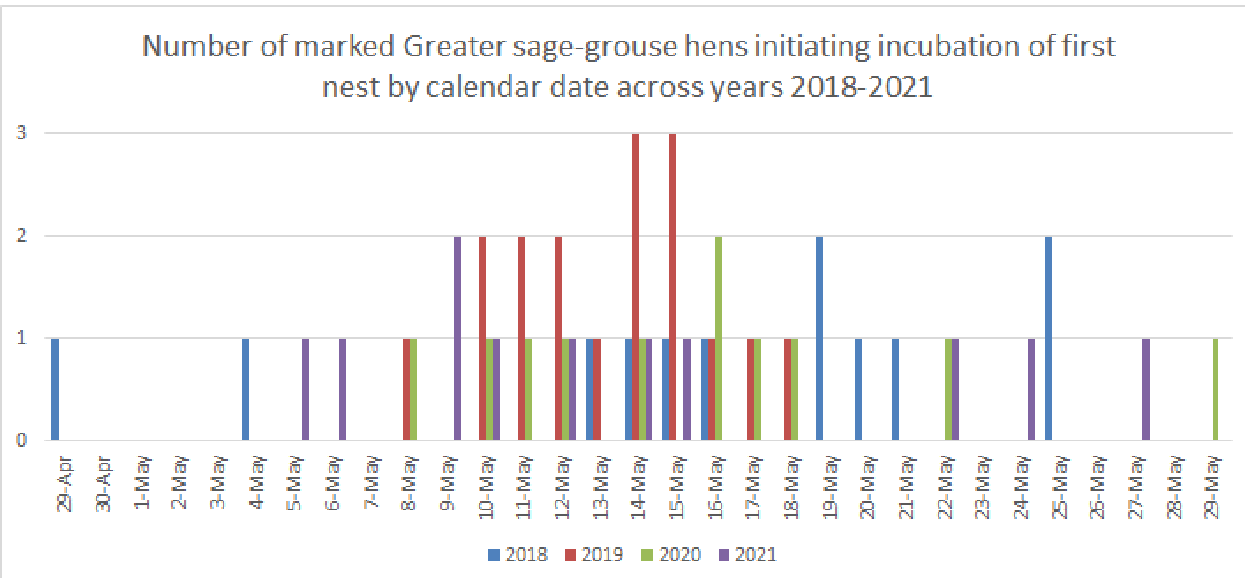

Figure 41. Number of GPS marked GSG hens in the Upper Big Hole Valley that initiated incubation by calendar date across all years of the study, 2018–2022.

Clutch Size

Where it could be determined, clutch size ranged from 5–10 eggs with an average of 7 (n=29). This is consistent with findings in Colorado (Peterson 1980, Hausleitner 2003) and Wyoming (Patterson 1952, Holloran 2005) while studies in Alberta (Aldridge and Brigham 2001), Montana (Wallestad and Pyrah 1974, Moynahan 2004) and South Dakota (Herman-Brunson 2007) found average clutch size of 8 eggs.

We found variation in clutch size by age and nesting attempt. Clutch size for first nest attempts averaged 7 eggs (n=9) for yearling hens and 8 eggs (n=16) for adult hens. When ages were combined, the average clutch size for first nest attempts was 8 eggs (n=25) and 6 eggs for renests (n=4). Other studies also found variation in clutch size attributed to age (Wallestad and Pyrah 1974, Petersen 1980, Hausleitner 2003) and nesting attempt (Kaczor 2008). Caution is advised in interpreting these results since clutch size estimates were based on post-hatching nest examinations and partial clutch loss may have occurred prior to hatch.

Nest Likelihood

The likelihood of a greater sage-grouse nesting (1st nest attempt) during the period of this report was 94% (n=54). This is higher than the average likelihood of 78% reported for the western portion of the species' range (Knick and Connelly 2011). Assessed by age category, the nest likelihood was 85% (n=20) for yearlings and 100% for adults (n=34). This is consistent with findings from studies in Idaho (Connelly et al. 1993, Wik 2002) and Wyoming (Holloran 2005) that found nest initiation rates of 55–79% for yearlings and 78–100% for adults, although our rates were higher, especially for yearling hens.

The likelihood of renesting when the first nest attempt failed was 28% (n=25). This is consistent with an average likelihood of 30% reported for the western portion of the species' range (Knick and Connelly 2011). Assessed by age category resulted in 25% likelihood for yearlings (n=12) and 29% likelihood for adults (n=14).

Nest Success

Nest success for all known-fate nests, pooled across all marked hens and years of this study, averaged 32% (n=54) and ranged from 8–50% during 2018–2022. A nest was considered successful if ≥1 egg hatched. Nest success averaged 33% for both 1st nest attempts (n=46) and 2nd nest attempts (n=6). Apparent nest success in central Montana ranged from 30 – 71% during 2011 – 2020 (Berkeley et al. 2020). Reported nest success for Greater sage-grouse elsewhere across the species' range vary between 15 – 86%, depending on habitat condition, methodology and female age (Knick and Connelly 2011). Of the 29 studies reporting nest success rates in Knick and Connelly (2011, Table 3.3 therein), 23 reported greater success than what we found in the UBHV. It is likely that nest success for the UBHV would have been higher except for two years (2020 and 2021) of exceptionally wet, cold weather during the period when many nests were expected to hatch. Berkeley et al. (2020) found that greater amounts of rainfall over a 4-day period prior to the occurrence of nest fates were associated with lower daily nest survival.

Nest desertion by Greater sage-grouse is relatively common during laying and early incubation. Because of this, we avoided checking nests prior to expected hatch date. Therefore, abandonment did not appear to be a factor in our study.

We found nest success of adult hens to be numerically greater than that of yearlings (44%, n=32 versus 7%, n=14, respectively). This is consistent with findings reported in Knick and Connelly (2011, Table 3.3 therein) where 13 of 15 radiotelemetry studies found the same age-effect. Sample sizes were too small in our study to assess for age effect of 2nd nests. Most failed nests in this study were caused by mammalian predators, e.g., red fox *(Vulpes vulpes*), coyote *(Canis latrans*) and striped skunks (*Mephitis mephitis),* (Figure 42).

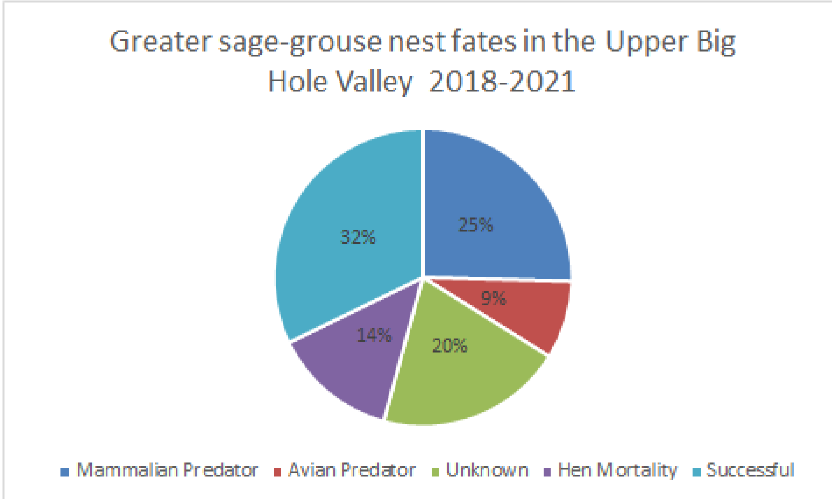

Figure 42. Summary of nest fates for GPS marked GSG hens in the Upper Big Hole Valley, 2018–2022.

Annual Reproductive Success

Annual reproductive success (probability of a female hatching ≥1 egg in a season) is more complex than nest success because it includes the likelihood of nesting and renesting. For our study, we found 31% of females successfully hatched one or more eggs in the first nest attempt (94% likelihood of 1st nest X 33% average 1st nest success). When renest attempts are considered (28% likelihood of renest X 33% average renest success) the average annual reproductive success for the UBHV increased to 37% with 9% of the average annual productivity due to renesting. This is consistent with the average annual reproductive success derived from 16 studies from the eastern portion of the species' range (Knick and Connelly, 2011).

NESTING HABITAT

Greater sage-grouse nesting habitat usually includes a broad area within or adjacent to winter range or between winter and summer range (Klebenow 1969, Wakkinen 1990, Fischer 1994) dominated by sagebrush with horizontal and vertical structural diversity (Wakkinen 1990, Gregg 1991, Schroeder et al. 1999, Connelly et al. 2000). The understory of nesting habitat is composed of native grasses and forbs that provide herbaceous forage for pre-laying and nesting hens, concealment of the nest and hen, and a food source of insects (Gregg 1991, Schroeder et al. 1999, Connelly et al. 2000, Holloran et al. 2005). In the UBHV, nesting habitat is dominated by Mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*) and perennial grasses such as Idaho fescue (*Festuca idahoensis*) and Bluebunch wheatgrass (*Pseudoroegneria spicata*). The habitat supports a variety of perennial forbs with the most prevalent species being Pussytoes (*Antennaria spp.*), Sulphur buckwheat (*Erigonum umbellatum*), and Common yarrow (*Achillea millefolium*).

From 2018 to 2022, nest site characteristics were measured and recorded at all known nests from marked Greater sage-grouse hens in the UBHV. Measurements of both the **nesting site** and **nest shrub** were collected. Vegetation measurements were made as close to the date of expected hatch as possible, regardless of nest fate. The Beaverhead-Deerlodge National Forest's (USFS) Botany/Wildlife crew conducted all nesting site assessments. Nest shrub assessments were done by the USFS crew and FWP. Data was used to describe vegetative characteristics of Greater sage-grouse nests in the UBHV, show how those characteristics might affect nest success, and compare our findings to those in Connelly et al. (2000b).

Nesting Site Characteristics

Nesting site vegetation was sampled using the 4th Order Habitat Assessment Framework (HAF) protocol outlined by Stiver et. al. (2015). Habitat suitability at this scale describes the more detailed vegetation indicators such as canopy coverage, height and shape of sagebrush and the associated understory vegetation. Based on extensive research in many western states, Connelly et al. (2000b) developed, and Hagen et al. (2007) reviewed, habitat criteria or indicators required by Greater sage-grouse for specific seasonal needs. While general criteria were recommended, Connelly et al. (2000b) recognized that ecological site potential should be considered at the site scale. Generally, suitable nesting habitat provides appropriate protective cover (sagebrush and herbaceous plants), food (forbs, insects, and sagebrush), and security (few or no trees or tall structures for predators) (Connelly et all. 2000b; Sather-Blair et al. 2000).

For the UBHV study, we assessed cover and food characteristics at each nesting site. We did not assess potential predator perches, e.g., trees, tall structures, fence posts, etc. nor did we conduct HAF surveys at paired random sites. Vegetation data were collected using line point intercept (LPI) methodology and a 3-spoke design originating at the nest shrub. The three transect spokes oriented radially from the nest shrub and were 54m long, at 120° intervals, creating a “plot” of 2.26 acres. The following vegetation characteristics were collected within each plot: sagebrush cover (%), sagebrush height (cm), sagebrush shape (spreading or columnar), perennial forb cover (%), perennial forb height (cm), perennial grass cover (%), perennial grass height (cm), and the number of Greater sage-grouse preferred forbs. We also recorded the number of active ant mounds within each plot (2020-2022) because this represents an important GSG food source. Mounds were counted as observers systematically walked between each transect spoke. Mounds were considered active if there were >12 ants on the surface.

Sagebrush plants that are more tree- or columnar-shaped, with no or few lower branches, provide less protective cover near the ground than sagebrush plants with a spreading shape. Basin big sagebrush (*Artemisia tridentata spp. tridentata*) plants often have this columnar shape, as do other sagebrush species or subspecies that have been heavily browsed or rubbed. Sagebrush communities in which the columnar shrub shape is predominant are assumed likely to require more herbaceous cover to compensate in providing adequate protection for nesting sage-grouse and young broods. Conversely, in suitable habitat, the spreading shape should be predominant; however, there may be a small proportion of columnar plants present.

Preferred Greater sage-grouse forbs in the UBHV include 20 perennial species and 2 annual species (Stiver et al. 2015; Table 15).

Table 15. Greater sage-grouse preferred forbs in the Upper Big Hole Valley.

Scientific name	Common name	Annual or Perennial
Achillea millefolium	Common yarrow	Perennial
Agoseris glauca	Pale agoseris	Perennial
Antennaria spp.	Pussytoes	Perennial
Astragalus agrophyllus	Silverleaf milkvetch	Perennial
Balsamorhiza sagittata	Arrowleaf balsamroot	Perennial
Collinsia parviflora	Blue eyed Mary	Annual
Eriogonum umbellatum	Sulphur-flower buckwheat	Perennial
Fritillaria pudica	Yellow fritillary	Perennial
Geranium viscosissimum	Sticky purple geranium	Perennial

Linanthus ssp.	Linanthus	Perennial
Lomatium triternatum	Nineleaf biscuitroot	Perennial
Mertensia oblongifolia	Oblongleaf bluebells	Perennial
Microseris spp.	Silverpuffs	Perennial
Penstemon procerus	Littleflower penstemon	Perennial
Phlox hoodia	Spiny phlox	Perennial
Phlox longifolia	Longleaf phlox	Perennial
Sedum lanceolatum	Spearleaf stonecrop	Perennial
Senecio integerrimus	Lambstongue ragwort	Perennial
Solidago missouriensis	Missouri goldenrod	Perennial
Taraxacum officinale	Common dandelion	Perennial
Trifolium spp.	Clover	Annual
Viola nuttallii	Nuttall's violet	Perennial

We used analysis of variance (ANOVA) to estimate how vegetation cover, height, and shape varied by year, and how those vegetative characteristics affected nest fate (successful or depredated). We used linear regression (lm) to estimate how vegetation characteristics affected ant mound abundance. Data from all years were combined to assess trends. Nests whose fate were undetermined were not used in the analyses.

Habitat data was recorded at 58 nests from 2018 to 2022 (Table 16). Percent cover within vegetation type varied across years yet the relative abundance of percent cover from each vegetation type was constant across years, i.e. grasses contributed most of the cover, followed by sagebrush, then forbs (Figure 43). Grass cover decreased from 2018 to 2021 and was highest in 2018 (ANOVA, $F = 5.02$, $p < 0.001$; Tukey HSD, $p < 0.05$), while sagebrush and forb cover remained relatively consistent ($p > 0.05$). Sagebrush provided most of the structural height at nesting sites across all years (Figure 44). Sagebrush (ANOVA, $F = 2.54$, $p = 0.05$), forbs ($F = 3.76$, $p = 0.01$), and grass ($F = 3.20$, $p = 0.02$) height varied by year. Sagebrush was taller in 2019 than 2018 (Tukey HSD, $p < 0.05$), and forb and grass height varied from 2018 to 2021 ($p < 0.05$). Columnar shaped sagebrush plants averaged <15% of all sagebrush plants at nest sites, regardless of year, suggesting that most sites had adequate spreading sagebrush that could provide GSG hen concealment (Figure 45).

Table 16. Number of nests by fate from marked Greater sage-grouse hens in the Upper Big Hole Valley, 2018–2022.

Year	***Successful Nests***	***Depredated Nests***	***Undetermined***	***Total Nests***
2018	1	10	0	11
2019	9	8	1	18
2020	5	6	2	13
2021	3	8	0	11
2022	0	5	0	5
Total	**18**	**37**	**3**	**58**

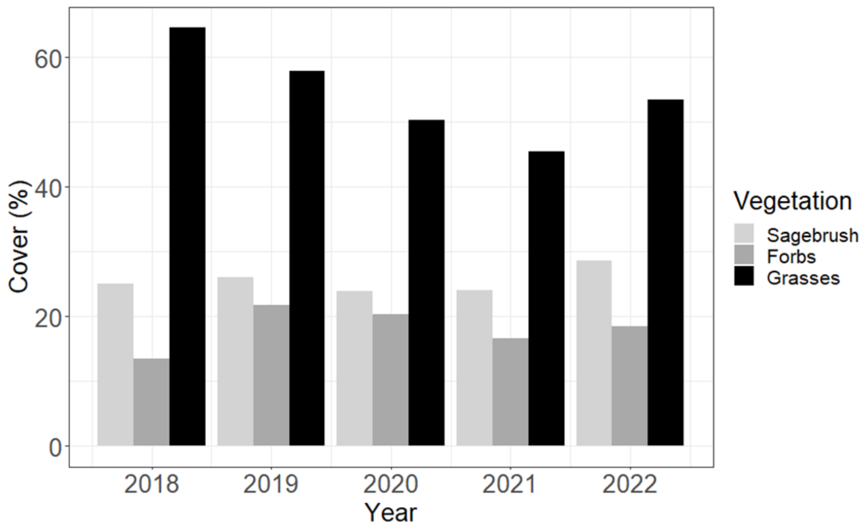

Figure 43. Percent cover of sagebrush, forbs and grasses at nest sites of GPS marked GSG hens in the Upper Big Hole Valley, 2018–2022. While there is variability within vegetation type across years, the relative abundance of % cover from each vegetation type is constant.

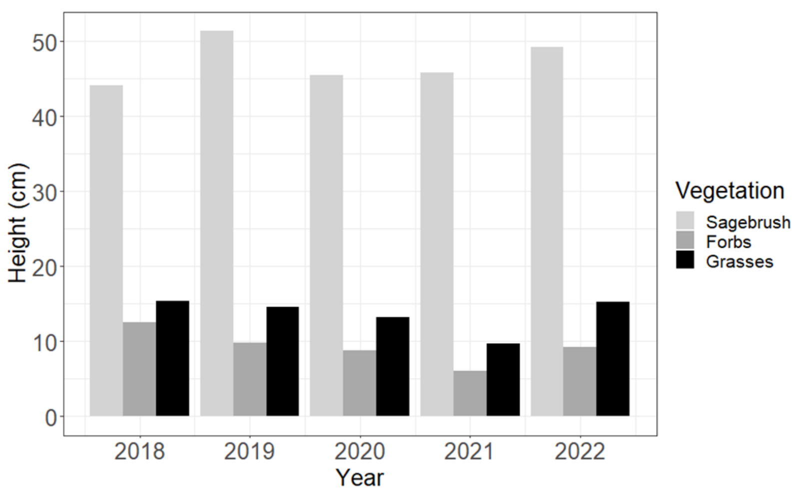

Figure 44. Average height of sagebrush, forbs and grasses at nest sites of GPS GSG hens in the Upper Big Hole Valley, 2018–2022. Most of the structural height for concealment comes from sagebrush.

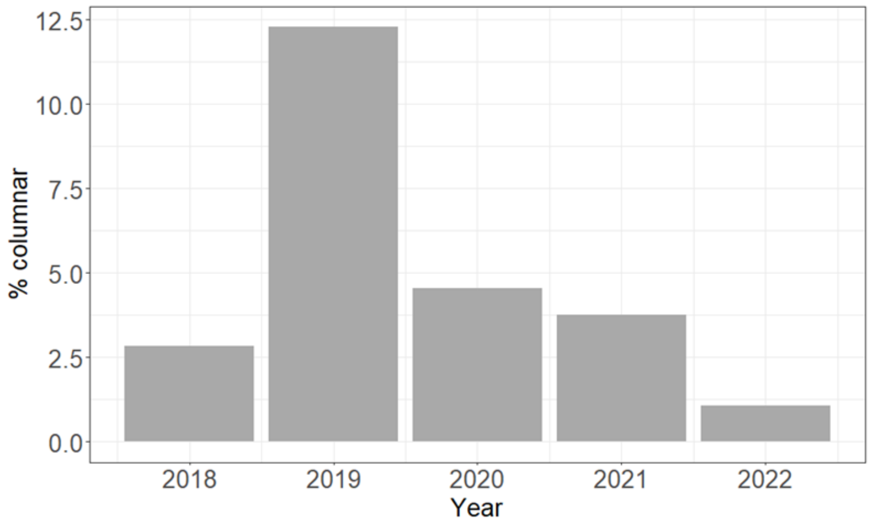

Figure 45. Percent sagebrush plants within nest sites having a columnar versus spreading shape, aver-aged by year, 2018–2022.

The average number of preferred forbs for sage-grouse at nesting sites ranged from 15–19 species across all years, with some annual variation (ANOVA, $F = 3.77$, $p = 0.01$; Figure 46). The number of active ant mounds ranged from 20–41, with annual variation (ANOVA, $F = 2.84$, $p = 0.07$; Figure 46). There were less preferred forbs in 2022 than 2019 (Tukey HSD, $p < 0.05$); however, this is unexpected because 2022 was a wet spring and was noted for abundant wildflowers, but possibly was due to a delayed onset of spring growth due to the cold temperatures. There were more ant mounds in 2022 than 2020 and 2021 ($p = 0.08$), but more data is needed to observe a stronger trend.

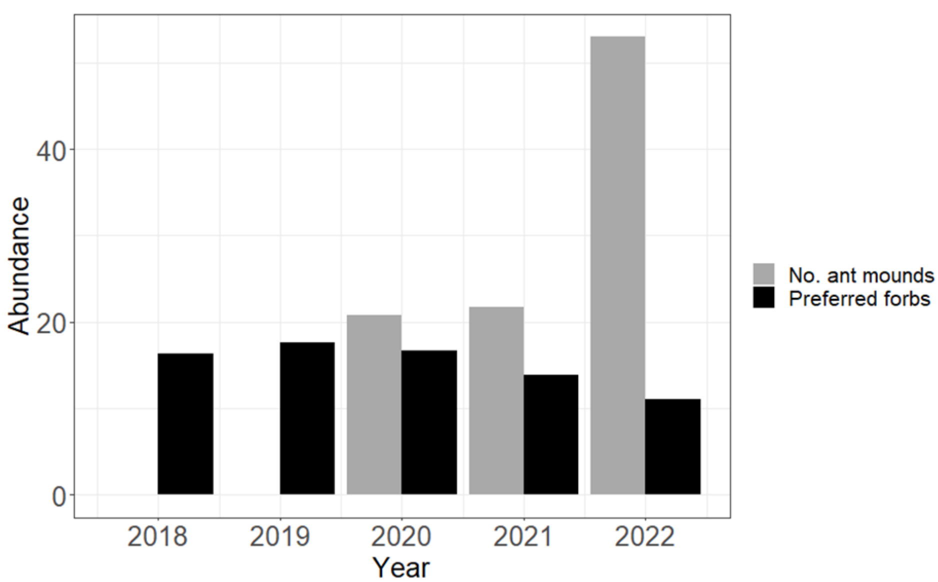

Figure 46. The yearly average number of greater sage-grouse preferred forb species and the number of active ant mounds at nesting sites of GPS marked GSG hens in the Upper Big Hole Valley, 2018–2022. Data on ant mounds was not collected in 2018 and 2019.

Vegetative characteristics were poor indicators of sage-grouse nest success, likely because of limited sample size (n = 55) and highly variable vegetation characteristics between years. Neither vegetative cover (ANOVA, F = 0.12 – 1.12, p = 0.29 – 0.72; Figure 47), vegetative height (F = 0.02 – 1.5, p = 0.22 – 0.87; Figure 48), or sagebrush shape (F = 0.55, p = 0.46; Figure 49) explained variance. Smith et al. (2020) found context-dependent and generally weak relationships between fine scale measurements and both nest site selection and survival.

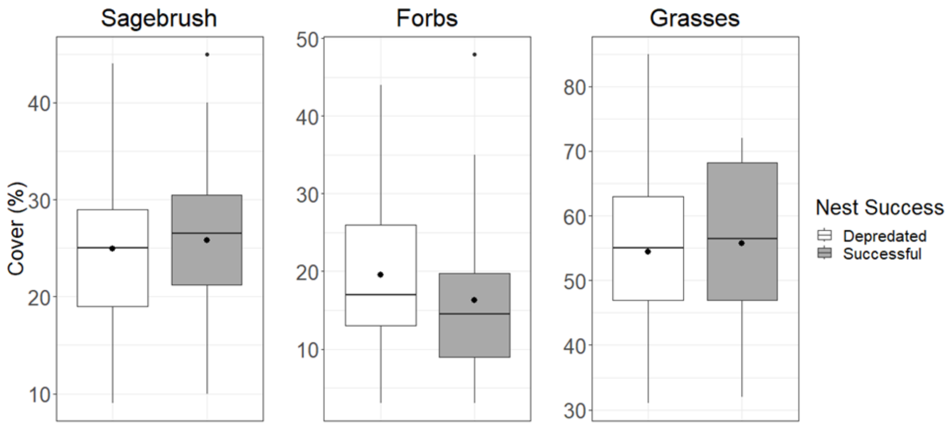

Figure 47. Nest fate of GPS marked GSG hens in the Upper Big Hole Valley relative to percent cover averaged across all years of three vegetation types at the nesting site (sagebrush, forbs and grasses). There was no significant difference in nest fate within or between vegetation types.

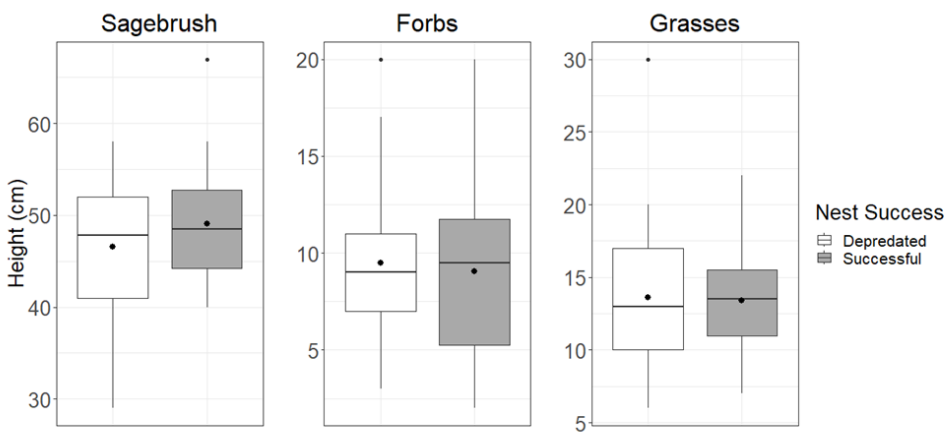

Figure 48. Nest fate of GPS marked GSG hens in the Upper Big Hole Valley relative to vegetation height averaged across all years of three vegetation types at the nesting site (sagebrush, forbs and grasses). There was no significant difference in nest fate within or between vegetation types.

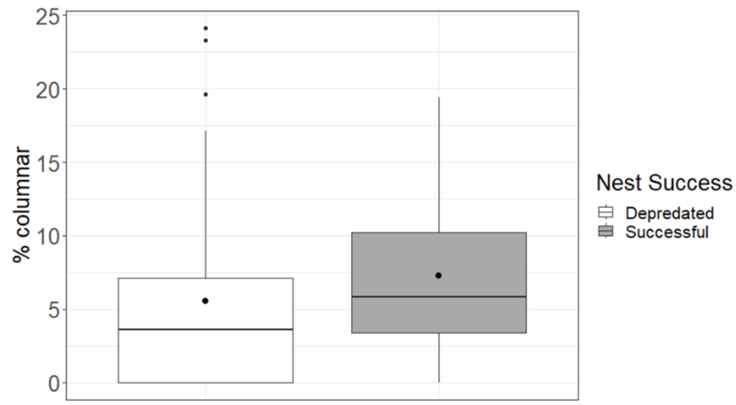

Figure 49. Nest fate of GPS marked GSG hens in the Upper Big Hole Valley relative to percent of columnar shaped sagebrush averaged across all years at the nesting site. There was no significant difference in nest fate relative to the average amount of columnar sagebrush present at nesting sites.

On average, successful nests occurred at sites with high grass cover (55.7%), followed by sagebrush (25.8%) and forb (16.3%) cover. Successful nests were most often recorded at sites with taller sagebrush (49.1 cm) and shorter grasses (13.4 cm) and forbs (9.1 cm). Columnar sagebrush was present at all sites with successful nests, though at low abundances (mean 8.3%). The number of preferred forbs by sage-grouse (ANOVA, F = 0.14, p = 0.70) and number of ant mounds (F = 0.88, p = 0.35) did not explain nest fate (Figure 50). Both characteristics were highly variable, and successful nests were associated with 6–28 preferred forbs and 6–43 ant mounds.

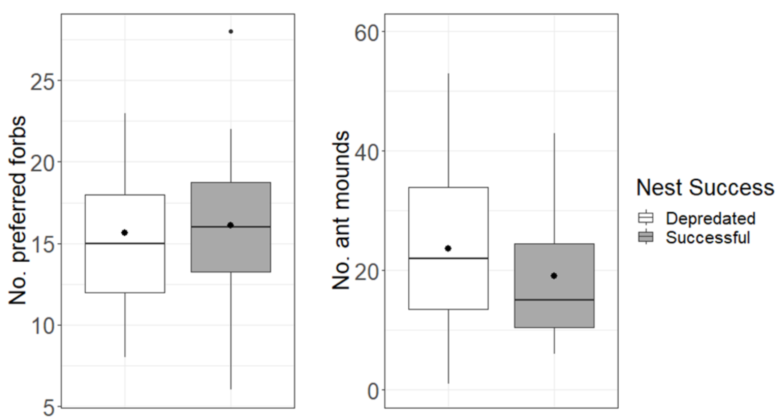

Figure 50. Nest fate of GPS marked GSG hens in the Upper Big Hole Valley relative to the number of preferred forb species and the number of active ant mounds at nesting sites. There was no significant difference in nest fate relative to either variable.

Ants have been found to modify vegetative communities (Rodgers and Lavigne 1974); however, we did not observe that vegetative cover (lm, t = -1.15 – 0.61, p = 0.26 – 0.82) or height (t = 0.32 – 0.96, p = 0.34 – 0.75) predicted ant mound abundance.

Because we could not detect any statistical difference between nest fates and any of the nesting site characteristics, we combined data from all known-fate nests across all years to determine average values and the range for each. We then compared our results to those described by

Stiver et al. (2015) (Table 17). These published guidelines describe characteristics of productive sage-grouse habitats based on a large number (n=24) of studies conducted throughout the species' range (Connelly et al., 2000b, Hagen et al., 2007). These guidelines serve as a tool for assessing habitats and guiding management actions.

Our results suggest that nesting sites in the UBHV provide suitable habitat overall. It should be noted that "suitable" is not synonymous with "optimal". While perennial grass and forb heights in our study were lower than published guidelines, nesting sites in the UBHV had average sagebrush cover at the upper end of the published range and a high percentage of spreading sagebrush. These factors could compensate for lack of concealment cover provided by perennial grasses and forbs. Stiver et al. (2015) noted that in some parts of the range, indicators will need to be interpreted with a regional perspective. For example, the sagebrush cover may be naturally high in some portions of the sage-grouse range but herbaceous cover capability, based on site potential, may be below the height identified in the guidelines; thus, adequate cover for Greater sage-grouse may still be present.

Table 17. Comparison of nesting site characteristics for marked GSG hens in the Upper Big Hole Valley to nesting site characteristics from Connelly et al. (2000b).

Nesting Site Characteristics	***Metric Description***	***Suitable condition for mesic sites (Connelly et al.)***	***Average Upper Big Hole Valley***	***Range Upper Big Hole Valley***
Sagebrush cover	Average % cover for land cover type	15 – 25%	25%	9 – 45%
Sagebrush height	Average sagebrush height for land cover type	40 – 80 cm	47 cm	29 – 67 cm
Predominant sagebrush shape	Most common sagebrush shape for land cover type	Spreading	94% Spreading	76–100% Spreading
Perennial grass height	Average maximum height for land cover type	≥18cm	14 cm	6 – 30 cm
Perennial forb height	Average maximum height for land cover type	≥18cm	9 cm	2 – 20 cm
Perennial grass cover	Average % cover for land cover type	≥ 15%	55%	33 – 85%
Perennial forb cover	Average % cover for land cover type	≥ 10%	18%	3 – 48%
Preferred forbs availability	Number of preferred forbs in land cover type	Preferred forbs are common with several species present	16	6–28

We previously suspected that wet springs would result in highly productive vegetation and increased nest success. In 2019, the UBHV experienced a cool, wet spring and more nests were successful than depredated. Interestingly, 2022 experienced similar conditions, but all nests were depredated. The spring may have been *too* wet and cold in 2022, forcing hens to leave their nests more often to forage for food and warm themselves up. As a result, nests were left unprotected and open to predation. Timing of cool temperatures and moisture in the spring appears to have the greatest impact on nest survival. Overall, more data is needed to better predict the relationship between vegetative characteristics and sage-grouse nest success in Montana. We suspect that vegetation height, cover, and shape will predict suitable nesting habitat (Stiver et al. 2015), but we are largely unaware of what suitable conditions are required in Montana. We further predict that successful nests will be associated with increased preferred forbs and ant mound abundance because these characteristics often provide forage (Drut et al. 1994; Tronstad et al. 2021).

Nest Shrub Characteristics

In addition to characterizing vegetation at nesting sites, we also characterized morphological features of the nest shrub itself for all known nests of marked Greater sage-grouse hens in the UBHV, 2019–2022 (n=44, Table 18). We did not compare nest shrub characteristics to random sites. Vegetation surveys were conducted at each nest site at the time of expected hatch regardless of nest fate, once we were certain the hen had moved off. We collected the following data at each nest shrub: shrub species, shrub height, shrub width at the widest axis of the crown and along a 90° axis, height and length of the nest branch at a point directly above the nest bowl, % aerial nest cover from both live and dead vegetation, and the % lateral nest cover. Without exception, all nests were under *Artemisia tridentata* spp*. vaseyana* plants (ARTRV).

Table 18. Average nest shrub characteristics for nests of marked Greater sage-grouse hens in the Upper Big Hole Valley, 2019–2022.

Nest Shrub Characteristics	**Average**	**Range**
Shrub height (cm)	61	35–97
Shrub width @ widest (cm)	100	59–158
Shrub width @ 90° (cm)	78	50–122
Nest branch height (cm)	30	17–56
Nest branch length (cm)	32	10–74
% Aerial nest cover – ARTRV Live	73%	5–100
% Aerial nest cover – ARTRV Dead	27%	5–85
% Lateral nest cover	66%	25–95

Findings in the UBHV align with other studies, accounting for regional land cover differences. In central Montana, 97% of GSG nests were under Wyoming big sagebrush (*Artemesia tridentata* spp. w*yomingensis)* and shrub height averaged 57cm (Lane 2017)*.* In the Centennial Valley in southwestern Montana, 89% of GRG nests were under a sagebrush plant (45% Mountain big sagebrush, 21% three-tip sagebrush, and 20% basin big sagebrush) (Schroff 2016). In addition, Schroff (2016) found the average nest shrub height to be 75.3cm, the average height of the nest branch to be 21.4cm, the average length of the nest branch to be 56.8cm, the average width at the widest point of the crown to be 105.6cm, the average aerial nest cover to be 76.6% and average lateral cover of the nest bowl to be 72.3%. Throughout Wyoming, 92–100% of nests were under sagebrush (Patterson 1952, Holloran 1999) and in northern Colorado 94% of GSG nests were under big sagebrush plants. In Utah, only 70% of nests were under big sagebrush while 30% were under black sagebrush and other shrubs or grass (Dahlgren 2006). In Wyoming, 83% of nests were under bushes between 25 and 51 cm in height (Patterson 1952).

GENETICS

The greater sage-grouse of the UBHV are part of the *Central Rockies* genetic subpopulation (Oyler-McCance et al. 2022) and, at a finer scale and temporal resolution, the *Southwestern-North* subpopulation which is part of the greater *Southwestern* subpopulation (Cross et al. 2017,

Figure 51)[1]. To assess the genetic diversity and structure and to compare to prior research findings within the UBHV, we extracted DNA from 45 females and 6 males, and genotyped each sample across 15 microsatellite loci following Oyler-McCance et al. (2023). Within the UBHV sample, P_{ID} (2.08×10^{-16}) and P_{IDsib} (9.56×10^{-07}) were sufficiently small so as to ensure confidence in our ability to discern individuals via our genetic panel (Evett and Weir 1998). The genetic structure within and among these three subpopulation samples likely results from both their geographic and temporal relationships (Figure 52), i.e., the UBHV sample represents the most constrained geographic area, and the most recent time period, while the *Southwestern-North* and *Central Rockies* subpopulations represent increasingly large geographic areas and time periods. Samples from the UBHV were collected from 2018–2022, while samples from the *Central Rockies* subpopulation were collected from 2007–2014, and samples from the *Southwestern-North* subpopulation were collected from 2009–2012. The 4–15 year difference between the samples from the UBHV and the subpopulations likely constitutes approximately 2–7 generations (~2–3 years, Dahlgren *et al*. 2016). Therefore, we think that temporal differentiation (genetic drift) in addition to geographic extent likely drives the pattern seen in the principal components analysis, especially the differentiation of UBHV and the Southwestern-North samples from the Central Rockies (PCA; Figure 52).

As a peripheral population of a species that has experienced a range contraction, it might be expected that the UBHV sage grouse would exhibit loss of genetic diversity. However, to the contrary, the per locus (Table 19) and overall genetic diversity (Table 20) within this population appears to be comparable to the previous assessments of the greater subpopulations, indicative of stable population dynamics (Table 20). Across all loci, the number of alleles (A), the number of alleles with a frequency at least five percent (A95; which excludes the effect of rare alleles), and the effective number of alleles (Ae; the number of equally frequent, idealized alleles in a population) all show overlapping interquartile ranges (IQR) suggesting that the variation within the data in the different groups is not significantly different (Table 20 and Figure 53A). Similarly the IQRs overlap for observed heterozygosity (the actual genetic diversity observed within a population; H_O) and expected heterozygosity (measure of the genetic diversity that would be expected in a ideal population; H_E) within each subpopulation (Table 20 & Figure 53B), indicating no significant deviations from Hardy-Weinberg proportions. Across all loci, the slightly positive values of Wright's inbreeding statistic ($F_{IS} = 1 - (H_O / H_E)$, which can range from –1 to 1) within each sample reflect the small deficiency of heterozygotes (Table 20 and Figure 53C) likely due to the assumptions of the a genetically idealized population (e.g., random mating, no genetic drift, no migration into the population).

[1] When comparing the contemporary Upper Big Hole Valley sample collected for this project to the supopulatons, we rarified (sub-sampled) to the same number of individuals as included from the contemporary UBHV sample.

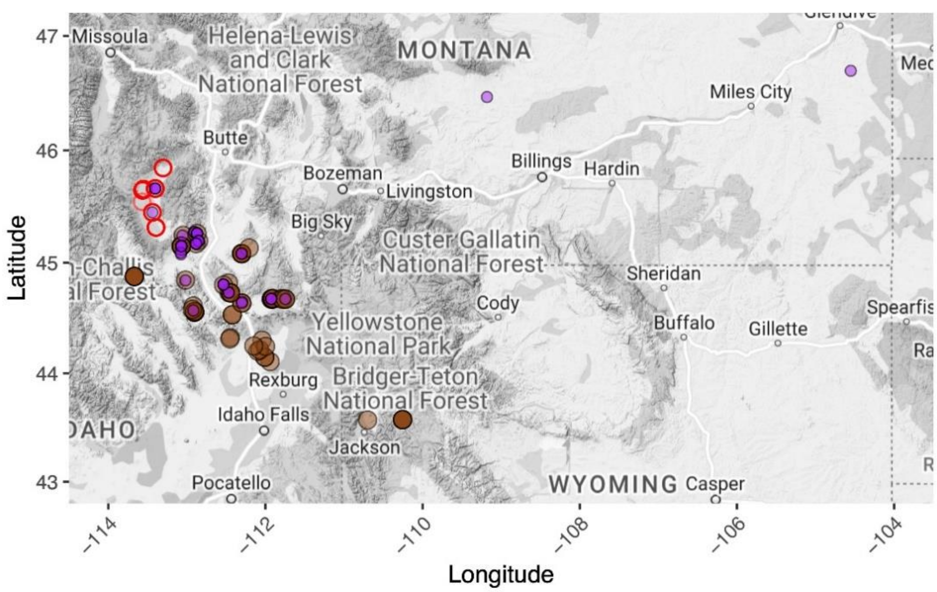

Figure 51. Upper Big Hole Valley contemporary samples (this study, open red circles), and the 2 genetic subpopulations to which these birds belong: the Southwestern-North subpopulation (purple) which is part of the greater Southwestern subpopulation identified by Cross et al. (2017), and the Central Rockies subpopulation (brown) identified by Oyler-McCance et al. (2022).

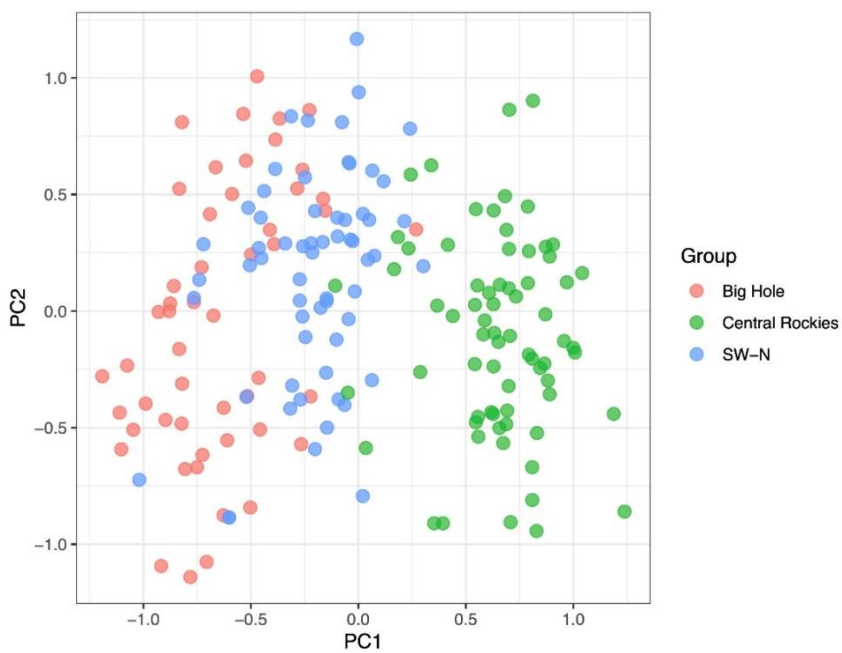

Figure 52. The first two components of the individual-based principal components analysis (PCA) of the Upper Big Hole Valley contemporary samples (this study, red circles) and the previously sampled genetic subpopulations to which the Big Hole belongs.

Table 19. Per-locus genetic diversity across 15 loci for all 51 samples from the Upper Big Hole Valley where A: number of alleles, Ae: effective number of alleles, A95: number of alleles with a frequency at least five percent, H_O: observed heterozygosity, H_E: expected heterozygosity, F_{IS} = 1-(H_O/H_E)—a measure of departure from Hardy-Weinberg Proportions (HWP) within groups/sub-populations (positive values indicate a deficit of heterozygotes, negative values indicate an excess of heterozygotes).

Locus	A	Ae	A95	Ho	He	Fis
bg6	11	6.97	9	0.78	0.86	0.09
sgms064	8	3.33	5	0.63	0.70	0.10
sgms066	10	5.71	6	0.75	0.82	0.10
sgms068	10	5.22	6	0.79	0.81	0.02
msp11	11	5.03	4	0.74	0.80	0.08
msp18	7	2.95	4	0.70	0.66	-0.06
sg28	10	6.05	6	0.75	0.83	0.11
sg29	9	3.98	4	0.69	0.75	0.08
sg36	5	3.25	4	0.64	0.69	0.08
sg39	6	3.76	5	0.57	0.73	0.22
resgca5	8	3.38	4	0.75	0.70	-0.06
resgca11	9	5.03	6	0.81	0.80	-0.01
sgctat1	4	3.66	4	0.51	0.73	0.30
tut3	5	2.69	4	0.63	0.63	-0.00
tut4	7	3.98	5	0.61	0.75	0.18

Table 20. Per-lek and overall genetic diversity of Upper Big Hole Valley greater sage-grouse compared to the genetic diversity of the greater subpopulations to which birds in this valley belong (the Southwestern-North subpopulation, SW-N, identified by Cross et al., 2017 and the Central Rockies subpopulation, 1b1a, identified by Oyler-McCance et al. 2022). Genetic diversity measures are reported as the mean across all loci. See Table 19 for description of table headings.

Lek Name	n	A	Ae	A95	Ho	He	Fis
Fox Gulch	4	3.60	2.87	3.60	0.67	0.62	-0.06
Highland	1	1.80	1.80	1.80	0.80	0.40	-1.00
McVey	1	1.80	1.80	1.80	0.80	0.40	-1.00
Mud Lake 1	9	5.47	3.69	5.47	0.64	0.71	0.09
Palisades	4	3.20	2.41	3.20	0.62	0.53	-0.15
Spencer	8	4.87	3.34	4.87	0.74	0.66	-0.13
Spokane Ranch 1	5	4.33	3.25	4.33	0.68	0.67	-0.01
Spokane Ranch 2	20	5.87	3.61	4.93	0.68	0.71	0.05
BHSG	51	8.00	4.33	5.07	0.69	0.75	0.08
SW-N Subpopulation	62	8.73	–	–	0.75	0.75	0.02
SW-N (subset)	51	9.27	5.03	5.53	0.72	0.76	0.05
Central Rockies Subpopulation	70	11.47	6.59	6.93	0.81	0.83	0.03
Central Rockies (subset)	51	11.40	6.73	6.40	0.79	0.83	0.04

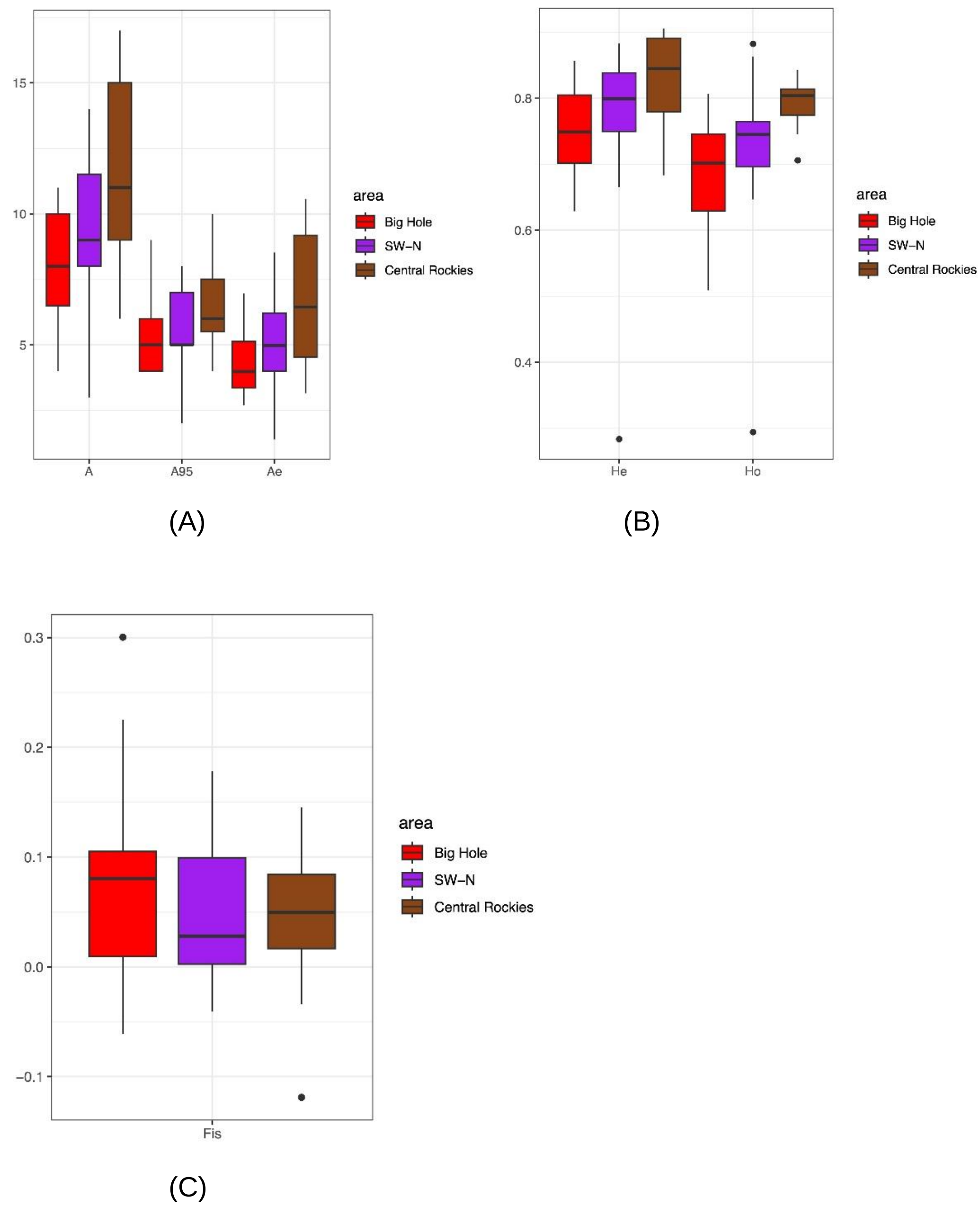

Figure 53. Overall genetic diversity of Upper Big Hole Valley greater sage-grouse compared to the genetic diversity of the greater subpopulations to which birds in this valley belong: the Southwestern-North subpopulation, SW-N (identified by Cross et al., 2017), and the Central Rockies subpopulation, 1b1a (identified by Oyler-McCance et al. 2022). Genetic diversity measures are reported as the mean across all loci and are grouped as A: number of alleles, Ae: effective number of alleles, A95: number of alleles with a frequency at least five percent (Plot ***A****), H_O: observed heterozygosity, H_E: expected heterozygosity (Plot* ***B****), $F_{IS} = 1-(H_O/H_E)$—a measure of departure from Hardy-Weinberg Proportions (HWP) within groups/subpopulations (positive values indicate a deficit of heterozygotes, negative values indicate an excess of heterozygotes) (Plot* ***C****).*

Within the UBHV sample, Mud Lake 1 and Spokane 2 show increased genetic diversity across all measures (Table 20). Due to smaller sample sizes from two of the leks (Highland and McVey), it is difficult to draw comparisons to these leks since the number of alleles, effective number of alleles, and A95 are all lower than might be observed otherwise if the sample size were greater.

A principal components analysis (PCA) is a means by which to reduce the multidimensionality of a large dataset by identifying major clusters within the data. Therefore, a PCA is well suited to characterizing the allelic variation across 15 microsatellite loci in a simplified form. In our approach, genotypes are converted to a multivariate format, then analyzed via PCA. The individual-based PCA shows overlap in genetic composition of leks (Figure 54). However, individuals from the same lek still form "clouds" of similar genetic composition, that becomes more apparent in the lek-based PCA (Figure 55). This may well be reflective of lek philopatry and lek attendance by individuals that are more closely related intra-lek when compared to inter-lek.

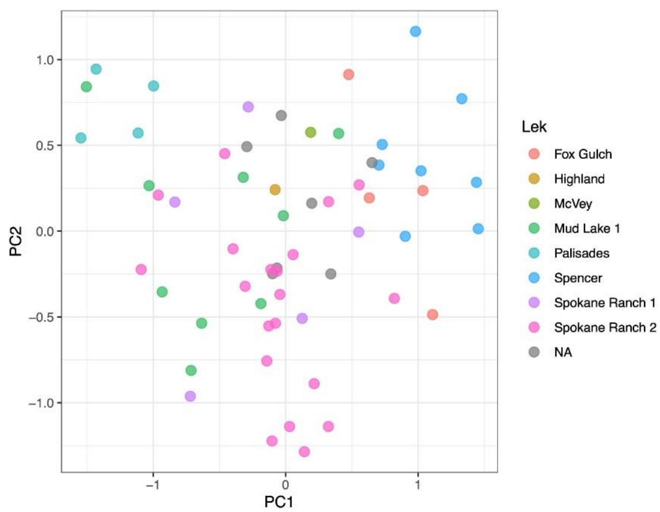

*Figure 54. First 2 components of **individual-based** PCA color coded by lek of capture.*

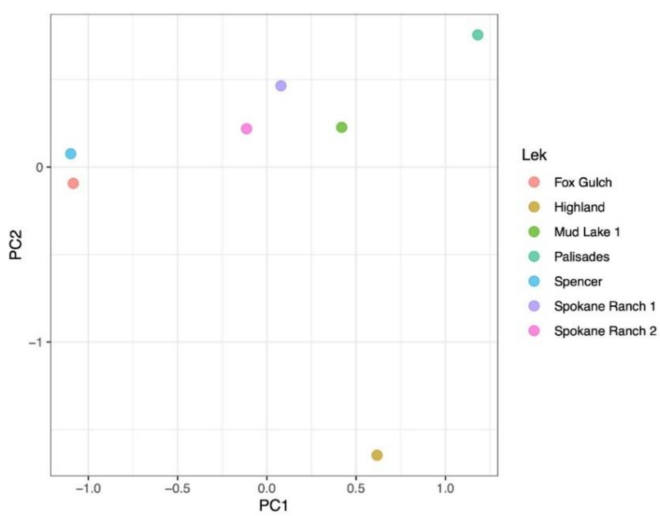

*Figure 55. First 2 components of the **lek-based** PCA color coded by lek of capture.*

When plotted, the mean PC1 and PC2 scores for each lek reveals the geographic position of leks within the UBHV (Figure 55). The relative south to north lek positions are reflected in the increasing first principal component scores. Proximal leks (PC1) are more closely related than are distal, this fine scale structure is reflective of the demographic structure known to result from lek philopatry. Highland's apparent genetic isolation in the PC plot is most likely due to the small sample size of a single individual, which could be spuriously driving principal component 2 (PC2).

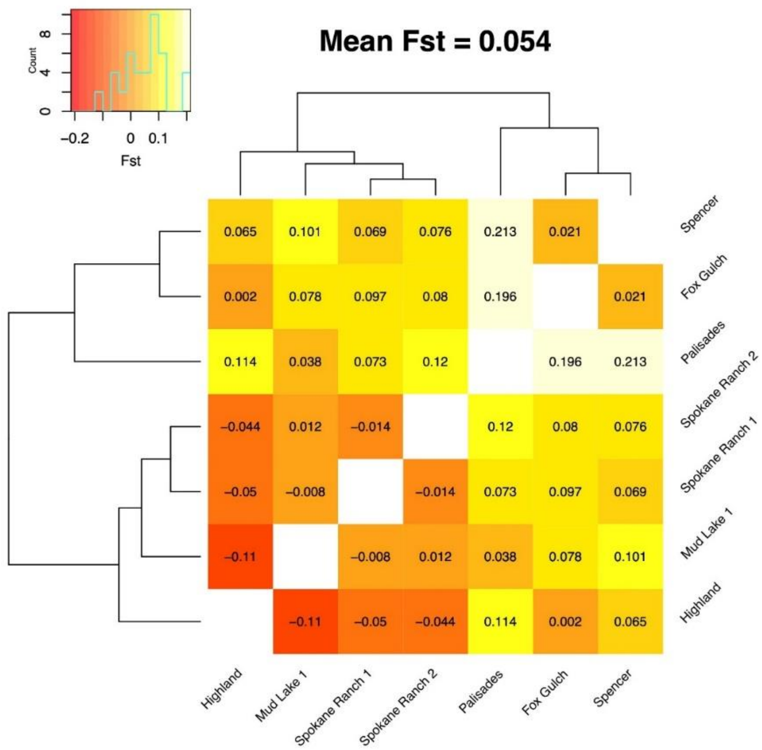

Figure 56. Pairwise genetic divergence (FST) among leks, and dendrogram of genetic relatedness based thereupon. Inset on the top left is the legend showing the range of FST values from similar (low, red) to dissimilar (high, white) and a histogram of their distribution.

F_{ST} is a measure of genetic divergence among groups of individuals where, theoretically, a value of 0 indicates panmixia and a value of 1 indicates complete isolation. In reality, the range of values is more restricted. Within the UBHV, divergence among leks ranged from –0.11 (essentially panmixia), between Highland and Mud Lake 1, to 0.21 between Palisades and Spencer (the two most distal leks). The FST-based dendrogram (Figure 56) seems driven primarily by the spatial proximity such that genetic interrelatedness among the proximal northern leks (the Highland, Mud Lake 1, and Spokane lek complex) breaks out first, with the southernmost leks clustering next most closely to one another (the Fox Gulch, Spencer complex). Though Palisades falls on the same branch of the dendrogram as Fox Gulch and Spencer, F_{ST} indicates that it is less diverged from the northern complex. F_{ST} reflects those patterns shown within the PCA.

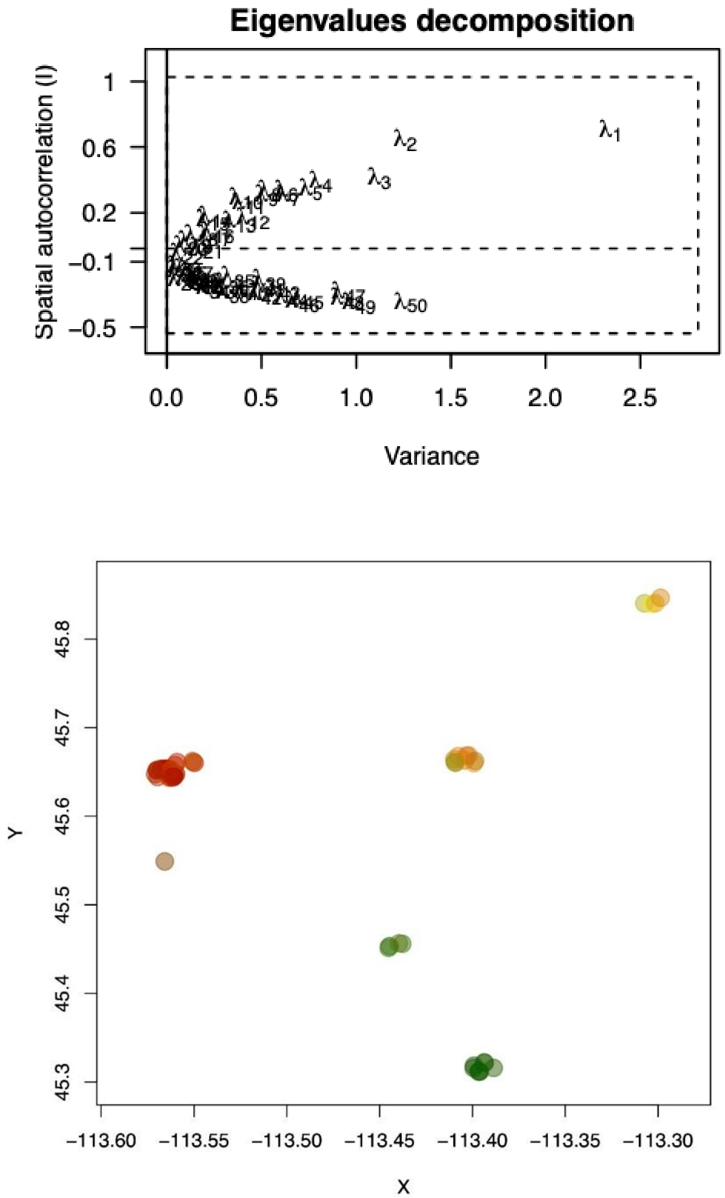

Figure 57. Spatial principal components analysis (sPCA) of individuals within the Upper Big Hole Valley of Montana. The top plot shows the disintegration of spatial autocorrelation (Moran's I) and variance.

The incorporation of spatial autocorrelation into the principal components analysis via the individual based sPCA reveals the genetic neighborhoods of individuals within the UBHV (Figure 57). The first two components (PC1 & PC2) captured the largest portion of both the spatial autocorrelation and the genetic variance of the data (top plot; eigenvalues 1 & 2), and so were retained for mapping (bottom), where color indicates the groups of genetically similar individuals. Three distinct spatio-genetic groups were identified: the northeastern (yellow), the southeastern (green), and the western (red) sub-groups (Figure 57).

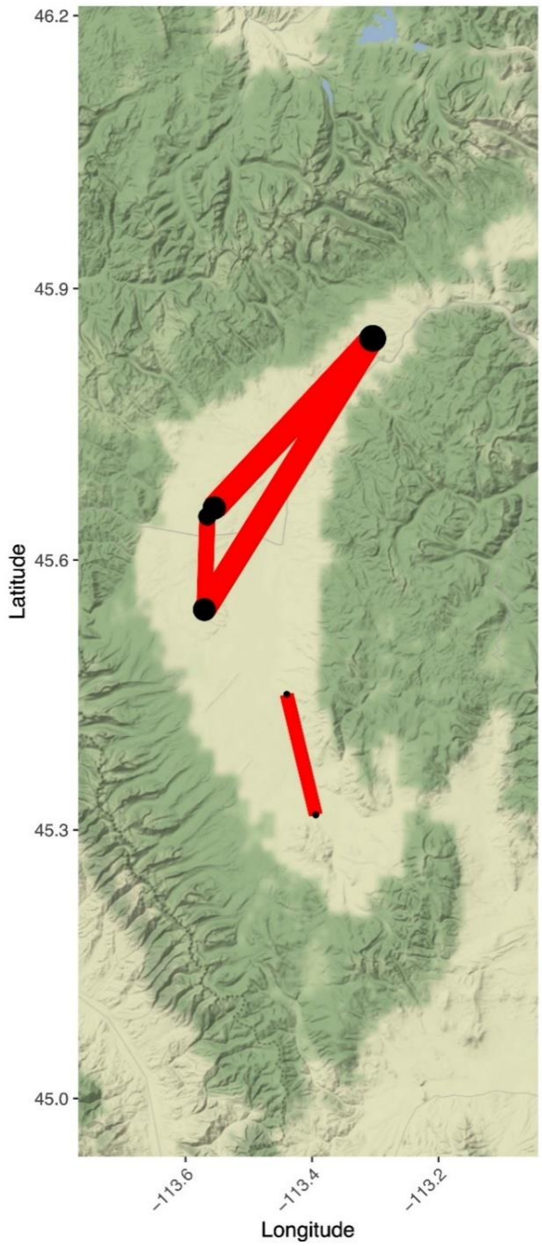

Figure 58. The genetic network of spatial principal components analysis (sPCA) of individuals within the Upper Big Hole Valley of Montana. The size of the nodes (leks, black) indicates the strength of their connection within the network. The width of the edges (red) indicates their weight (i.e. the magnitude of genetic exchange between any two connected nodes.)

In previous network analysis (Cross et al. 2018), the leks within the study area were clustered to constitute a single node. Here, we analyzed the network structure among these leks individually, but using the same network parameters (alpha and tolerance) as prior. The network structure is simple, consisting of little redundancy in connections. At this finer resolution, the southern lek complex of Fox Gulch and Spencer formed their own sub-graph apart from the northern lek complex of Highland-Mud Lake (grouped to ensure the inclusion of the single sample from Highland), Spokane 1 & 2 and Palisades (Figure 58). This network structure mirrors the pattern of genetic relatedness seen in the PCA (Figure 55), sPCA (Figure 57), and FST values (Figure 56). Node strength—the sum of all edge weights connected to that node, i.e., the magnitude of genetic exchange with all nodes connected to a given node—ranged from 0.31 at Fox Gulch to 1.61 at Palisades. The weight of connections was greatest among the northern leks.

CONSERVATION IMPLICATIONS AND APPLICATIONS

Results from this study are helping to define land management actions in the UBHV and across SW Montana. In 2018, a Montana statewide GSG Candidate Conservation Agreement with Assurances was released that assists private landowners with conservation of GSG and their habitat on their properties. The Natural Resources Conservation Service Sage Grouse Initiative has taken a proactive approach to conserve sagebrush habitat with private landowners in SW Montana since 2012. In addition, the SW MT Sagebrush Partnership made up of state and federal agencies, conservation and watershed groups formed in 2018 to implement sage-brush conservation projects across landowner boundaries in SW Montana. The Beaverhead-Deerlodge National Forest is currently implementing a landscape-level habitat project in the UBHV (Pintler Face Project) that aims to improve sagebrush, riparian, and forested habitats across 20,000 acres. Knowledge of GSG habitat use in the UBHV will and already has helped guide these efforts and make them more effective at meeting their goal of GSG and sagebrush habitat conservation. Knowledge gained from this study is directly applicable to land use practices and projects to allow for multiple use and also minimize loss, fragmentation, or degradation of sagebrush habitat in the UBHV.

The purpose of this study has always been to utilize knowledge gained from the birds to direct our conservation efforts on their behalf. Ensuring key seasonal and stop-over habitat remains intact for Greater sage-grouse will benefit the sagebrush-steppe ecotype at a landscape scale and all the many wildlife species that use it. Since the start of this project, we have used the data to prioritize and secure funding for habitat protection and improvement projects, including:

COMPLETED

1. HCR Conifer Removal Project: 110 acres of conifer removal in sagebrush-steppe habitat
2. Fence marking: 1 mile of fence marking to reduce GSG collisions near the lek.
3. HCR Mesic Restoration: 6 acres with 32 water-spreading structures
4. HCR Grazing Management: 4,891 upland acres improved plus 2 stock wells installed.
5. Vaquero Mesic Restoration: 0.7 miles of intermittent stream improved with 110 water-spreading structures.
6. Vaquero Conifer Removal: 5.1 acres of conifer removal in sagebrush-steppe habitat
7. Carrol Hill Conifer removal: 252 acres of conifer removal in sagebrush-steppe habitat

IN PROGRESS

8. Smith Springs Mesic Restoration: 12 acres mesic restoration and 571 feet of bank restoration
9. HR Conservation Easement: 9,163 acres
10. JR Conservation Easement: 4,640 acres
11. Comparison with movement and genetic dataset of 120 hens in northeastern Wyoming

Knowledge learned and summarized in this report will provide the framework for conservation work in the Upper Big Hole Valley and surrounding watersheds. We will continue and expand our work through multiple partnerships and the SW Montana Sagebrush Partnership across boundaries to protect and conserve this landscape. Underway, too, is a collaboration with researchers at the University of Waterloo (Ontario, Canada) where we will be comparing our findings here to a dataset of 120 genetically-sampled and genotyped GPS collared greater sage-grouse from a comparably-sized geographic area in northeastern Wyoming. We hope to learn whether movement (including seasonal migration), habitat use, home ranges, genetic diversity, and connectivity are similar or differ in this separate part of the species range known to be a major corridor of genetic connectivity.

BUDGET

This project was funded by many partners (Table 21). The BLM through an Interagency Agreement with the USFWS was the primary funder contributing approximately 85% of the project budget. Most of the BLM funding was used to purchase the GPS units and assisted with the satellite subscriptions. Other funders include the USFWS, USFS, The Nature Conservancy and MFWP. In-kind contributions include labor for captures, tracking, Habitats Framework Assessment surveys and vehicle cost, lodging and meals.

Table 21. Ecology of Greater Sage-Grouse in the Upper Big Hole Valley, Montana budget.

Source	Amount	For
BLM	$240,335	PPTs, Satellite Subscription, HAF Surveys, Captures, Analysis and Reporting
USFWS	$18,000 + In Kind	HAF Surveys, Genetic Analysis, Miscellaneous Equip
USFS	$13,000 + In Kind	Satellite Subscription
TNC	$8,000 + In Kind	Satellite Subscription
MFWP	$ 2,000 + In Kind	Miscellaneous Equip
Total	$281,335	

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