Evaluating GPS-Derived Estimates of Livestock Use and their Value in Assessing Impacts of Spring Cattle Grazing on Greater Sage-Grouse Demographics

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by

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Authorization to Submit Thesis

This thesis of Taylor Fletcher, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Evaluating GPS-Derived Estimates of Livestock Use and their Value in Assessing Impacts of Spring Cattle Grazing on Greater Sage-Grouse Demographics," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Domestic livestock grazing has been suggested as one of several factors contributing to the range-wide decline of the greater sage-grouse (*Centrocercus urophasianus*; GRSG). However, inclusion of livestock grazing as one of the main causes of GRSG declines remains controversial because the short- and long-term effects of this land use on GRSG demographics are still not well understood. This is due to the fact that livestock utilization measures may be limited by observer bias and the plot-level scale at which data is often collected. Utilization measurements on a limited spatial and temporal scale may not lend well to informing large-scale management decisions or assessing livestock-wildlife interactions. However, the advancement of Global Positioning Systems (GPS) has introduced new opportunities to efficiently and accurately collect livestock use and behavior data. I developed a metric of estimating the intensity of livestock use at pasture-scales based on location data obtained from low-cost GPS collars. I also evaluated how the estimates of livestock use and distribution changed with the number of GPS collars that were analyzed and the influence of extent and grain on the livestock use and distribution metrics. I then used a bivariate version of the Ripley's cross-K function to assess any co-occurrence or separation between the livestock GPS locations and confirmed GRSG nest locations. The results of the cross-K function produced differing results between the two study pastures. However, characterization of the vegetation structure around livestock hot spots and GRSG nests identified similarities between the portions of the landscape that each species used. This suggests that livestock and GRSG nests may occur in similar microhabitats of the landscape. Thus improperly managed grazing may have negative consequences for GSRG populations. Further research is needed to determine if GRSG hens and livestock occur in similar areas irrespective of the presence of the other or if GRSG hens are preferentially selecting areas where livestock are actively grazing or have recently visited.

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Acknowledgements must go to the volunteers and staff at the Nature Conservancy for their support of my work on the Zumwalt Prairie Preserve. Thanks also to Courtney Conway, Andrew Meyers, Cody Tisdale, and all of the field crews with the Idaho Grouse and Grazing Project for their support at the Idaho sites in collecting livestock and sage-grouse data.

Finally, thanks to the ranchers who participated in this study and allowed their cattle to be collared. Thank you to Cody Morgan and Ken Nelson at PAVA, Richard Ward at JISA, and Alan Klages and J.B. Warnock at the ZPP.

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Chapter 1

1. Introduction

Domestic livestock grazing is the most common land use on rangelands in the western United States (Connelly et al., 2004; Holechek et al., 1995). Currently, livestock grazing is managed across 229 million acres of public land in the US by the Bureau of Land Management (BLM) and the United States Forest Service (USFS) (Glaser et al., 2015). The vast majority of this public lands grazing occurs in the 11 western states of Arizona, California, Colorado, Idaho, Oregon, Montana, New Mexico, Nevada, Utah, Washington, and Wyoming (Glaser et al., 2015). Recent USDA reports suggest that the gross income of the cattle industry is an approximate $67.1 billion annually with all cattle and calves in the United States totaling 94.4 million head (National Agricultural Statistics Service, 2020, 2019).

Managing such a prolific land use requires a robust monitoring program and a reliable understanding of the short and long-term effects of domestic livestock use (Ortega-S et al., 2013; Veblen et al., 2014; West, 2003). Attempts to standardize livestock monitoring so that federal agencies, rangeland managers, or private operators may consistently and objectively measure domestic livestock use have proven challenging (Veblen et al., 2014; West, 2003). The variety of terminology, definitions, and associated methods often render use-based livestock monitoring inadequate in providing unbiased and consistent measures over space (e.g., allotments) and time (e.g., years). Biases and inconsistencies in data may occur as a result of landscape heterogeneity and inter-observer variation during the data collection and estimation process (Jansen et al., 2021; Laurence-Traynor et al., 2020; SRM Rangeland and Assessment Monitoring Committee, 2018). Landscape heterogeneity due to topography, vegetation structure, soil productivity, and precipitation may affect the consistency of utilization metrics (Glaser et al., 2015). Inter-observer variation may be caused by variation in observer experience, training, calibration, familiarity with the area of interest, and technique choice (Laurence-Traynor et al., 2020).

Collecting accurate utilization data is made more complex by the fact that in-field utilization data is difficult to scale up to a pasture or landscape level that is valuable in making management decisions. In-field utilization data is frequently collected at the plot level, but plot sizes may vary from a sampling unit as small as a 2.5m-diameter paired plot (e.g., Laurence-Traynor et al., 2020) to a 100m-diameter monitoring plot (e.g., Herrick et al., 2005). Data collection at this scale is limited by both the time it takes to conduct in-field protocols as well as the financial expenditures associated with paying staff to complete the work

(Caughlan and Oakley, 2001). This level of data collection may provide insufficient information to make assessments about pastures or allotments that may span thousands of acres (Booth and Cox, 2011). Utilization measurements on a limited spatial and temporal scale may not lend well to informing large-scale management decisions or ecological assessments (Jansen et al., 2021; Laycock, 1998).

The decreasing cost of Global Positioning Systems (GPS) has introduced new opportunities to efficiently and accurately collect livestock use and behavior data (Bailey et al., 2018). This technology has already been widely applied to assess wildlife and livestock activity, movement, distribution, and resource use. In the last 25 years, studies have demonstrated the value of GPS devices in identifying forage preference and selection (Ganskopp and Bohnert, 2009), differentiating grazing versus non-grazing activity (Augustine and Derner, 2013), predicting livestock distribution given ecological variabilities (Gersie et al., 2019; Sheehy, 2007; Turner et al., 2000), and mitigating wildlife-livestock depredation (Clark et al., 2020). GPS collars allow for continuous monitoring of livestock location and behavior which provides an accuracy and completeness not provided by other methods (Brennan et al., 2019). Data can be collected efficiently in a way that reduces observer disturbance and bias and provides a greater breadth of spatiotemporal information that offers opportunities to better understand and manage grazed landscapes (Anderson et al., 2013; Augustine and Derner, 2013).

While the use of GPS collars on domestic livestock has become an increasingly popular means of monitoring movement, distribution, and resource use, several research gaps still exist. Previous research using GPS collars to monitor livestock has focused largely on individual movement, behavior, and resource selection based on relatively few collared animals per herd. Prior studies have typically used between 2-10 GPS collars, meaning that collars were deployed on 2-8% of the herd (e.g. Clark et al., 2020; Ganskopp and Bohnert, 2009; Gersie et al., 2019).

Because herd-wide assessments are uncommon, it is still unclear how many collars need to be deployed on a herd of cattle to accurately capture the entire herd's activity. Furthermore, pasture-scale assessments of livestock distribution and use are rare. Augustine and Derner (2013) recorded head movements of 5-9 steers to determine the reliability of GPS activity sensors in predicting grazing versus non-grazing behavior. Gersie et al. (2019) collared two steers in two ~130-ha pastures to determine how several topographical variables may influence movement and resource selection. Ganskopp and Bohnert (2009) tracked the preferential selection of forage based on several indicators of forage quality. Kawamura et al. (2005) attempted to use a GPS-based metric to quantify grazing intensities in a grassland ecosystem; however, they deployed GPS collars on only 12 animals across three herds of 300-700 individuals each. While this previous work has been useful in demonstrating the value of GPS technology and has advanced knowledge of livestock behavior in large landscapes, an opportunity exists to fill the data gap relating to herd movement and activity as a whole by collaring a much larger proportion of the herd.

I pursued three objectives to further explore the role that the number of GPS collars per herd plays in evaluating livestock distribution and use of rangeland pastures. The first objective was to develop a metric for estimating the intensity of domestic livestock use at pasture scales based on location data collected by low-cost GPS collars deployed on domestic cattle herds. The second objective was to investigate how the estimates of livestock use and distribution changed with the number of GPS collars that were deployed and analyzed. The third objective was to assess the influence of extent (i.e., pasture area) and grain (e.g., pixel size) on the livestock use and distribution metrics.

2. Methods

2.1 Study Areas

GPS collars were deployed at study areas in both Oregon and Idaho. In Oregon, collars were distributed throughout pastures on the Zumwalt Prairie Preserve (ZPP, Table 1.1, Figure 1.1) in Wallowa County (45°319N, 117°39W) at an elevation of 1,050 – 1,650m. The region receives a mean annual precipitation of 38-43cm and is characterized as an upland plateau, though deeply incised canyon areas exist as well. The prairie is dominated by native bunchgrasses, including Idaho fescue (*Festuca idahoensis*), Sandberg bluegrass (*Poa secunda*), prairie Junegrass (*Koeleria macrantha*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) along with over 112 different forb species (Schmalz, 2017).

The ZPP is owned and managed by The Nature Conservancy (TNC). TNC has implemented a grazing regime on the ZPP that monitors the long-term impacts of different grazing intensities determined by the stocking rate of each study pasture. Livestock grazing is the predominant land use across the landscape (“Zumwalt Prairie | The Nature Conservancy in Oregon,” 2021), so TNC has implemented an experimental grazing regime in an effort to maintain both the ecological health of the prairie and the livelihood of local ranchers. GPS collars were distributed amongst livestock herds involved in this ongoing grazing regime. The data that I used for this study was a subset of the complete GPS dataset obtained from the ZPP. In 2019, I used GPS livestock data from a single 40.47 hectare “High-Use” paddock from the Food Web pastures. This pasture was grazed by approximately 200 head of cattle for 4.5 days. In 2020, I used GPS data from the 91.46 hectare Big North pasture. This pasture was grazed by approximately 200 head of cattle for nine days. The ZPP pastures were selected to provide insight into how estimates of livestock use and distribution changed in smaller-sized pastures with the number of GPS collars that were analyzed.

In Idaho, collars were deployed at the Pahsimeroi Valley study area (PAVA, Table 1.1, Figure 1.1) in central Idaho east of Challis (44°51N, 113°91W) between the Lemhi and Big Lost ranges at an elevation of ~2000m. The site receives a mean annual precipitation of 22.1cm and is characterized by river flats, toe slopes, and irrigated agricultural fields. (2019). Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) is the dominant woody species, with low sagebrush (*Artemisia arbuscula*), rubber rabbitbrush (*Ericameria nauseosa*), and green rabbitbrush (*Chrysothamnus viscidiflorus*) occurring in smaller amounts. Sandberg bluegrass, bottlebrush squirreltail (*Elymus elymoides*), bluebunch wheatgrass, western wheatgrass (*Pascopyrum smithii*), and needlegrass (*Achnatherum* spp. and *Hesperostipa* spp.) are common in the understory (Conway et al., 2019).

The PAVA study area is associated with the Idaho Grouse and Grazing project. The Idaho Grouse and Grazing project represents a collaborative effort by the Idaho Cooperative Fish and Wildlife Research Unit, the Bureau of Land Management, Idaho Department of Fish and Game, and several private ranchers to understand the impacts of cattle grazing on sage-grouse demographics (https://idahogrousegrazing.org/). Each study pasture in the Grouse and Grazing project has been subject to one of four grazing treatments: no grazing, spring grazing in even years, spring grazing in odd years, or annual alternation between spring and fall grazing. GPS collars were distributed throughout cattle herds in the PAVA pastures. In 2019, I used GPS data from the River East and Donkey Creek pastures. River East is a 2,699-hectare pasture that was grazed by 100 cattle for 31 days. Donkey Creek is a nearly 549-hectare pasture that was grazed by 100 cattle for 13 days. In 2020, I used GPS livestock data from the 1,614-hectare Big Gulch pasture. This pasture was grazed by 100 cattle for 30 days. The three PAVA pastures were selected to provide insight into how estimates of livestock use and distribution changed in larger-sized pastures with the number of GPS collars that were analyzed.

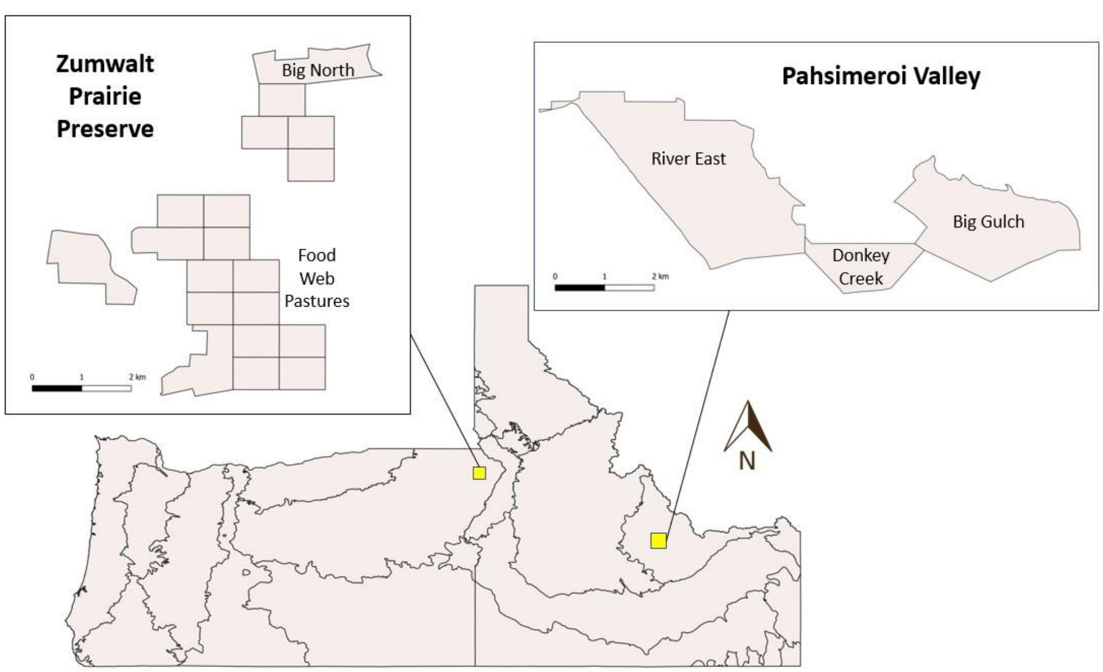

Figure 1.1 – GPS collars were deployed in five study pastures between the Zumwalt Prairie Preserve in northeastern Oregon and the Pahsimeroi Valley field site in central Idaho. The boundaries within each state designate the different ecoregions within Oregon and Idaho.

2.2 GPS Collar Design and Implementation

Low-cost GPS collars were made using a modification of Karl and Sprinkle's (2019) design. For PAVA and ZPP in 2019 and PAVA in 2020, "Version 2" GPS collars were developed using custom circuit boards to address many of the consistency and wiring issues of the original Karl and Sprinkle (2019) design. At ZPP in 2020, a "Version 3" GPS collar was deployed that used surface-mount circuitry to reduce size and cost, plug-in cables to improve reliability of connections to battery and GPS and added a 50mW solar cell to provide supplemental power. Both the Version 2 and Version 3 designs used a custom circuit board with a ATMEGA 328p microcontroller running the Arduino development environment. Version 2 GPS collars used UBlox m8n GPS receivers, and Version 3 collars used Beitian BN-180 GPS receivers. Both GPS receivers showed similar accuracy and performance in tests. Version 2 GPS collars were equipped with a 3.7V 3,500 mAh lithium polymer (LiPo) battery, while the Version 3 collars used a 3.7V 3,750 mAh LiPo battery. Complete design specifications, bills of materials, and assembly instructions for the Version 2 and Version 3 GPS collars are at https://github.com/Open-Source-Range/OSR_GPS_Collar.

Both the Version 2 and Version 3 GPS collars had similar accuracy to the Karl and Sprinkle (2019) GPS collars (Version 2 devices used the same GPS receiver as the Karl and Sprinkle devices). Average displacement was 2.5m (95% circular error probability of 4.5m) when sampling at 1s intervals, and 10.5m (95% circular error probability of 26.5m) at 5min intervals. Due to their improved design, the Version 2 and Version 3 GPS collars had much fewer dropped GPS readings than the original Karl and Sprinkle (2019) devices. The GPS units in all years and study pastures were set to record location with a date and time stamp at 10-minute intervals, with the device entering a deep-sleep mode between readings to conserve power. Data were written to a comma-separated-values file on each device's micro-SD card. If a valid GPS coordinate could not be established within a minute of waking at each interval, the location attempt was aborted and a location value of zero latitude and longitude was written to the output file. This was done to conserve power by limiting the time the GPS would be running.

Cattle were fitted with these low-cost GPS collars prior to entering the study pastures. Cows that received collars were selected haphazardly from the herd for each pasture. Between 25-75% of the cows in each study herd were collared. Collars were retrieved after the cattle left the study pastures. All livestock GPS collaring for this research was performed under approval from the University of Idaho's Animal Care and Use Committee (IACUC-2018-25).

Table 1.1 – Site-specific details related to GPS collar deployment at study sites in Oregon and Idaho in 2019 and 2020. In Oregon, GPS collars were distributed throughout pastures on the Zumwalt Prairie Preserve in Wallowa County, Oregon. In Idaho, GPS collars were distributed throughout pastures at the Pahsimeroi Valley field site near Challis, Idaho.

Pasture Name	Pasture Size (hectares)	Number of Collars Deployed	Number of Collars Returned*	Dates of Collar Deployment	Total Herd Size
Oregon					
2019					
Food Web**	40.47	50	45	June 2019	200
2020					
Big North	91.46	150	131	June 2020	200
Idaho					
2019					
River East	2,699	50	45	May 2019	100
Goldburg SW - Donkey Creek	549	50	48	May 2019	100
2020					
Goldburg NE - Big Gulch	1,614	60	44	June 2020	100

*Number of Collars Returned includes only collars that were returned with usable data. Some collars returned with little to no data recorded on the device.
**The 40.47-hectare Food Web pasture is part of a series of pastures used in a long-term study. In total there are twelve 40.47-hectare Food Web pastures grazed on the Zumwalt Prairie Preserve by the Nature Conservancy. For our purposes, only a single 40.47-hectare pasture out of the 12 was used.

2.3 Developing Estimates of Domestic Livestock Activity

2.3.1 Livestock Use

Prior studies have used GPS location data in several ways to estimate livestock use (Augustine and Derner, 2013). However, Laurence-Traynor et al. (2020) found strong correlations between in-field measures of utilization and simple occurrence-based estimates of livestock use. For this reason, I implemented a simple occurrence-based metric in which the GPS livestock locations were used to generate pasture-wide estimates of livestock use. This estimate of livestock use included all types of behavior (e.g. walking, grazing, loafing) because each activity had the potential to affect the landscape. All points that occurred outside of the pasture extent were excluded. All remaining GPS points were overlaid on a 30x30m grid associated with their corresponding pasture for a given year. This grid cell size was selected to help account for the GPS location error (10m) (Karl and Sprinkle, 2019) and to align with satellite data provided by Landsat being used in a related ongoing study. To quantify the livestock use for a given 900-m^2 cell *i* at time *t*, the following equation was used:

$$G_{it} = \left(\frac{p_{it} * N}{c_t * A}\right)$$

where p_{it} was the number of GPS points summed per cell *i* for each day *t*, *N* was the total number of animals in the herd, c_t was the number of active GPS collars per day *t*, and *A* was the area of the cell. The total livestock use for each cell (G_i) within the pasture was obtained by summing the G_{it} for each day across the entire grazing period:

$$G_i = \sum_{t=1}^{T} G_{it}$$

where *T* was the total time spent grazing in the pasture. The total livestock use for the entire pasture across the entire grazing period *(G)* was then calculated as:

$$G = \sum_{i=1}^{I} G_i$$

where *I* was the total number of grid cells in the pasture. This raster layer containing the G_i values for each grid cell represented the total livestock use surface and was calculated for each study pasture separately.

The grazing use equation took into consideration the interplay of several variables that influence estimates of livestock use in a complex grazing system. The variable c_t addressed fluctuations in the number of active collars per day. Due to limited battery life or poor GPS fixes, the number of collars available to provide information on the activity of the herd was different for each calculation. The variable *N* was included to account for stocking rates which varied considerably between pastures and had a direct impact on the outcome of a grazing period. *N* also corrected for the number of animals in the herd that were not collared. Inclusion of the area of each grid cell (*A*) accounted for pixels along the perimeter of the pasture whose area varied as a result of overlaying a fixed grid on irregularly shaped pastures.

2.3.2 Presence-Absence Distribution

A simple presence-absence approach was also used to assess livestock distribution in each of the study pastures. From the total livestock use surface for each pasture, each grid cell was classified with a 1 if it experienced any livestock use or a 0 if it experienced no livestock use. Thus, presence was denoted by the occurrence of one or more GPS fixes within a cell, while absence was assigned to all cells that contained no GPS fixes.

2.3.3 Hot Spot Distribution

The presence-absence method above was adapted to track "hot spots" or regions of repeated or extended livestock use. To map hot spots by pasture, I classified the livestock use surfaces with all cells at or above the 90^{th} percentile of use as 1 and all other cells as 0. The 90^{th} percentile value was selected because it characterized the highest use areas based on a visual assessment of the livestock use surfaces. This highlighted the extent of the pasture that experienced the greatest amount of use.

2.4 Calculating Information Lost as a Function of the Number of GPS Collars Used

I assessed the effects of information loss on the livestock use estimates by limiting the number of collars that were used to compute the metrics above (cattle use, presence-absence, and hot spots). I did this across different pasture and pixel sizes. Information loss represents information on the distribution or intensity of grazing that becomes unavailable as a result of using fewer GPS collars. To investigate the effect that the proportion of collared animals has on the ability to estimate livestock use and distribution, I used a sequential subsetting analysis of the GPS collar data. This was achieved by: 1) randomly selecting collars (from 1 to *n*-1), where *n* was the total number of active collars in the pasture, 2) calculating livestock use using only the GPS points from the subset of collars, 3) quantifying the difference between the subset livestock use layer and the original, full-collar livestock use layer, and 4) sequentially decreasing the size of the subset until the set contained data from only a single collar. This procedure was repeated 1,000 times for each subset size. I then calculated the 95^{th} and 5^{th} percentiles of the relative difference values across the 1,000 iterations for each subset size to evaluate the range in variability between random collar subsets.

From each subset, an average percent difference from the original surface was calculated to assess how estimates of livestock use changed with the use of fewer collars. This was performed for each pixel using the following equation:

$$PD = \frac{V1 - V2}{V1} * 100$$

where *PD* represented the relative difference by pixel between the original livestock use surface and each subset livestock use surface, *V1* represented the pixel value from the original livestock use surface, and *V2* represented the corresponding pixel value on the subset livestock use surface. I then calculated the average relative difference across all pixels within each subset livestock use surface.

For the presence-absence estimates, the same subsetting procedure was used to understand the ability to estimate livestock distribution. However, instead of calculating an average percent difference between the original surface and each reduced collar surface, the presence-absence distribution was reassessed and the ratio of presence to absence cells was recounted for each reduced collar surface.

For the hot spot data, I used the same subsetting procedure to estimate the ability to discern high-use areas from infrequently visited areas as the number of collars were sequentially decreased. Instead of calculating an average percent difference, each reduced collar surface was reclassified so that all cells at or above the 90th percentile were marked as 1 and all other cells as 0. I selected the 90th percentile because after visually inspecting the livestock use surfaces for each pasture, I determined that this delineation captured the areas of heaviest livestock use. I then assessed how the ratio of presence to absence designations changed with the sequential reduction of GPS collars.

2.5 Analyzing the Effects of Scale on Efficient GPS Collar Implementation

2.5.1 Pasture Size

To understand the effect that pasture size has on our livestock metrics, GPS livestock data was analyzed from four different pastures ranging in size from ~40 hectares to 2,699 hectares. The Food Web and Big North pastures on the ZPP were 40.47 hectares and 91.46 hectares in size, respectively. Goldburg SW – Donkey Creek and River East at the PAVA field site were ~549 hectares and ~2,699 hectares in size, respectively. While the number of collars that were deployed (50-150) and the duration of grazing (from 5 to 28 days) varied by pasture, I limited the number of collars used in this analysis to 45 and the grazing duration to 5 days to be consistent across pastures. This helped isolate the effect of pasture size on measures of livestock use.

The average percent difference and presence-absence approaches described above were used to determine a recommended proportion of collared animals for the four pastures of varying sizes mentioned above. Using the presence-absence data, I calculated how many collars were needed to maintain a 95%, 90%, 75%, 50%, and 25% similarity to the original distribution surface. To do this, I calculated the mean number of presence designations across the 1000 iterations for each collar subset size. I then divided the mean presence of each subset size by the number of presence designations in the total distribution surface to determine the percentage of the whole that each subset size represented. I recorded the number of GPS collars used in each subset size that was 95%, 90%, 75%, 50%, and 25% similar to the original distribution surface. The same procedure was used to calculate how many collars were needed to track hotspots.

2.5.2 Pixel Size

Pixel sizes of 30m, 60m, 90m, 120m, and 250m were assessed using the average percent difference and presence-absence methods for each pasture. 45 GPS collars were assessed in each pasture across a five-day grazing period. Varying pixel sizes were assessed within the same pasture to ensure that the only significant variation in the analysis was the pixel size. River East, Donkey Creek, and Big North were all assessed in the pixel size analysis. The Food Web pasture was not included because the small size of the pasture resulted in few pixels at the coarsest (i.e., 250m pixel size) resolution.

3. Results

3.1 Estimates of Livestock Use

Livestock use surfaces provided an estimate of grazing intensity within each pasture (Figure 1.2). All estimates of livestock use were reported in 10 minutes of animal time per m^2. Across all pastures, the maximum value of livestock use per pixel was 1.175 ten minutes of animal time per m^2 (Table 1.2). However, the average values of livestock use per pixel ranged from 0.0017 – 0.0997 ten minutes of animal time per m^2. Across all pastures, livestock distribution values ranged from 7.89% - 100% of pixels per pasture having been visited by cows. Distribution percentage decreased as pasture size increased. The percentage of each pasture that was considered a hotspot of livestock use ranged from 0.76% - 9.97% and also decreased with increasing pasture size.

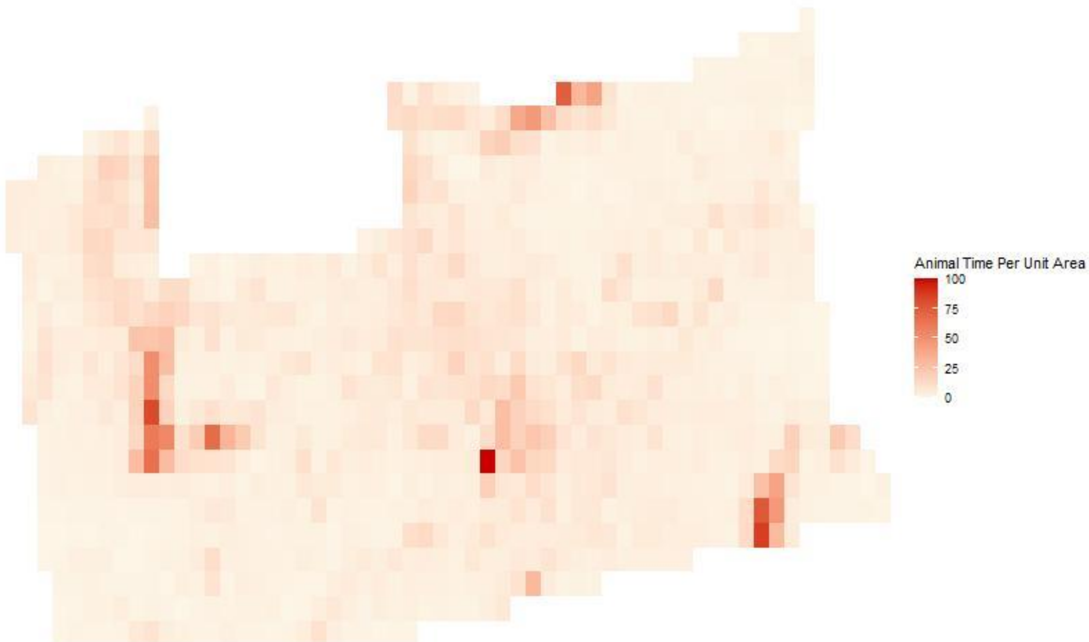

Figure 1.2 – Example of estimated livestock use generated from 2020 GPS collar data in the Big North pasture on the Zumwalt Prairie Preserve.

Table 1.2 – Livestock use and distribution values for four study pastures

Pasture	Pasture Area (hectares)	Average Livestock Use	Maximum Livestock Use	% of Cells Marked Present	% of Cells in Hotspots
Food Web	40.47	0.0997	1.175	100	9.97
Big North	91.46	0.016	0.287	67.21	6.39
Donkey Creek	549	0.0071	1.059	46.25	4.62
River East	2,699	0.0017	0.474	7.89	0.767

3.2 Information Loss as a Function of the Number of GPS Collars and Pasture Size

The number of GPS collars needed to accurately track herd use was strongly related to pasture size (Figure 1.3). Across all pastures, as more collars were removed, I observed larger differences between the subset livestock surfaces and the original livestock surface. Also, as pasture size increased the average percent difference increased more rapidly with the sequential reduction of collars.

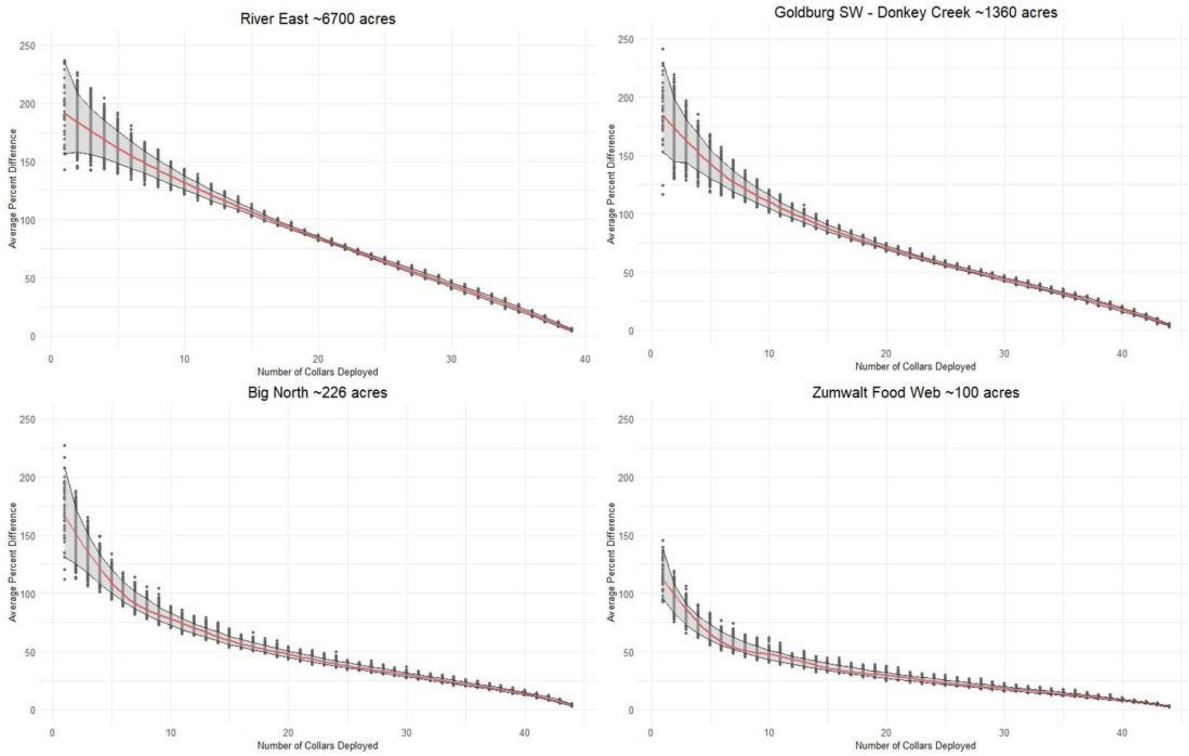

Figure 1.3 –The average percent difference between each subset livestock use surface (using 1 to *n*-1 collars) in relation to the original surface (using all available collars) at four pasture sizes. This was assessed at a 30m pixel size. The shaded area in each plot represents the range from the 95th – 5th percentile of relative difference values for each subset size.

Across all pastures, the number of GPS collars needed to obtain a specified level of certainty in the data increased as the size of the pasture increased. Maintaining a ≤75% average percent difference to the original grazing intensity surface required the use of at least 23 GPS collars in the largest pasture, River East. In the smaller pastures, maintaining a ≤75% average percent difference required at least 19 GPS collars in Goldburg SW – Donkey Creek, 10 GPS collars in Big North, and only 4 GPS collars in the Food Web pasture.

As the number of active GPS collars decreased, so did the number of cells containing at least one GPS location (Figure 1.4). However, the rate at which cells switched from a presence to an absence designation with the subsetting of collars was dependent upon the size of the pasture. In the River East pasture, the loss of any single collar's data resulted in fewer cells marked as present (Figure 1.5). However, in the Food Web pasture, nearly 75% of the collars could be dropped before a cell switched from presence to absence (Figure 1.6, see Appendix A for Donkey Creek and Big North figures).

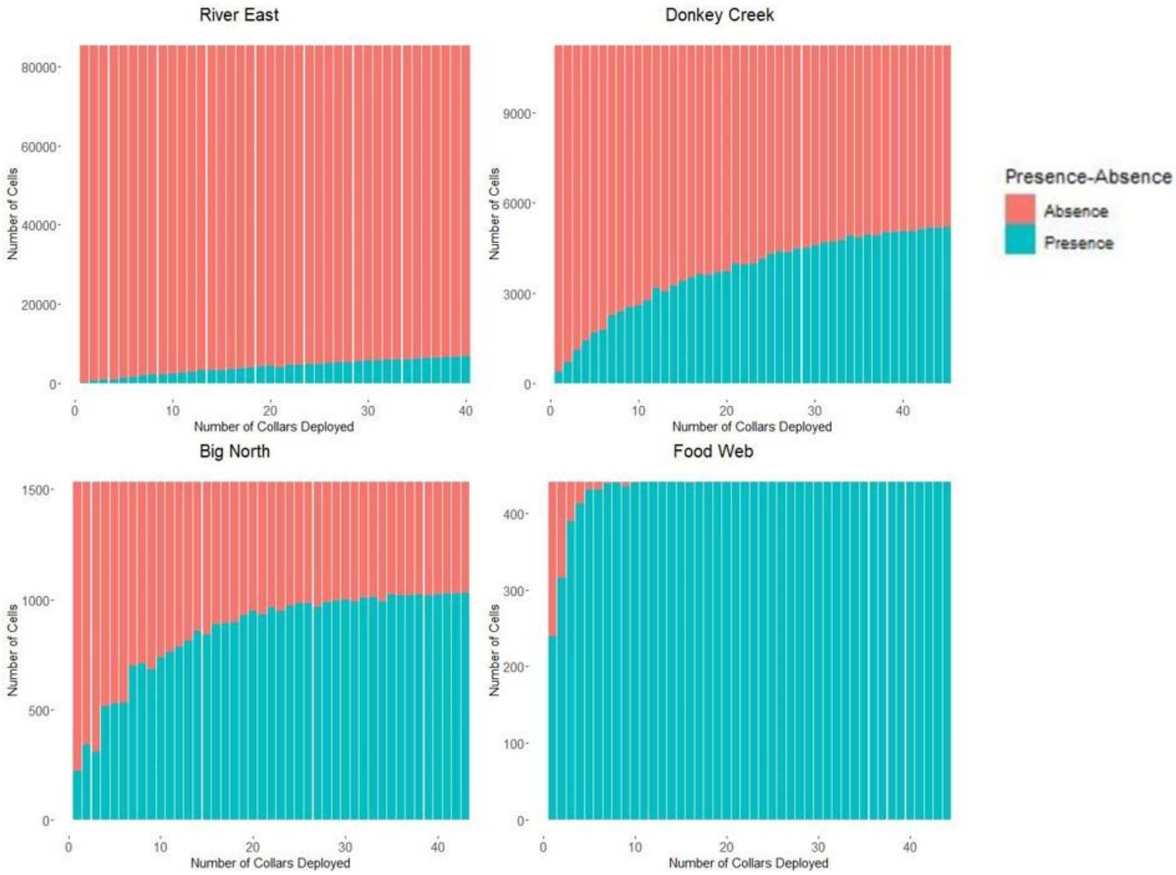

Figure 1.4 – Changes in the number of presence and absence designations by pasture. As the number of livestock collars were reduced, the number of cells that contained >0 GPS locations decreased at a greater rate in larger pastures compared to smaller pastures.

Figure 1.5 – Changes in livestock distribution in the River East pasture as a result of using fewer GPS collars. River East was the largest grazed pasture in the study at ~2,699 hectares and demonstrated the most rapid shift in estimated distribution as a result of collaring a smaller proportion of the herd.

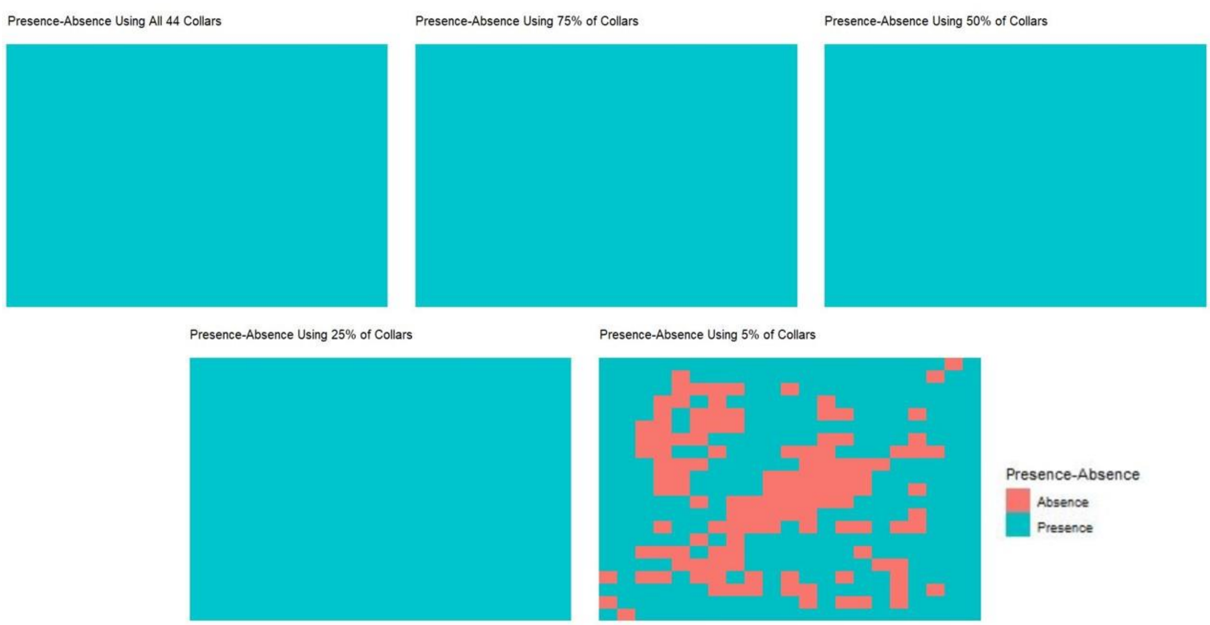

Figure 1.6 – Changes to livestock distribution in the Food Web pasture as a result of using fewer GPS collars. The Food Web pasture on the Zumwalt Prairie Preserve was the smallest pasture analyzed in the study. While deploying collars on only 5% of the individuals might still provide insufficient information, a pasture of this size required less than half of the individuals to be collared to obtain the same estimated livestock distribution.

In the largest study pasture, River East, approximately 37 GPS collars were required to obtain a distribution surface that was at least 95% similar to the original distribution surface (Figure 1.7). Conversely, in the smallest pasture, only approximately 5 GPS collars were needed to obtain a distribution surface at least 95% similar to the original distribution surface. The difference between the number of collars that were needed between pasture sizes to meet a given similarity to the original surface decreased as the percent similarity decreased. For example, to generate a pasture-wide livestock distribution estimate that was at least 25% similar to the pasture-wide estimate using all available collars, 7 GPS collars were required in the largest pasture and 1 GPS collar was needed in the smallest pasture.

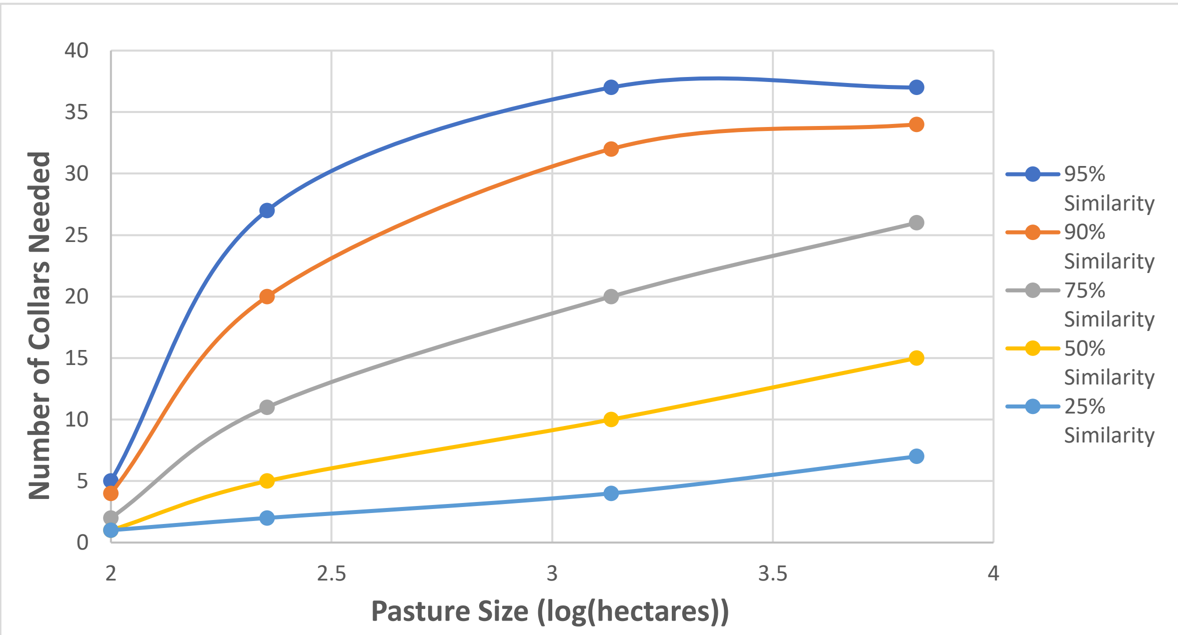

Figure 1.7 – Comparison of the number of collars needed to achieve the same level of similarity to the full presence-absence estimate of livestock distribution. The logged value of each pasture size was used to more clearly display the trend by pasture size.

The trend was reversed when assessing the number of GPS collars that were required to track hotspots in each pasture size (Figure 1.8). To meet a 95% similarity to the original hotspot surface, 39 collars were needed in the largest pasture while 43 collars were needed in the smallest pasture. Furthermore, the difference between the number of collars required in larger and smaller pastures increased as the percent similarity decreased. To achieve approximately 25% similarity to the original surface, 12 GPS collars were needed in the largest pasture while 26 GPS collars were needed in the smallest pasture.

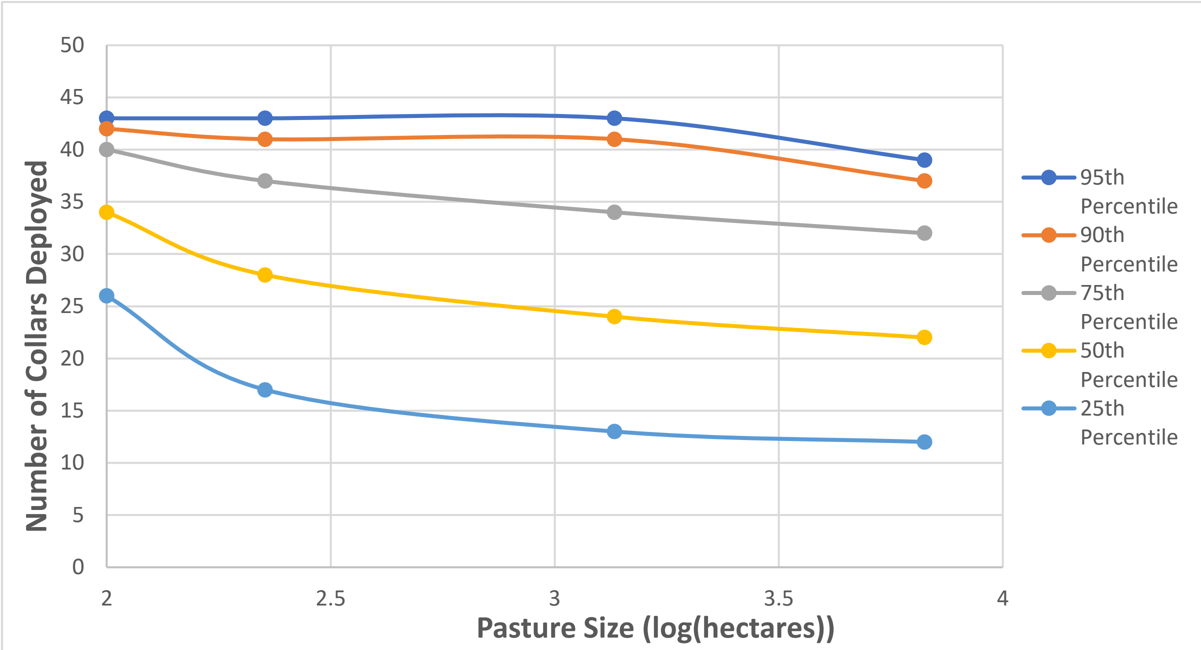

Figure 1.8 – Comparison of the number of collars needed at each pasture size to achieve the same level of certainty in identifying high-use areas. High-use areas were regions that were visited repeatedly thus experienced a high degree of livestock use. The logged value of each pasture size was used to more clearly display the trend by pasture size.

3.3 Information Loss as a Function of the Number of GPS Collars and Pixel Size

The number of collars needed to accurately track herd use in a pasture was influenced by the size of the pixel used to generate estimates of livestock use (Figure 1.9). Across the three pastures assessed, the number of GPS collars needed to generate the same level of similarity to the original, all-collar surface decreased as the size of the pixel increased (Figure 1.10). In River East, to maintain ≤50% average percent difference to the original livestock use surface would require 28 GPS collars at a 30m scale but 22 collars at a 250m scale. In Donkey Creek, a ≤50% average percent difference would require 27 GPS collars at 30m but only 12 collars at 250m. Lastly in the smallest pasture, Big North, to maintain ≤50% average percent difference would require 18 GPS collars at a 30m scale but as few as 3 GPS collars at a 250m scale. However, the variation among the 1,000 iterations with each subset size increased as the pixel size increased. The range between each iteration was much greater at 250m than at 30m. Depending on the GPS collar that was randomly removed at each sequential subset size, the subset livestock use surface could present a wide range of average percent difference values. For example, in the Donkey Creek pasture with a subset of five GPS collars, it was possible to end up with a livestock use surface ranging from 120-

170 average percent difference at 30m but 55-122 average percent difference at 250m. A complete list of figures depicting the average percent difference and livestock use estimates at different pixel sizes for all pastures is in Appendix B.

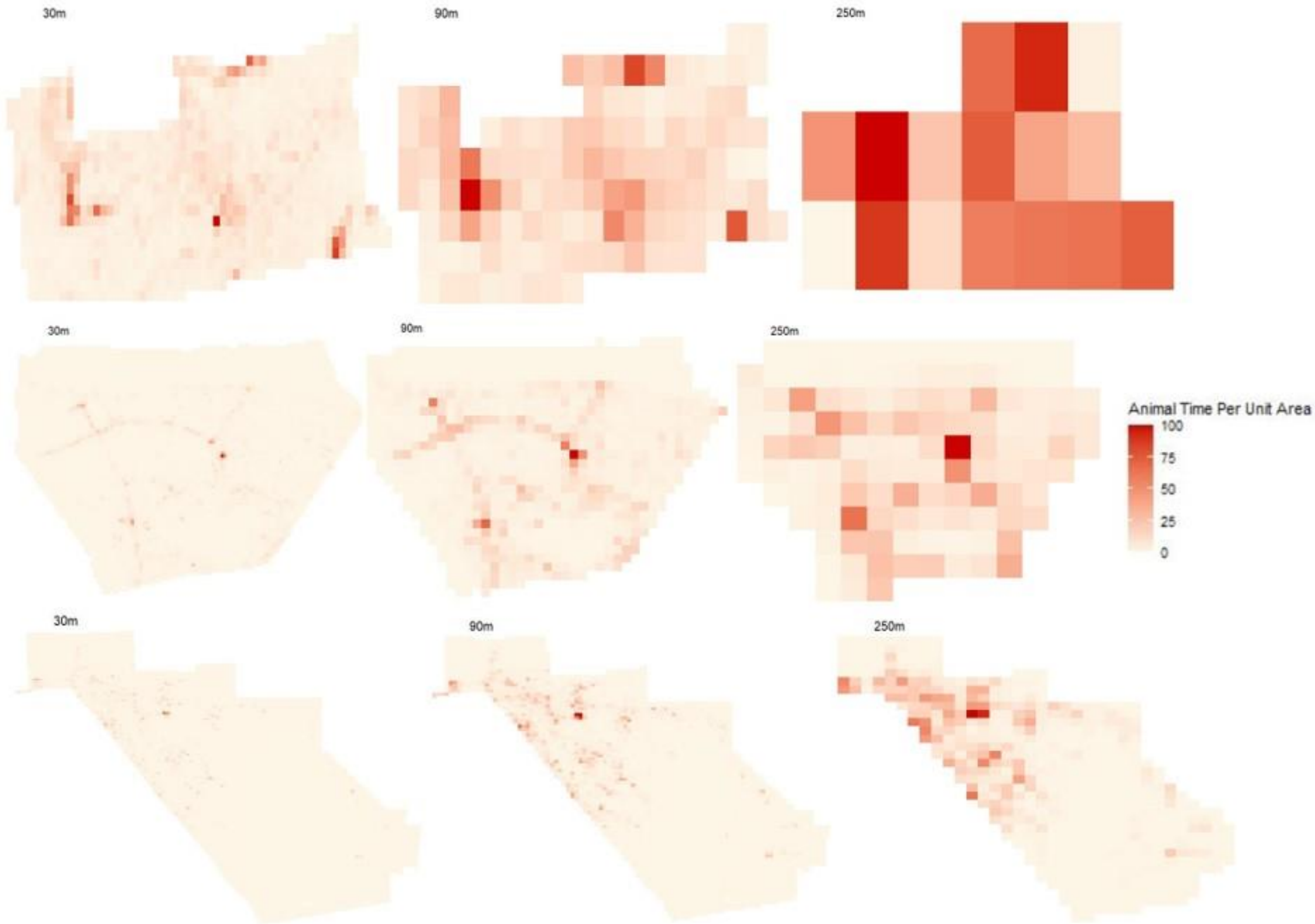

Figure 1.9 – Comparison of the livestock use surfaces at 30m, 90m, and 250m pixel sizes within the Big North, Donkey Creek, and River East study pastures.

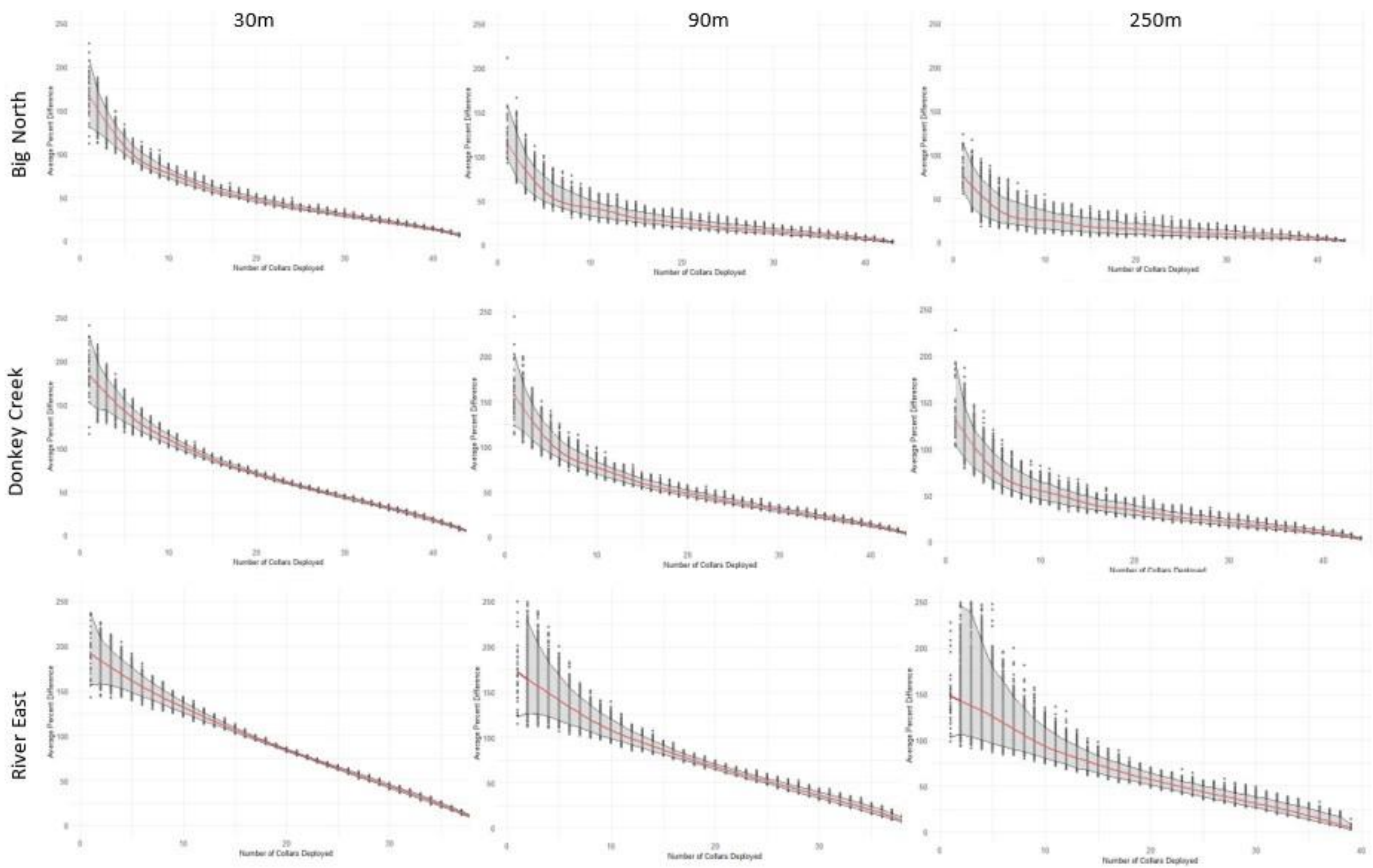

Figure 1.10 – Average percent difference between each subset livestock use surface (using 1 to *n*-1 collars) in relation to the original surface (using all available collars) across 30m, 90m, and 250m pixel sizes for the Big North, Donkey Creek, and River East study pastures. The shaded area in each plot represents the range from the 95th – 5th percentile of relative difference values for each subset size.

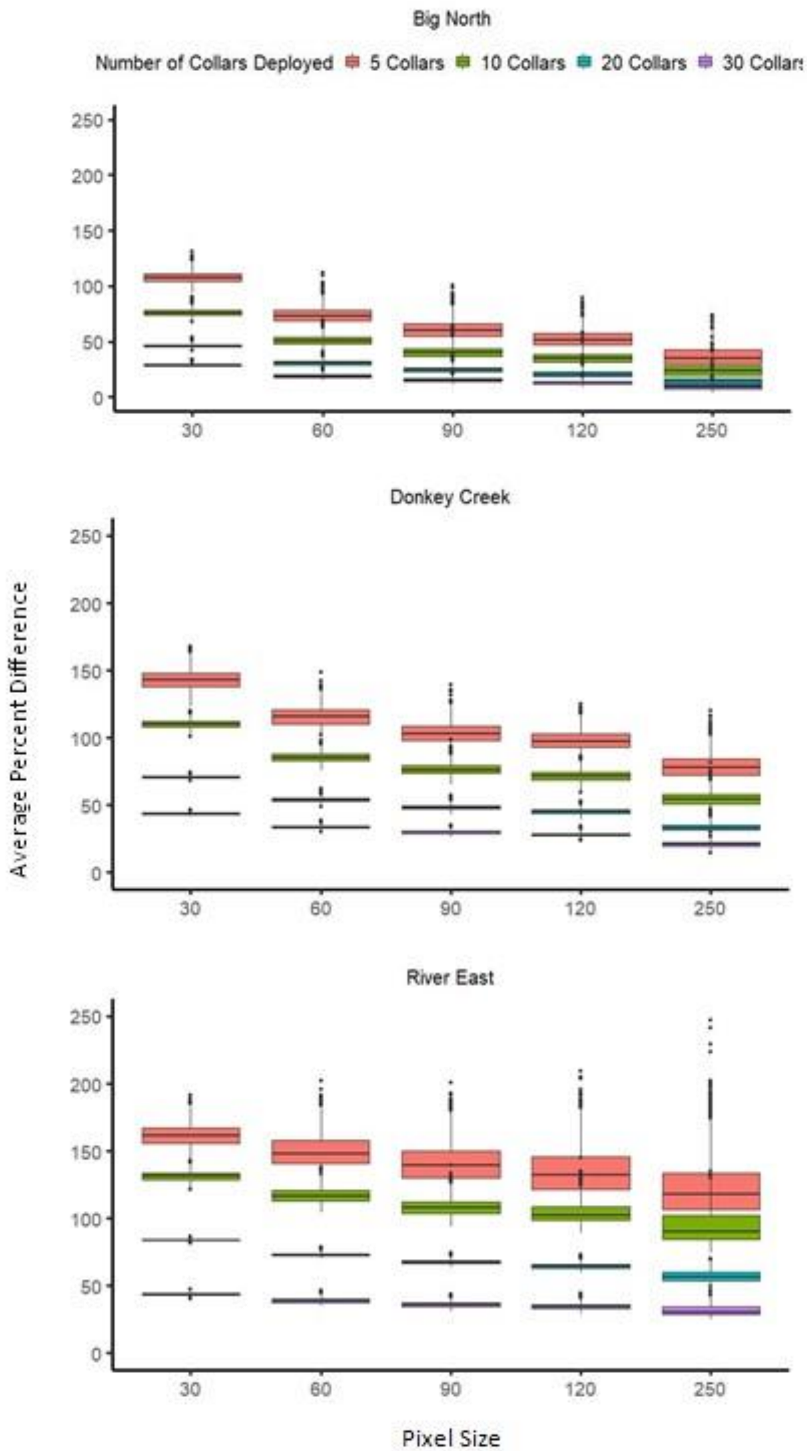

Figure 1.11 – The relationship between pasture and pixel size as it relates to the number of GPS collars that need to be deployed to accurately estimate livestock use. Pasture size and pixel size are inversely related. More GPS collars were needed as pasture size increased and pixel size decreased.

Both pasture and pixel size impacted the number of GPS collars that were needed to accurately estimate livestock use, but pasture size and pixel size were inversely related (Figure 1.13). More GPS collars were needed as the pasture size increased and as the pixel size decreased. The inter-subset variability of average percent difference values decreased as pasture size decreased and pixel size increased. The intra-subset variability of average percent difference values also decreased as pasture size decreased and as pixel size increased.

4. Discussion

This study clarified the impacts of spatial scale on livestock assessment by approaching the use of GPS data from two angles: extent and grain. Extent refers to breadth of the area of interest, in this case the size of the pasture (Farina, 1998). Grain refers to the smallest observable unit used to assess the entire area of interest, in this case the pixel size (Kotliar and Wiens, 1990). It is evident from my results that both the extent and grain of assessment had a significant impact on estimates of livestock use and distribution and the number of collars needed to accurately estimate both. The effects of changing extent and grain were inversely related regarding their impact on the number of GPS collars needed. Thus, the greatest number of GPS collars were needed in the largest pasture when assessed with the smallest pixel size.

When assessing both livestock use and distribution, information loss occurred steadily with the random removal of the first 10-15 GPS collars from consideration, then rapidly increased as ≥50% of the collars were removed. This indicates that collaring between 5-15% of a herd is likely to be insufficient in collecting enough data to accurately track livestock use and distribution for pastures between the sizes of ~40 – 2,699 hectares. Insufficient data from using too few collars could result in misinterpretation of study results or misunderstanding of the impacts or severity of a grazing regime. Either outcome could lead to ineffective rangeland management practices. This pattern of information loss was more pronounced in larger pastures. The largest pasture in this study required nearly 3 times more GPS collars than the smallest pasture to maintain the same level of confidence in estimates of livestock use and 15 times more GPS collars when assessing livestock distribution. The larger pastures required more collars because there was more opportunity for livestock to disperse and create unique patterns of use. This created a greater amount of variability in the data which required a greater number of GPS collars to capture that variability.

Pasture size also had an impact on the number of collars needed to track high-use areas within a pasture. Fewer collars were needed in larger pastures compared to smaller pastures to detect high-use areas. I attributed this to the fact that in larger pastures, most individuals likely visit highly desirable areas with palatable forage first before spreading out and creating unique paths of travel throughout the pasture. Deploying a small number of collars on the herd would be sufficient in highlighting this activity in larger pastures. In smaller pastures, however, most individuals likely visit high-use areas and still disperse throughout the pasture because the smaller pasture offers fewer opportunities for unique patterns of utilization and distribution. Use of only a small number of collars in these pastures may make it difficult to differentiate hotspots from other less frequently used areas. Thus, collaring a greater proportion of the herd might be necessary in smaller pastures to track areas where multiple individuals in the herd repeatedly returned to versus areas that were visited only once or twice.

At nearly 2,700 hectares, I anticipated that the River East pasture would show a significantly greater rate of information loss in comparison to the smaller pastures. While River East did match the expected trend in requiring a greater number of collars than the smaller pastures, it did not demonstrate as great of a difference as expected given that it was more than four times as large as the next pasture. This can likely be explained in two ways: 1) the five-day grazing period used to assess all pastures was not enough time for the livestock herd to disperse throughout the entire pasture, or 2) the topography of the pasture did not allow the herd to fully utilize all of the pasture. Either case is an issue of saturation and resulted in River East presenting as a much smaller pasture.

There was a consistent scaling relationship between pixel size and the number of GPS collars needed for accurate assessment as well. Across all pastures, as the spatial resolution coarsened, the number of collars that were needed to track herd-wide livestock use and distribution decreased. For example, within the Donkey Creek pasture, to measure livestock use with ≤50% average difference to the original surface required the use of 27 GPS collars at a 30m pixel size but only 13 GPS collars at a 250m pixel size. When comparing the smallest and the largest pixel sizes, the 250m pixel size required, on average, about half as many GPS collars to accurately track livestock use as the 30m pixel size. More GPS devices were required when estimating livestock use and distribution at a fine spatial resolution.

While the larger pixel sizes required fewer collars for the same level of accuracy in assessment, they offered a coarser-scale view of livestock use and distribution within pastures and may not be appropriate for some objectives. Use of a 250m pixel size resulted in estimates that overstated both livestock use and the extent of livestock distribution within each of the study pastures, though this was more pronounced in the smaller-sized pastures. When estimating livestock use with a 30m pixel size in the Big North pasture, high-use areas and paths of frequent travel were distinct from areas that were not visited at all or used infrequently. Areas that experienced moderate use were visible throughout the center to northern portions of the pasture. In contrast, a much larger portion of the pasture was grouped into a high-use designation at a 250m pixel size, including portions that may have otherwise been designated as little to no use with a smaller pixel size. In this case, few pixels were considered moderately grazed. At the 250m scale, almost the entire pasture appeared to have experienced a high degree of livestock use. Thus, the tradeoff between the number of collars that are deployed and the grain of the spatial resolution is something that should be weighed and adjusted amongst different study designs.

This study was unique in its assessment of livestock use and distribution at the pasture scale. Previous research involving GPS livestock monitoring has focused largely on individual movement, behavior, and resource selection utilizing a small number of GPS devices (typically between 2-8% of the herd) in their evaluations (e.g. Augustine and Derner, 2013; Gersie et al., 2019; Thomas et al., 2011). Herd-wide assessments of livestock use are uncommon, but the studies that exist have based their results on collaring only 1-5% (Agouridis et al., 2004; Bailey et al., 2018; Bailey and Welling, 2007; Butt, 2010; Deck, 2006; Kawamura et al., 2005; Putfarken et al., 2008), 6-10% (Haan et al., 2010; Schauer et al., 2005; Sickel et al., 2004; Tomkins and O'Reagain, 2007; Yule et al., 2010), and 11-15% (Bailey et al., 2010; Ganskopp, 2001; Oudshoorn et al., 2008; Ungar et al., 2005) of the herd. This study used large quantities of GPS collars to make herd-wide assessments of livestock use and distribution. Across the five pastures used in this study, I deployed a minimum of 50 GPS devices and a maximum of 150 amounting to 25-75% of the individuals in each study herd.

The large number of collars that we deployed was important because both the pasture and pixel size analyses indicated that it was advantageous to deploy as many GPS collars as resources allowed to measure both livestock use and distribution. The contrast between each subset surface and the original surface in both the livestock use and distribution assessments suggested that individuals within each herd demonstrated unique patterns of use. While some overlap did occur, there was less redundancy in the data than expected. Each additional GPS collar was useful in providing information on the use and distribution of the herd as a whole. Use of a greater number of GPS collars allowed me to track overlaps in the data to identify high-use areas and track areas of the pasture that were less frequently used; areas that might have otherwise been unknown. Thus, while GPS monitoring has become an increasingly popular means of estimating livestock use, the accuracy of this method at the pasture-scale may be limited by the proportion of the herd that can be collared.

While my results suggest that it is advantageous to utilize large numbers of GPS devices, it is not feasible to collar every individual in a herd. Livestock GPS devices can be expensive if purchased commercially and time consuming to attach and deploy in large quantities. The number of GPS collars used in any project should be selected based on the study's specific objectives and constraints. However, deploying GPS collars on 50% of the individuals in a herd generally provided enough information to estimate the use and distribution of the herd as a whole. This recommendation shifts based on the extent and grain of spatial assessment.

While pasture-scale assessments of livestock use and distribution are uncommon, other studies have produced similar results demonstrating the value of using large quantities of GPS collars to accurately monitor livestock activity. While using GPS collars to monitor the grazing preferences of beef cattle, Turner et al. (2000) found that significant errors were introduced when fewer collars were used to track livestock locations. They observed a high degree of variability between grazing animals and noted a 30% increase in error rate when collaring 5% of the herd compared to 30% of the herd. While using the same low-cost GPS devices as this study to evaluate the efficacy of several field-based grazing intensity measurements, Laurence-Traynor et al. (2020) found that there was more intra-animal than inter-animal redundancy, therefore, deploying more collars with a longer sampling interval would be more likely to provide an accurate depiction of a herd's use and distribution than using fewer collars with a shorter sampling interval.

While the results above clearly demonstrate the relationships between information loss and scale, effects of the number of GPS collars on estimates of grazing intensity or distribution measures may vary by system. As a product of this study design and the incorporation of elements from other ongoing grazing experiments, factors such as the livestock operator, the breed of cattle, and variability in topography, elevation, and vegetation species amongst study areas that may influence results. In Oregon, the data collected from the ZPP was facilitated by TNC's ongoing grazing experiment using pre-established pastures and relationships with local ranchers. In Idaho, the pastures associated with the Grouse and Grazing project were selected and established as many as 10 years ago to meet the specific needs of the project and reflect a willingness by ranchers to participate in grazing-related research. The selection of pastures for deploying GPS collars at both study sites was based primarily on the interest and willingness of the ranchers to participate, first in the ongoing grazing experiment, and second in the deployment of GPS collars. Because of this, the selection of livestock breed and type were beyond our control in both study areas. There is evidence that different cattle breeds or types (e.g., yearling heifer, cow-calf pair) may exhibit different behaviors and patterns of use (Sheehy, 2007). Different breeds or types may graze for longer periods, travel further, or travel collectively as opposed to independently creating unique patterns of use (Aharoni et al., 2009), thus the impact of breed on the deployment of GPS collars to track behavior and distribution should be explored further. Additionally, because I worked with different operators in different locations for each site, I did not have the means to standardize the way the collars were distributed and placed on individuals within the herd. Therefore, the collars could not, by the statistical definition, be randomly distributed throughout the herd.

Additionally, the study sites sit at varying elevations, experience different levels of precipitation, and exhibit a wide range of plant species, soils, and topographies. There is evidence that cattle use and distribution is impacted by vegetation structure, topography, and moisture (Raynor et al., 2021), thus further research is needed to determine how variations in these ecological elements impacts the quantity of GPS collars needed to accurately track pasture-wide use and distribution.

5. Management Implications

Accurately estimating livestock use is essential to effective rangeland management (Eyre et al., 2011; Ortega-S et al., 2013; West, 2003). GPS collars have been shown to be an effective means of estimating livestock use and distribution at pasture scales, but the accuracy of this method may be limited by the number of collars that can be utilized. Historically, the number of collars that are deployed in a study has been limited by the cost of the devices and the logistics associated with deploying large numbers of them. However, the availability of low cost devices (e.g., Karl and Sprinkle 2019) or the emergence of other location-based livestock management technologies (e.g., virtual fencing, Campbell et al., 2018) have made it feasible to track much larger portions of a herd. The GPS collar recommendations above are intended for use in pasture-wide studies of livestock use and distribution. Studies focusing on individual behavior or movement or studies that model livestock resource selection likely do not need as many GPS devices as are advised by this study. The recommendations offered here should be considered within the context of each unique ecosystem, management framework, and established long-term monitoring objectives.

Improperly managed livestock grazing may have serious consequences for vegetation structure, soil characteristics, and wildlife demographics. It is important that an adequate number of GPS collars are deployed to collect enough information to sufficiently answer specific research and management questions. If an insufficient number of collars are employed to ensure the accuracy of livestock use and distribution estimates, we risk misinterpreting the impacts of the most common land use on rangelands in the western United States.

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Chapter 2

1. Introduction

The greater sage-grouse (*Centrocercus urophasianus*; GRSG) is a sagebrush (*Artemisia* spp.) obligate species whose population trends are closely associated with changes to the health and connectivity of the sagebrush steppe (Aldridge et al., 2008). The GRSG is a keystone species of sagebrush ecosystems (Blomberg et al., 2013; Connelly et al., 2004; Conover and Roberts, 2016; Lyon and Anderson, 2003), meaning that changes in GRSG populations may be reflective of underlying changes in the ecosystem as a whole. Furthermore, conservation efforts designed to benefit keystone species like the GRSG may benefit other wildlife species who also depend on sagebrush communities (Conover and Roberts, 2016; Hanser and Knick, 2011). Preserving large areas of sagebrush necessary for greater sage-grouse persistence may benefit other native sagebrush steppe species that have similar habitat requirements like pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), pygmy rabbits (*Brachylagus idahoensis*), and sage sparrows (*Amphispiza belli*) (Aldridge et al., 2008; Sage Grouse Initiative, 2020).

For more than a century, researchers have documented declines in GRSG populations (Conover and Roberts, 2017; Hornaday, 1916). Historically, the GRSG inhabited 15 states and 3 Canadian provinces across an estimated 1.2 million km^2 (Connelly and Braun, 1997; Sage Grouse Initiative, 2020; Schroeder et al., 2004). Today, the bird occupies 11 states and 2 Canadian provinces, only 56% of its historical range (Schroeder et al., 2004). Braun (1998) estimated that the range-wide breeding distributioni has declined 45–80% since the 1950s. Connelly et al. (2004) concluded that GRSG breeding populations have been declining range-wide since 1965 at a rate of approximately 2% per year. A third report confirmed the overarching suspicion that GRSG populations have been experiencing a long-term (1965–2015) decline throughout the species' range, with an estimated range-wide 0.83% decline in average males per lek per year (Western Association of Fish and Wildlife Agencies, 2015). State wildlife agencies have reported that the population decline has continued between 2015-2019. In the last three years, virtually all populations in North America have declined (Connelly et al., 2019). In a recent comprehensive analysis of GRSG population dynamics, Garton et al. (2015) reported that relatively small sage-grouse populations or populations that are most exposed to known threats are faring poorly and are continuing to decline despite various conservation efforts to halt declines. The report found no evidence of stable to increasing GRSG populations, even in larger or less exposed populations (Garton et al., 2015).

The observed declines in GRSG populations have been attributed to widespread habitat loss and fragmentation. Declining quality and connectivity of western rangelands has been attributed to energy and gas development (Allred et al., 2015; Holloran, 2005; Lyon and Anderson, 2003), conversion to agriculture (Braun, 1998; Connelly et al., 2004), conifer encroachment (Commons et al., 1998), expansion of cheatgrass (*Bromus tectorum*) (Connelly et al., 2004; Knick et al., 2003), fire (Connelly et al., 2000a; Connelly and Braun, 1997), and domestic livestock grazing (Beck and Mitchell, 2000; Crawford et al., 2004). While the detrimental effects of the other five primary causes of rangeland deterioration are clear and convincing, the effects of domestic livestock grazing remain either contradictory or inconclusive (Beck and Mitchell, 2000; Connelly and Braun, 1997; Smith et al., 2018).

Livestock grazing is suspected to influence GRSG via a removal of herbaceous material needed for adequate nesting habitat, a decrease in the vegetative heterogeneity of the landscape, and trampling of nests (Connelly et al., 2011; Knick et al., 2003). According to Laycock (1991), long-term or poorly managed grazing can reduce the amount of perennial herbaceous content in sagebrush communities. This decreased herbaceous productivity allows for increased sagebrush growth, crossing a threshold into a sagebrush-dominated state (Beck and Mitchell, 2000). Tall, dense herbaceous cover is essential to providing adequate GRSG nest cover (Braun, 1998), and lack of such cover leaves nests susceptible to increased avian and mammalian predation (Delong et al., 1995; Gregg et al., 1994; Sveum et al., 1996; Watters et al., 2002). Furthermore, the decrease in herbaceous growth as a result of greater livestock production reduces the natural variability in vegetation across the landscape (Krausman et al., 2009). Greater sage-grouse require different vegetation characteristics during their lekking, nesting, and brood-rearing stages and, therefore, greatly benefit from the mosaic of vegetation that a diverse sagebrush steppe ecosystem provides (Crawford et al., 2004). Aside from modifications to vegetation composition, livestock may directly impact GRSG populations through increased mortalities due to fence collisions, stock tank drownings, and nest trampling and desertion (Boyd et al., 2014; Stevens et al., 2012).

However, other literature has suggested that there is a positive association between livestock grazing and GRSG populations. Conover and Roberts (2016) contended that appropriate grazing strategies have the potential stabilize GRSG populations, one benefit being an increase in the quantity and quality of forbs available for chicks to consume. Similarly, Call (1974) argued that the creation of openings in the sagebrush as a result of livestock use may produce areas that support successful breeding, feeding, and brood rearing behaviors. The

U.S. Fish and Wildlife Service concluded that “grazing that is managed to maintain or promote sagebrush with a healthy understory of grasses and forbs benefit sage-grouse” (United States Fish and Wildlife Service, 2020). As far as direct impacts, Shultz (2009) maintained that the magnitude of effects like nest trampling have been overstated and are largely unsupported by local data. He asserted that while nest trampling is possible, it is uncommon in sagebrush communities that provide ample protection and coverage for GRSG nests.

There is a third subset of research that has concluded that domestic livestock grazing has little to no direct effect on GRSG populations. Smith et al. (2018) published results from a project evaluating differences in nest fate and herbaceous height and cover between sites that adhered to strict rotational grazing standards (utilization rates <50%, duration <45 days) and sites that did not (season-long grazing or slower rotations). They reported only minor differences in herbaceous height and cover, bare ground, and visual obstruction between the two treatments suggesting that grazing had little effect on GRSG nest survival.

Because domestic livestock graze over most areas used by GRSG, a more complete understanding of the impacts associated with domestic livestock grazing is necessary to effectively manage GRSG populations (Aldridge et al., 2008; Beck and Mitchell, 2000; Braun, 1998; Connelly et al., 2000a; Connelly and Braun, 1997; Crawford et al., 2004). However, defining the impacts of livestock grazing on GRSG demographics is complex because grazing practices are often assessed at varying spatial and temporal scales (Connelly and Braun, 1997). For example, livestock grazing may be evaluated at a plot, pasture, allotment, or landscape level across spring, summer, or fall. Analyzing the relationship between grouse and grazing is challenging because the scales used to evaluate livestock grazing often do not align with the scales of assessment used to evaluate GRSG demographics (i.e., nest site, seasonal habitat, home range, or species range scales throughout the year). Comparing a few dozen ≤100m-diameter livestock monitoring plots to GSRG demographic data that spans a few thousand acres is likely insufficient in assessing the dynamic relationship between grazing and sage-grouse populations. Accurately evaluating the effects of grazing on sage-grouse demography requires data collection and analysis that is consistent, clearly defined, and scaled across the pasture, ranch, and landscape.

The decreasing cost of Global Positioning Systems (GPS) has introduced new opportunities to efficiently and accurately collect livestock use and behavior data (see Bailey et al., 2018) at a scale that could match GRSG data collection. Previous studies have demonstrated the value of GPS collars in assessing other livestock-wildlife interactions. These studies have used GPS collars to predict and mitigate livestock-wildlife encounters and depredation (Atickem and Loe, 2013; Clark et al., 2020), track livestock-wildlife disease transmission (Cowie et al., 2016; Deck, 2006), and quantify the impact of livestock grazing on wildlife habitat (Valls-Fox et al., 2018). GPS collars allow for continuous monitoring of livestock location and behavior which provides an accuracy and completeness not found in other methods (Brennan et al., 2019). Data can be collected efficiently in a way that reduces observer bias and documents grazing with the fine-scaled temporal and spatial context that is more consistent with the scale at which wildlife data is often collected. The use of GPS collars to track livestock use and distribution within a pasture offers an opportunity to better evaluate the interaction between cattle and GRSG, allowing for a more rigorous investigation of the larger impacts of livestock grazing on GRSG populations. More specifically, the use of GPS collars on spring-grazing cattle offers an opportunity to investigate the impacts of livestock use on nesting hens at a time of the year when grazing is thought to have the greatest potential adverse effects on sage-grouse populations (Boyd et al., 2014).

The objective of this study was to evaluate the spatial relationship between spring-grazing cattle and GRSG nest sites at a pasture scale by comparing GPS-derived estimates of livestock use with confirmed GRSG nest locations. The goal of this evaluation was to determine if livestock and GRSG use similar portions of pastures or if there is spatial separation of microhabitats within pastures. I first tested for co-location or separation between the cattle GPS locations and GRSG nests to determine if the two groups occurred in similar or opposing portions of the landscape. Second, I investigated the vegetation structure around the livestock and GRSG locations to identify similarities or differences between the portions of the landscape used by cattle and grouse.

2. Methods

2.1 Study Areas

I collected livestock GPS data and GRSG nesting data from the Pahsimeroi Valley (PAVA) and Jim Sage (JISA) study areas associated with the Idaho Grouse and Grazing project (Figure 2.1, Table 2.1). The Idaho Grouse and Grazing project represents a collaborative effort by Idaho Cooperative Fish and Wildlife Research Unit, the Bureau of Land Management, Idaho Department of Fish and Game, and several private ranchers to understand the impacts of spring cattle grazing on sage-grouse demographics (https://idahogrousegrazing.org/).

Lying between the Lemhi and Big Lost mountain ranges, the PAVA study area is situated in Lemhi County, Idaho at an elevation of ~2000m. The site receives a mean annual precipitation of 22.1cm and is characterized by river flats, toe slopes, and irrigated agricultural fields. (2019). Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) is the dominant woody species, with low sagebrush (*Artemisia arbuscula*), rubber rabbitbrush (*Ericameria nauseosa*), and green rabbitbrush (*Chrysothamnus viscidiflorus*) occurring in smaller amounts. Sandberg bluegrass, bottlebrush squirreltail (*Elymus elymoides*), bluebunch wheatgrass, western wheatgrass (*Pascopyrum smithii*), and needlegrass (*Achnatherum* spp. and *Hesperostipa* spp.) are common in the understory (Conway et al., 2019). At PAVA, livestock GPS data and GRSG nesting data were collected from three pastures: River East (2019), Donkey Creek (2019), and Big Gulch (2020). These pastures were 2,699, 549, and 1,614 hectares, respectively.

The JISA study area is located in Cassia County, Idaho between the City of Rocks National Reserve and the Jim Sage mountains. The site sits at an elevation of ~1650m, receives a mean annual precipitation of 24.6cm, and is characterized by gentle toe slops and large dairy operations (Conway and Meyers, 2019). Low sagebrush, Wyoming big sagebrush, and mountain big sagebush (*Artemisia tridentata ssp. vaseyana*) are all common woody species at this site. Sandberg bluegrass, bottlebrush squirreltail, and bluebunch wheatgrass are the most common understory grasses (Conway et al., 2019). At JISA, livestock GPS data and GRSG nesting data were collected from the 552-hectare Kane Springs study pasture in 2018.

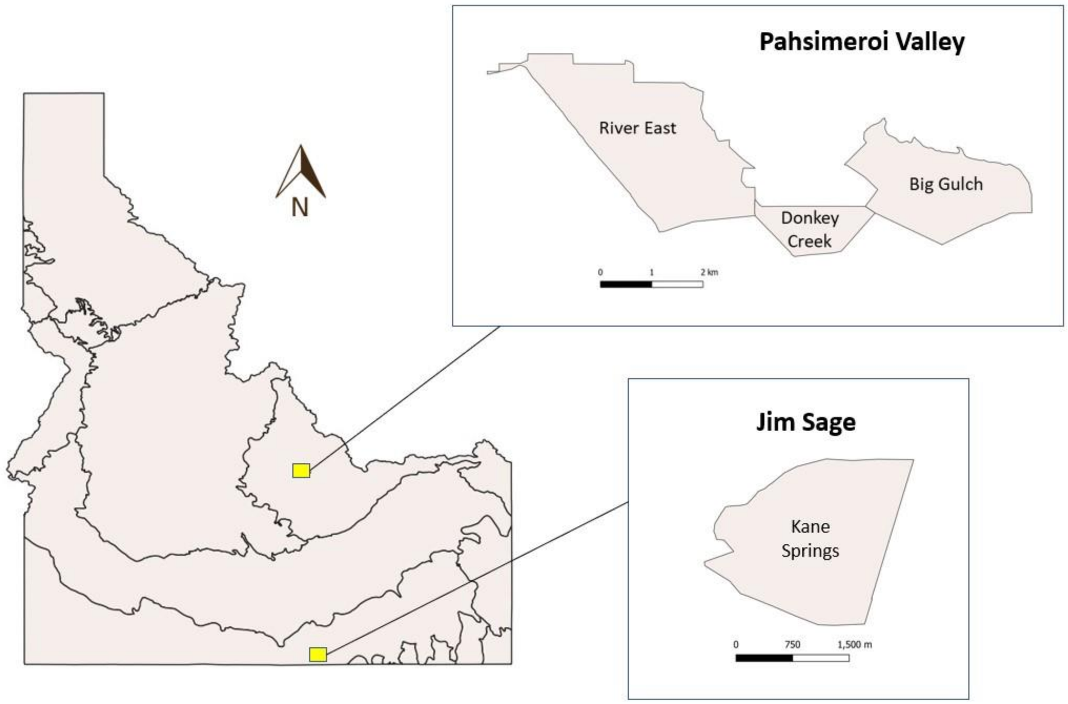

Figure 2.1 – Livestock GPS and GRSG nest locations were collected from three pastures at the PAVA field site and one pasture at the JISA study site. The boundaries within the state designate the different ecoregions of Idaho.

2.2 GPS Collar Implementation

This project used successive versions of a low-cost GPS collar using an open-source microcontroller system (Karl and Sprinkle, 2019). For JISA in 2018, "Version 1" GPS collars following Karl and Sprinkle's (2019) design were deployed. For PAVA in 2019-2020, "Version 2" GPS collars were developed using a modification of the original design where custom circuit boards addressed many of the consistency and wiring issues of the original Karl and Sprinkle (2019) design. Both GPS collar versions used a ATMEGA microcontroller running the Arduino development environment and a uBlox m8n GPS receiver and were powered by a 3.7V 3,500 mAh lithium polymer (LiPo) battery. Complete design specifications, bills of materials, and assembly instructions for the Version 1 and Version 2 GPS collars are at https://github.com/Open-Source-Range/OSR_GPS_Collar.

Both the Version 1 and Version 2 GPS collars had similar accuracy (both devices used the same GPS receiver) – average displacement of 2.5m (95% circular error probability of 4.5m) when sampling at 1s intervals, and average displacement of 10.5m (95% circular error probability of 26.5m) at 5min intervals. The GPS units in all years and study pastures were set to record a location with a date and time stamp at 10-minute intervals, with the device entering a deep-sleep mode between readings to conserve power. Data were written to a comma-separated-values file on each device's micro-SD card. If a valid GPS coordinate could not be established within a minute of waking at each interval, the location attempt was aborted and a location value of zero latitude and longitude was written to the output file. This was done to conserve power by limiting the time the GPS would be running.

Cattle were fitted with the low-cost GPS collars prior to entering the study pastures (Table 2.1). Cows that received collars were selected haphazardly from the herd for each pasture. Between 50-60% of the cows in each study herd were collared. Collars were retrieved after the cattle left the study pastures. All livestock collaring for this research was performed under approval from the University of Idaho's Animal Care and Use Committee (IACUC-2018-25).

Each of the four pastures used in this study were grazed according to one of three experimental grazing treatments outlined in the Idaho Grouse and Grazing Project's methodology. The three grazing treatments included spring grazing in even years, spring grazing in odd years, and annual alternation between spring and fall grazing. Because of our adherence to this study design and because of the financial and logistical constraints associated with deploying large numbers of the devices, GPS collars were not deployed in each study pasture each year. GPS collars were deployed to capture one year of spring grazing in each study pasture. Spring grazing occurred between 1 March and 15 June (Conway et al., 2019). At the Jim Sage study site, the Kane Springs pasture was spring grazed in even years so GPS data were obtained in 2018. At the Pahsimeroi Valley study site, the Donkey Creek pasture was grazed spring and fall alternate years so GPS data were obtained in the spring of 2019. The River East pasture was spring grazed in odd years so GPS data were obtained in 2019. The Big Gulch pasture was spring grazed in even years so GPS data were collected in 2020.

However, to increase the amount of data available for use in the spatial analysis, I needed livestock GPS data from each year that the study pastures were actively grazed during 2017-2020. When assessing the mechanisms that drive large herbivore grazing distribution patterns, Bailey et al. (1996) found that abiotic factors such as slope and distance to water more reliably and consistently predicted grazing patterns than biotic factors. They also found that large herbivores have accurate spatial memories. Cattle can remember nutrient rich portions of the landscape or patches that offer little to no food. Because factors like slope, topography, and distance to water in each pasture would have a similar influence on grazing distributions year after year and because these pastures are often grazed by returning, experienced animals, I assumed that the livestock GPS data that I had for a single year from each study pasture was likely representative of livestock use for each year the pastures were grazed as part of the study. This assumption allowed me to include livestock use data from years that each study pasture was spring-grazed (i.e., to include years when cows were not collared in those pastures). For example, the GPS data that I obtained from Jim Sage in 2018 was likely representative of how the pasture was utilized by livestock again in 2020. Thus, we obtained estimates of livestock use and GRSG nesting data from River East and Donkey Creek in 2017 and 2019 and from Kane Springs and Big Gulch in 2018 and 2020.

After all GPS data were downloaded from the returned collars, GPS points that occurred outside of the pasture extent were excluded and data were screened to remove erroneous points caused by poor GPS fixes.

Table 2.1 – Site-specific details related to GPS collar deployment at the Pahsimeroi Valley and Jim Sage study sites.

Pasture Name	Pasture Size (hectares)	Number of Collars Deployed	Number of Collars Returned*	Total Herd Size	Dates of Collar Deployment	Grazing Treatment
2018						
Kane Springs	552	50	45	100	May 2018	Spring-grazed even years
2019						
River East	2,699	50	45	100	May 2019	Spring-grazed odd years
Donkey Creek	549	50	48	100	May 2019	Spring and Fall alternate years
2020						
Big Gulch	1,614	60	44	100	June 2020	Spring-grazed even years

*Number of Collars Returned includes only collars that were returned with usable data. Some collars returned with little to no data recorded due to device failure.

2.3 Collection of GRSG Nesting Data

GRSG nesting data was collected for four years (2017-2020, Table 2.2) at the PAVA and JISA study areas as part of the ongoing Idaho Grouse and Grazing project (https://idahogrousegrazing.org/). Hens were captured in February through April each year and fitted with a VHF radio transmitter for continued monitoring. Females were tracked through their initial nesting attempt as well as any attempts to re-nest within the same year. An explicit minimum disturbance protocol was implemented on the project to reduce any observer-induced stress on the birds or bias of the results. Hens were never intentionally flushed from their nests and any approach closer than 100m to the nest was limited. A nest location was confirmed when a GRSG hen had been triangulated in the same location for 2-3 consecutive visits. The nesting location was then monitored from >100m away every 2-3 days until the hen's signal was no longer localized in the perceived nesting location. At that point, observers moved in to document the precise location and fate of the GRSG nest. The nest location was recorded using a Garmin eTrex 20x handheld GPS device. Observers recorded the fate of the nest (hatched or failed).

Only GRSG nests located within the boundaries of the study pastures in the years that each pasture were grazed were used. The filtered nest and cattle GPS data were merged by site so that all three PAVA pastures and their corresponding nest and cattle GPS data for each year were combined into a single dataset and all JISA nest and cattle GPS data from each year in another.

Table 2.2 – GRSG nest data obtained from the four study pastures at the Pahsimeroi Valley and Jim Sage study areas.

Pasture Name	Pasture Size (hectares)	Years Collected	Number of Nests from Both Years
PAVA			
River East	2,699	2017, 2019	4
Goldburg SW - Donkey Creek	549	2017, 2019	2
Goldburg NE - Big Gulch	1,614	2018, 2020	7
JISA			
Kane Springs (Line Canyon)	552	2018, 2020	12
			Total: 25

2.4 Data Analysis

To understand the spatial relationship between cattle and nesting GRSG hens, I used a bivariate version of the Ripley's K function. The cross-K function identifies the extent to which the observed locations of two point patterns are associated, separated, or consistent with what would be expected under complete spatial randomness (CSR) in relation to each other across a range of scales (Dixon, 2014). In the context of this study, the cross-K function tested whether, for a given search radius, nest locations were closer to or farther away from cow locations compared to what would be expected if the points were randomly distributed. For any given distance (i.e., search radius), the observed cross-K function that was generated from the study data was compared to a theoretical function that would be consistent with CSR. If the observed cross-K curve was above the theoretical curve, this represented an association or a co-location between the two point-pattern types at that distance, greater than what can be expected by chance. For this study, that would indicate that the GRSG nest sites and GPS livestock locations were similarly located within the pastures. If the observed cross-K curve was below the theoretical curve, this would indicate a distancing or separation between GRSG nest sites and GPS livestock locations.

The cross-K function was run separately for the two study sites. To run the analysis, I first merged the cow and nest datasets while keeping the type of point (cow or nest) aligned with its dataset of origin. Next, I limited the window of the analysis to the extent of the pasture boundaries and computed the cross-K function for each study area. Finally, I tested the statistical significance of the observed curves in relation to the theoretical curves through simulations. To do this, all points in the dataset were randomly assigned as either “cow” or “nest” regardless of their true designation and the cross-K function computed. This random assignment simulation was repeated 30 times and a CSR prediction interval was created for each study site. If the observed curve fell within this prediction interval, the observed curve was not significantly different from CSR. If the observed curve fell outside of the prediction interval, the point type designations were meaningful to the arrangement of the points in space, and the suggested association or separation between cows and nests may be a significant deviation from what would be expected under CSR.

Calculations of the cross-K function and the simulations for determining significance of the results were performed using the Spatstat package version 2.0 (Baddeley et al., 2015) in R version 3.6.2 (R Core Team, 2019).

2.5 Characterization of the Utilized Landscape

To support the cross-K analysis and further investigate whether livestock and nesting hens use similar portions of the pastures, I quantified the median percent cover for shrubs, perennial grasses and forbs (PFG), annual grasses and forbs (AFG), and bare ground around each of the GRSG nest locations and in portions of each pasture that experienced the highest levels of livestock use. This was accomplished by calculating the median value per pixel for each of the vegetation indices from 2017 through 2020 from the Rangeland Analysis Platform (RAP) across each of the four study pastures (https://rangelands.app/). The RAP estimates are produced by combining approximately 60,000 field plots from the BLM Assessment, Inventory, and Monitoring (AIM) datasets and NRCS National Resources Inventory (NRI) with the historical Landsat satellite record (Allred et al., 2021a). Each RAP vegetation raster was aligned and cropped to the extent of its corresponding pasture.

Livestock use was estimated for each pasture according to the methodology outlined in Chapter One for generating GPS-derived estimates of livestock use. To determine which portions of each study pasture constituted the highest level of livestock use, I binned the GPS-derived livestock use surface for each pasture into percentiles. Portions of each study pasture that were above the 95th, 85th and 75th percentiles were considered the “hot spots” of livestock use. These percentiles were selected to encompass the commonly used areas throughout the pasture without limiting the hot spots to only severely used areas. The more severely used areas around stock ponds, supplemental feed sites, or entry/exit points in the pasture are likely to be heavily trampled and thus may bias the results towards a lower vegetation cover that may not be representative of areas of livestock use across the entire pasture. Using the ‘sp’ package (version 1.4.2, Bivand et al., 2013) in R, I extracted the RAP vegetation cover values for each vegetation index for all pixels that fell within the 95th, 85th, and 75th percentile areas for each pasture.

To determine the buffer size around each of the GRSG nest locations on which to compute the median percent cover by indicator, I used the distance of the cross-K function where nests began to significantly deviate from CSR in relation to the livestock GPS locations and doubled that distance to be sure that I was estimating vegetation indices in an area in which site selection was attributed to more than just chance. I overlaid the nest locations on the RAP cover rasters and extracted the median cover values for each vegetation indicator within the radius of significant deviation from CSR around each nest site using the ‘sp’ package in R (Bivand et al., 2013). I then compared the mean and range of cover values within the highest percentile areas of livestock use to the mean and range cover values within the distance buffers of the GRSG nest sites to determine if the two groups occurred in similar or dissimilar portions of the pasture.

3. Results

3.1 Spatial Correlation Between GRSG Nests and GPS Livestock Locations

The results of the Ripley's cross-K function were different between the JISA and PAVA study areas. For the JISA study site, results suggest a positive association between cows and nests (Figures 2.2, 2.3). At a distance of ≤75m, the location of the nest sites in relation to the livestock GPS locations was not significantly different from what would be expected under CSR. At a distance of ≥75m, GRSG nest sites appeared to co-occur with livestock locations.

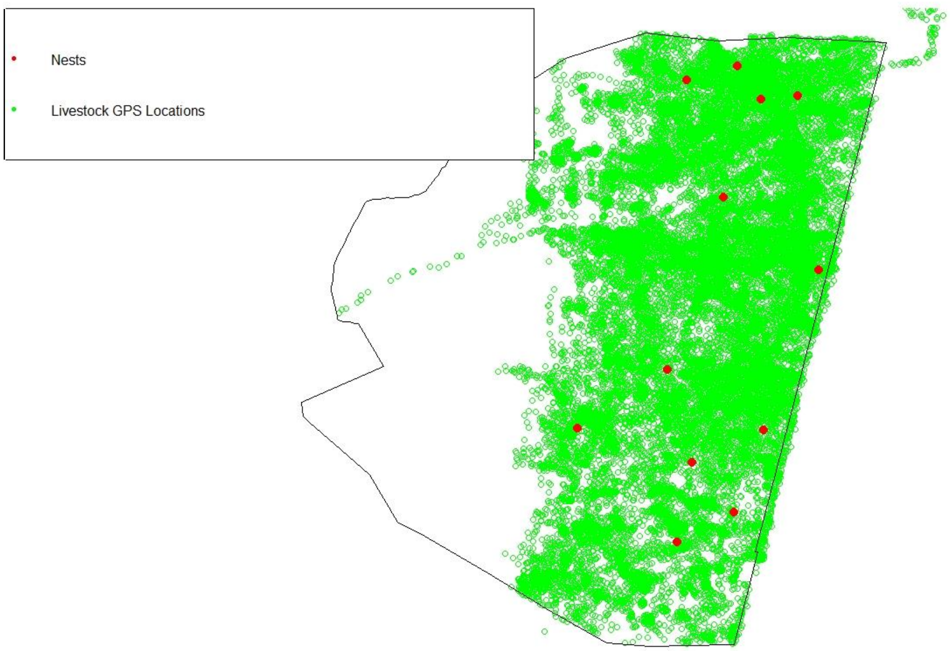

Figure 2.2 – The location of GRSG nests and livestock GPS locations at the JISA study area

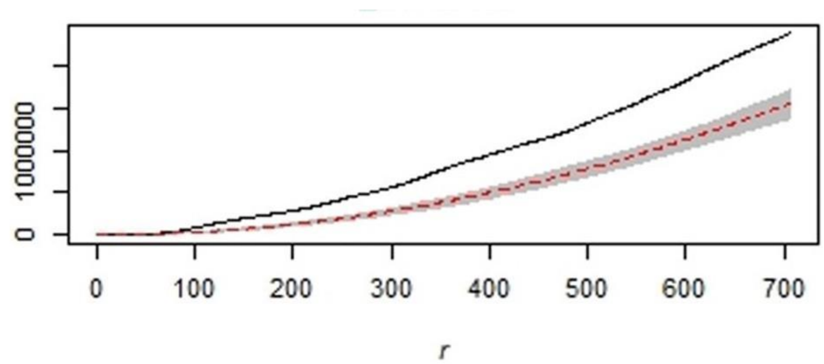

Figure 2.3 – The relationship between GRSG nest locations and livestock GPS locations at the JISA study area assessed using the Ripley's cross-K function. The results suggest a general association of livestock GPS locations and nest locations in relation to each other. The observed cow-nest relationship falls outside of the prediction interval; thus the association of points may be a significant deviation from CSR.

However, the results of the cross-K function for the PAVA study area suggested a different relationship between the GRSG nest and livestock GPS datasets (Figures 2.4, 2.5). Similar to the results from JISA, at a distance of ≤100m, the location of the nest sites in relation to the livestock GPS locations was not significantly different from what would be expected under CSR. However, at a distance of ≥100m, GRSG nest sites appeared to show separation from livestock locations (i.e., a negative association).

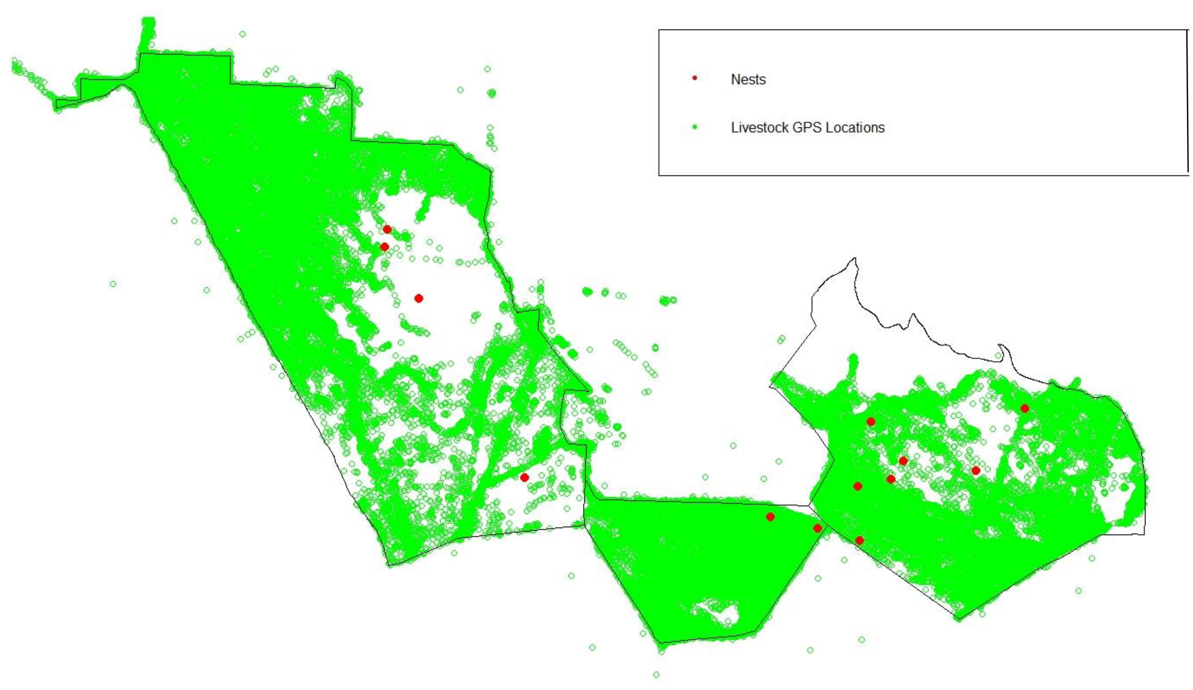

Figure 2.4 – The location of GRSG nests and livestock GPS locations at the PAVA study area

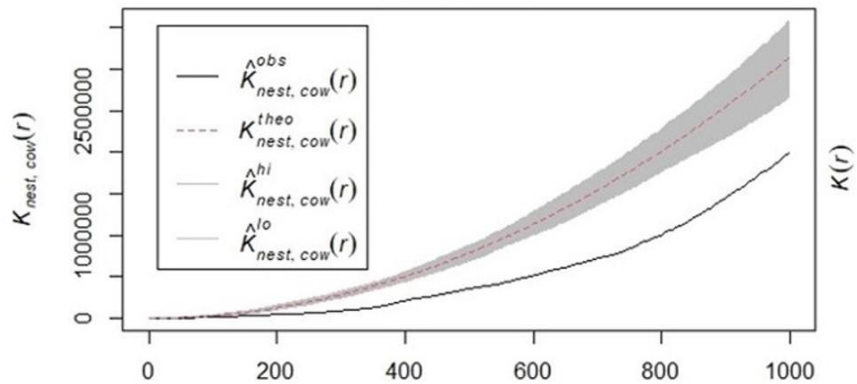

Figure 2.5 – The relationship between GRSG nest locations and livestock GPS locations at the PAVA study area assessed using the cross-K function. The results suggest a separation between livestock GPS locations and nest locations. The observed cow-nest relationship falls outside of the prediction interval, indicating a significant deviation from CSR.

3.2 Landscape Characterization

According to the results obtained from the cross-K function, GRSG nest-site selection began to differ significantly from CSR around ~75-100m from nest center at both study areas. Thus, I created a 200m buffer around each nest site.

Based on the median percent cover values for shrubs, perennial grasses and forbs, annual grasses and forbs, and bare ground, livestock and GRSG nests appear to be occurring in areas with a similar vegetation structure (Table 2.3). For shrubs across all four pastures, the difference between the average of the median cover values for the three highest livestock use percentiles and the average of the median cover values around GRSG nest sites was a maximum of 2.2% and a minimum of 0.16% (Figures 2.6, 2.7). For perennial grasses and forbs across all four pastures, the difference between the average of the median cover values for the three highest livestock use percentiles and the average of the median cover values around GRSG nest sites was a maximum of 6.26% and a minimum of 1.22% (Figures 2.8, 2.9). For annual grasses and forbs across all four pastures, the difference between the average of the median cover values for the three highest livestock use percentiles and the average of the median cover values around GRSG nest sites was a maximum of 2.48% and a minimum of 1.43% (Figures 2.10, 2.11). For bare ground across all four pastures, the difference between the average of the median cover values for the three highest livestock use percentiles and the average of the median cover values around GRSG nest sites was a maximum of 3.93% and a minimum of 0.16% (Figures 2.12, 2.13).

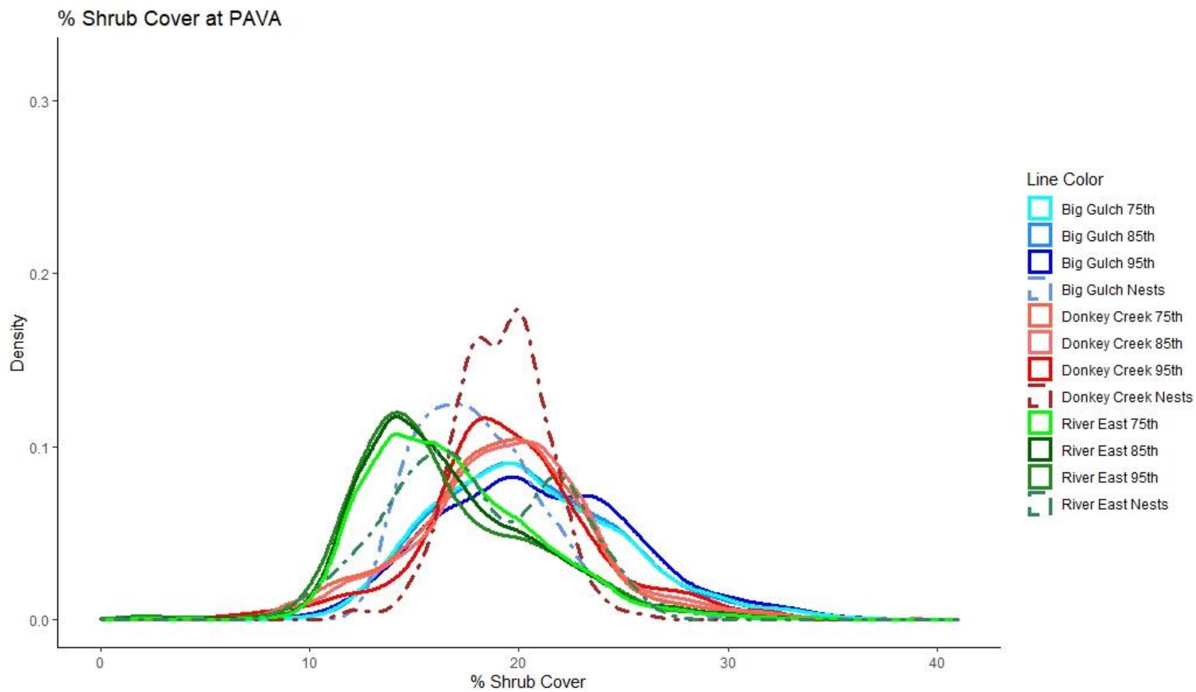

Figure 2.6 – Median % shrub cover values for the 95th, 85th, and 75th percentile values of livestock use in each of the three PAVA study pastures. This is compared to the median % shrub cover values within 200m of each GRSG nest site in the PAVA study pastures. This suggests that livestock and GRSG hens at the PAVA field site are using areas with a similar amount of shrub cover.

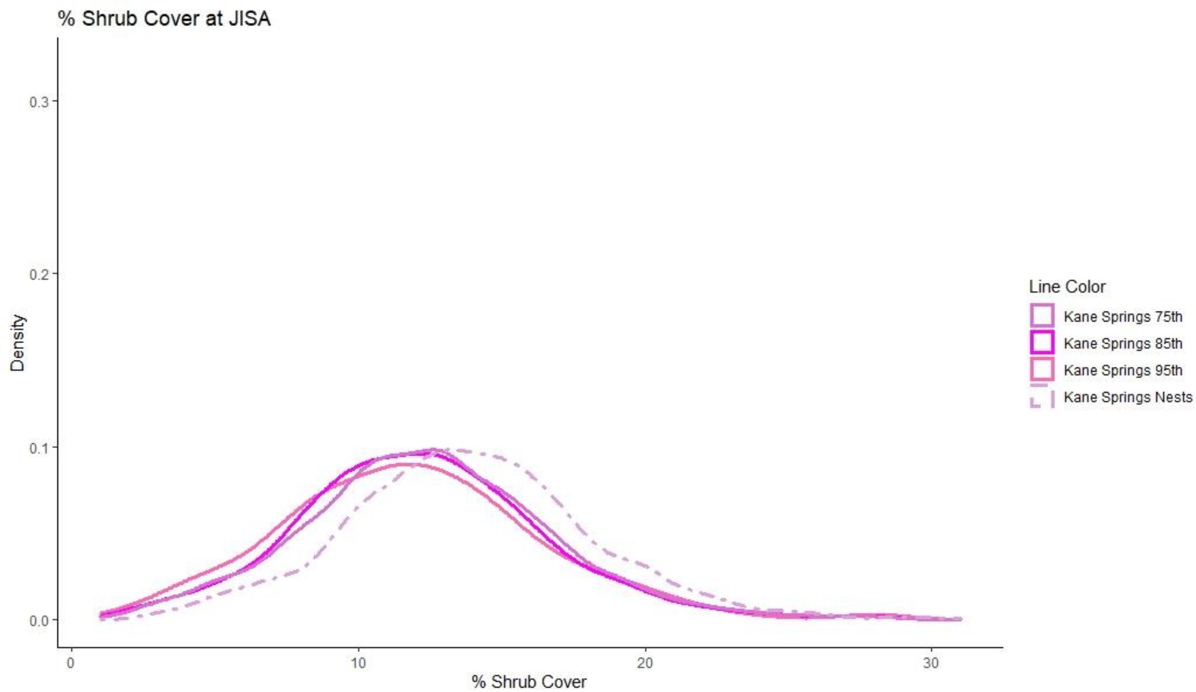

Figure 2.7 – Median % shrub cover values for the 95th, 85th, and 75th percentile values of livestock use in the JISA study pasture. This is compared to the median % shrub cover values within 200m of each GRSG nest site at JISA. This suggests that livestock and GRSG hens at the JISA field site are using areas with a similar amount of shrub cover.

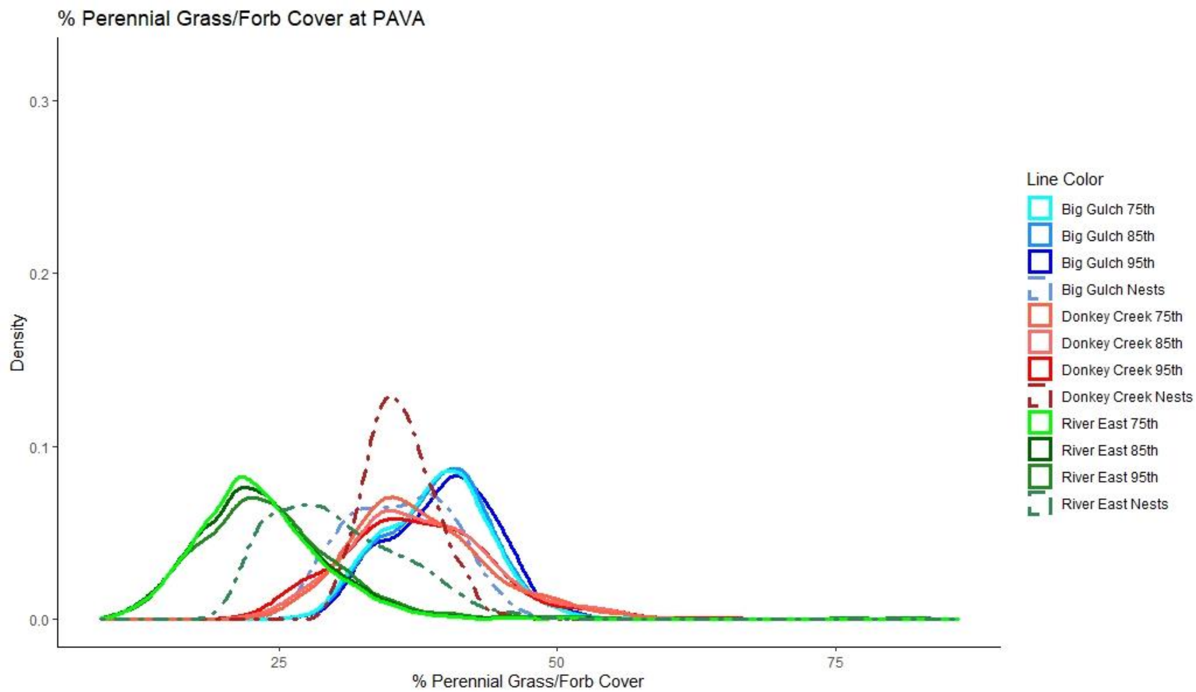

Figure 2.8 – Median % PFG values for the 95th, 85th, and 75th percentile values of livestock use in each of the three PAVA study pastures. This is compared to the median % PFG cover values within 200m of each GRSG nest site in the PAVA study pastures. This suggests that livestock and GRSG hens at the PAVA field site are using areas with a similar amount of perennial grass and forb cover.

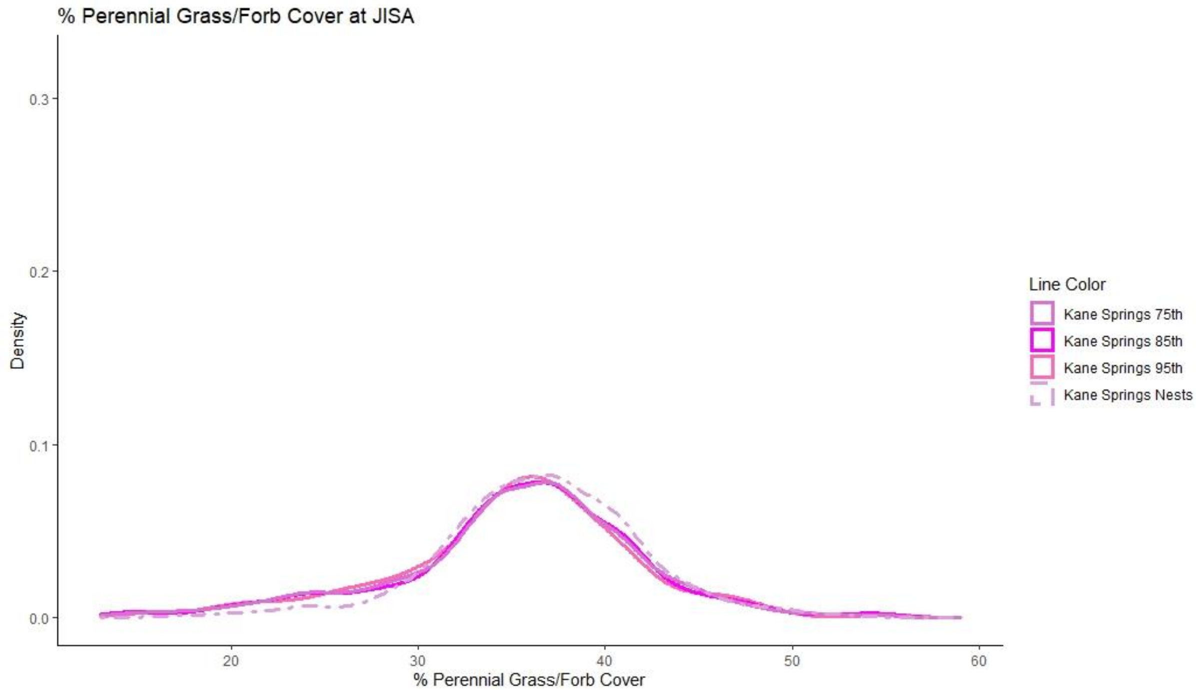

Figure 2.9 – Median % PFG cover values for the 95th, 85th, and 75th percentile values of livestock use in the JISA study pasture. This is compared to the median % PFG cover values within 200m of each GRSG nest site at JISA. This suggests that livestock and GRSG hens at the JISA field site are using areas with a similar amount of perennial grass and forb cover.

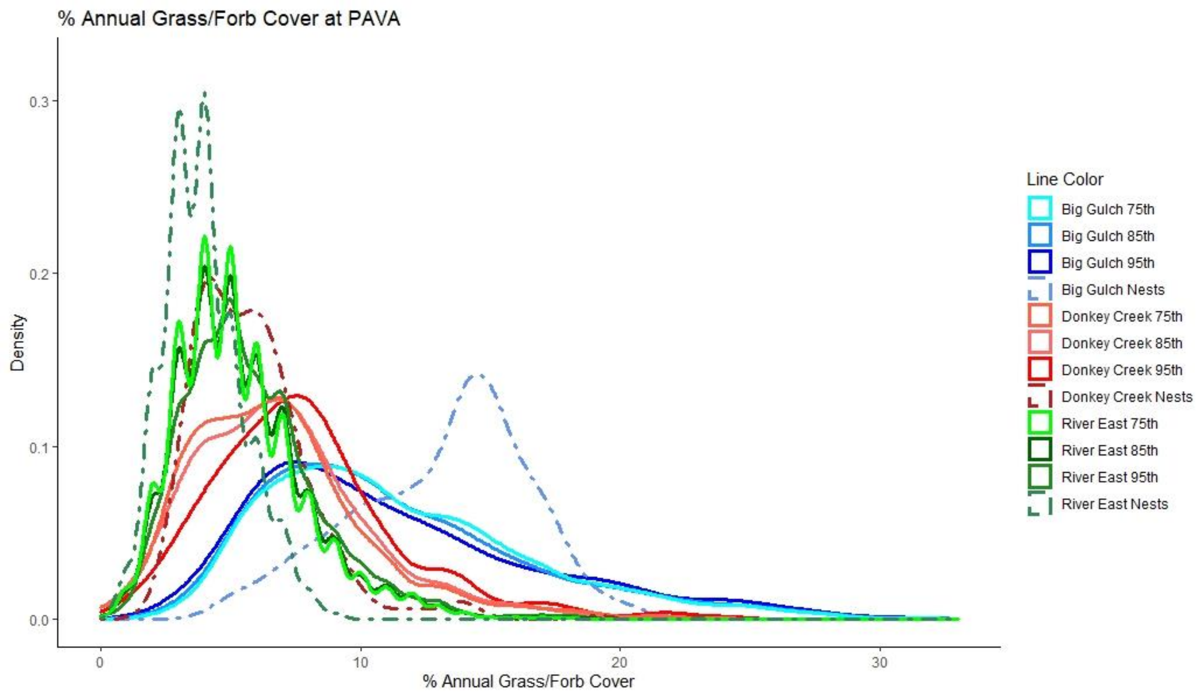

Figure 2.10 – Median % AFG values for the 95th, 85th, and 75th percentile values of livestock use in each of the three PAVA study pastures. This is compared to the median % AFG cover values within 200m of each GRSG nest site in the PAVA study pastures. This suggests that livestock and GRSG hens at the PAVA field site are using areas with a similar amount of annual grass and forb cover.

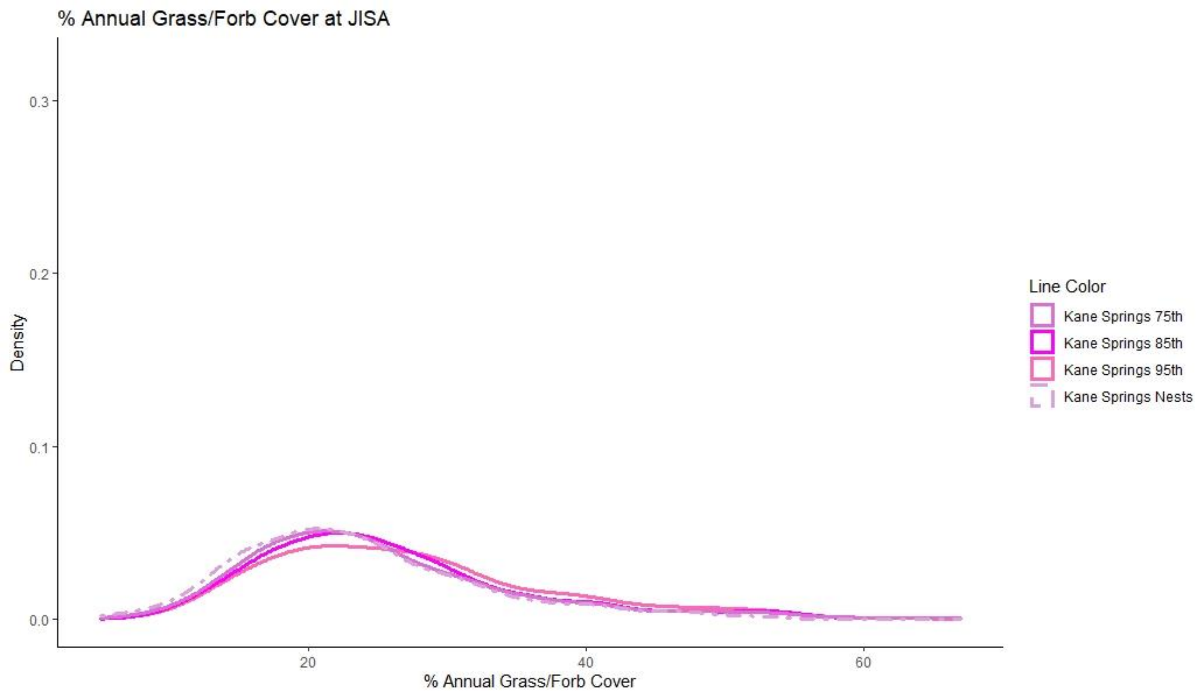

Figure 2.11 – Median % AFG cover values for the 95th, 85th, and 75th percentile values of livestock use in the JISA study pasture. This is compared to the median % AFG cover values within 200m of each GRSG nest site at JISA. This suggests that livestock and GRSG hens at the JISA field site are using areas with a similar amount of annual grass and forb cover.

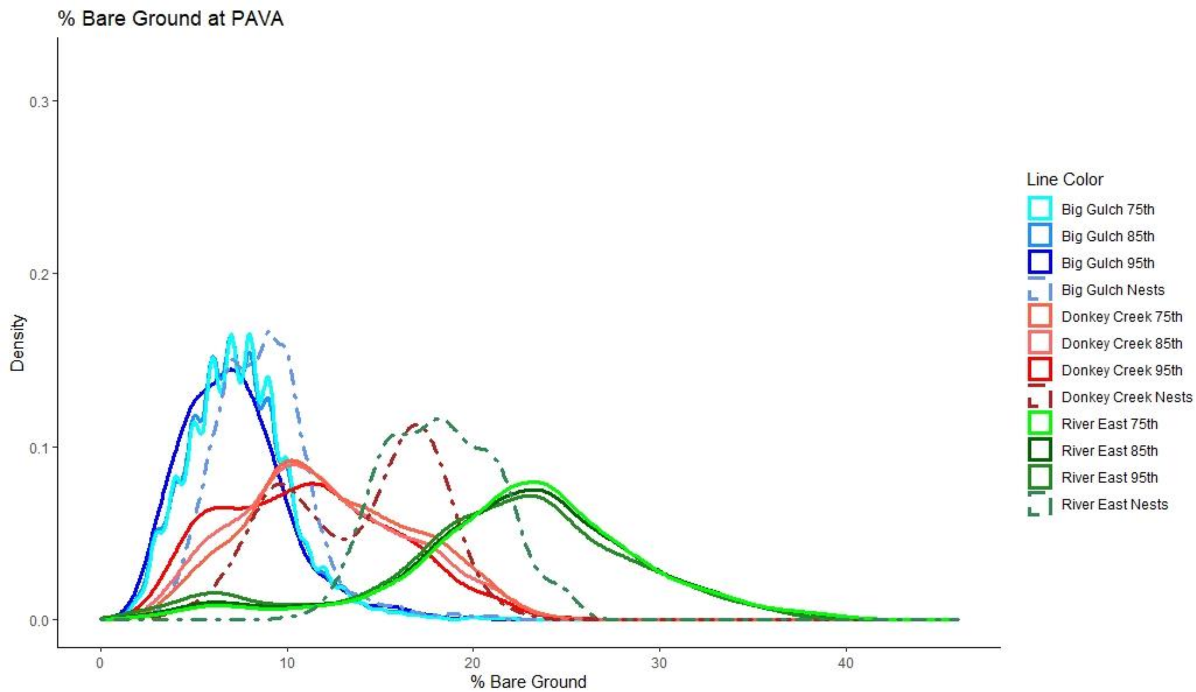

Figure 2.12 – Median % bare ground values for the 95th, 85th, and 75th percentile values of livestock use in each of the three PAVA study pastures. This is compared to the median % bare ground cover values within 200m of each GRSG nest site in the PAVA study pastures. This suggests that livestock and GRSG hens at the PAVA field site are using areas with a similar amount of bare ground.

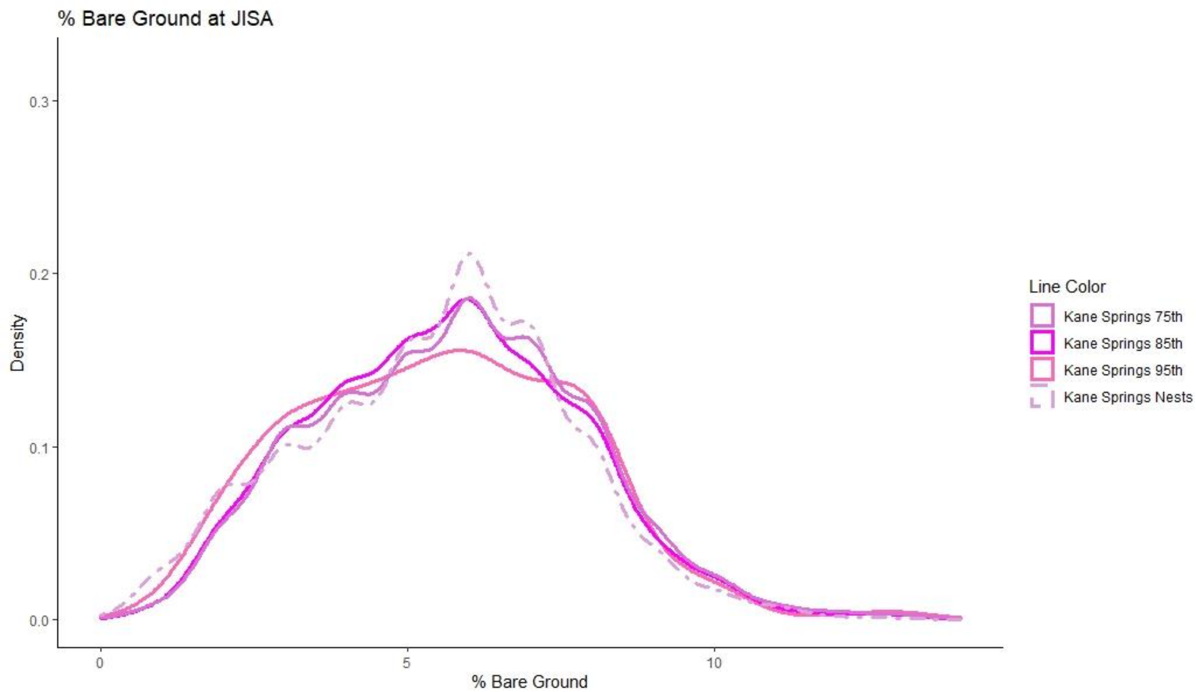

Figure 2.13 – Median % bare ground cover values for the 95th, 85th, and 75th percentile values of livestock use in the JISA study pasture. This is compared to the median % bare ground cover values within 200m of each GRSG nest site at JISA. This suggests that livestock and GRSG hens at the JISA field site are using areas with a similar amount of bare ground.

Table 2.3 – Mean values of the median % cover for each of the vegetation indices across the four study pastures. The four vegetation indices were shrub cover, perennial grass and forb cover (PFG), annual grass and forb cover (AFG), and bare ground (BG). While there was a pasture in which PFG cover varied between livestock and nest areas by as much as ~6%, most vegetation indicators varied by 0.5 - 2.0%.

	PAVA			**JISA**
	Big Gulch	**Donkey Creek**	**River East**	**Kane Springs**
Shrub 95th	20.46	19.54	16.4	11.9
Shrub 85th	20.5	19.49	16.69	12.23
Shrub 75th	20.46	19.08	16.88	12.46
Average of the Top Percentiles	20.47	19.37	16.65	12.19
Shrub Nest	18.27	19.21	17.96	13.87
PFG 95th	39.89	37.55	24.81	35.23
PFG 85th	39.45	37.84	23.76	35.44
PFG 75th	39.22	37.67	23.45	35.36
Average of the Top Percentiles	39.52	37.68	24	35.34
PFG Nest	35.87	35.96	30.26	36.56
AFG 95th	11.41	7.9	5.83	27.19
AFG 85th	11.4	7.03	5.48	26.02
AFG 75th	11.52	6.83	5.37	25.41
Average of the Top Percentiles	11.44	7.25	5.56	26.2
AFG Nest	13.11	5.82	3.97	23.72
BG 95th	7.18	11.23	21.42	5.54
BG 85th	7.44	11.9	22.4	5.65
BG 75th	7.48	12.42	22.72	5.75
Average of the Top Percentiles	7.36	11.85	22.18	5.64
BG Nest	8.76	13.8	18.25	5.48

4. Discussion

This study assessed the co-occurrence of domestic livestock grazing and GRSG nest-site locations at a pasture-scale. The use of GPS devices to track and measure livestock use provided an accurate and comprehensive estimate of use across the entire extent of the study pastures which was consistent with the scale at which GRSG nesting data was collected. The use of GPS devices also allowed tracking of the timing of grazing activity to ensure that estimated livestock use corresponded with the timing of the GRSG activity that was being analyzed.

Assessment of the two groups' locations and calculation of vegetation indices in the corresponding areas suggests that cows and GRSG hens are using similar parts of the landscape. There was little difference between the cover estimates for all of the vegetation indices measured. Shrub cover, annual grass and forb cover, and bare ground estimates between livestock hotspots and GRSG nesting sites varied by no more than 3.9%. There was a single pasture where perennial grass and forb cover varied by 6.3% between the two, but the difference between PFG cover was between 1.22-3.6% for the other three study pastures.

Two possible explanations can be drawn from this. First, domestic livestock and GRSG hens prefer similar microhabitats and they are drawn to these areas irrespective of the presence of each other. Both groups were associated with areas of high perennial grass and forb cover. Cattle need dense, nutritious forage (Heady, 1964) and GRSG hens need tall bunchgrasses for nest and brood concealment (Boyd et al., 2014; Braun, 1998). Literature suggests both groups may avoid areas with high invasive annual grass cover. Aside from a short green period in early spring, large swaths of cheatgrass have a lower nutritional content for grazing animals (Young et al., 1987) and offer inadequate nest concealment from predators (Connelly et al., 2004; Knick et al., 2003). Both groups also likely avoid areas with a large amount of bare ground as this offers less forage and concealment (Dzialak et al., 2013).

Shrub cover, particularly sagebrush cover, is essential to successful GRSG nesting and brooding (Boyd et al., 2014). Adequate shrub cover provides food as well as protection and concealment from predators (Connelly et al., 2000b; Conover and Roberts, 2016; Crawford et al., 2004). While there is not much literature suggesting livestock prefer a greater amount of shrub cover, they do benefit from expansive, unfragmented grazing landscapes with ample forage. These contiguous areas often include substantial shrub cover. The cornerstone of this conclusion is that cattle and GRSG hens make resource selection decisions independent of each other based upon their resource needs and those decisions do not appear to be related to the presence or resource use of the other group.

A second possible explanation for my results is that GRSG hens are preferentially selecting areas that cows have visited or are actively grazing. Some literature suggests that livestock grazing creates openings in the sagebrush that create a mosaic of vegetation that supports successful breeding, feeding, and brood rearing behaviors (Call, 1974). Other studies have asserted that livestock grazing supports an increase in the quantity and quality of forbs available for hens and chicks to consume (Conover and Roberts, 2016). Local knowledge and anecdotal evidence have suggested that cattle may act as a predator deterrent. Ranchers have noted instances in which GRSG have followed livestock because the presence of the cattle lessened the threat of GRSG predation by coyotes (Knapp et al., 2013). It is possible that GRSG hens select areas that have experienced some degree of livestock use to take advantage of these potential benefits. Thus, the selection of a nesting site may be influenced by the presence of livestock.

The association between cow and nest points at the JISA study site supports the idea that livestock and GRSG hens may be selecting similar portions of the landscape. The opposite relationship between the cow and nest locations at the PAVA study site seems to suggest a separation between the two species, but the results are not robust enough to provide definitive evidence to refute the conclusion that cattle and hens are selecting similar areas on the landscape. There were only 13 GRSG nest locations obtained from the PAVA study area and 12 GRSG nest locations from JISA, yet the PAVA study area encompassed 6.5% more acreage than the JISA study area. It is possible based on the characterization of the utilized landscape that the GRSG hens and cows in the PAVA pastures were still selecting areas with a similar vegetation structure. However, the PAVA study area was so large (or cattle stocking rate low enough) that there was enough room for the two groups to use a similar vegetation structure without overlapping. More GRSG nest locations would be needed to assess the relationship between domestic livestock and GRSG nest-site selection across such a large study site.

In general, this study was limited by the number of GRSG nests that were available to analyze. There were only 25 nests total that were located and tracked across four pastures, two study sites, and four years of field work. A similar analysis should be conducted using more GRSG nesting data and a larger set of pastures to determine the validity of these findings and to more rigorously examine the spatial relationships between cattle grazing and GRSG nesting.

It is also important to note that vegetation and bare ground cover estimates in this study were based off modelled vegetation data from the RAP. The RAP’s estimated error rate is different for each cover type (Table 2.4), but mean absolute error ranged from 5.8% for shrub cover to

10.3% for perennial grass and forb cover (Allred et al., 2021). Thus, any observed differences in vegetation cover between cattle use areas and GRSG nests in the study pastures were within the error range of the RAP products and likely not significant.

Table 2.4 – Error rate estimates for the modelled vegetation data obtained from the Rangeland Analysis Platform (Allred et al., 2021).

Vegetation cover	Annual forbs and grasses	Perennial forbs and grasses	Shrubs	Trees	Bare ground
Mean absolute error (%)	7.0	10.3	5.8	2.8	6.7
Root mean square error (%)	11.0	14.0	8.3	6.8	9.8

5. Management Implications

Livestock grazing is the most common land use on western rangelands, so effective rangeland management depends upon a greater understanding of the short and long-term effects of this land use on vegetation structure and wildlife populations. This study found evidence that cows and nesting GRSG hens were spatially associated with each other within a set of southern Idaho pastures. If cows and GRSG hens are using similar portions of the landscape irrespective of the presence of the other, then there is a greater potential for GRSG nesting behaviors to be affected by grazing cattle and potentially negatively impacted by the consequences of mis-managed grazing. Overgrazing may remove too much of the herbaceous material necessary for successful nesting or decrease the vegetative heterogeneity of the landscape, and GRSG hens will experience the collateral damage of this mismanagement (Connelly et al., 2011; Knick et al., 2003). Additionally, if GRSG hens are selecting their nest-site locations based in part on the presence of livestock activity, then further research is needed to determine how the specific attributes of different grazing regimes (e.g., stocking rates, timing and duration of grazing periods) impact GRSG nest-site selection and ultimately nest success.

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Appendix A: Information Loss as a Function of the Number of GPS Collars and Pasture Size

Figure A1 – Changes to livestock distribution in Donkey Creek as a result of using fewer GPS collars. Significant changes in the estimated extent of livestock distribution are noted between the use of all 45 GPS collars and only 5% of the total collars.

Figure A2 – Changes to livestock distribution in the Big North pasture as a result of using fewer GPS collars. Grazing distribution patterns in this smaller (226ac) pasture were less sensitive to decreasing numbers of GPS collars than larger pastures. However, even in the Big North pasture collaring only 5% of the individuals in a herd provided insufficient information to accurately estimate the distribution of the whole herd.

Appendix B: Information Loss as a Function of the Number of GPS Collars and Pixel Size

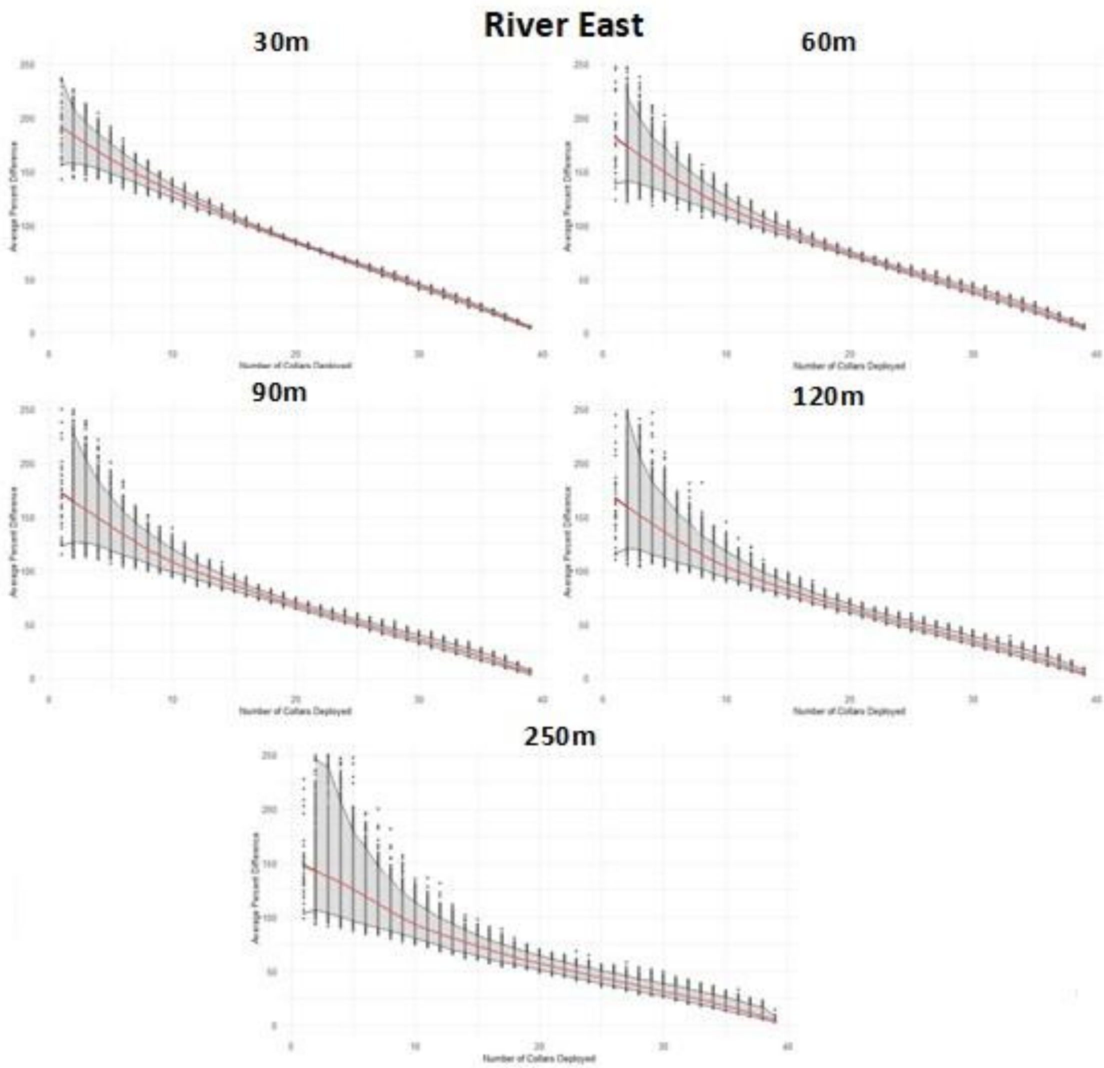

Figure B1 – The average percent difference between subset and original livestock use surfaces at five different pixel sizes. These five different pixels were all assessed within the River East pasture.

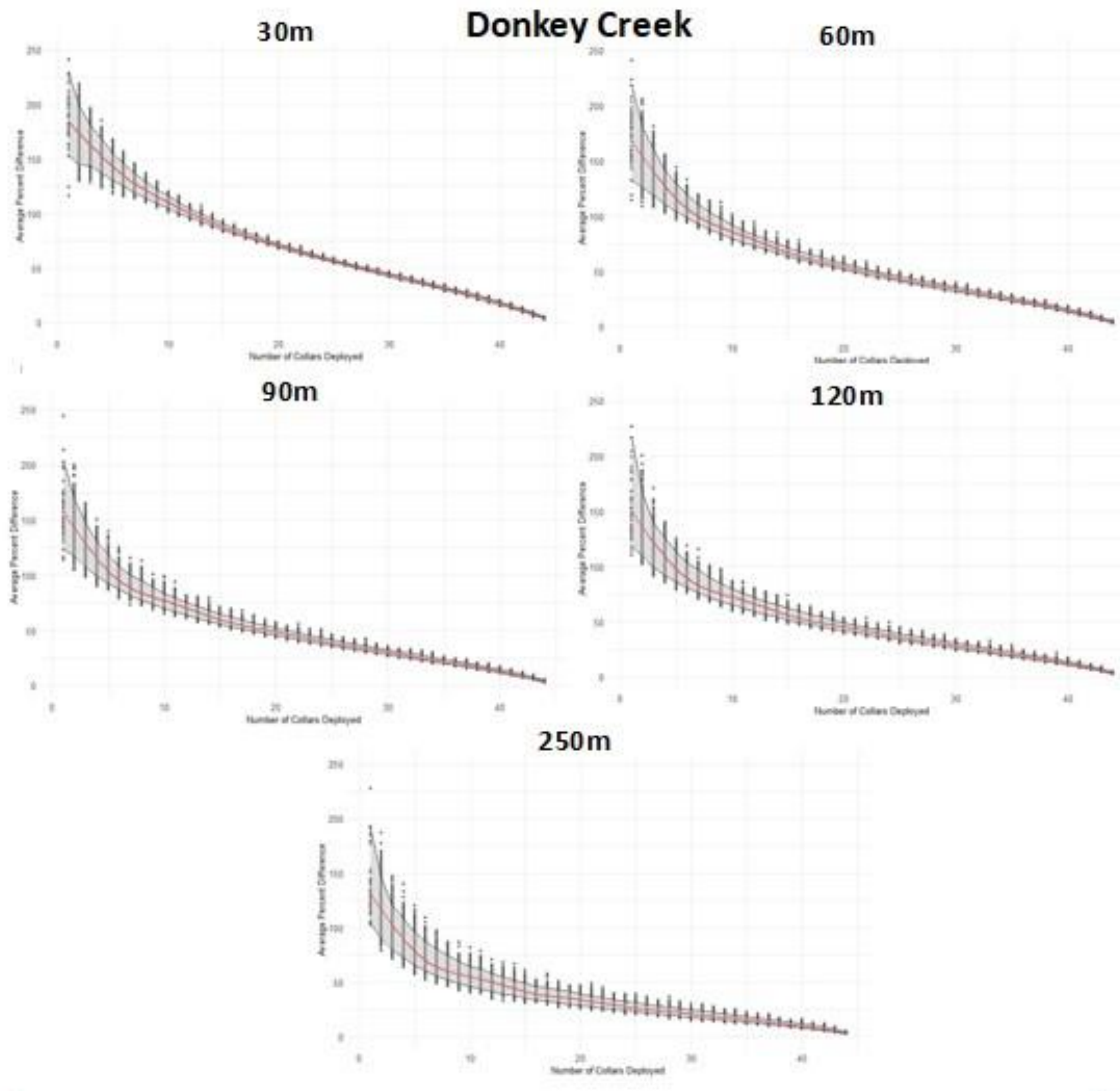

Figure B2 – The average percent difference between subset and original livestock use surfaces at five different pixel sizes. These five different pixels were all assessed within the Donkey Creek pasture.

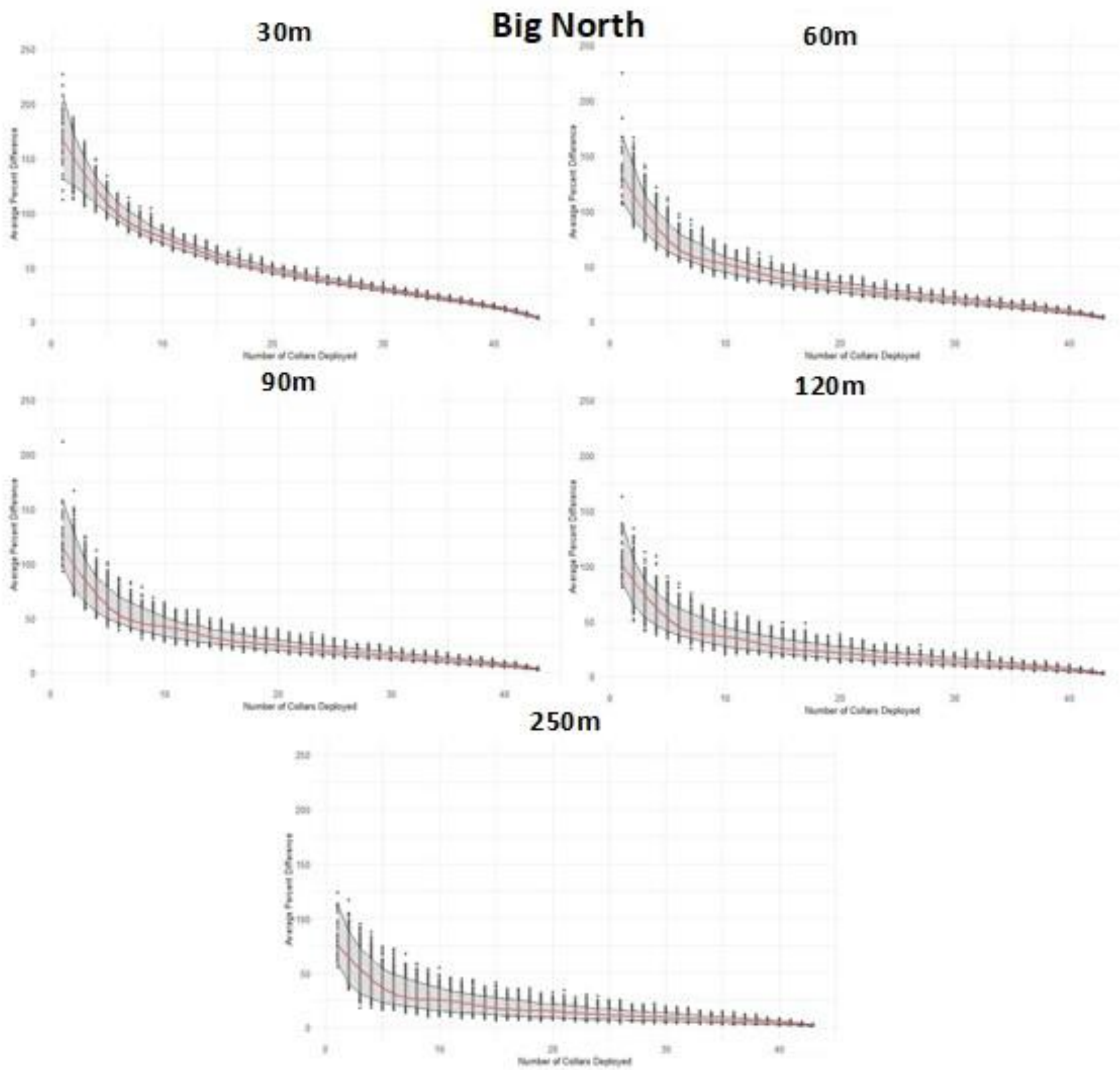

Figure B3 – The average percent difference between subset and original livestock use surfaces at five different pixel sizes. These five different pixels were all assessed within the Donkey Creek pasture.

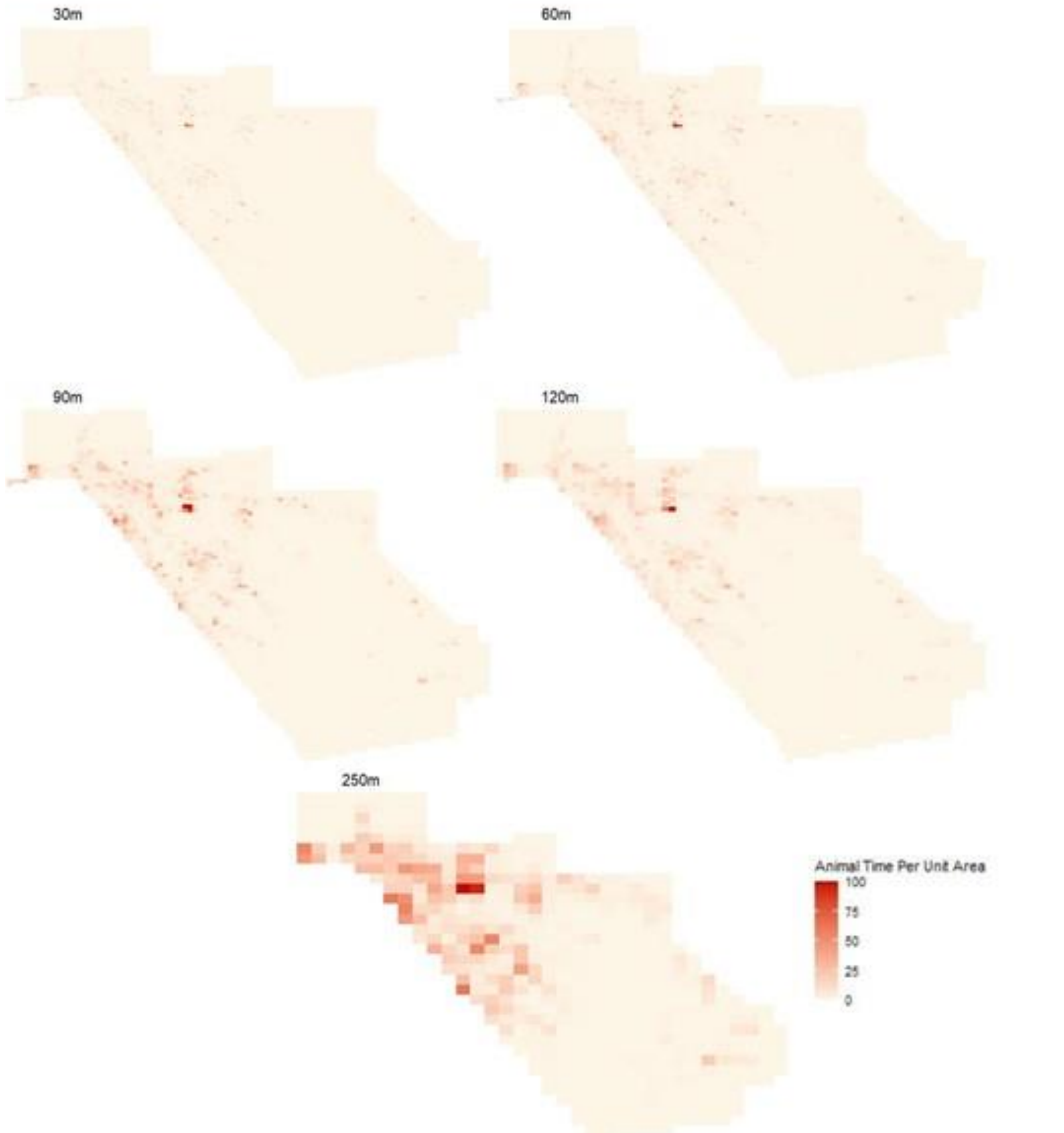

Figure B4 – The livestock use surfaces in River East at varying pixel sizes ranging from 30m – 250m.

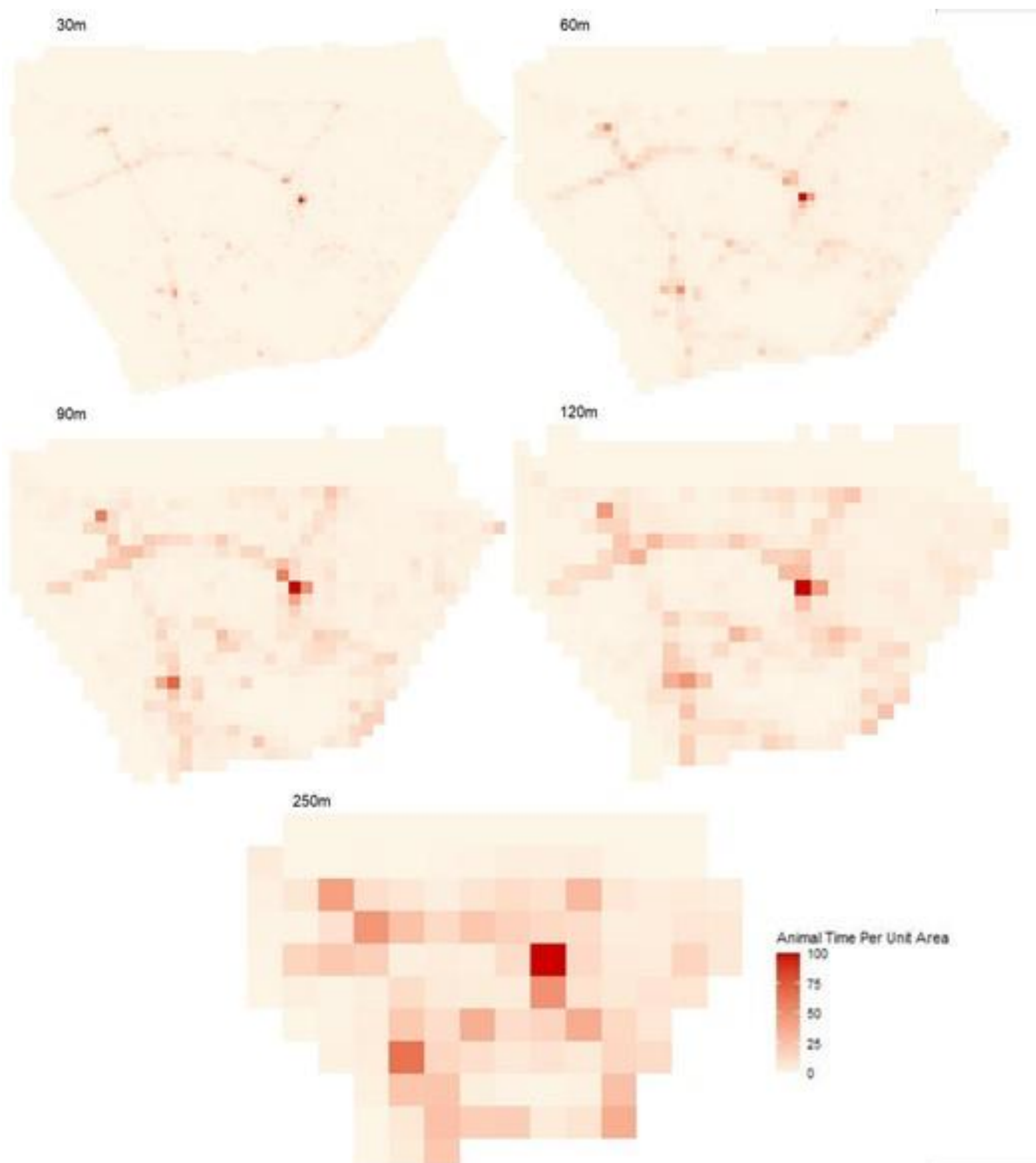

Figure B5 – The livestock use surfaces in Donkey Creek at varying pixel sizes ranging from 30m – 250m.

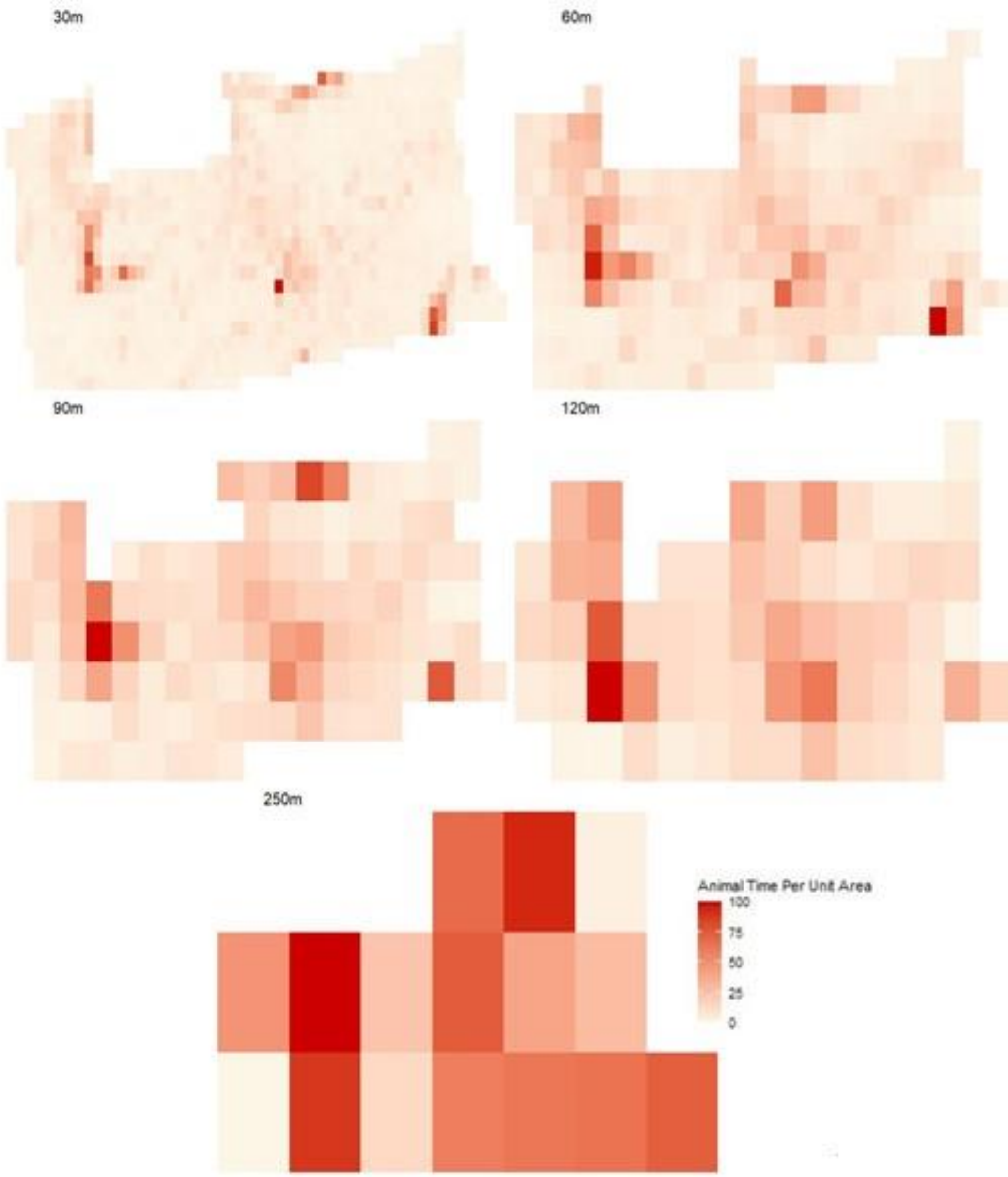

Figure B6 – The livestock use surfaces in Big North at varying pixel sizes ranging from 30m – 250m.