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Integrated Elk Management in Montana

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Table of Contents

Executive Summary

Montana Department of Fish, Wildlife, and Parks (FWP) and the Montana Fish & Wildlife Commission are statutorily obligated to manage elk population sizes within ranges specified in the Montana elk management plan; however, the efficacy of FWP management prescriptions and Commission decisions to meet this obligation is hampered by uncertainty about the drivers of elk populations and distributions in different ecological systems. The broad objective of this project is to develop the necessary components for an adaptive management program focused on management of elk populations and distributions in northwest Montana that will help FWP and the Commission manage elk populations and meet statutory obligations.

To initiate this program, we are establishing an adaptive management framework in hunting district (HD) 121, located in northwestern Montana, which includes 1) predicting how hunting, carnivores and habitat may influence elk population and distribution objectives, 2) monitoring habitat conditions, hunter access, elk vital rates, elk distributions and carnivore abundance for 3 years, 3) updating model predictions and reducing uncertainty in predictions for northwest Montana based on monitoring data, and 4) developing a framework for extending the adaptive management program to elk in different regions of Montana. The goal of developing this type of program is to better understand what types of factors influence elk populations and distributions in different ecological systems and develop management programs that integrate habitat management, carnivore harvest, and elk harvest recommendations to achieve elk population objectives.

To identify the current state of elk populations in northwestern Montana, we developed and updated an integrated population model (IPM) with available count and harvest data that estimates elk population trends, vital rates, and the factors affecting vital rates/population trends in HD 121. Overall, the model suggested that elk populations have been relatively stable or slightly increasing since 2013, with estimated total population sizes averaging approximately 1,779 individuals (323 calves, 1,270 adult females, and 185 adult males) and geometric mean λ = 1.010 (95% credible interval [CrI] = 1 – 1.024). Mean estimated annual natural survival (excluding harvest) of adult elk ($\geq$1 year old) from 2013 – 2023 was 0.96 (95% CrI = 0.92 – 0.99), while mean annual natural survival of calves (<1 year old) was 0.29 (95% CrI = 0.21 – 0.38). Estimated mean harvest rates of adult females, adult males available for harvest (i.e., possessed brow tines), and calves was 0.062 (95% CrI = 0.046 - 0.081), 0.76 (95% CrI = 0.5 – 0.94), and 0.0036 (95% CrI = 0.0024 – 0.0049), respectively. While our preliminary analyses suggest a stable population in HD 121, we caution interpretation of these results at this time. The occasional disparity between aerial counts and harvest estimates, as well as a lack of region-specific demographic data, introduced uncertainty in the model, resulting in model sensitivity. Thus, we will wait to update the model with additional demographic information collected as part of this study before making management recommendations.

In addition to monitoring elk populations, there is shared interest of wildlife managers, public land managers, hunters using public lands, and private landowners in identifying factors affecting elk distributions during autumn hunting seasons. Thus, we used elk location data from autumn 2023 to identify what resources elk use and how those resources change throughout 4 hunting periods: “prehunt” (August 1 – September 1, 2023), “archery” (September 2 – October

15, 2023), “rifle” (October 21 – November 26, 2023), and “posthunt” (i.e., post-general rifle season; November 27 – December 31, 2023). Using one year of data from 58 females (53 adults and 5 yearlings) and 10 males (6 adults and 4 yearlings), we found, on average, both males and females became less accessible for harvest (lower proportion of locations on public lands or BMAs) during rifle season, although there was considerable variability among elk. Average canopy cover, distance to road, elevation, slope, and use of forest by females also tended to decline in a similar pattern as accessibility, suggesting some elk moved out of forested, high-elevation public areas to grass/shrub, low-elevation private lands as hunting seasons progressed. Males followed similar use patterns as females, except differences between hunting periods were more subtle and distance to road increased between archery and rifle seasons. While there were fewer elk locations within accessible areas during the rifle season, a large proportion of elk remained on public lands a majority of the time. Approximately 88% of females and 100% of males were on accessible lands at least half the time during legal hunting hours in archery season. This percentage dropped to 67% of females during rifle season, but male accessibility remained at 100%, suggesting the majority of elk were largely accessible to hunters throughout autumn. However, we caution interpretation of results regarding male distribution, given the low sample size.

To improve our understanding of elk population dynamics, demographic processes, and distributions, we began a monitoring program that included collaring elk and carnivores; estimating elk and carnivore abundance; and measuring the elk nutritional landscape in HD 121. Since December 21, 2022 we have captured and collared 121 elk > 6 months old (94 adult females, 12 female calves, 7 adult males, 8 male calves) with global positioning system (GPS) radio-collars programmed to record a location every 2 hours. As of July 1, 2024, we have collected 463,092 locations from these individuals. So far, 13 collared elk > 1 year old have died; 3 due to natural or unknown causes (2 adult female, 1 yearling female), 4 due to predation by either mountain lions (2 adult females) or wolves (1 adult female, 1 yearling male), and 6 due to hunter harvest (3 adult females, 3 adult males). Natural annual survival estimates (excluding harvest) from June 1, 2023 – May 30 2024 were 0.946 (95% confidence interval [CI] = 0.888 – 1) for females and 0.900 (95% CI = 0.732 – 1) for males. Total annual survival estimates (including harvest) were 0.897 (95% CI = 0.822 – 0.978) for females and 0.600 (95% CI = 0.362 – 0.995) for males. Pregnancy rates were estimated as 87.5% (95% CI = 77.1% - 95.8%) in 2023 and 85.4% (95% CI = 73.2% - 95.1%) in 2024.

We captured and collared 91 elk neonates (55 males and 36 females) with expandable GPS collars in May and June, 2023 and 2024. In 2023, 8 collared calves (<1 year old) died (3 mountain lion predation, 1 black bear predation, 3 natural mortality, and 1 unknown cause), 1 died due to capture myopathy, 14 collars fell off prematurely (before December 1, 2023), 1 collar malfunctioned, and 11 survived until scheduled collar drop-off. We are currently monitoring the survival of the calves collared in 2024.

In summer 2022, FWP management staff captured and collared one subadult male wolf and this individual emigrated from the study area in December 2022. During summer 2024, FWP management staff collared one adult female wolf. During January and February 2023 and 2024, we captured and collared 9 mountain lions (7 females, 2 males). As of July 1, we have collected a total of 12,569 locations from these individuals. One female mountain lion died due to natural causes. Since summer 2023, we have captured and collared 1 female and 6 male black bears and collected 4,694 locations from these individuals. One adult male black bear dropped its collar during hibernation in winter 2023-24 and was then harvested in May 2024, and one adult male died of unknown causes in August 2024. All other collared bears are alive with functional collars.

In May and June 2023, we deployed trail cameras at sites randomly located throughout HD 121 to estimate elk and carnivore abundance. At half of these random sites, we placed a "predator camera" on a dirt bottom trail within 250 meters of the random site to increase the likelihood of detecting predators. At each site, we mounted trail cameras to trees or t-posts approximately 1.5 meters off the ground at optimal angles for elk and carnivore species. We set each camera on both "time lapse" and "motion capture" trigger settings to capture images every 10 minutes and when motion triggered the camera. In total, we deployed 80 random cameras and 39 predator cameras paired with the random cameras across HD 121. These cameras were serviced (batteries and SD cards changed) in September/October 2023 and May/June 2024. Cameras set in summer 2023 (May – August, 2023) collected 10,083 elk photos (95 timelapse captures), 2,894 black bear photos (24 timelapse captures), 26 mountain lion photos (0 timelapse captures), and 14 wolf photos (0 timelapse captures). Elk, black bears, mountain lions, and wolves were detected on 65 (55%), 69 (58%), 4 (3%), and 1 (<1%) cameras, respectively.

To understand elk habitat conditions and evaluate the effects of timber harvest history on elk nutritional resources and resource use in HD 121, we first developed a landcover layer that included 25 unique strata combinations of landcover type, timber harvest strategy, and years-since-harvest. We generated 375 random sites each year that were spatially-distributed within landcover strata and across the study area, with the intent to sample vegetation at each location once from May-August 2023 and 2024. At each sampling site, we established a 40m transect with 1 m^2 quadrats along the transect at 10m intervals, for a total of five quadrats at each site. At each quadrat, we recorded species composition and visually estimated percent cover of each species. At the 0m, 20m, and 40m quadrats, we established a 0.25 m^2 clip plot in the bottom right corner of the quadrat. We clipped all herbaceous vegetation >2cm above ground within the clip plot and sorted it by growth habit (i.e., shrub, grass, forb). We also collected elk fecal pellet samples each week from May through August, and during the winter 2022-23 capture season, to determine important forage species for elk in HD 121. In total, we have measured vegetation at 323 sites, collected 112 forage samples, and collected 17 and 6 composite fecal pellet samples in summer and winter, respectively. Biomass of forbs, grass, and shrubs in forests was generally highest 1-5 years after timber harvest, with decreasing biomass as the time since harvest increased. Canopy cover was also highest in older timber harvests or forests without a history of harvest. Vegetation data will be used to model forage quantity and quality across HD 121.

Ultimately, these data will be used within an adaptive framework to improve the IPM and distribution models we developed from available data. These models will then be applied across northwest Montana to facilitate elk and carnivore management actions in Region 1.

The results provided here outline our progress in this project through June 30, 2024.

Project Background and Objectives

Elk (*Cervus canadensis*) management is a high priority to a variety of stakeholders in Montana, given elk are one of the most popular game animals, with >187,300 elk licenses sold across the state in 2021. Montana Department of Fish, Wildlife, and Parks (FWP) and the Montana Fish & Wildlife Commission are statutorily obligated to manage elk population sizes within ranges specified in the Montana elk management plan; however, the efficacy of FWP management prescriptions and Commission decisions to meet this obligation is hampered by uncertainty about the drivers of elk populations and distributions in different ecological systems. Additionally, the outcomes of FWP management prescriptions and Commission decisions are not always completely predictable because individual decisions by landowners and hunters also affect elk populations and distributions.

Adaptive management programs that emphasize "learning while doing" have been proposed to address uncertainty and improve management outcomes through an iterative learning process that promotes flexible decision making when new data are available (e.g., Williams et al. 2009). An effective adaptive management program for elk would help FWP and the Commission manage elk populations and meet statutory obligations. Thus, the broad objective of this project is to develop the necessary components for an adaptive management program focused on management of elk populations and distributions in northwest Montana. These components include: 1) predicting how hunting, carnivores, and habitat may influence elk population and distribution objectives; 2) monitoring habitat conditions, hunter access, elk vital rates, elk distributions, and carnivore abundance for 3 years; 3) updating model predictions and reducing uncertainty in predictions for northwest Montana based on monitoring data; and 4) developing a framework for extending the adaptive management program to elk in different regions of Montana. This program will help identify what factors influence elk populations and distributions in different ecological systems and develop management programs that integrate habitat management, carnivore harvest, and elk harvest recommendations to achieve elk population objectives.

Ungulate populations are affected by many biotic and abiotic factors, including predation (e.g., Hebblewhite et al. 2002, Creel et al. 2007, Hebblewhite et al. 2018, Tatman et al. 2018, Horne et al. 2019, Proffitt et al. 2020, Berg et al. 2022), habitat/nutrition (Parker et al. 2009, Cook et al. 2016, Proffitt et al. 2016a), and climatic conditions (Wang et al. 2002, Garrot et al. 2003; Hebblewhite 2004; Schooler et al. 2022). However, the contribution of these factors on ungulate population dynamics are often interconnected and can vary across ecosystems with different habitats, carnivore communities, climatic conditions, and hunting regulations (Wang et al. 2009, Proffitt et al. 2014, Proffitt et al. 2020, Trump et al. 2022). To achieve ungulate population abundance goals and address concerns regarding effects of predation, carnivore management programs designed to reduce carnivore populations and increase ungulate recruitment and population growth have been implemented in a variety of ecological systems (e.g., Boertje et al. 1996, Hayes et al. 2003, Schwartz et al. 2003, White et al. 2010, Hurley et al. 2011, Keech et al. 2011, Proffitt et al. 2020). However, the effectiveness of these management programs on ungulate populations has varied across studies and time, highlighting the need for wildlife managers to better understand the uncertainties associated with the effects of predators, and the contribution of other factors on ungulate populations.

The first goal of this project is to develop an adaptive management framework for reducing uncertainty in predicting elk population trajectories and for better understanding the biological effects of integrated habitat-carnivore-ungulate management in northwest Montana (i.e., Region 1; Figure 1). Elk-carnivore studies in Region 3 of Montana revealed the important role of predation from multiple carnivores, particularly gray wolves (*Canis lupus*) and grizzly bears (*Ursus arctos horribilis*), simultaneously limiting elk vital rates and population growth (e.g., White and Garrott 2005, Proffitt et al. 2014). Yet, in Region 2, elk-carnivore studies found mountain lion (*Puma concolor*) predation, and to a lesser extent habitat conditions, limited elk vital rates and population growth (Proffitt et al. 2020). Further, other studies in Montana have demonstrated that habitat/nutrition (e.g., Proffitt et al. 2016a), climatic conditions (Creel and Creel 2009), and the interactions between climate and predation (Wilmers et al. 2020) can affect elk populations and demographic rates. Currently, it is uncertain how different carnivore communities interact with factors such as habitat and weather to influence elk population dynamics in different ecological systems, such as northwest Montana. Thus, additional elk vital rate data from northwest Montana is required to reduce uncertainty in predicting regional elk population trajectories. This effort will initially rely on elk vital rate and population dynamics data from other regions in Montana and Idaho to forecast elk population dynamics in northwest Montana. Then, we will update the model with elk vital rate data from northwest Montana collected as part of this study to reduce uncertainties in northwest Montana elk population predictions.

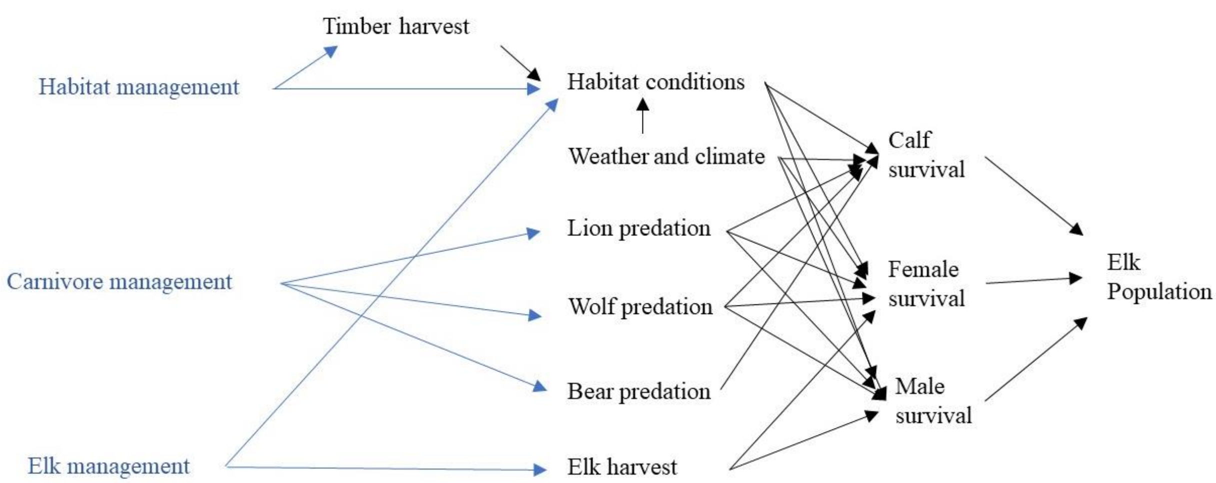


Figure 1. A conceptual model of factors influencing elk population dynamics.

Our second goal of this project is to develop an adaptive management framework for reducing uncertainty in predicting elk distributions and better understand how carnivores, habitat, harvest regulations, and hunter access management influence elk distribution. The distribution of elk across public and private lands provides additional challenges for managing elk populations (Haggerty and Travis 2006) because not all elk may be available for harvest, depending on hunter access management. Even within desired population abundances, problematic distributions of elk across the landscape may increase property damage on private lands and hunter frustrations when elk are not available on public lands (Burcham 1956, Haggerty and Travis 2006, Krausman et al. 2014, Fontaine et al. 2019, Gruntorad and Chizinski 2020), resulting in harvest that is too low to meet social objectives related to hunter satisfaction. Thus, achieving an acceptable distribution of elk across public and private lands is also required for more effective elk management. FWP has collected elk movement data during the hunting season in > 20 populations across Regions 2, 3, 4 and 6, and these previous studies commonly identify hunter access management as an important driver of elk distributions during the hunting season (e.g., Proffitt et al. 2013, Proffitt et al. 2016b, Ranglack et al. 2017, DeVoe et al. 2019, Lowrey et al. 2020, Snobl et al. 2024). However, there are many diverse factors including landscape features and harvest regulations that also influence elk distributions, creating uncertainty about which set of factors influence elk distributions in different landscapes. In northwest Montana, we predict timber management history (Ruprecht et al. 2023), and the effects on forest successional stage (Irwin and Peek 1983, Proffitt et al. 2019, Monzingo et al. 2023), will be an important driver of habitat conditions and elk distributions. However, little information on the effects of timber management history on elk distributions is available. Therefore, our goal for northwestern Montana is to monitor elk movements, carnivore distributions, habitat conditions, and hunter access and develop elk distribution models that incorporate both the effects of timber harvest management and hunter access (Figure 2). This model will then be used to refine predictions of the effects of changes in habitat management or hunter access on elk distributions in northwest Montana.

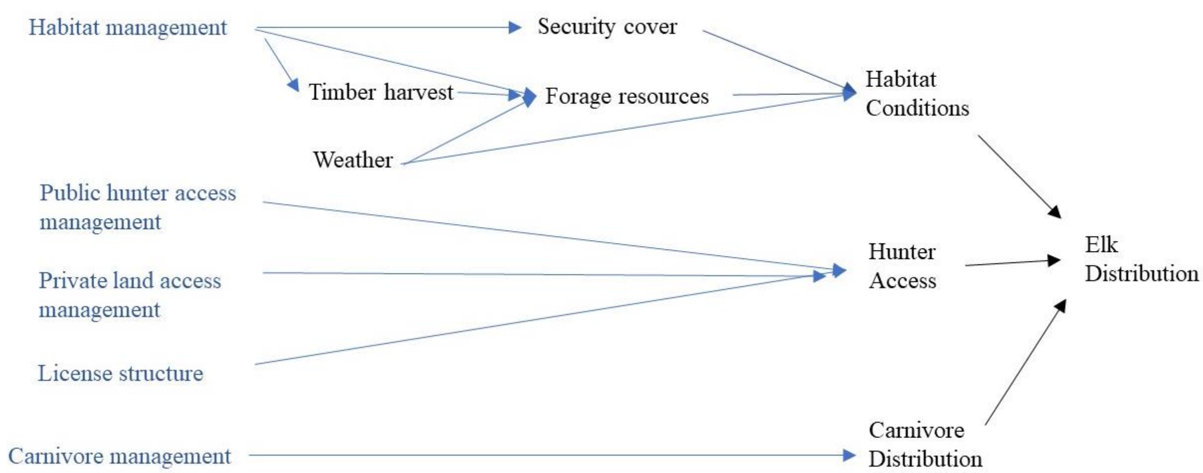


Figure 2. A conceptual model of factors influencing elk distributions during the fall hunting seasons.

We will formally integrate research findings with the northwestern Montana elk and carnivore management programs in a way that will improve FWP and partners' ability to meet elk population and distribution objectives in the future. This study will support development of analytical tools to forecast elk populations and distributions, monitor populations and distributions in northwest Montana, and integrate monitoring results into revised models predicting elk populations and distributions in northwest Montana (Figure 3). This adaptive management framework and the analytical tools developed will be transportable to other areas in

Montana, so that adaptive management and the associated learning can continue and be implemented around the state.

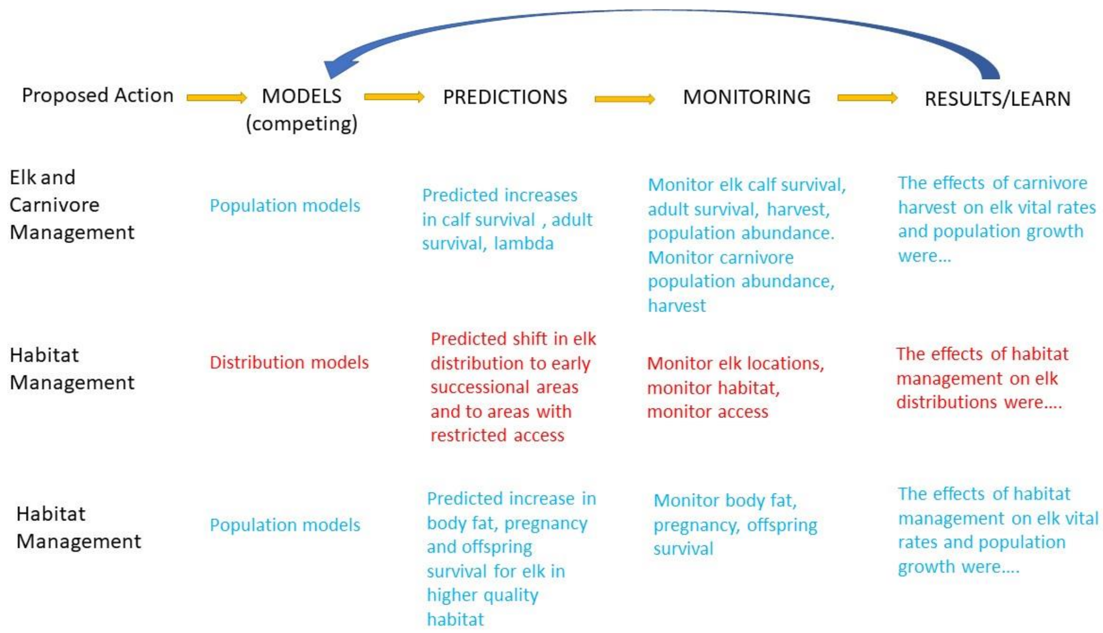


Figure 3. Conceptual diagram of the proposed study design and adaptive learning framework.

The objectives of this project include:

1. Based on past research findings, develop predictive models of elk population dynamics in northwest Montana, including the effects of habitat, elk, and carnivore management decisions.
2. Based on past research findings, develop predictive models of elk hunting season distributions in northwest Montana, including the effects of forest disturbance and hunter access.
3. Design monitoring programs for elk and carnivores that will provide necessary information to evaluate the effects of management actions, as they are implemented on elk population dynamics and hunting season distributions.
4. Integrate findings from the monitoring program into predictive models, such that predictions of elk population dynamics and hunting season distribution become more accurate in the future in northwest Montana and can be exported to other regions of Montana.

During this reporting period, our goals were to continue work towards addressing Objectives 1, 2, and 3.

Study Location

The study area is defined by the administrative boundary of Hunting District (HD) 121, which is in the Noxon – Thompson Falls area of Sanders County, Montana (Figure 4) and includes the annual range of the Pilgrim Creek elk population. The majority of HD 121 is public land managed primarily by the Kootenai National Forest Cabinet Ranger District, and the lower elevation valley bottom is dominated by private properties. Timber harvest has been common in the study area for decades, although the number of acres harvested per year has declined since the 1980's (USFS unpublished data). The forests in the study area are largely dominated by fir (*Abies* spp.), spruce (*Picea* spp.), or Douglas fir (*Pseudotsuga menziesii*). The average minimum elk count over the past 10 years in HD 121 is approximately 1,533 animals and average observed recruitment is approximately 22 calves per 100 adult females. Carnivores include black bear (*Ursus americanus*), mountain lion, and gray wolves.

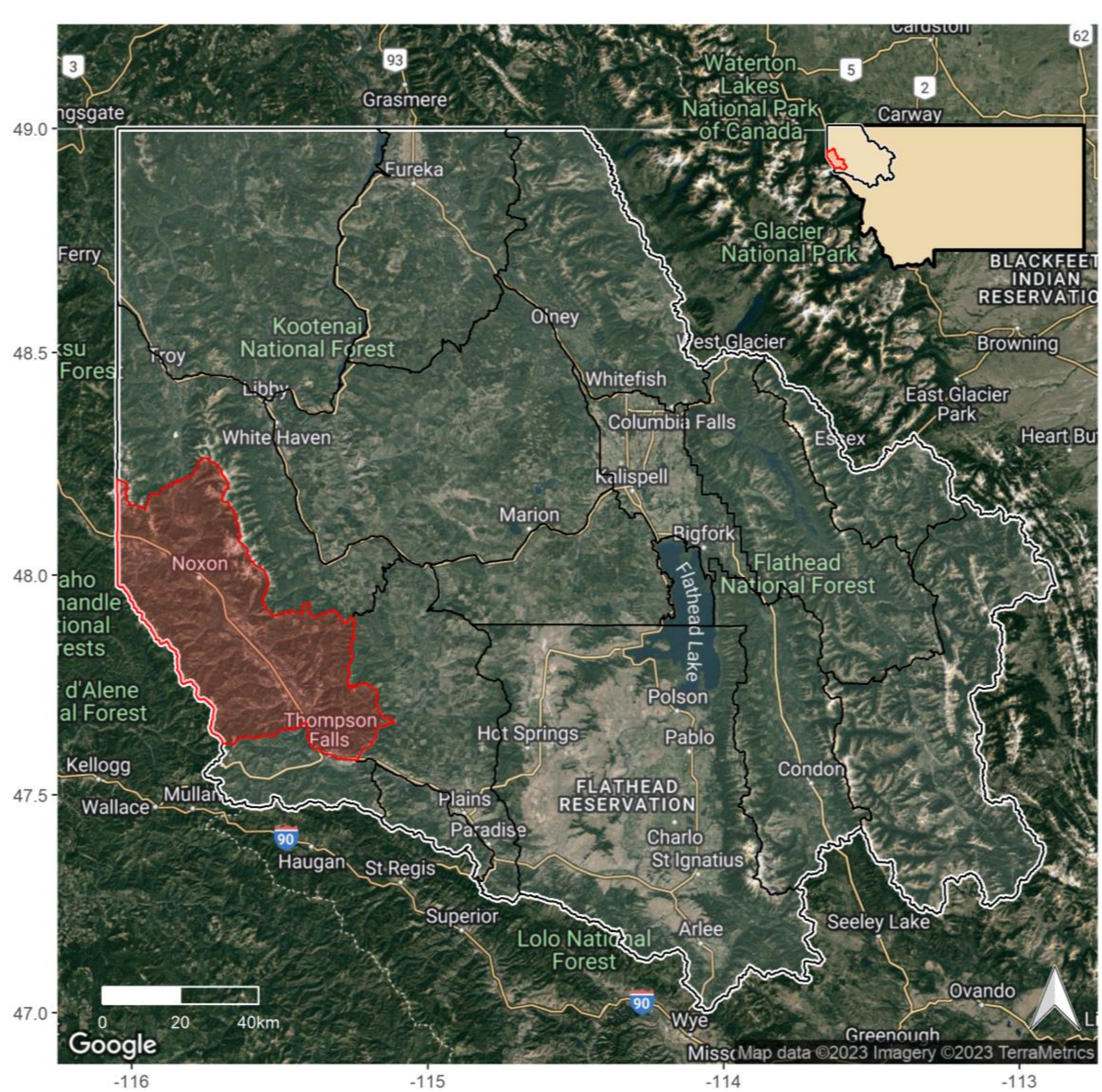


Figure 4. Location of the study area (hunting district 121; red area) within Region 1 (white area) in northwest Montana.

Objective #1: Based on past research findings, develop predictive models of elk population dynamics in northwest Montana, including the effects of habitat, elk, and carnivore management decisions.

1.1 Background

Currently, elk population monitoring in Region 1 primarily consists of aerial- or ground-based counts and estimates of hunter harvest via phone surveys. These monitoring methods provide the information necessary for managers to monitor elk populations relative to their objective as defined in the 2023 state Elk Management Plan, but provide less information regarding demographic rates or the factors driving population trends. Due to the difficulty in counting elk in densely forested areas, only portions of the area with good visibility are surveyed and trends in these counts are tracked over time as an index of population performance. Current monitoring methods are not designed to estimate population size or for use in population modeling.

Population models use existing knowledge of life history characteristics and demographic processes of a species to describe and predict population dynamics. Thus, these models can be powerful tools for wildlife biologists and managers to assess the status and trends of wildlife populations, determine the drivers of observed trends (e.g., habitat, predators, disturbance), and predict the outcomes of proposed management actions. Integrated population models (IPMs) have become increasingly more common (Schuab et al. 2004, Johnson et al. 2010, Eacker et al. 2017, Paterson et al. 2022) because IPMs jointly analyze datatypes which provide insight into the factors influencing population growth and overall population demography (Schuab and Abdai 2011). Further, managers can use IPMs to forecast the consequences of management actions by projecting population trends under different management scenarios. This allows managers to develop management plans based on the observed population vital rates and identify the management actions predicted to be most effective for meeting population objectives. Thus, our first research objective was to develop an IPM with available count and harvest data to estimate elk population trends, vital rates, and the factors affecting vital rates/population trends in HD 121. We developed the elk IPM in the previous reporting period and have updated that IPM with new elk aerial count, harvest, and demographic information to identify the current state of elk population in HD 121.

1.2 Data Collection and Description

1.2.1 Elk Observations

Observation data for the IPM consisted of population counts from aerial surveys and harvest estimates from FWP harvest surveys. During March and April each year, observers in a helicopter count the number of elk in three age/sex classes, including calves (young of the year, approximately 10-11 months old), adult females (any female >1 year old), and adult males. Elk that cannot be identified to age/sex are marked as unknown. In HD 121, as well as most HDs in Region 1, counts are completed within “trend” areas; thus, counts are not considered a full population census (e.g., Figure 5). Elk harvest estimates also primarily track three age/sex classes (calves, adult females, adult males); however, in contrast to elk counts, elk harvest estimates are assumed to represent harvest across the entire district.

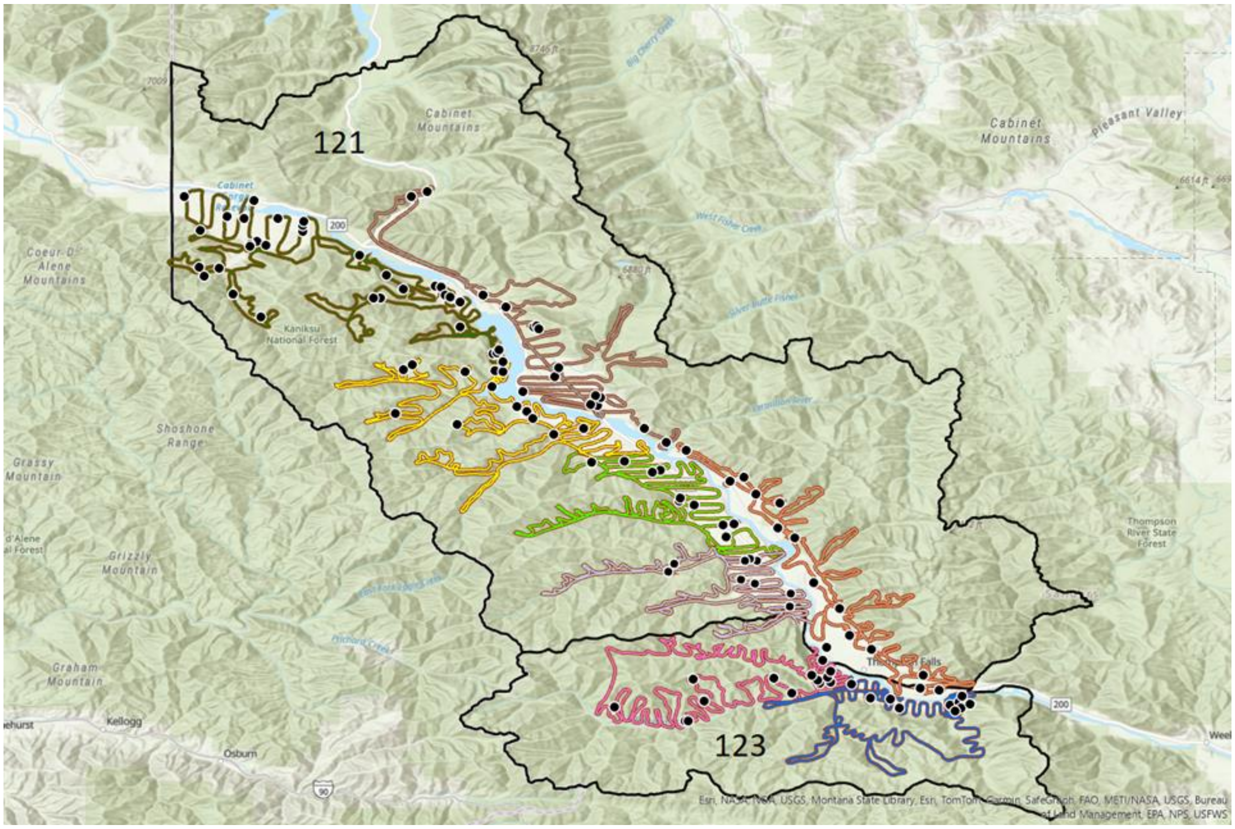


Figure 5. Aerial tracks from elk counts in hunting district 121 and 123 (black borders) in April 2024. Colored lines represent tracks from separate flights completed within approximately one week.

Elk counts since 2005 in HD 121 suggest elk populations have been relatively stable at approximately 1,500 individuals, which is within the population objective range (1,350 – 1,890) outlined in the 2023 Elk Management Plan. However, elk harvest data show that elk harvest, especially adult male harvest, has decreased over time, with a large drop in harvest occurring from 2010 – 2013 (Figure 6). It is largely unknown what factors have caused a drop in harvest, while elk populations appear to be stable. The IPM we developed, in concert with the new data we will collect as part of this study, will help identify the state of elk in HD 121 and Region 1 and identify what factors are most influential on elk population dynamics.

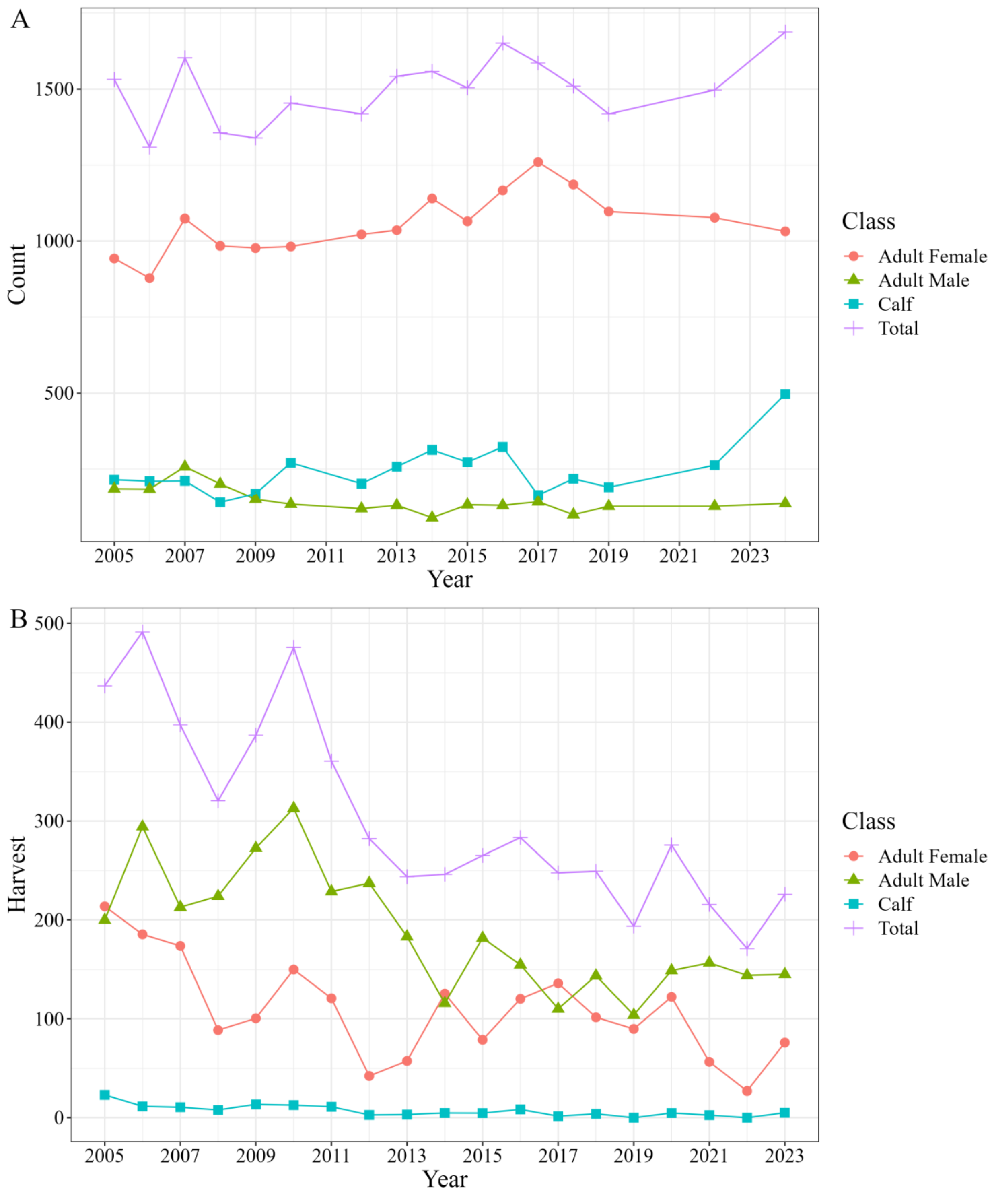


Figure 6. Elk population counts (panel A) and harvest estimates (panel B) for calves (<1 year old) and adult (>1 years old) females and males in hunting district 121 from 2005 – 2024. Note, limited aerial surveys were completed in 2011, 2014, 2018, 2020, 2021, and 2023 due either to poor conditions or COVID-19 restrictions.

1.3 Integrated population model development

1.3.1 Population model

Given count data in the region were collected in spring, we defined the population cycle as starting pre-birth, when the age classes observed were calves born the previous spring (approximately 10-11 months old) and "adult" (≥ 22 months old) females and males. Calves observed during aerial counts transitioned to either adult male or adult female classes the following year. A proportion of male calves observed became "available" for harvest (i.e., assumed to possess brown tines, thereby becoming legal to harvest; see below) the following autumn, when they were 1.5 years old; the remaining male calves were assumed to not have brow tines the following autumn, so did not become available for harvest until they were 2.5. Adult females and males stayed within the adult class, and females produced more individuals in the calf class to be observed the following year (Figure 7).

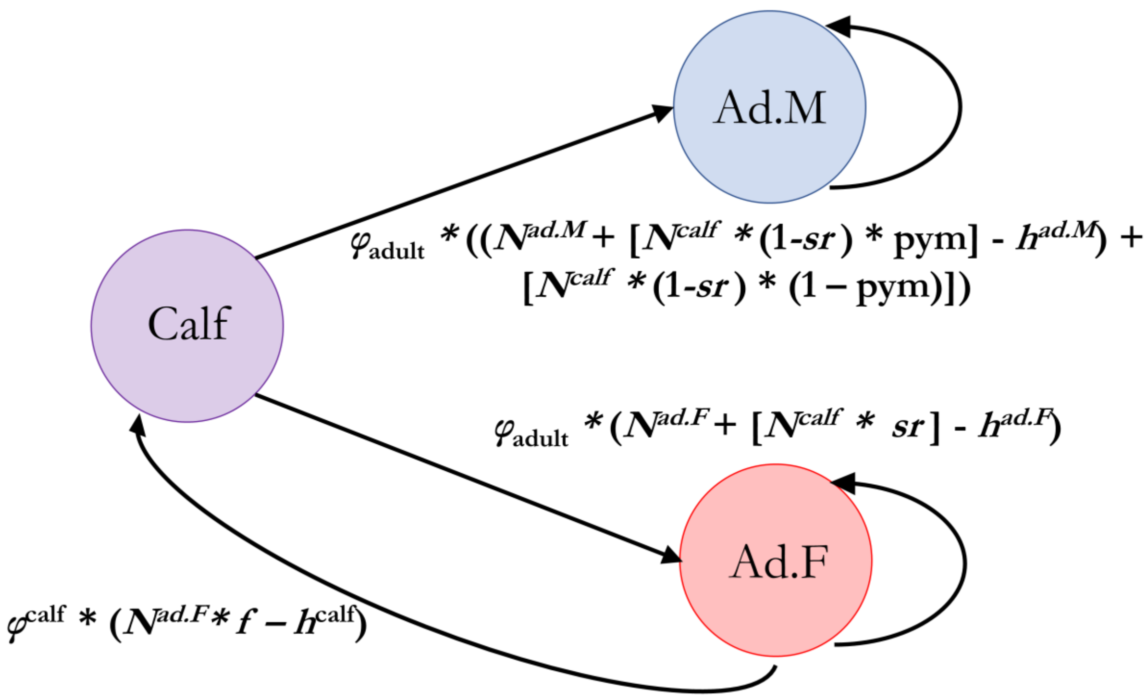


Figure 7. Life cycle diagram demonstrating transition probabilities among sex/age groups included in the integrated population model developed for hunting district 121. sr is the sex ratio at 1 year of age; pym is the proportion of male calves that are legal to harvest as yearlings (i.e., possess brow tines); φ^{adult} and φ^{calf} are annual natural survival of adults (≥ 1 year old) and calves (<1 year old), respectively; h is the harvest number of the designated age/sex class (calf, adult female [ad.F], and adult male [ad.M]); and f is the number of calves produced per adult female, which, assuming 1 calf/pregnant female, reduces down to pregnancy rate.

Thus, the expected number of calves in year *t* included calves produced in year *t* – 1 that did not get harvested and survived other mortality. Further, the expected number of adult females and males in year *t* included adult and calf females/males that did not get harvested and survived other mortality in year *t* – 1:

$$\begin{Bmatrix} N_t^{calf} \\ N_t^{ad.F} \\ N_t^{ad.M} \end{Bmatrix} = \begin{Bmatrix} \varphi_{t-1}^{calf} * \left(N_{t-1}^{ad.F} * f - h_{t-1}^{calf}\right) \\ \varphi_{t-1}^{ad} * \left(\left[N_{t-1}^{ad.F} + N_{t-1}^{calf} * sr\right] - h_{t-1}^{ad.F}\right) \\ \varphi_{t-1}^{ad} * \begin{pmatrix} \left(N_{t-1}^{ad.M} + [N_{t-1}^{calf} * (1 - sr) * pym] - h_{t-1}^{ad.M}\right) + \\ [N_{t-1}^{calf} * (1 - sr) * (1 - pym)] \end{pmatrix} \end{Bmatrix} \qquad \text{Eq. 1}$$

where *φ* is annual natural survival (excluding harvest), *f* is the number of calves produced per female, *h* is the number of individuals harvested, *sr* is proportion of calves that were female at the time of observation (~10-11 months old), and *pym* is the proportion of male calves that are available for harvest the following autumn (i.e., possess brow tines). For simplicity, we assumed a 0.5 sex ratio and adult natural survival did not vary by age or sex (e.g., Keller et al. 2015). To determine *pym*, we consulted check station data and previous literature. If we assume males with 3 points or more on at least one side had brown tines, then check station data in hunting district 121 suggested ~5.4% of 1.5-year-old males (i.e., males that were observed as calves the previous spring in our model) had brow tines. Further, 4.8% of harvested males with 2 points on one or both sides had brow tines (Z. Farley, Montana Fish, Wildlife & Parks, personal communication). Using these criteria, Thelen (1991) and Boyd (1970) suggested ~12% and 8.7% of 1.5-year-old males had brow tines in Washington and Colorado, respectively. Given these data, we assumed 10% of observed male calves possessed brow tines the following autumn, so *pym* = 0.1 each year. If necessary, the *pym* value could easily be changed, and these changes would only be reflected in male harvest rate estimates (i.e., lower *pym* values would result in higher harvest rate estimates because fewer males would be available for harvest, but overall male population estimates would not likely change greatly).

We included demographic stochasticity in our population model by assuming the number of individuals in each sex/age class was a realization of a Poisson process with the mean equal to the expected values from Eq. 1 and the variance equivalent to the mean. For example, we estimated the number of calves as:

$$N_t^{calf} \sim \text{Poisson}\left(\varphi_{t-1}^{calf} * \left(N_{t-1}^{ad.F} * f - h_{t-1}^{calf}\right)\right) \qquad \text{Eq. 2}$$

1.3.2 Observation models

We assumed aerial elk counts were a minimum representation of the true population, so we modeled age/sex counts as a binomial random variable. The binomial model structure is useful when it is assumed that counts represent a minimum population size because it constrains the true population to be equal to (if $p = 1$) or greater than (if $p < 1$) the counts, while most other distributions allow the true population size to be less than counts. We set the number of “trials” equal to the latent true population size, the probability of “success” equal to the proportion of individuals in the population that were counted (p), and the variance equal to $N^{Age/Sex} * p(1 - p)$:

$$\text{Count}_t^{Age/Sex} \sim \text{Binomial}\left(N_t^{Age/Sex}, p_t^{Age/sex}\right) \qquad \text{Eq. 3}$$

We also assumed adult males would have a different probability of being counted than adult females and calves, so we estimated a separate p for these two age/sex groups.

We modeled harvest observations (h) using a normal distribution with a mean equivalent to the harvest rate (hr) multiplied by the latent true population size immediately after the birth pulse (N), and variance equal to the variance on harvest observations ($h\sigma^2$). For example, we modeled the number of harvested adult females as:

$$h_t^{ad.F} \sim \text{Normal}\left(hr_t^{ad.F} * \left[N_t^{ad.F} + N_t^{calf} * sr\right], h^{ad.F}\sigma_t^2\right) \qquad \text{Eq. 4}$$

We estimated survival and pregnancy rates of collared elk as a part of Objective 3 (see Section 3.3.1). Thus, we related these survival estimates (ϕ, σ^2) to associated survival parameters within the IPM (S) in the year they were collected using a Normal distribution:

$$\phi_t \sim \text{Normal}(S_t, \sigma^2) \qquad \text{Eq. 5}$$

Similarly, we related the number of pregnant females (*n.preg*) out of the total females tested (*n.tot*) to associated pregnancy rate parameters within the IPM (f) in the year they were collected using a Binomial distribution:

$$n.preg_t \sim \text{Binomial}(n.tot_t, f) \qquad \text{Eq. 6}$$

1.3.3 Model fitting

We assigned prior distributions for each demographic parameter within the population model that were informed by past literature (Table 1).

Table 1. Prior distributions and references for parameters included in elk integrated population models in hunting district 121 from 2013– 2024. Parameters include calf and adult natural survival (φ), number of calves produced per female (i.e., pregnancy rate; f), harvest rate (hr), and initial population size N_1.

Parameter	Prior Distribution	References
φ^{calf}	Unif(0, 0.6)	Singer et al. 1997; Smith and Anderson 1998; Raithel et al. 2007; Eacker et al. 2016; Paterson et al. 2019
φ^{ad}	Unif(0.8, 1)	Unsworth et al. 1993; Raithel et al. 2007; Brodie et al. 2013; Keller et al. 2015; Hegel et al. 2014; Horne et al. 2019; Sergeyev et al. 2021; Paterson et al. 2022
f	Unif(0, 1)	Raithel et al. 2007; Paterson et al. 2022
hr^{calf}	Unif(0, 0.1)	Conversations with FWP personnel
$hr^{ad.F}$	Unif(0, 0.2)	Conversations with FWP personnel
$hr^{ad.M}$	Unif(0.2, 0.8)	Conversations with FWP personnel
$N_1^{calf,ad.F,ad.M}$	$\text{Unif}\left(\text{Count}_1^{calf,ad.F,ad.M}, 10000\right)$	NA

We also developed link functions for each parameter, which allowed for the addition of covariates that explained variation in the response. Given the lack of strong associations we observed between biotic/abiotic factors and calf survival in a previous iteration of the model (Proffitt et al. 2023), we removed these covariates from the current model. However, we maintained a harvest effort covariate, equivalent to the number of elk hunter days in hunting district 121, in linear models predicting harvest rate to account for changes in harvest rates related to effort, rather than population change. Additionally, we included a temporal random effects structure for annual survival and harvest rate parameters, but left other parameters constant over time.

We fit models using a Bayesian framework and estimated posterior distributions of parameters by running 3 Markov Chain Monte Carlo (MCMC) chains, each for 100,000 iterations, with a burn-in of 50,000, and thinning of 10. We identified whether models converged by ensuring $\hat{R}$ values were <1.1 and by visually inspecting posterior distributions for adequate mixing. Using the models described above, we estimated true population size for each sex/age class, as well as population growth rates (λ) and demographic rates over time.

1.4 Results

1.4.1 Population Dynamics

Due to uncertainties in elk population dynamics before 2013 (i.e., strong drop in harvest, but consistent aerial counts), we decided to only use data after 2012 to estimate elk population dynamics.

Results from the IPM suggested elk populations have been relatively stable or slightly increasing since 2013, with estimated total population sizes averaging approximately 1,779 individuals (323 calves, 1,270 adult females, and 185 adult males) and geometric mean λ = 1.010 (95% credible interval [CrI] = 1 – 1.024; Figure 8). Model results suggested the annual proportion of adult females and calves counted averaged 0.87 (SD = 0.012), while the proportion of adult males counted averaged 0.69 (SD = 0.094).

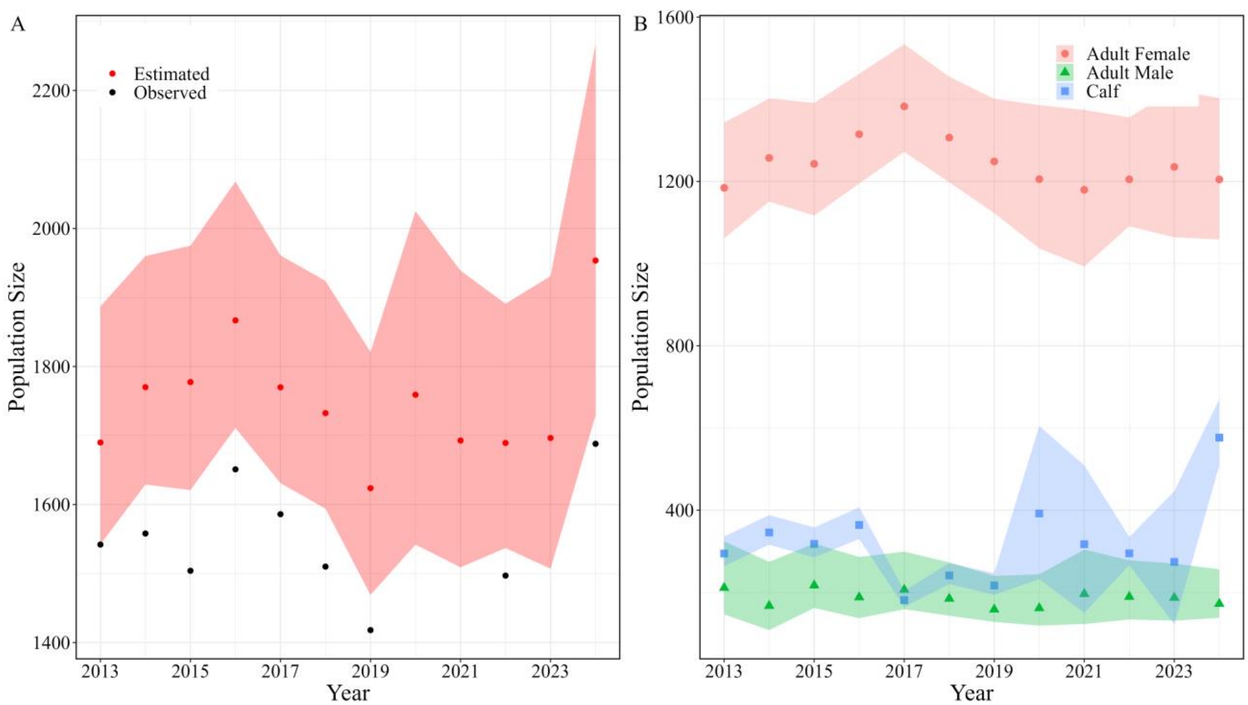


Figure 8. Total elk population estimates (A) and age/sex-specific estimates (B) in hunting district 121 from 2013 – 2024 based on a preliminary elk population model. Red dots in panel A represent model estimates, while black dots represent observations from aerial counts. All values in panel B are model-estimated and ribbons in both panels represent 95% credible intervals. Note: y-axis scales differ between panels to improve display.

1.4.2 Demographic Rates

Mean estimated annual natural survival (excluding harvest) of adult elk (≥1 year old) from 2013 – 2023 was 0.96 (95% CrI = 0.92 – 0.99), while mean annual natural survival of calves (<1 year old) was 0.29 (95% CrI = 0.21 – 0.38). Estimated mean harvest rates of adult females, adult males available for harvest (i.e., possessed brow tines), and calves was 0.062 (95% CrI = 0.046 - 0.081), 0.76 (95% CrI = 0.5 – 0.94), and 0.0036 (95% CrI = 0.0024 – 0.0049), respectively (Figure 9). Estimated harvest rate of all males >1 year old (including those without brow tines) was 0.44 (95% CrI = 0.35 – 0.49). The model-estimated pregnancy rate was 0.85 (95% CrI = 0.76 – 0.93).

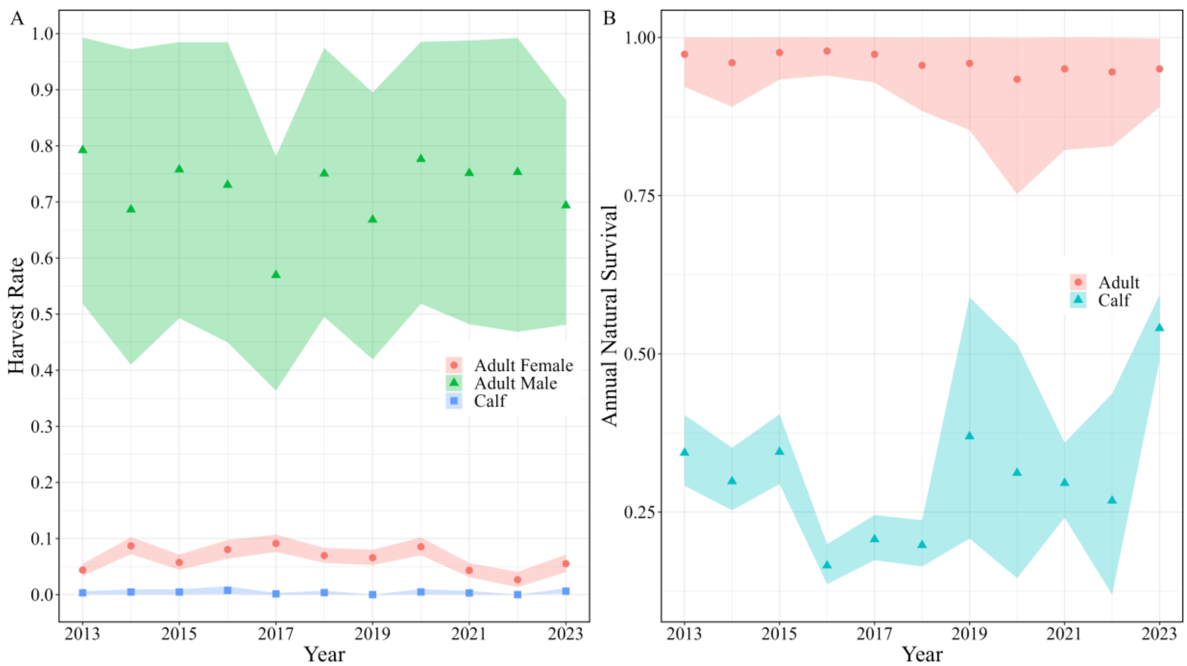


Figure 9. Estimated harvest rates of adult female, adult male, and calf elk (A) and estimated annual natural survival of adult and calf elk (B) from 2013 – 2023 in hunting district 121. Dots represent mean estimates and ribbons represent 95% credible intervals. Note: y-axis scales differ between panels to improve display.

1.5 Discussion/Interpretation

Our results suggest that elk populations have been stable over the past decade and estimated elk demographic rates were consistent with rates documented in other elk literature. The calf:cow ratio in 2024 was the highest recorded in the last 34 years. This, along with high neonate survival in 2023 (Section 3.3.2) resulted in highest estimates of calf survival in the IPM in the previous decade. Although we are uncertain, high calf survival in 2023 could be related to a number of factors, including a reduction in predator densities through harvest and a mild winter.

While our analyses suggest a stable population in HD 121, we caution interpretation of these results at the current time. The occasional disparity between aerial counts and harvest estimates introduced uncertainty in the model, resulting in model sensitivity to the observation distributions and priors used. Space use patterns of collared individuals and population estimates from camera trap methods in this study may help identify the cause of the discrepancy between counts and harvest and indicate appropriate distributions to use in future IPMs. Additionally, while we expect elk demographic rates in our study area to be similar to what we estimated, given their consistency with rates in the literature, it is possible that true rates, the annual variability in rates, or the importance of rates in elk population dynamics will differ (e.g., Eacker et al. 2017). We will continue to add demographic information collected as part of this study (see Section 3) before finalizing the model and developing management recommendations.

Another objective of this research was to develop a user-friendly tool to facilitate elk management decisions. Thus, we have begun development of a shiny app that incorporates user data inputs into the IPM described above and provides estimates of elk abundance, vital rates, and population dynamics (Figure 10). Users can forecast management scenarios, such as changing elk harvest or other demographic rates, and view population projections based on those forecasted scenarios. We will continue development of this app in the next year and solicit feedback from intended users.

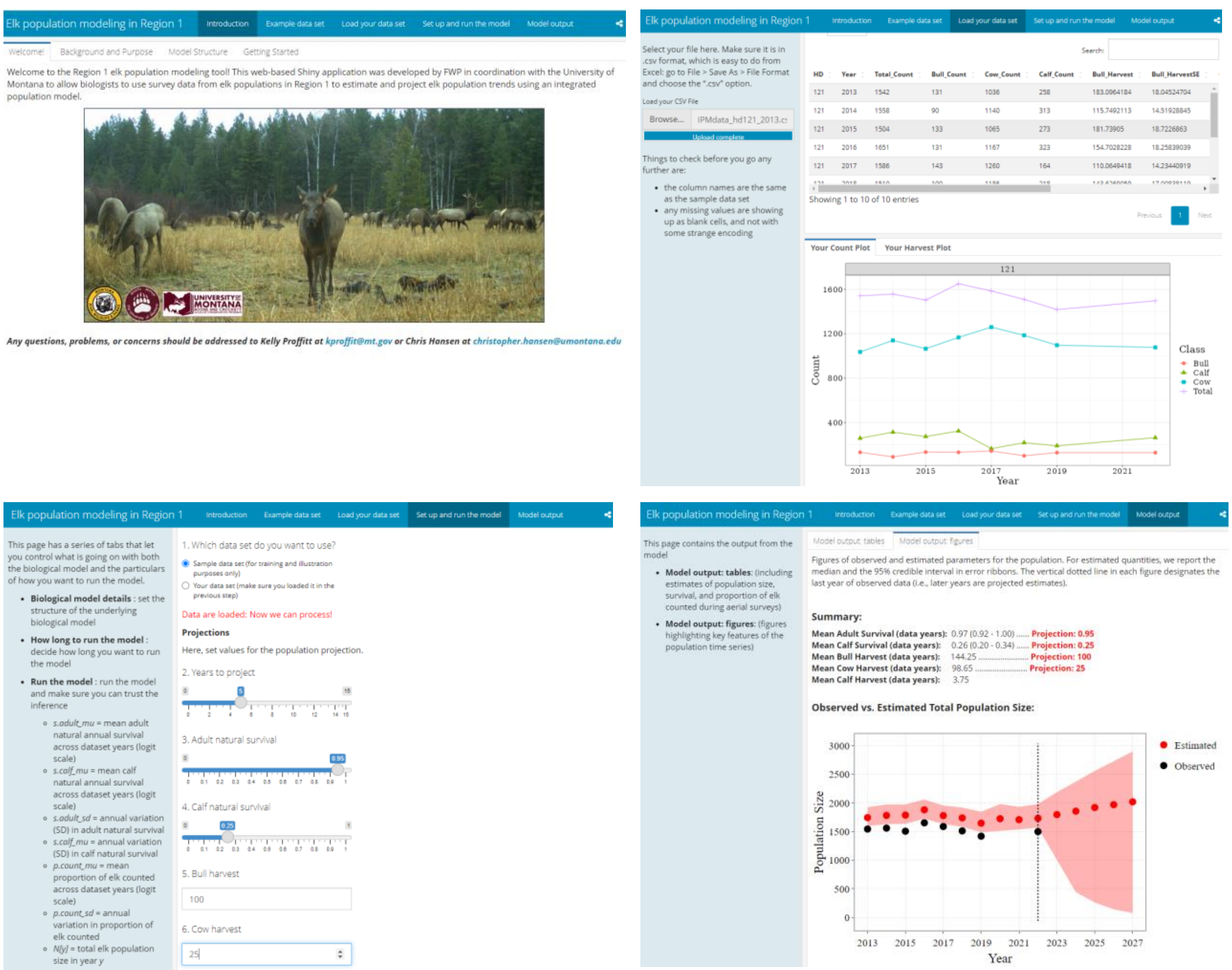


Figure 10. Example workflow of shiny app tool that incorporates user inputs into an integrated population model and provides estimates of elk population dynamics and vital rates.

Our ultimate objective is to develop predictive models of elk population dynamics in northwest Montana. Thus, we will eventually use the IPM we developed to monitor elk populations across HDs in Region 1. However, elk count datasets from other HDs in Region 1 are typically less consistent and have more uncertainty than those in HD 121. Given the challenges we highlighted above in HD 121, we decided not to conduct a formal population analysis for other HDs in Region 1 at this time. We will update and extend the model to other HDs once we have collected additional data.

Objective #2: Based on past research findings, develop predictive models of elk hunting season distributions in northwest Montana, including the effects of forest disturbance and hunter access.

2.1 Background

Elk distribution and migratory behavior are of concern to wildlife managers, land managers, hunters, and private landowners due to concerns with elk availability for harvest and elk-related damage on private lands. In some areas, elk hunters and wildlife managers are observing declines in public-land hunting opportunities and agricultural producers are experiencing increased property damage (Burcham 1956, Haggerty and Travis 2006, Krausman et al. 2014, Fontaine et al. 2019). As such, there is shared interest of wildlife managers, public land managers, hunters using public lands, and private landowners in identifying factors affecting elk distributions during autumn hunting seasons. Our objective was to use elk location data from autumn 2023 to identify what resources elk use and how those resources change throughout hunting seasons. At this time, with only one year of information, we present basic summaries of elk landscape use. However, our goal after data collection is complete will be to formally model elk resource selection during the hunting seasons.

2.2 Data collection and analytical methods

We evaluated autumn elk use of the landscape in hunting district 121 in relation to nine variables that could influence elk resource selection during the hunting season (Ranglack et al. 2017; Table 2, Figure 11). We selected these variables to address hypotheses of elk resource use related to elk avoidance of humans (e.g., private vs. public lands and distance to road; Proffitt et al. 2016a, Lowrey et al. 2020, Snobl et al. 2024), acquisition of forage/nutrition (NDVI; Ranglack et al. 2022), security cover (canopy cover, solar radiation, landcover; Proffitt et al. 2016b, DeVoe et al. 2019), topography (elevation and slope), and snow cover (snow water equivalent [SWE]; Messer et al. 2009, Snobl et al. 2024).

We summarized elk use of these variables (i.e., resources) using location data from collared male and female elk (see Section 3.2.1) during 4 hunting periods: “prehunt” (August 1 – September 1, 2023), “archery” (September 2 – October 15, 2023), “rifle” (October 21 – November 26, 2023), and “posthunt” ” (i.e., post-general rifle season; November 27 – December 31, 2023). We removed nighttime locations (31 minutes after sunset – 31 minutes before sunrise) so locations represented elk locations during legal shooting light (Figure 12).

Using these data, we calculated each elk’s mean use of every resource during each hunting period, then calculated the mean, median, and variability of these elk-specific values across elk. We also calculated the elk-specific percent change in use of each resource between prehunt and archery periods, archery and rifle periods, and rifle and posthunt periods. Finally, we determined the proportion of elk that had >50% of locations on public or block management area (BMA) lands during each hunting period to identify what proportion of elk were available for harvest.

Table 2. Description of variables used to evaluate elk resource use during the hunting season in hunting district 121.

Variable	Description and Source	References
Access	Areas accessible to hunters (public lands and Block Management Areas [BMA; Type 1 and 2]). Developed from Montana Cadastral ownership parcels and FWP BMA shapefiles.	Proffitt et al. 2016b; Ranglack et al. 2017; Lowrey et al. 2020; Snobl et al. 2024
Canopy cover	Percent forest canopy cover. Obtained from LANDFIRE 2020 Forest Canopy Cover (USGS 2022b).	Proffitt et al. 2016b; Ranglack et al. 2017; DeVoe et al. 2019
Distance to road (archery)	Distance (m) to open motorized routes during the archery season. Developed from a combination of Forest Service (FS) and Montana Department of Transportation (MDT) roads layers.	Ranglack et al. 2017; Lowrey et al. 2020; Snobl et al. 2024
Distance to road (rifle)	Distance (m) to open motorized routes during the rifle season. Developed from a combination of FS and MDT roads layers.	Ranglack et al. 2017; Lowrey et al. 2020; Snobl et al. 2024
Elevation	Elevation (m). Obtained from the National Elevation Dataset (using FedData package in R; Bocinsky 2023).	Ranglack et al. 2017
Slope	Percent slope. Calculated from elevation layer.	Ranglack et al. 2017
Snow water equivalent	Maximum snow water equivalent (SWE; kg/m^2) during hunting seasons. Obtained from ORNL DAAC (using FedData package in R; Bocinsky 2023).	Messer et al. 2009; Snobl et al. 2024
Solar radiation	Solar radiation (kWh/m^2). Calculated using the Area Solar Radiation tool and elevation layer in ArcMap (ESRI, Redlands, CA).	Proffitt et al. 2016; Ranglack et al. 2017; DeVoe et al. 2019
Time-integrated NDVI	Time-integrated normalized difference vegetation index: USGS Remote Sensing Phenology (http://phenology.cr.usgs.gov/get_data_250w.php). Average from 2001 – 2015.	Ranglack et al. 2017; Ranglack et al. 2022
Landcover	Landcover types from the National Land Cover Database (https://www.usgs.gov/centers/eros/science/national-land-cover-database).	Proffitt et al. 2016; Ranglack et al. 2017; DeVoe et al. 2019

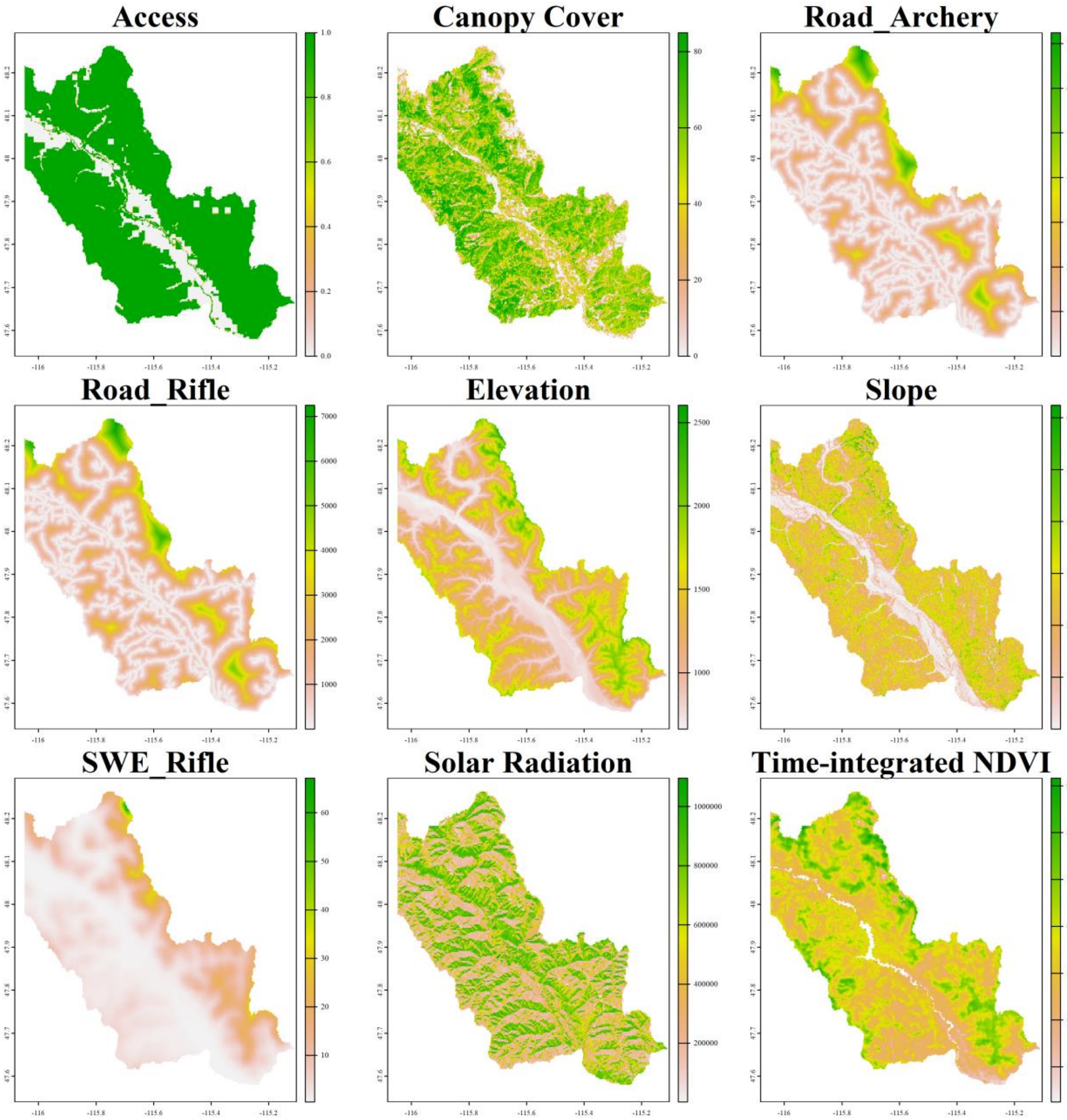


Figure 11. Rasters of factors potentially influencing elk use during the hunting season in hunting district 121.

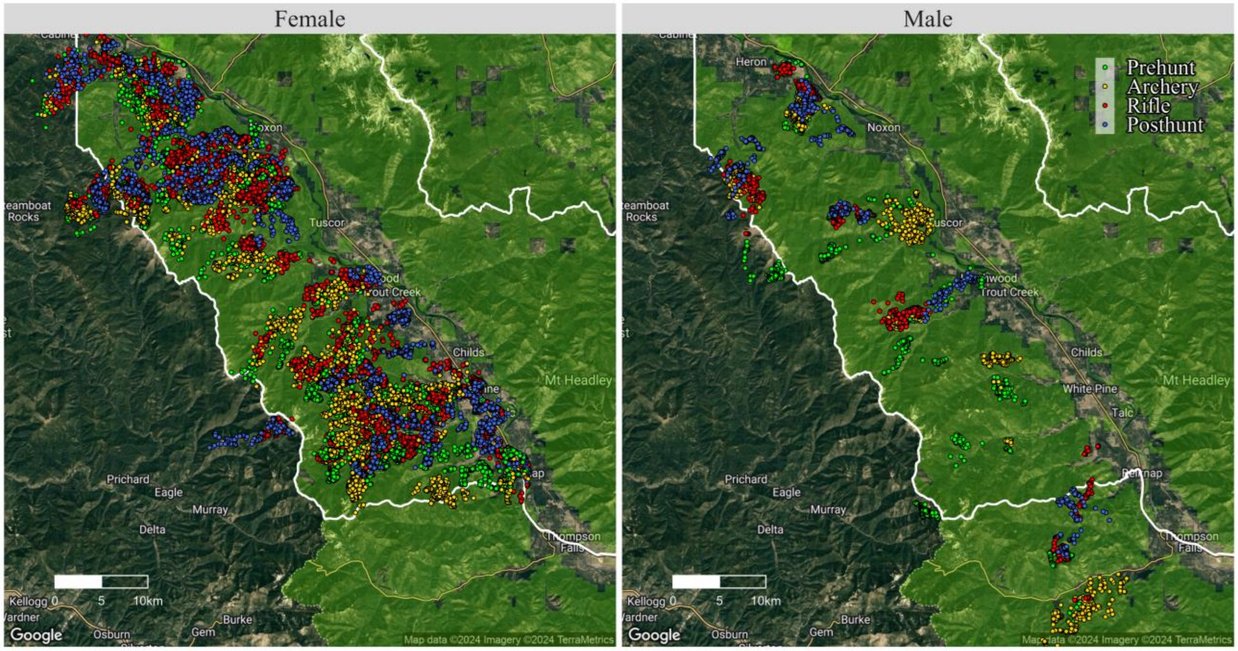


Figure 12. Male and female elk daytime locations during the hunting season in 2023 within and adjacent to hunting district 121 (white border). Green, yellow, red, and blue dots represent locations during prehunt, archery, rifle, and posthunt periods, respectively. The green overlay represents areas accessible for hunting by the general public (i.e. either public lands or block management areas).

2.3 Results and Discussion

We collected 43,696 locations of 58 females (53 adult and 5 yearling) and 5,942 locations of 10 males (6 adult and 4 yearling) during the hunting season in 2023 (Table 3). Both female and male elk demonstrated changes in use of some resources from August – December. On average, both males and females became less accessible for harvest (lower proportion of locations on public lands or BMAs) during rifle season; although, there was considerable variability among elk (Table 4, Figure 13, Figure 14). Average canopy cover, distance to road, elevation, slope, and use of forest by females also tended to decline in a similar pattern as accessibility, suggesting some elk moved out of forested, high-elevation public areas to grass/shrub, low-elevation private lands as hunting seasons progressed. Males followed similar use patterns as females, except differences between hunting periods were more subtle and distance to road increased between archery and rifle seasons.

Table 3. Number of elk locations used to summarize elk resource use during hunt periods (prehunt, archery, rifle, posthunt) in hunting district 121 during autumn 2023.

Sex	Age Class	Hunt Period	Number of Elk	Number of Locations
Female	Adult	Prehunt	53	10,190
		Archery	53	13,055
		Rifle	51	8,825
		Posthunt	48	7,885
	Yearling	Prehunt	5	903
		Archery	5	1,176
		Rifle	5	875
		Posthunt	5	787
Male	Adult	Prehunt	6	1,280
		Archery	6	1,244
		Rifle	3	556
		Posthunt	3	504
	Yearling	Prehunt	4	622
		Archery	3	763
		Rifle	3	504
		Posthunt	3	469

Table 4. Mean female and male elk resource use (see Table 2 for resource descriptions) during prehunt, archery, rifle, and posthunt periods for individuals collared in hunting district 121. Landcover values (Barren, Developed, Forest, Grass, Shrub) represent the mean proportion of locations occurring in those landcover types. Accessibility values represent the proportion of elk locations occurring on public lands or block management areas (i.e., available to the public for harvest). Standard deviation of mean values across elk are provided in parentheses.

Sex	Variable	Prehunt	Archery	Rifle	Posthunt
Female	Accessibility	0.87 (0.25)	0.86 (0.27)	0.68 (0.4)	0.6 (0.44)
	Canopy Cover (%)	56.24 (8.09)	59.7 (8.58)	52.04 (12.68)	43.9 (12.91)
	Distance to Road (m)	731.33 (376.01)	702.68 (348.71)	683.26 (256.35)	579.58 (266.25)
	Elevation (m)	1222.28 (200.18)	1208.14 (201.04)	1068.06 (211.19)	1054.86 (250.22)
	NDVI	52.21 (4.53)	51.58 (4.1)	50.5 (3.63)	51.46 (4.9)
	SWE (kg/m^2)	0 (0)	0 (0)	0.25 (0.56)	3.91 (3.63)
	Slope (%)	0.21 (0.05)	0.21 (0.06)	0.18 (0.09)	0.15 (0.1)
	Solar (kWh/m^2)	379.03 (108.37)	372.68 (132.3)	404.73 (102.49)	443.73 (106.99)
	Barren	0 (0)	0 (0)	0 (0)	0 (0.01)
	Developed	0 (0)	0 (0)	0 (0)	0 (0.01)
	Forest	0.91 (0.1)	0.94 (0.09)	0.81 (0.19)	0.74 (0.22)
	Grass	0.03 (0.05)	0.01 (0.01)	0.02 (0.03)	0.06 (0.08)
	Shrub	0.07 (0.08)	0.05 (0.08)	0.16 (0.19)	0.2 (0.17)
Male	Accessibility	0.96 (0.09)	0.99 (0.01)	0.88 (0.18)	0.94 (0.14)
	Canopy Cover (%)	61.36 (4.75)	60.91 (6.03)	60.31 (7.21)	58.69 (3.74)
	Distance to Road (m)	967.52 (339.73)	696.87 (246.05)	928.24 (460.76)	1001.64 (189.69)
	Elevation (m)	1273.71 (116.72)	1189.15 (136.92)	1143.19 (196.11)	1204.68 (101.59)
	NDVI	52.72 (4.44)	51.07 (5.28)	50.9 (5.19)	51.66 (2.34)
	SWE (kg/m^2)	0 (0)	0 (0)	0.11 (0.2)	6.3 (3.43)
	Slope (%)	0.25 (0.03)	0.24 (0.02)	0.22 (0.06)	0.24 (0.03)
	Solar (kWh/m^2)	322.46 (91.25)	469.34 (138.6)	377.63 (79.55)	395.64 (152.8)
	Barren	0 (0)	0 (0)	0 (0)	0 (0)
	Developed	0 (0)	0 (0)	0 (0)	0 (0)
	Forest	0.96 (0.07)	0.96 (0.05)	0.9 (0.1)	0.95 (0.02)
	Grass	0.03 (0.07)	0.02 (0.05)	0.01 (0.02)	0.01 (0.02)
	Shrub	0.02 (0.02)	0.02 (0.02)	0.09 (0.09)	0.04 (0.01)

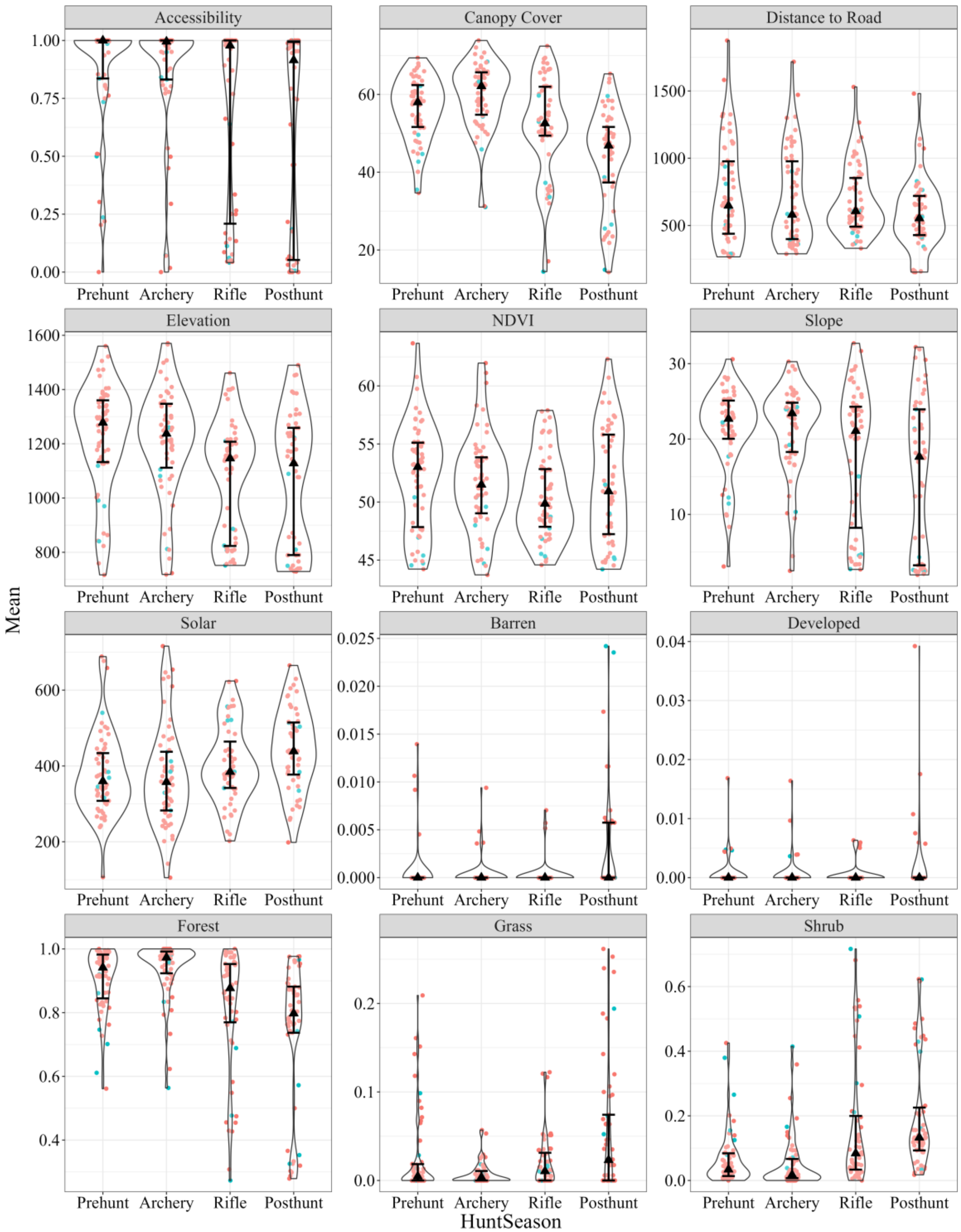


Figure 13. Female elk use of resources (see Table 2 for resource descriptions) during the hunting season for individuals collared in hunting district 121. Red and blue dots represent adult and yearling elk-specific mean use of each resource during hunting periods, respectively. Violin plots show the distribution of use across elk, while the black triangle and bars show the median and 50% quantile of use across elk. Landcover values (Barren, Developed, Forest, Grass, Shrub) represent the proportion of locations occurring in those landcover types. Accessibility values represent the proportion of elk locations occurring on public lands or block management areas (i.e., available to the public for harvest).

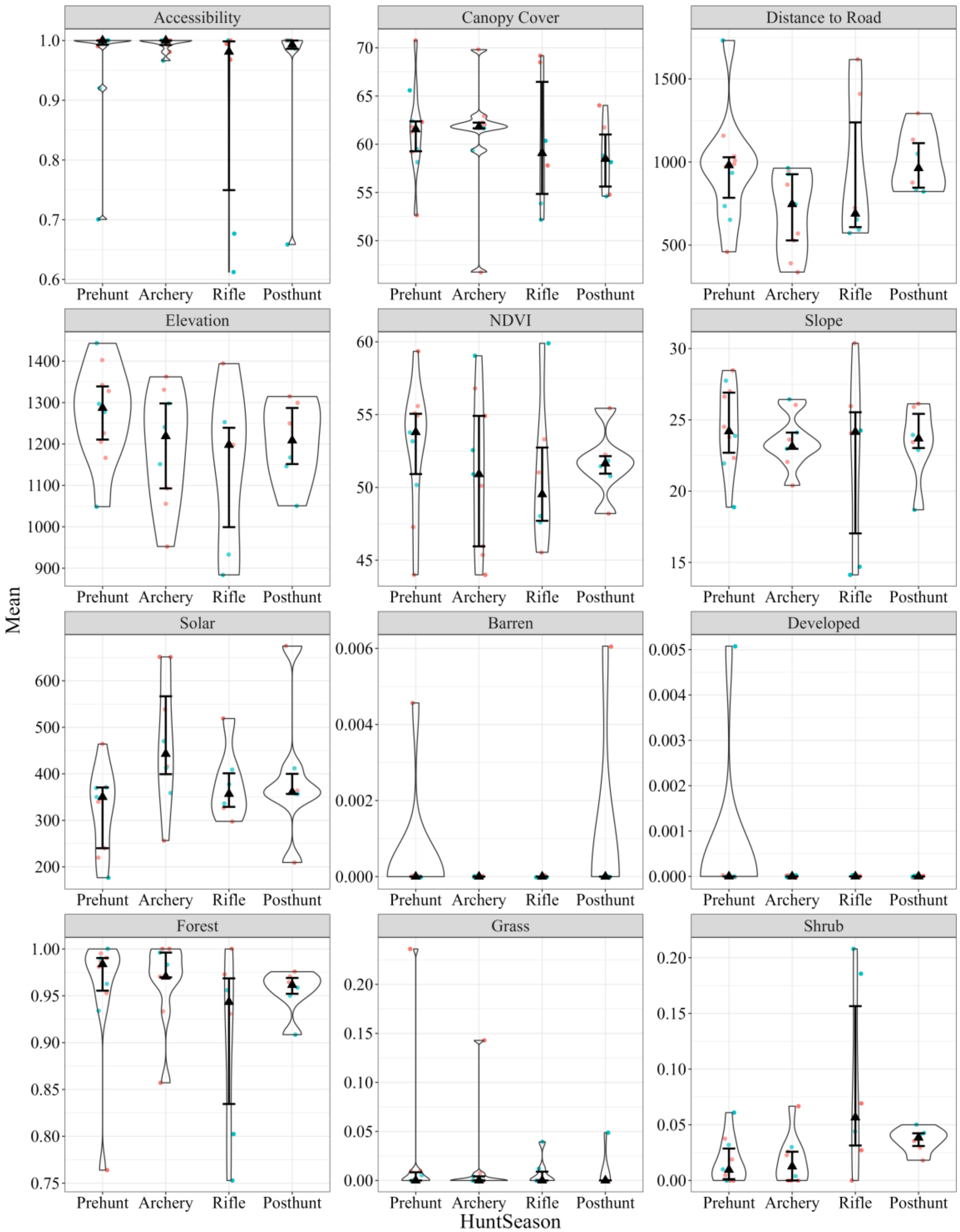


Figure 14. Male elk use of resources (see Table 2 for resource descriptions) during the hunting season for individuals collared in hunting district 121. Red and blue dots represent adult and yearling elk-specific mean use of each resource during hunting periods, respectively. Violin plots show the distribution of use across elk, while the black triangle and bars show the median and 50% quantile of use across elk. Landcover values (Barren, Developed, Forest, Grass, Shrub) represent the proportion of locations occurring in those landcover types. Accessibility values represent the proportion of elk locations occurring on public lands or block management areas (i.e., available to the public for harvest).

The pattern of changing resource use throughout autumn was not consistent across all elk, with some individuals increasing, decreasing, or maintaining resource use across hunting periods (e.g., Appendix A). For example, many elk maintained accessibility throughout all hunting periods, while others became more accessible. Further, while there were fewer elk locations within accessible areas during the rifle season, a large proportion of elk remained on public lands the majority of the time. Approximately 88% of females and 100% of males were on accessible lands at least half the time during archery season. This percentage dropped to 67% of females during rifle season, but male accessibility remained at 100% (Figure 15).

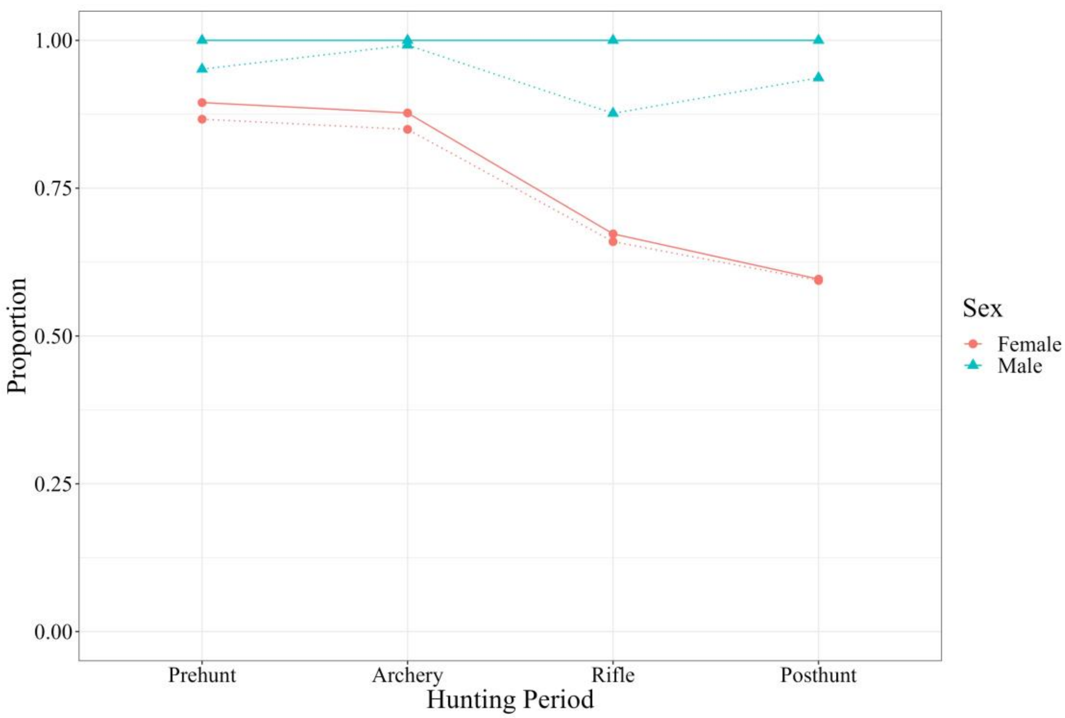


Figure 15. Proportion of collared female and male elk with >50% of daytime locations on publicly accessible land (solid lines) and proportion of total elk locations on publicly accessible land (dotted lines) during each hunting period in hunting district 121.

These results suggest that the majority of elk were largely accessible to hunters throughout autumn, regardless of a decrease in proportion of elk locations on publicly accessible lands during the rifle season. However, we caution interpretation of results regarding male distribution, given the low sample size. Only 6 adult males and 3 yearling males were being monitored at the beginning of archery season. Five of the 6 adult males had been captured by helicopter the previous winter in higher elevations, and the other adult male, which was caught in the valley, was harvested during archery season on public land. All 3 collared yearling males alive at the start of archery season were caught in the valley the previous winter and all three moved to private land, at least temporarily, during the rifle season (e.g., Figure 16). Thus, it is possible that males that use the valley in winter are also more likely to use private lands in the valley during hunting seasons. Alternatively, our findings could be due to our valley sample of males being completely composed of yearlings, which may be more likely to follow cows onto private lands during rifle season. We will continue to explore these possibilities as we collect more data.

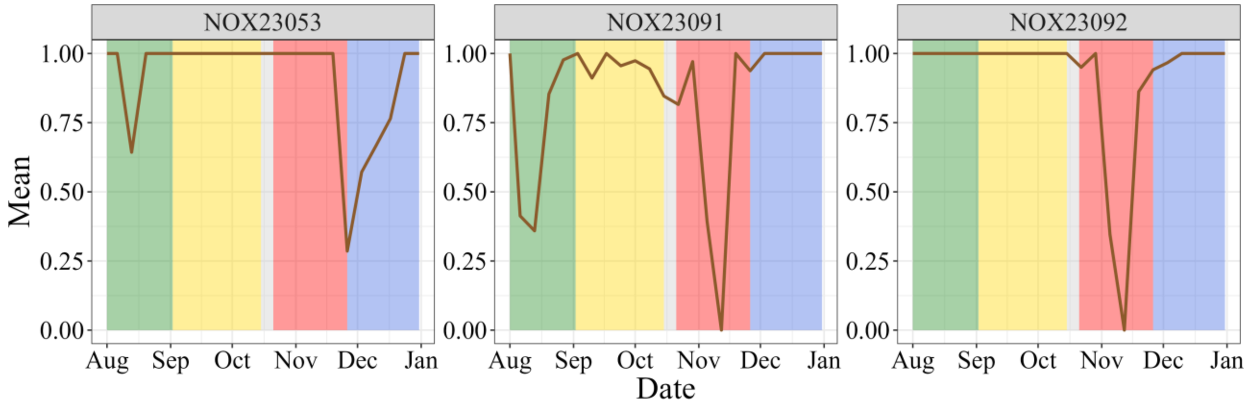


Figure 16. Proportion of accessible locations (located on public lands) by week for three collared yearling male elk throughout autumn in hunting district 121. Brown lines represent elk-specific mean weekly proportion of locations on public land. Green, yellow, gray, red, and blue regions represent prehunt, archery, rest (no hunting), rifle, and posthunt periods. Note, each yearling made movements toward private (i.e., inaccessible) lands during the rifle season and returned to public lands during the posthunt period. NOX23091 and NOX23092 traveled together.

While many elk were on public lands, they may have still been difficult to find and access, given landscape features they used. Over 90% of male daytime locations during rifle season occurred in forest landcover types with average canopy cover >60%, slope > 22%, and distance from roads near 1 km (Table 4). All these values exceeded female use values, suggesting males used areas more difficult for hunters to access, on average. We will continue to assess this complex "accessibility" landscape in future analyses to help determine the demographic tradeoffs of different resource use strategies by elk during autumn and how this relates to hunter opportunity.

Objective #3: Design monitoring programs for elk and carnivores that will provide necessary information to evaluate the effects of management actions as they are implemented on elk population dynamics and hunting season distributions.

3.1 Background

To improve our understanding of elk and carnivore population dynamics, demographic processes, and distributions in Region 1, information about elk and carnivore survival, movements, and abundances are necessary. Below, we outline our methods and current progress related to collaring of elk and carnivores; estimating elk and carnivore abundance; and measuring the elk nutritional landscape in HD 121.

3.2 Data Collection Methods

3.2.1 Adult Elk Capture and Monitoring

From December through March, 2022-23 and 2023-24, we captured male and female elk by a combination of Clover trapping (Thompson et al. 1989; Figure 17) and helicopter netgunning with chemical immobilization following approved University of Montana animal capture protocols (003-23JMWB-011823). Each captured elk was outfitted with Iridium remote upload global positioning system (GPS) radio-collars (Lotek Wireless, model LiteTrack Iridium 420, New Market, Ontario, Canada) programmed to record a location every 2 hours and transmit a mortality notification 6 hours post-mortality.

Figure 17. Female elk captured and chemically immobilized in a Clover trap.

We fit females that were suspected to be pregnant with vaginal implant transmitters (VIT; Lotek Wireless, Newmarket, Ontario, Canada) to assist with neonatal captures in spring (see Section 3.2.2). We also attempted to collect blood during all captures to confirm pregnancy status based on the presence of pregnancy-specific protein-B in the blood serum (Noyes et al. 1997; Herd Health Diagnostics/BioTracking Testing Lab, Pullman, WA) and extracted a lower incisor for cementum aging analysis.

In 2023, we assayed blood serum samples for evidence of exposure to pathogens including *Brucella abortus*, Anaplasma bacteria, parainfluenza-3 (P13), bovine respiratory syncytial virus (BRSV), bovine viral diarrhea type 1 (BVD1) and 2 (BVD2), bovine herpesvirus (BHV1), epizootic hemorrhagic disease (EHD), and 5 strains of Leptospira (*L. canicola*, *L. ictero*, *L. grippo*, *L. pomona*, and *L. hardjo*). These pathogens were selected for screening because of their potential to influence individual or herd health in wildlife and/or livestock. All disease assays were conducted by the Montana Veterinary Diagnostic Laboratory (Bozeman, Montana).

We investigated elk mortalities as soon as possible after being alerted of a mortality event. We determined the cause of mortality based on evidence surrounding the mortality site, including teeth marks, carcass condition, and predator signs (e.g., tracks, scat, hair). We calculated annual (June 1, 2023 – May 31, 2024) natural survival (harvest excluded) and total survival (harvest included) for males and females ≥ 1 year old using the Kaplan-Meier estimator in the “survival” package (Therneau 2023).

Ultimately, these data will be used to evaluate elk survival, movements, and space use, which will inform population and distribution models described in Sections 1 and 2.

3.2.2 Neonate Elk Capture and Monitoring

In May and June 2023 and 2024, we located, captured, and collared neonatal elk calves following approved University of Montana animal capture protocols (003-23JMWB-011823). We used multiple methods to locate and capture neonatal calf elk, including: 1) monitoring VITs (see Section 3.2.1) for expulsion from the adult female elk during parturition; 2) monitoring female elk movement metrics to detect parturition behavior (e.g., Figure 18 and below); and 3) opportunistically searching calving areas.

Elk and other ungulates generally display distinct movement patterns around parturition, including a reduction in movement and localization around the birth site and/or neonate. These unique parturition movement patterns may be observed in GPS data from collared female animals. We developed a method to identify potentially parturient female elk by deriving four movement metrics from GPS data and developing parturition-associated thresholds for each metric. The four movement metrics we evaluated were 24-hour rolling MCP home range size, 100m radius residence time with 12-hour rolling average, 24-hour rolling displacement with a 12-hour rolling average, and 12-hour rolling velocity, each of which captured an aspect of reduced or localized movement behavior. To develop threshold values associated with parturition behavior, we used known birth data from the previous neonate capture season and identified the lowest (home range, displacement, velocity) or highest (residence time) value for each metric associated with each individual's known birth event (two days before or after the estimated birth date to account for birth timing uncertainty). We then used the 80th percentile metric value from this distribution of individual extreme birth values as the threshold for that metric. During calving season, female elk whose movement metric values crossed one or more of these parturition-associated thresholds were flagged as potentially parturient (Figure 18). We examined time series graphs of these individual's movement metrics as well as raw GPS data for final decision-making before sending a field team to investigate the individual and search for a neonate.

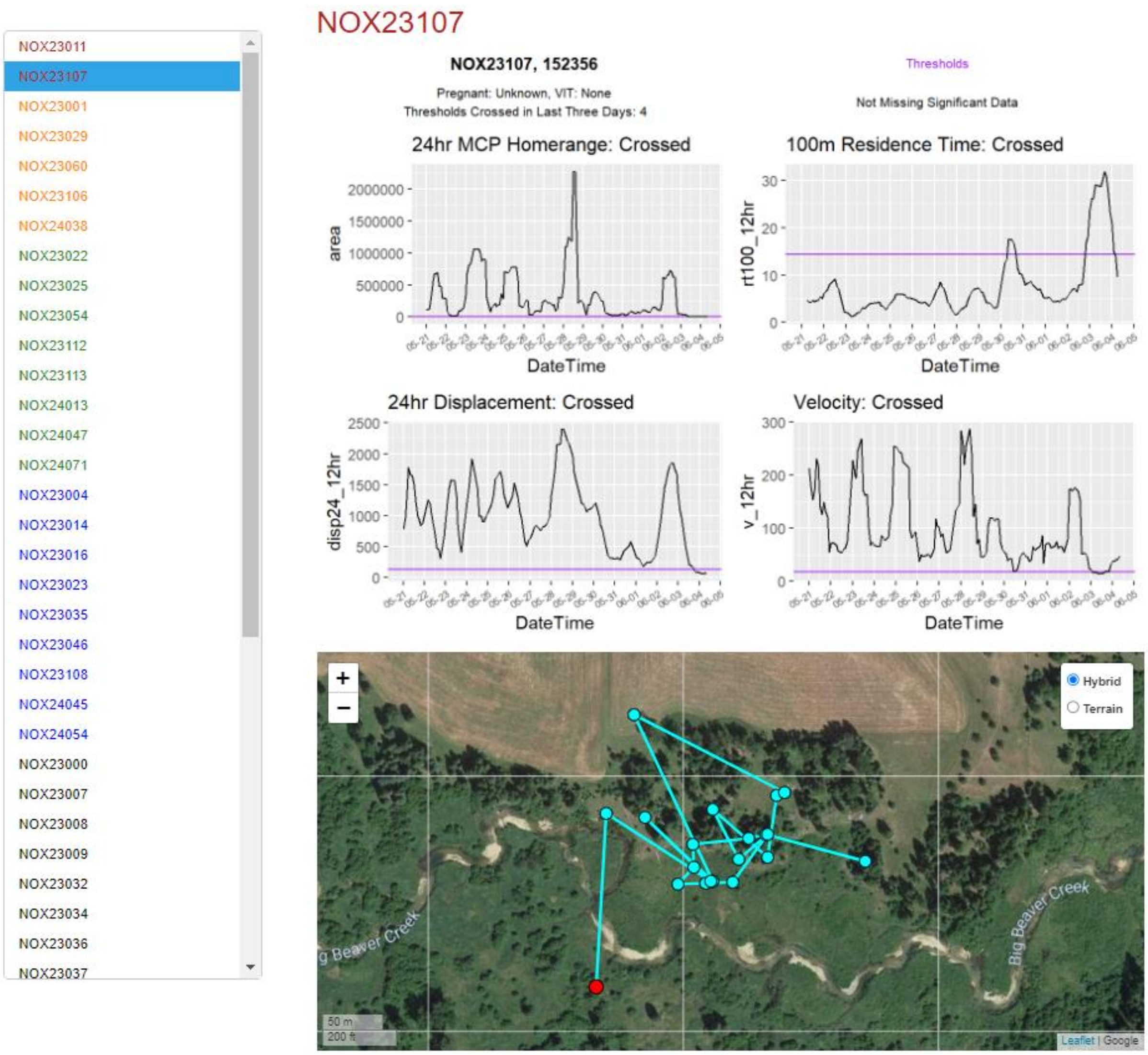


Figure 18. Example output from code developed to identify potential elk parturition events, based on adult female movement metrics in hunting district 121.

Within 12 hours of being alerted of a VIT expulsion (Turnley et al. 2022) or a female elk crossing multiple movement metric thresholds, a team of 2-4 people investigated the area around the expulsion/GPS cluster, using telemetry to locate both the VIT/parturition site and the collared female. Finally, we used a helicopter during peak calving in both 2023 and 2024 to help locate "opportunistic" neonates and to assist ground crews in locating well-hidden neonates.

When located, the neonate was caught by hand, blindfolded, and physically restrained with hobbles. We recorded the neonate's sex, body mass, and estimated age. We outfitted all neonates with expandable GPS collars that collected GPS location data for up to one year or until the collar breaks off (model VERTEX Mini Fawn-1C GLOBALSTAR; VECTRONIC Aerospace Inc.; Figure 19). Due to issues with elastic on collars breaking in 2023, causing the collar to fall off prematurely, collars in 2024 were equipped with an abrasion-resistant sheath wrapped around the elastic band. All GPS collars had a mortality sensor that sent a mortality signal if the GPS collar remained motionless for ≥ 6 hours.

Figure 19. Capture and collaring of elk neonates in hunting district 121 in May - June 2023/24.

We searched mortality sites and conducted field necropsies to determine cause of death, including predation, natural mortality (i.e., disease, injury), or hunter harvest. We documented all evidence of predation including claw marks, canine punctures, broken vertebrae, or internal hemorrhaging on the calf carcass (Wade and Bowns 1993, Mattson 1997). We also documented predator sign at and around the kill site including tracks, scat, or hair (Smith et al. 2006, Eacker et al. 2016). We identified black bear predation by evidence of broken vertebrae and puncture wounds found on or near the dorsal inferior portion of the neck and withers, or a carcass with the hide peeled back and most the carcass consumed (including the rumen and intestine). We identified mountain lion or felid predation by evidence of puncture wounds or claw marks on or near the head or neck; a cached carcass; plucked hair around areas of consumption; and/or a completely consumed carcass, except the rumen, starting from the hind to front quarters. We identified canid predation by evidence of lacerations and tearing to the ventral superior portions of the neck, or evidence of multiple feeding sites, depending on the number of animals present. For all predation events, we examined subcutaneous hemorrhaging patterns around wounds, including puncture wounds and claw marks, to determine predation (pre-mortem hemorrhaging) versus scavenging (post-mortem seepage). For any unknown predation events, where the carnivore species could not be identified with certainty, we swabbed bite mark locations to collect DNA samples from saliva for carnivore species identification.

3.2.3 Mountain Lion Capture and Monitoring

During winter 2022-23 and 23-24, we used trained hounds to track, tree, and chemically immobilize mountain lions following approved University of Montana animal capture protocols (002-23JMWB-010423). We fit adult mountain lions with Iridium remote upload GPS radio-collars (Lotek Wireless, model LiteTrack Iridium 420, Newmarket, Ontario, Canada) programmed to record a location every 4 hours and transmit a mortality notification 6 hours post-mortality (Figure 20).

Figure 20. Mountain lion capture and collaring in hunting district 121 in winters 2022-23 and 2023-24.

3.2.4 Wolf Capture and Monitoring

During summer and fall 2022, 2023, and 2024, FWPs wolf management staff conducted wolf trapping operations. We conducted aerial helicopter searches for fresh wolf sign or activity during two days in February.

3.2.5 Black Bear Capture and Monitoring

During spring and summer 2023 and 2024, we used culvert traps and chemical immobilization to capture and collar black bears following approved University of Montana animal capture protocols (004-23JMWB-012323). We fit captured bears with Iridium remote upload GPS radio-collars (Lotek Wireless, New Market, Ontario, Canada) programmed to record a location every 4 hours and transmit a mortality notification 6 hours post-mortality (Figure 21).

Figure 21. Capture and collaring of black bears with culvert traps in hunting district 121 in summer 2023.

3.2.6 Trail Camera Deployment

In May and June 2023, we deployed remote trail cameras (HyperFire 2 Professional Covert IR Camera OD Green) at random locations across HD 121. We selected 100 random locations using generalized random tessellation stratified (GRTS) sampling (Stevens and Olsen 2004), then paired a "predator camera" with 50 of these cameras, selected at random. We placed predator cameras on a dirt bottom trail within 250 meters of the paired random camera to increase the likelihood of detecting predators.

We mounted cameras to trees or t-posts approximately 1.5 meters off the ground at optimal angles for elk and target predator species (Figure 22). We placed predator cameras at a downward angle perpendicular to the trail to capture movement as animals entered or exited the viewshed. We set each camera on both "time lapse" and "motion capture" trigger settings to capture images every 10 minutes and when motion triggered the camera.

In September/October 2023 and May/June 2024, we returned to the camera sites and switched camera batteries and SD cards. We ran photos from summer 2023 through an AI photo classifier that uses Microsoft's MegaDetector model in Python to identify empty photos and photos with animals present (Beery et al. 2019, Fennell et al. 2022). We classified animal photos to species and counted the number of individuals of each species in each photo.

Figure 22. Trail camera deployment in hunting district 121.

3.2.7 *Landcover Layer Development, Fecal Pellet Collection, and Vegetation Surveys*

Landcover Layer Development

Before completing vegetation surveys across HD 121, we developed a landcover layer that included vegetation type, timber harvest strategy, and time-since-harvest so that vegetation sampling sites could be appropriately stratified by landcover classification. We obtained landcover type data from LANDFIRE's 30-meter resolution 2020 Existing Vegetation Type raster dataset (USGS 2022a) and reclassified them into 8 generalized landcover types: mesic forest, xeric forest, deciduous forest, shrubland, grassland, agriculture, wetland, and other. Mesic forests included coniferous forests associated with spruce and fir species. Xeric forests included coniferous forests associated with ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*) and limber pine (*Pinus flexilis*). Douglas fir-dominated forests were classified as either mesic or xeric depending on the secondary tree species associated with the vegetation type. Deciduous forests included forests associated with aspen (*Populus tremuloides*), cottonwood (*Populus* sp.), and western larch (*Larix occidentalis*). Shrublands and grasslands included any shrub- or grass-dominated vegetation type, respectively. Agriculture included cultivated crops and irrigated agriculture. Wetlands included any wet meadows, marshes, herbaceous riparian areas, or wetlands. "Other" included the remaining cover types such as human development, sparse vegetation, snow or ice, and open water.

We obtained timber harvest strategy and time-since-harvest spatial data from the USFS and the Montana Department of Natural Resources. We defined timber harvest strategy as the various combinations of treatment types, defined by the Forest Activity Tracking System and Powell (1993), and post-treatment activities utilized by managers when harvesting timber designed to result in a certain stand-age class. We categorized timber harvest polygons into one of four timber harvest strategies: even-age, two-age, uneven, and intermediate, as defined in the USFS Forest Service Manual (USFS FSM 2400 Chapter 2470). Even-age cuts are designed to maintain and regenerate a stand with one age class and <10% leave trees (e.g., clearcutting). Two-age cuts are designed to maintain and regenerate a stand with two age classes (e.g., any method retaining reserve trees). Uneven cuts are designed to maintain and regenerate a stand with 3 or more age classes (e.g., single and group tree selection regeneration). Intermediate cuts are defined as any treatment designed to enhance growth, quality, vigor, and composition of the stand after establishment or regeneration (e.g., commercial thinning, salvage and release cuts). There were very few two-age or uneven cuts in the study area, so we only sampled from even-age and intermediate cuts.

Our final stratified landcover layer included 25 unique strata in combinations of landcover type, harvest strategy, and years-since-harvest (Figure 23). However, we decided to not include deciduous forest, other, or wetland landcover types in sampling strata due to the low occurrence of these landcover types in the study area. We used the GRTS sampling method (Stevens and Olsen 2004) to generate 375 random sites that were spatially-distributed within landcover strata and across the study area (Figure 23), with the intention to visit each location once from May-August 2023 and visit another unique set of 375 random locations from May-August 2024.

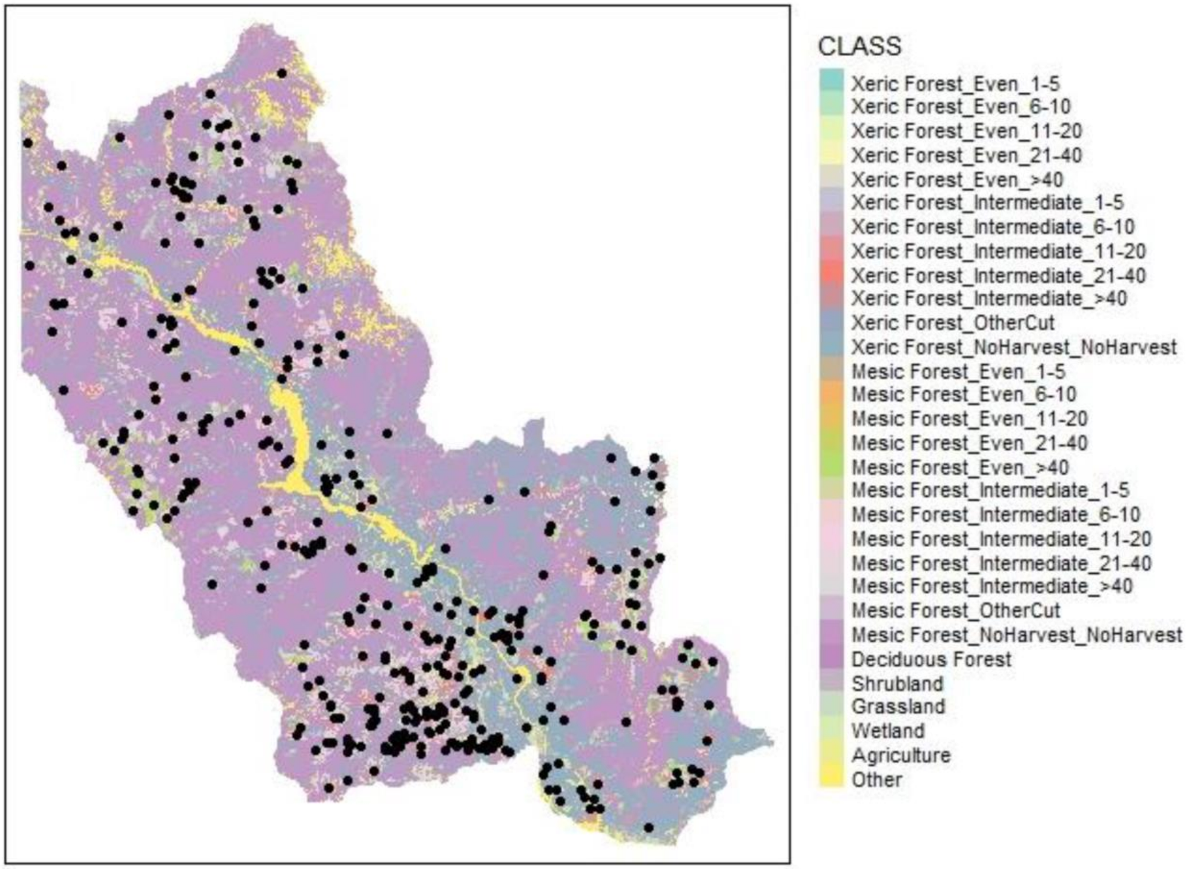


Figure 23. Reclassified landcover strata in hunting district 121 incorporating generalized landcover category, timber harvest strategy, and time-since-harvest. Black dots represent potential vegetation sites randomly selected by strata. The Xeric Forest_OtherCut, Mesic Forest_OtherCut, Deciduous Forest, Wetland, and Other strata were not included in the sampling stratification because of their low prevalence and/or inability to be sampled.

Fecal Pellet Collection

We collected composite elk fecal pellets to evaluate elk diet in the study area and identify the plant species that are important sources of forage for elk in this system. We used GPS locations obtained from collared elk to identify suspected elk bedding sites that were <3 days old. At these sites, we collected 2 pellets <1 week old from each of 2 distinct pellet piles within a 300 m^2 radius of the site. We collected pellets from 3-5 spatially distributed sites each week of the field season to create weekly composite samples.

We also collected fecal samples during the winter capture season in 2022-23. We combined 1 pellet from 6-8 individuals into a composite sample and assembled 3 composite samples per capture location classified into lower elevation valley and higher mountainous forest environments. Lower valley locations included animals primarily captured by clover traps, and higher forest locations included animals captured by helicopter. No individuals were repeat sampled.

We homogenized and froze composite samples from both seasons in a liquid salt-based RNA stabilizer. Then, we sent all samples to the Species From Feces – Bat Ecology and Genetics Lab at Northern Arizona University, where they used DNA metabarcoding to determine the plant species composition within the pellets.

Using these data, we calculated the percentage of composite samples which contained each forage species/item within each sample timing classification and, for winter only, within capture location classifications (i.e., lower valley and higher forest).

Vegetation Surveys

We measured forage quantity and quality at each vegetation sampling site to characterize the summer nutritional landscape for elk across hunting district 121 and to identify how timber harvest affects the nutritional landscape. We established a 40m transect with 1 m^2 quadrats along the transect at 10m intervals, for a total of five quadrats at each site. At each quadrat, we recorded species composition and visually estimated percent cover of each species. We also recorded phenological stage of each species (emergent, flowering, fruiting, and cured/mature) to be used for forage quality calculations. At the 0m, 20m, and 40m quadrats, we established a 0.25 m^2 clip plot in the bottom right corner of the quadrat (Figure 24). We clipped all herbaceous vegetation >2cm above ground within the clip plot and sorted it by growth habit (i.e., shrub, grass, forb). Within 24 hours of sampling, we dried clipped samples for 24-48 hours at 40-60 °C, then weighed the samples. The estimated cover percentages of each species will be applied to the clipped sample dry weight to estimate the biomass of each plant species in the clipped plot (g/0.25 m^2), which will then be applied to estimate understory biomass at the greater sampling site (kg/ha; forage quantity).

Figure 24. Vegetation sampling in hunting district 121.

We collected at least 3 samples (at least 20 g dry, total) of each elk forage species in each phonologic stage throughout the study area. Elk forage species were determined via DNA metabarcoding of elk fecal pellets collected in 2023 (see above). We included multiple plants from within a 300 m^2 radius in each forage sample to reduce individual plant bias. We did not collect any samples from within 15 m of an active road to reduce effects of road dust and chemicals. We placed samples in drying ovens at 40-60 °C within 6 hours of collection and dried them for 48-72 hours. We are sending samples to the Forage Laboratory at DairyOne (Ithaca, NY), where they will use sequential detergent fiber assays (Goering and VanSoest 1970) to estimate the digestibility of the individual plant cell constituents for each forage item. We will then use equations developed by Robbins et al (1987) to relate these values to actual or in vivo (i.e., in the animal) digestibility.

We also collected select samples of forage items for tannin analysis to use in estimation of species and stage specific digestible energy. We collected 2 tannin samples (1 emergent phenostage, 1 cured/mature phenostage) for any forage forbs known to contain tannins and all forage shrub species. We included multiple plants from within a 300 m^2 radius in each tannin sample to reduce individual plant bias. We did not collect any samples from within 15 m of an active road to reduce effects of road dust and chemicals. We placed samples on ice immediately in the field and moved them to a freezer within 6 hours for storage. We are sending samples to the Wildlife Habitat and Nutrition Lab at Washington State University (Pullman, WA), where they will use the bovine serum albumin (BSA) method (Hagerman and Butler 1978) to measure tannin concentrations of each forage item.

Ultimately, these data will be combined with the estimated cover percentages of each species in each phenological stage at a sample plot to estimate forage biomass and digestible energy (kcal/g) at each sampling point. Forage biomass and digestible energy data will then be included in zero-inflated regression models predicting forage quantity and forage quality across the landscape during early (May-June) and late summer (July-August), based on covariates such as landcover strata, elevation, aspect, precipitation, canopy cover, and burn status. We will then evaluate the distribution of elk during early and late summer periods once these nutritional landscape maps have been completed.

3.3 Results as of July 1, 2024

3.3.1 Adult Elk Capture and Monitoring

In winter 2022-23, we captured and collared 71 adult elk (54 adult females, 6 female calves, 7 adult males, 4 male calves; Figure 25). We captured 37 of these elk in Clover traps over 314 trap-days (number of Clover traps * number of days active) and captured the remaining 34 elk in 2 days of helicopter captures. We took blood samples from 48 adult female elk, 42 of which were found to be pregnant, resulting in an estimated pregnancy rate of 87.5% (95% confidence interval [CI] = 77.1% - 95.8%), which is similar to the state-wide average (87%). Cementum aging results suggested female elk >1 year old ranged from 1.5 – 20.5 years old, with a median age of 7.5 years old (Figure 26).

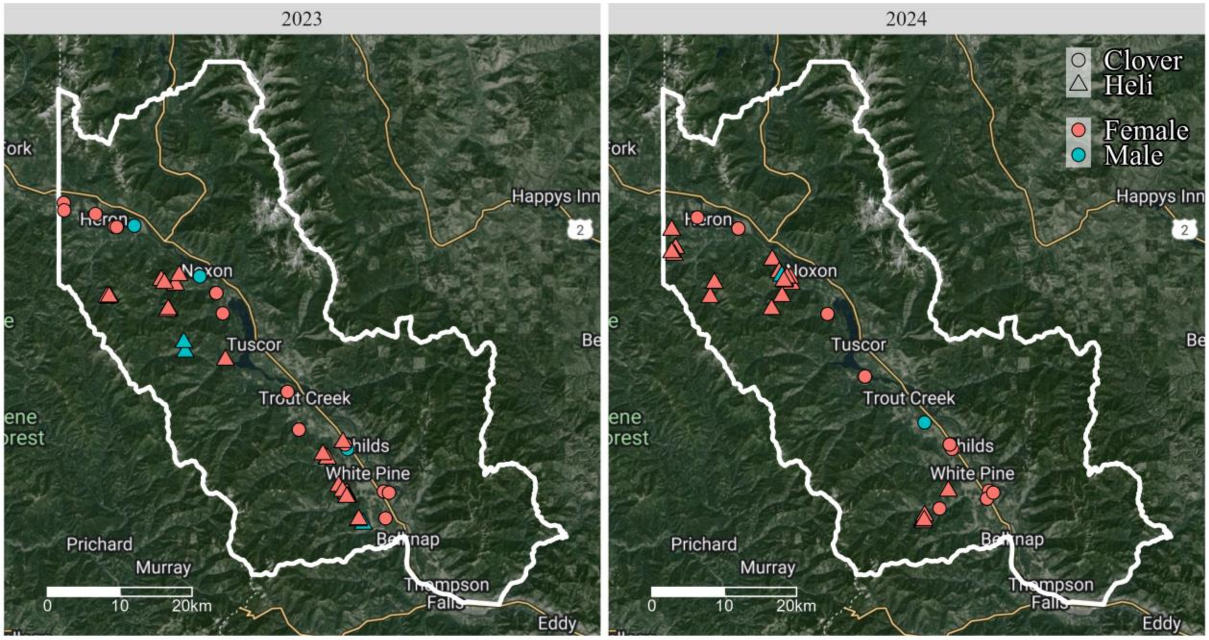


Figure 25. Locations of female (red) and male (blue) elk captures in hunting district 121 (white outline) in winter 2022-23 and 2023-24. Elk were captured via Clover trap (circles) and helicopter (triangles) methods. Some captures occurred close together, so locations are difficult to differentiate on the map.

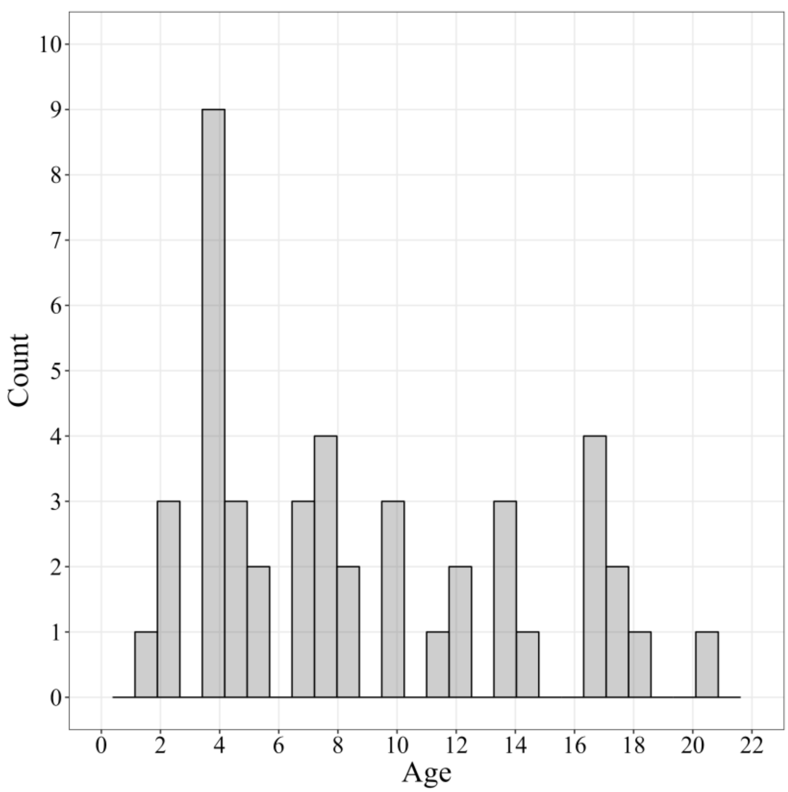


Figure 26. Histogram of ages of female elk >1 year old captured and collared in hunting district 121 in winter 2022-23.

In winter 2023-24, we captured and collared 50 additional elk (40 adult females, 6 female calves, and 4 male calves) and recaptured 5 adult females (Figure 25). We captured 32 of these elk in Clover traps over 346 trap-days and captured the remaining 23 elk in 3 days of helicopter captures. We took blood samples from 41 adult female elk, 35 of which were found to be pregnant, resulting in an estimated pregnancy rate of 85.4% (95% CI = 73.2% - 95.1%). We have not yet received cementum aging results for winter 2023-24 captures.

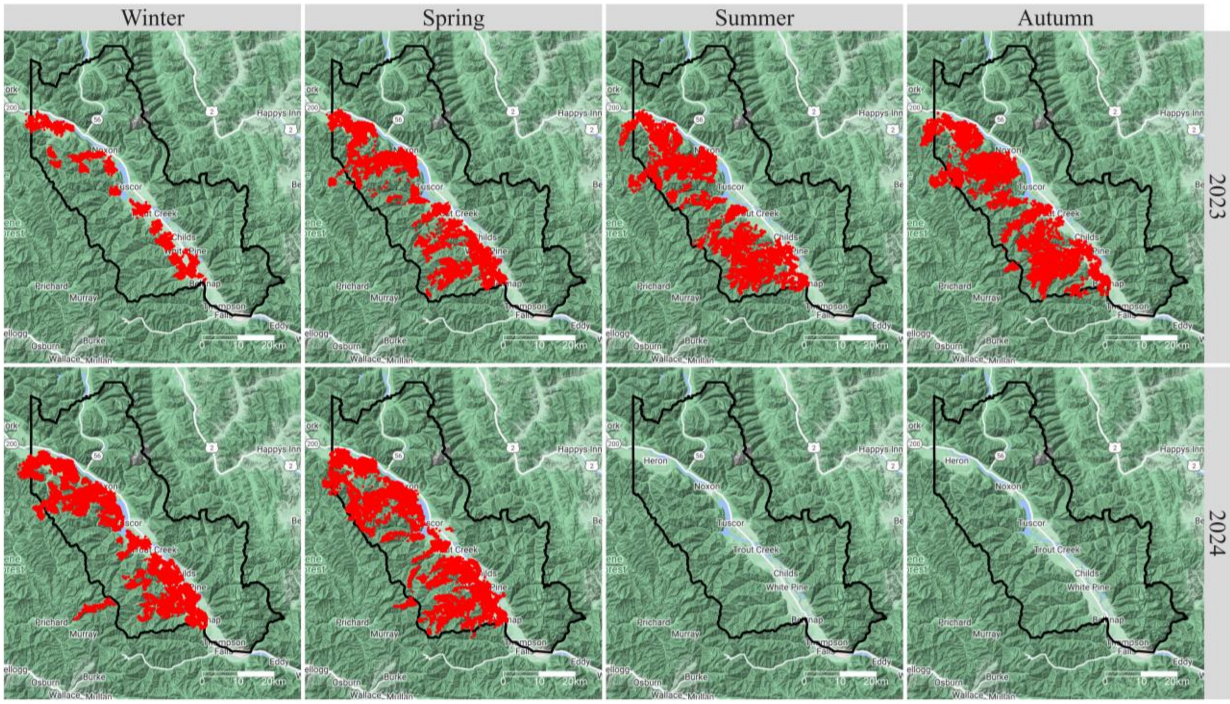
The serology screening in 2023 showed that elk in the area had exposure to multiple diseases known to effect wildlife and/or livestock populations. Evidence for exposure varied by pathogen (Table 5). We found no serological evidence of exposure to brucellosis, BRSV, BVD1, or BVD2. We did find evidence of exposure to Anaplasma (64.6% seroprevalence), PI3 (62.5% seroprevalence), BHV-1 (8.3% seroprevalence), EHD (2.1% seroprevalence), and Leptospira (6.2% seroprevalence). A brief description of each pathogen and its influence (if known) on individual or herd health can be found in Appendix B.

Table 5. Seroprevalence of brucellosis (Brucella abortus), anaplasmosis (Ana), parainfluenza-3 (PI3), bovine respiratory syncytial virus (BRSV), bovine viral diarrhea type 1 (BVD1), bovine viral diarrhea type 2 (BVD2), bovine herpesvirus-1 (BHV1), epizootic hemorrhagic disease (EHD), and Leptospira (Lepto) based on serological screening of adult female elk during the winter of 2023.

	Brucella	Ana	PI3	BRSV	BVD1	BVD2	BHV1	EHD	Lepto
#Sampled	48	48	48	48	48	48	48	48	48
#Exposed	0	31	30	0	0	4	1	1	3
%Exposed	0	64.6	62.5	0	0	8.3	2.1	2.1	6.2

As of July 1, 2024, after removing locations with dilution of precision >10, suggesting poor accuracy (D'Eon and Delparte 2005), we have collected a total of 144,477 locations from 106 female elk and 14,100 locations from 15 male elk in winter (December 1 – March 31); 172,707 locations from 102 female elk and 17,235 locations from 14 male elk in spring (April 1 – June 30); 40,988 locations from 58 female elk and 6,569 locations from 10 male elk in summer (July 1 – August 31); and 60,140 locations from 58 female elk and 6,876 locations from 9 male elk in autumn (September 1 – November 30; Figure 27).

A



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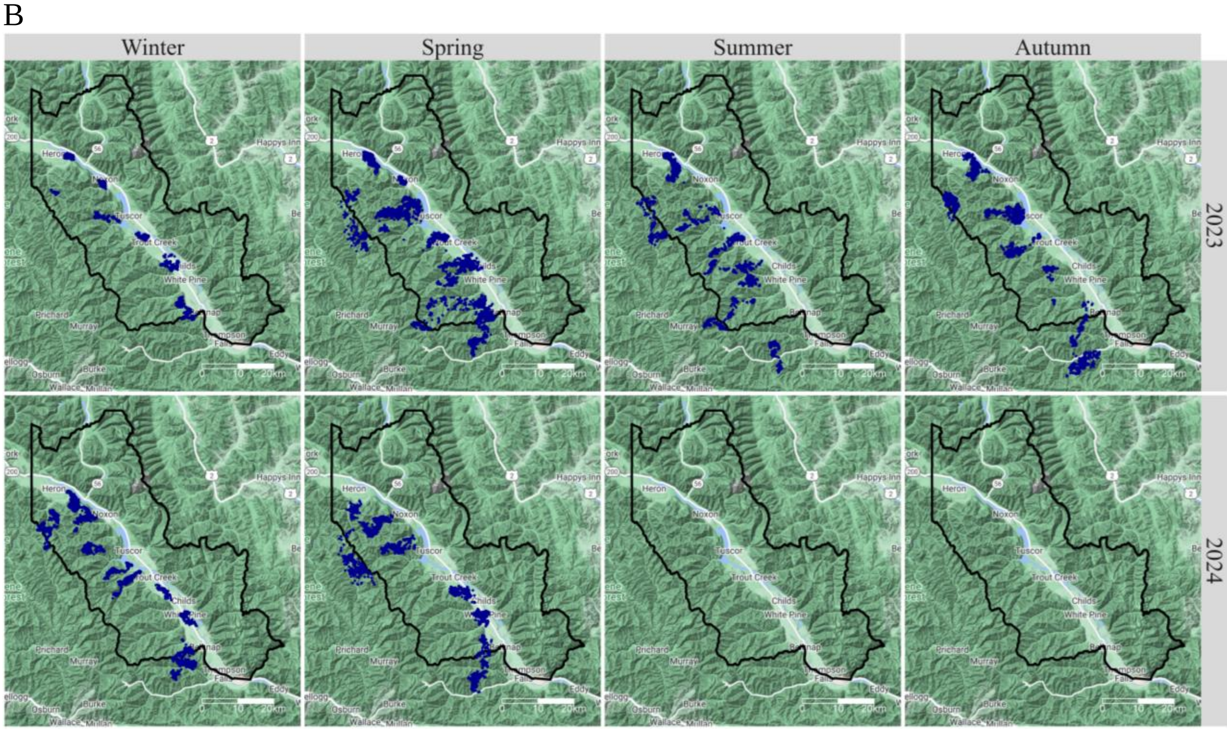

Figure 27. Winter (December 1 – March 31), spring (April 1 – June 30), summer (July 1 – August 31), and autumn (September 1 – November 30) locations of female (panel A; red dots) and male elk (panel B; blue dots) as of July 1, 2024 in and around hunting district 121 (black outline).

As of July 1, 2024, 13 collared elk > 1 year old have died; 3 due to natural or unknown causes (2 adult female, 1 yearling female), 4 due to predation by either mountain lions (2 adult females) or wolves (1 adult female, 1 yearling male), and 6 due to hunter harvest (3 adult females, 3 adult males). Two additional mortalities (2 adult females) occurred during Clover trapping due to capture myopathy, but these individuals were never included in the sample. Three collars (1 male and 2 females) have malfunctioned after deployment (stopped collecting and transmitting locations).

Kaplan-Meier natural annual survival estimates (excluding harvest) from June 1, 2023 – May 30, 2024 were 0.946 (95% CI = 0.888 – 1) for females and 0.9 (95% CI = 0.732 – 1) for males. Total annual survival estimates (including harvest) were 0.897 (95% CI = 0.822 – 0.978) for females and 0.6 (95% CI = 0.362 – 0.995) for males.

3.3.2 Neonate and Calf Elk Capture and Monitoring

We captured and collared 25 elk neonates (16 males and 9 females) in May and June 2023 and 66 neonates (27 females, 39 males) in 2024 (Figure 28). Many neonates collared were associated with collared females (*n* = 64); however, we also collared 27 opportunistic neonates not associated with a collared female. In 2023, neonate weights averaged 17.1 kg (SD = 2.7) for females and 18.4 kg (SD = 4.5) for males, and average age at capture was ~1.7 days (range = 0 – 4 days). In 2024, neonate weights averaged 19.0 kg (SD = 2.9) for females and 20.0 kg (SD = 4.05) for males, and average age at capture was ~2.3 days (range = 0 – 5 days).

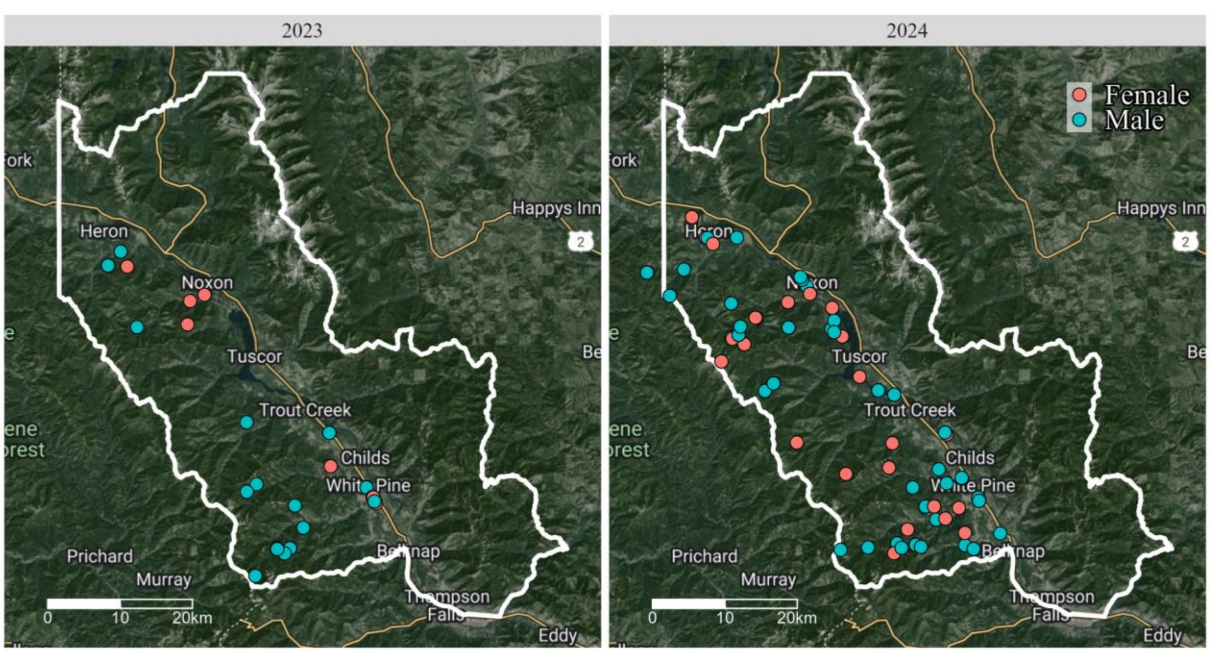

Figure 28. Locations of female (red) and male (blue) elk neonate captures in hunting district 121 (white outline) in May and June 2023 and 2024.

In 2023, 8 collared calves (<1 year old) died (3 mountain lion predation, 1 black bear predation, 3 natural mortality, and 1 unknown cause), 1 died due to capture myopathy, 14 collars fell off prematurely (before December 1, 2023), 1 collar malfunctioned, and 11 survived until scheduled collar drop-off. Annual Kaplan Meier survival estimates for neonates captured in 2023 was 0.768 (95% CI = 0.583 – 1).

We are currently monitoring the survival of the calves collared in 2024.

3.3.3 Mountain Lion Capture and Monitoring

We captured and collared 3 adult female mountain lions in January and February, 2023, and captured 6 additional mountain lions (4 females, 2 males) in 2024. As of July 1, 2024, we collected a total of 4,470 locations from these individuals in winter, 5,585 locations in spring, 1,024 locations in summer, and 1,490 locations in autumn (Figure 29). One collared adult female mountain lion died due to natural causes in January 2024 and all others are alive, with no collar malfunctions.

3.3.4 Wolf Capture and Monitoring

In summer 2022, one subadult male wolf was captured by FWP management staff. This individual emigrated from the study area in December 2022. In summer 2024, one adult female wolf was captured by FWP management staff.

3.3.5 Black Bear Capture and Monitoring

In 2023, we captured and collared 1 female and 4 male black bears. We also captured 2 subadult males, but did not fit these individuals with collars. USFWS captured and collared 2 male bears so far in 2024. As of July 1, 2024, we have collected 506 bear locations in winter, 2,180 locations in spring, 929 locations in summer, and 1,079 locations in autumn (Figure 30). One adult male black bear dropped its collar during 2023-24 winter hibernation and was then harvested in May 2024, and one adult male died of unknown causes in August 2024. All other collared bears are alive with functional collars.

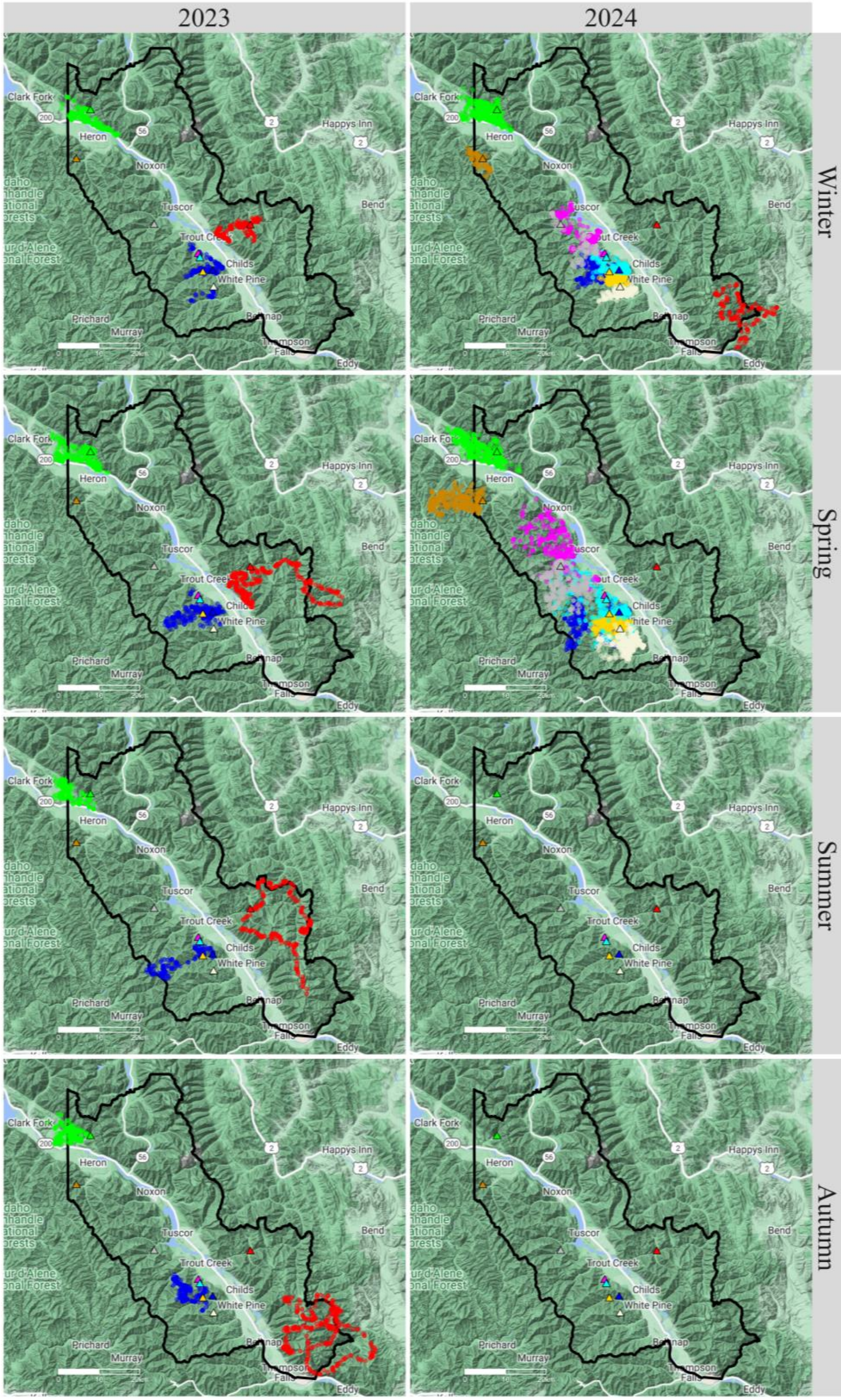

Figure 29. Winter (December 1 – March 31), spring (April 1 – June 30), summer (July 1 – August 31), and autumn (September 1 – November 30) locations of 9 mountain lions captured in hunting district 121 (black outline) as of July 1, 2024. Each color represents a different mountain lion and black outlined triangles represent the capture location for each individual.

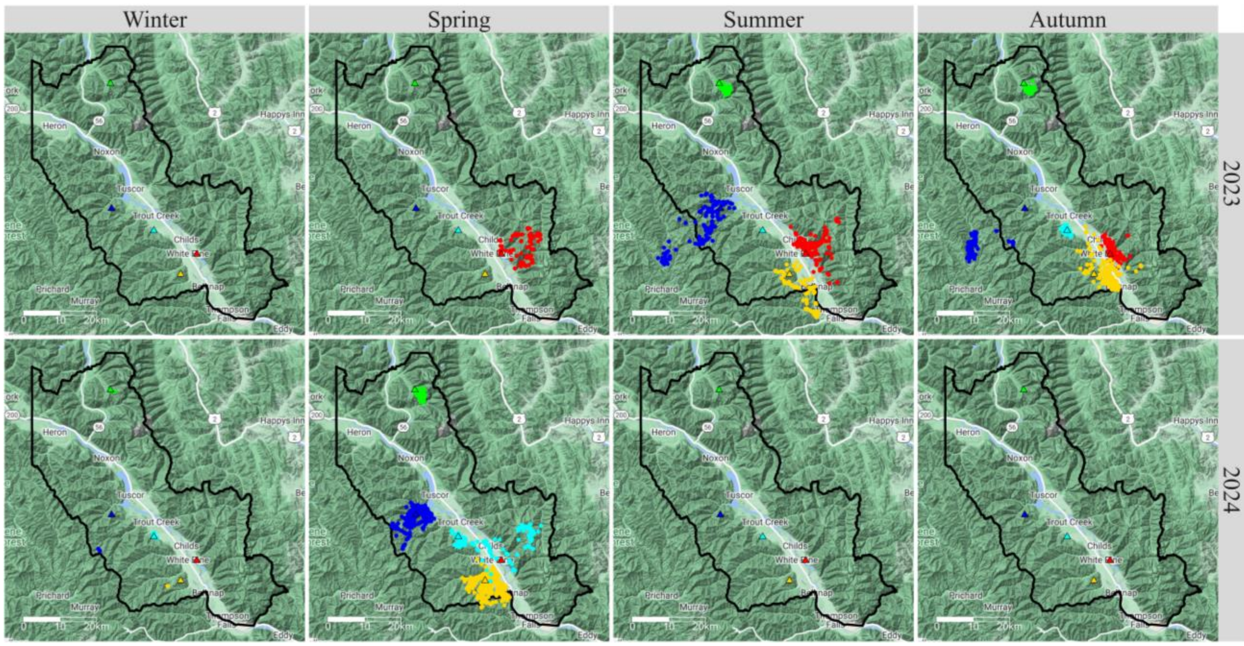

Figure 30. Winter (December 1 – March 31), spring (April 1 – June 30), summer (July 1 – August 31), and autumn (September 1 – November 30) locations of the 5 black bears captured in hunting district 121 (black outline) as of July 1, 2024. Each color represents a different black bear and black outlined triangles represent the capture location for each individual.

3.3.6 Trail Camera Placement and Photo Classification

In May and June 2023, we deployed 80 random cameras and 39 predator cameras paired with the random cameras across HD 121 (Figure 31). We serviced all 119 cameras in September and October 2023; all cameras except for 2 were functioning as expected (1 camera was missing an SD card and 1 camera only took motion-triggered photos). Cameras set in summer 2023 collected 10,083 elk photos (95 timelapse captures), 2,894 black bear photos (24 timelapse captures), 26 mountain lion photos (0 timelapse captures), and 14 wolf photos (0 timelapse captures; Figure 32). Elk were detected on 65 of the total 118 functional cameras (55%), black bears were detected on 69/118 cameras (59%), mountain lions were detected on 4/118 cameras (3%), and wolves were only detected on 1/118 cameras (<1%; Figure 33). Other species detected included mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), grizzly bear, coyote (*Canis latrans*), red fox (*Vulpes vulpes*), bobcat (*Lynx rufus*), American badger (*Taxidea taxus*), northern raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), short/long-tailed weasels (*Mustela erminea/Neogale frenata*), pine marten (*Martes americana*), lagomorphs (rabbits/hares), sciurids (squirrels), mice, and chipmunks.

We serviced all 119 cameras a second time in May and June, 2024. All cameras were functional for at least part of the fall-winter time period (i.e., most were active until late March, when camera batteries died) and the image classification process is currently in progress. We are currently using photo data from summer 2023 to estimate abundance of elk, mountain lions, black bears, and wolves in HD 121 using "space to event" methods (Moeller et al. 2018).

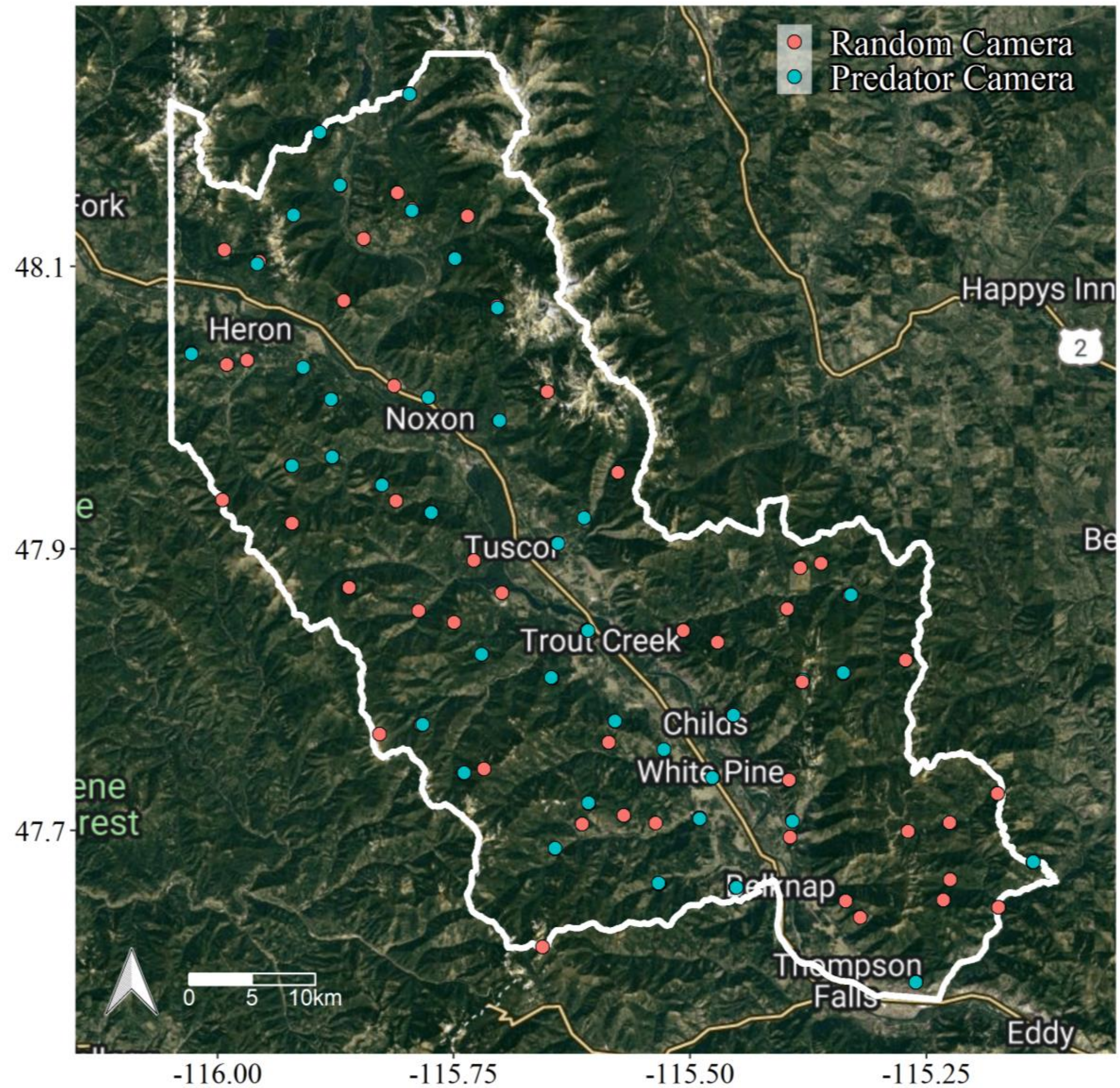

Figure 31. Location of random (red) and predator trail cameras (blue) in hunting district 121. Each predator camera was paired with a random camera within 250 m, so these locations are largely overlapping in the map.

Figure 32. Example photos from trail cameras set in hunting district 121 in 2023-24.

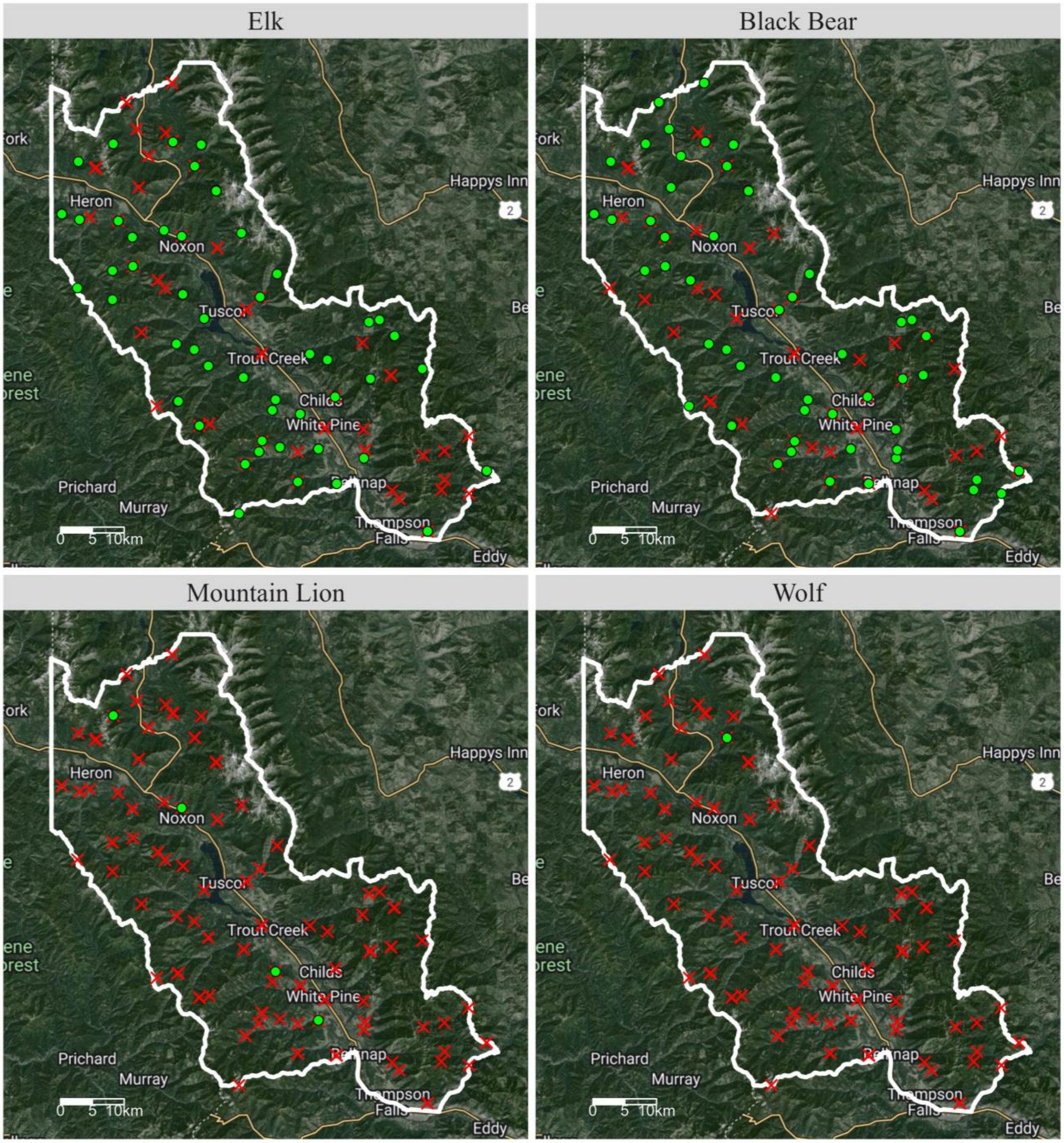

Figure 33. Locations of detections of elk, black bear, mountain lion, and wolf on trail cameras located across hunting district 121 (white outline) in summer 2023. Green dots represent detections of the species, while red exes represent no detection. Note, predator cameras were placed within 250 m of random cameras, so some points appear to overlap.

3.3.7 Vegetation/Fecal Surveys

We measured vegetation and collected biomass samples at 222 sites from May-August, 2023 and 101 sites from May – June, 2024 (ranging from 2 – 14 sites per landcover strata; Figure 34). Preliminary data from 2023 suggest biomass of forbs, grass, and shrubs was highest in forests that were harvested 1-5 years ago, with decreasing biomass as the age of the harvest increased, on average. Canopy cover was also generally highest in older timber harvests or forests without a history of harvest (Figure 35).

As of July 1, 2024, we have collected 112 forage samples of 38 taxon (65 emergent, 41 flowering, and 6 fruiting phenostage) and collected tannin samples from 25 forage species, each in the emergent phenostage. We collected fecal pellet samples at 45 sites in 2023 (ranging from 2 – 5 samples per week), resulting in 14 weekly composite samples (7 in early summer [May and June], 7 in late summer [July and August]). We collected 6 composite fecal pellet samples (3 in lower valley, 3 in higher forest) in winter 2022-23 and have collected 10 fecal pellet samples, resulting in 3 weekly composite samples so far in 2024 (May – June).

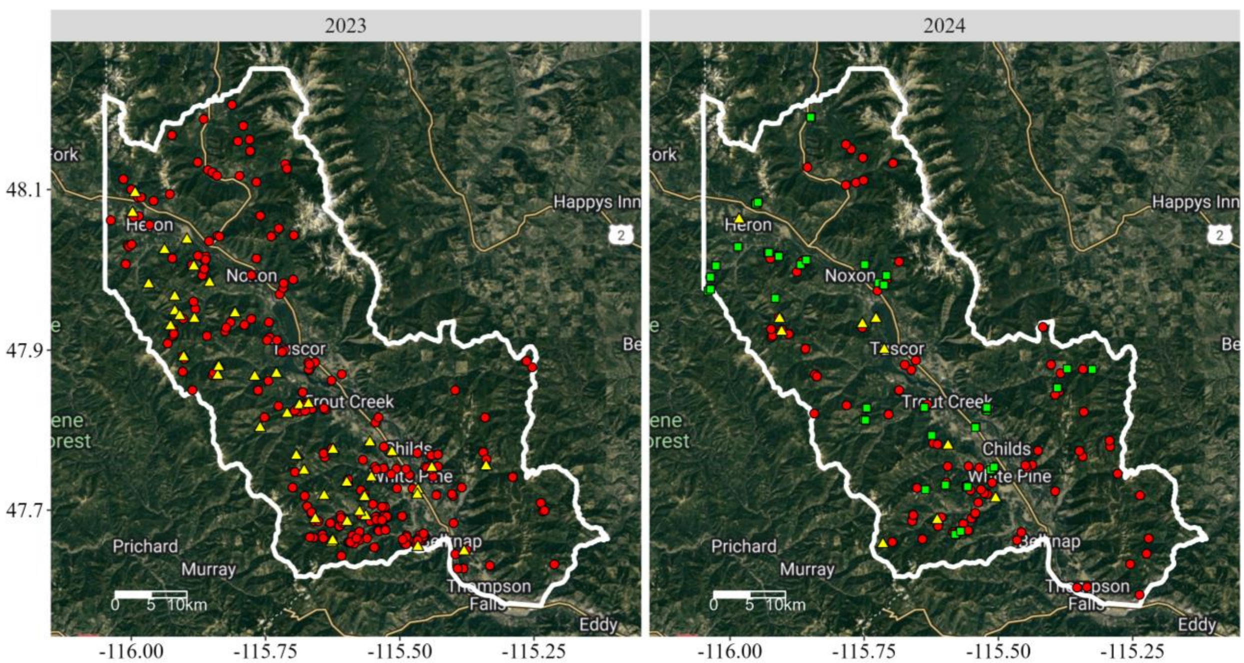

Figure 34. Locations of vegetation plots (red circles), forage samples (green squares), and fecal pellet samples (yellow triangles) collected within hunting district 121 (white outline) during spring and summer through July 1, 2024. No forage samples were collected in 2023 because study area-specific elk diets had not yet been identified.

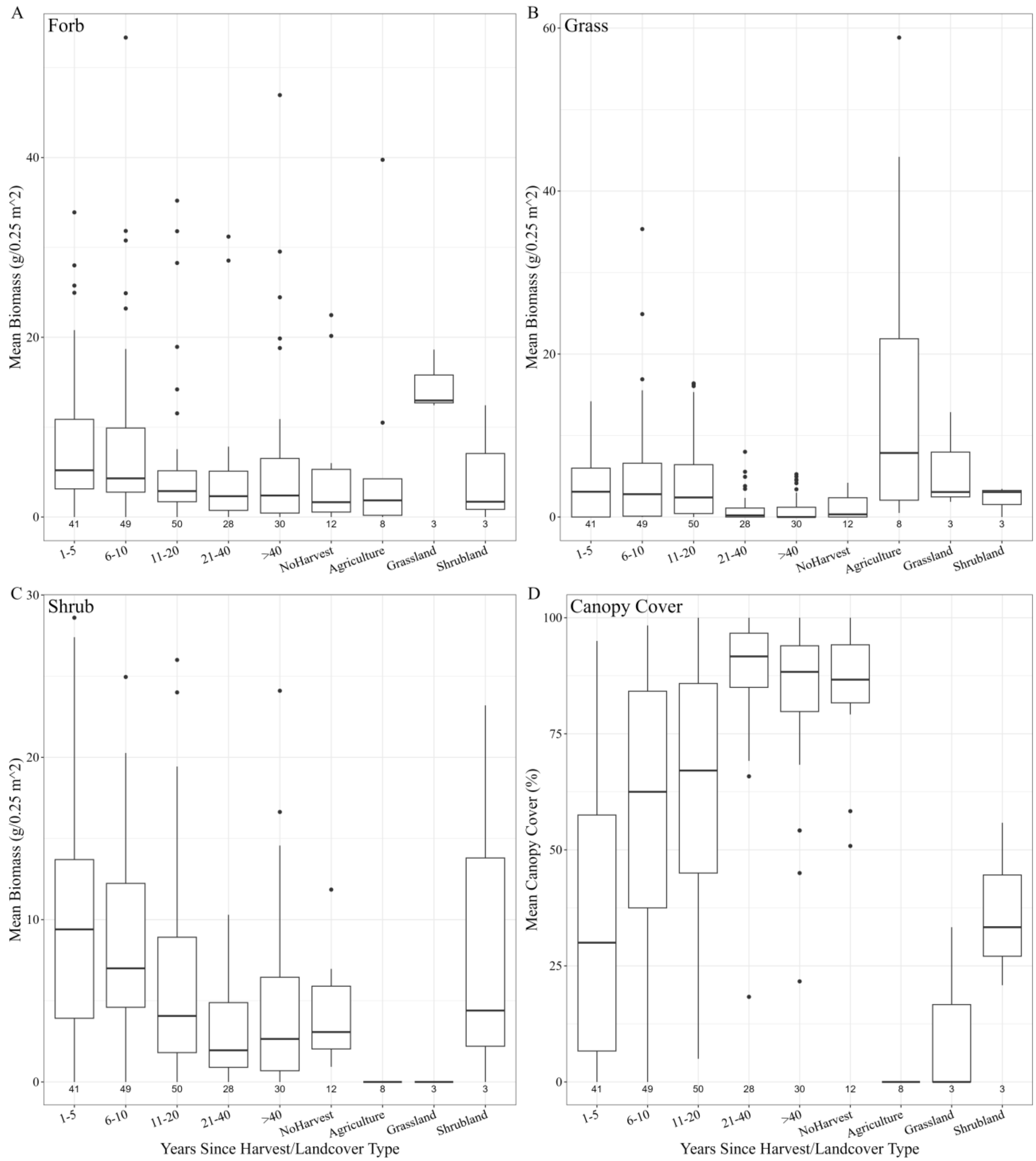

*Figure 35. Boxplots of mean biomass (g/0.25 m^2) of forbs (panel A), grass (panel B), and shrubs (panel C), and mean canopy cover (%; panel D) within sample plots measured during 2023 across timber harvest histories in hunting district 121. Boxplots show the median (middle horizontal line within the box), 25% and 75% quantiles (bottom and top of the box), minimum/maximum values (or 1.5 * the inter-quartile range; whiskers), and outliers (>1.5 * the inter-quartile range; black dots). Numbers at the base of boxplots are sample sizes (number of sampled plots). Non-forested landcover types (agriculture, grassland, and shrubland) are included for comparison.*

In total, there were 53, 103, and 96 forage items detected in winter 2022-23, early summer 2023, and late summer 2023 diets, respectively (Table 6). There were fewer forage species/items detected in winter, with higher proportion of trees and lower proportions of forbs in the diet, compared to early or late summer (Figure 36). Early and late summer diets were similar, but there were more grasses and fewer forbs in the early summer diet, compared to late summer. Further, low valley winter diets were composed of more forage species/items, with higher proportions of trees and forbs, but lower proportions of shrubs, compared to high forests (Figure 36).

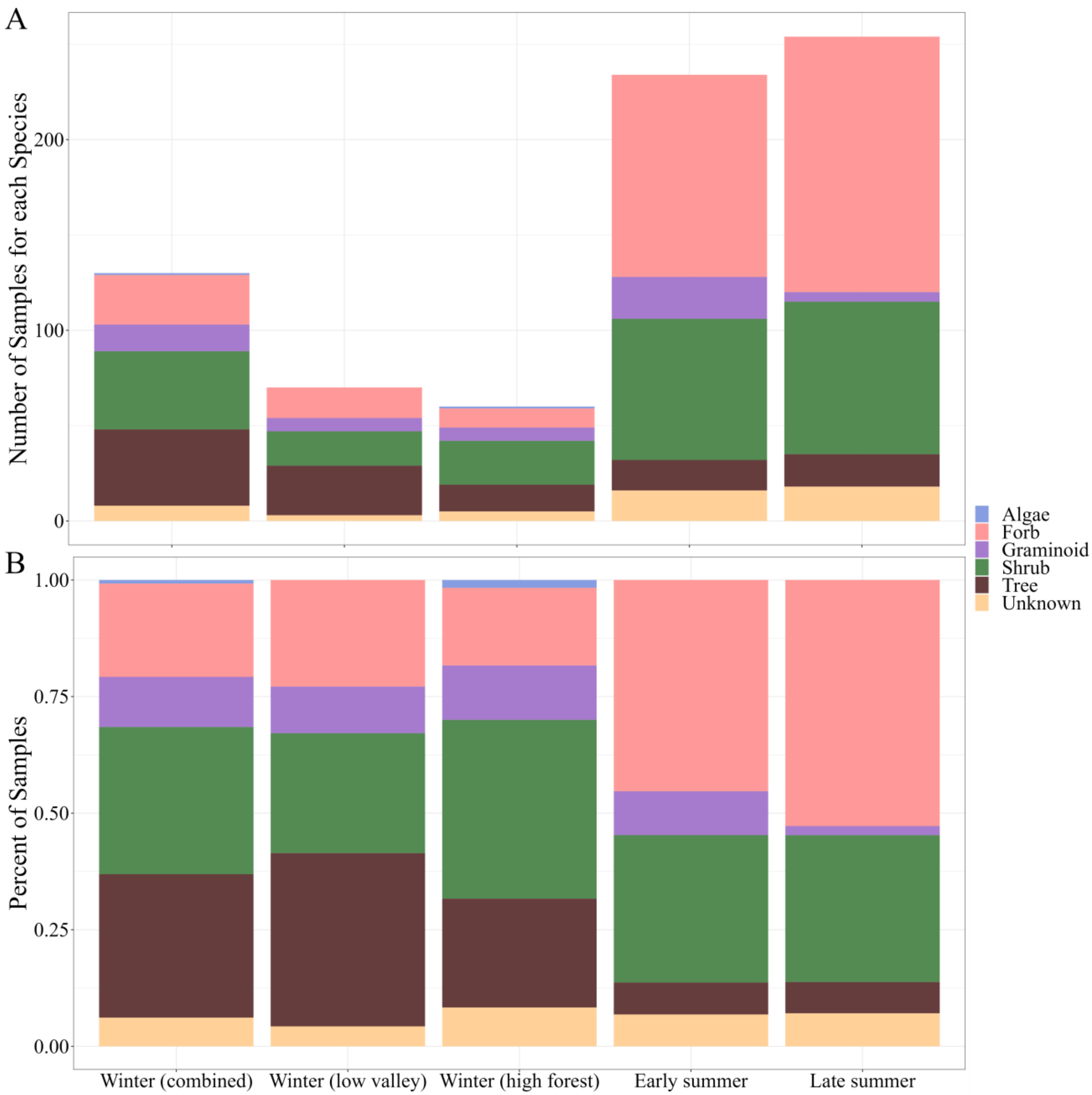

Figure 36. Number (panel A) and percent (panel B) of winter (low valley, high forest, and combined; December 2022 – March 2023), early summer (May – June 2023), and late summer (July – August 2023) forage species/items in each growth form class in hunting district 121.

Table 6. The number and percent of composite samples within each sample timing classification (winter = December 2022 – March 2023, early summer = May – June 2023, late summer = July – August 2023; total of 6, 7, and 7 composite samples, respectively) with a detection of each summer forage species/item for samples collected in hunting district 121. Winter samples are further delineated into low valley (n = 3) and high forest (n = 3) categories.

Sample Timing	Taxon	Growth Form	Samples	Percent
Winter (combined)	Abies sp.	Tree	6	100
	Ceanothus velutinus	Shrub	6	100
	Pseudotsuga menziesii	Tree	6	100
	Acer sp.	Tree	5	83.3
	Berberis sp.	Shrub	5	83.3
	Carex sp.	Graminoid	5	83.3
	Ceanothus sp.	Shrub	5	83.3
	Crataegus sp.	Shrub	5	83.3
	Rubus sp.	Shrub	5	83.3
	Acer glabrum	Tree	4	66.7
	Arctostaphylos uva-ursi	Shrub	4	66.7
	Medicago sp.	Forb	4	66.7
	Poaceae sp.	Graminoid	4	66.7
	Caryophyllales sp.	Unknown	3	50
	Chimaphila umbellata	Forb	3	50
	Datiscaceae sp.	Forb	3	50
	Festuca sp.	Graminoid	3	50
	Pinaceae sp.	Tree	3	50
	Pinus sp.	Tree	3	50
	Saxifragaceae sp.	Forb	3	50
	Thuja plicata	Tree	3	50
	Tsuga mertensiana	Tree	3	50
	Heuchera sp.	Forb	2	33.3
	Physocarpus sp.	Shrub	2	33.3
	Picea sp.	Tree	2	33.3
	Prunus sp.	Shrub	2	33.3
	Rosaceae sp.	Unknown	2	33.3
	Salix sp.	Shrub	2	33.3
	Sedum lanceolatum	Forb	2	33.3
	Verbascum thapsus	Forb	2	33.3
	Amelanchier sp.	Shrub	1	16.7
	Asterales sp.	Forb	1	16.7
	Betula sp.	Tree	1	16.7
	Brassicaceae sp.	Forb	1	16.7
	Cornus sp.	Unknown	1	16.7
	Fabaceae sp.	Unknown	1	16.7

Sample Timing	Taxon	Growth Form	Samples	Percent
	Gentianales sp.	Forb	1	16.7
	Larix sp.	Tree	1	16.7
	Plantago sp.	Forb	1	16.7
	Poa pratensis	Graminoid	1	16.7
	Poa sp.	Graminoid	1	16.7
	Podocarpaceae sp.	Tree	1	16.7
	Populus sp.	Tree	1	16.7
	Prunus avium	Shrub	1	16.7
	Prunus virginiana	Shrub	1	16.7
	Rosa sp.	Shrub	1	16.7
	Rubiaceae sp.	Unknown	1	16.7
	Rumex acetosella	Forb	1	16.7
	Taraxacum sp.	Forb	1	16.7
	Taxus sp.	Shrub	1	16.7
	Trebouxiaceae sp.	Algae	1	16.7
	Tsuga heterophylla	Tree	1	16.7
	Xerophyllum tenax	Forb	1	16.7
Winter (low valley)	Abies sp.	Tree	3	100
	Acer sp.	Tree	3	100
	Ceanothus velutinus	Shrub	3	100
	Crataegus sp.	Shrub	3	100
	Medicago sp.	Forb	3	100
	Pinaceae sp.	Tree	3	100
	Pseudotsuga menziesii	Tree	3	100
	Acer glabrum	Tree	2	66.7
	Arctostaphylos uva-ursi	Shrub	2	66.7
	Berberis sp.	Shrub	2	66.7
	Carex sp.	Graminoid	2	66.7
	Caryophyllales sp.	Unknown	2	66.7
	Ceanothus sp.	Shrub	2	66.7
	Chimaphila umbellata	Forb	2	66.7
	Festuca sp.	Graminoid	2	66.7
	Picea sp.	Tree	2	66.7
	Pinus sp.	Tree	2	66.7
	Rubus sp.	Shrub	2	66.7
	Saxifragaceae sp.	Forb	2	66.7
	Thuja plicata	Tree	2	66.7
	Tsuga mertensiana	Tree	2	66.7
	Verbascum thapsus	Forb	2	66.7
	Betula sp.	Tree	1	33.3
	Brassicaceae sp.	Forb	1	33.3
	Cornus sp.	Unknown	1	33.3

Sample Timing	Taxon	Growth Form	Samples	Percent
	Datiscaceae sp.	Forb	1	33.3
	Heuchera sp.	Forb	1	33.3
	Larix sp.	Tree	1	33.3
	Plantago sp.	Forb	1	33.3
	Poa pratensis	Graminoid	1	33.3
	Poa sp.	Graminoid	1	33.3
	Poaceae sp.	Graminoid	1	33.3
	Populus sp.	Tree	1	33.3
	Prunus avium	Shrub	1	33.3
	Prunus sp.	Shrub	1	33.3
	Rumex acetosella	Forb	1	33.3
	Salix sp.	Shrub	1	33.3
	Taraxacum sp.	Forb	1	33.3
	Taxus sp.	Shrub	1	33.3
	Tsuga heterophylla	Tree	1	33.3
	Xerophyllum tenax	Forb	1	33.3
	Abies sp.	Tree	3	100
	Berberis sp.	Shrub	3	100
	Carex sp.	Graminoid	3	100
	Ceanothus sp.	Shrub	3	100
	Ceanothus velutinus	Shrub	3	100
	Poaceae sp.	Graminoid	3	100
	Pseudotsuga menziesii	Tree	3	100
	Rubus sp.	Shrub	3	100
	Acer glabrum	Tree	2	66.7
	Acer sp.	Tree	2	66.7
	Arctostaphylos uva-ursi	Shrub	2	66.7
	Crataegus sp.	Shrub	2	66.7
	Datiscaceae sp.	Forb	2	66.7
	Physocarpus sp.	Shrub	2	66.7
	Rosaceae sp.	Unknown	2	66.7
	Sedum lanceolatum	Forb	2	66.7
	Amelanchier sp.	Shrub	1	33.3
	Asterales sp.	Forb	1	33.3
	Caryophyllales sp.	Unknown	1	33.3
	Chimaphila umbellata	Forb	1	33.3
	Fabaceae sp.	Unknown	1	33.3
	Festuca sp.	Graminoid	1	33.3
	Gentianales sp.	Forb	1	33.3
	Heuchera sp.	Forb	1	33.3
	Medicago sp.	Forb	1	33.3
	Pinus sp.	Tree	1	33.3

Sample Timing	Taxon	Growth Form	Samples	Percent
	Podocarpaceae sp.	Tree	1	33.3
	Prunus sp.	Shrub	1	33.3
	Prunus virginiana	Shrub	1	33.3
	Rosa sp.	Shrub	1	33.3
	Rubiaceae sp.	Unknown	1	33.3
	Salix sp.	Shrub	1	33.3
	Saxifragaceae sp.	Forb	1	33.3
	Thuja plicata	Tree	1	33.3
	Trebouxiaceae sp.	Algae	1	33.3
	Tsuga mertensiana	Tree	1	33.3
Early summer	Rosa sp.	Shrub	7	100
	Ceanothus sp.	Shrub	6	85.7
	Paxistima myrsinites	Shrub	6	85.7
	Rosaceae sp.	Unknown	6	85.7
	Rubus sp.	Shrub	6	85.7
	Acer sp.	Tree	5	71.4
	Asteraceae sp.	Unknown	5	71.4
	Ceanothus velutinus	Shrub	5	71.4
	Crataegus sp.	Shrub	5	71.4
	Moehringia lateriflora	Forb	5	71.4
	Poaceae sp.	Graminoid	5	71.4
	Vaccinium myrtillus	Shrub	5	71.4
	Vaccinium sp.	Shrub	5	71.4
	Chamerion angustifolium	Forb	4	57.1
	Holodiscus discolor	Shrub	4	57.1
	Moehringia macrophylla	Forb	4	57.1
	Onagraceae sp.	Forb	4	57.1
	Pinaceae sp.	Tree	4	57.1
	Plantago sp.	Forb	4	57.1
	Rumex acetosella	Forb	4	57.1
	Salix sp.	Shrub	4	57.1
	Symphoricarpos occidentalis	Shrub	4	57.1
	Trifolium repens	Forb	4	57.1
	Achillea millefolium	Forb	3	42.9
	Carex sp.	Graminoid	3	42.9
	Centaurea sp.	Forb	3	42.9
	Lonicera sp.	Shrub	3	42.9
	Physocarpus malvaceus	Shrub	3	42.9
	Pinus sp.	Tree	3	42.9
	Polygonum aviculare	Forb	3	42.9
	Prunus sp.	Shrub	3	42.9
	Ribes sp.	Shrub	3	42.9

Sample Timing	Taxon	Growth Form	Samples	Percent
	Saxifragaceae sp.	Forb	3	42.9
	Trifolium sp.	Forb	3	42.9
	Acer glabrum	Tree	2	28.6
	Anemone sp.	Forb	2	28.6
	Centaurea stoebe	Forb	2	28.6
	Cerastium beeringianum	Forb	2	28.6
	Chenopodium album	Forb	2	28.6
	Conimitella williamsii	Forb	2	28.6
	Ericaceae sp.	Unknown	2	28.6
	Hordeum sp.	Graminoid	2	28.6
	Leucanthemum vulgare	Forb	2	28.6
	Lolium sp.	Graminoid	2	28.6
	Maianthemum racemosum	Forb	2	28.6
	Menziesia ferruginea	Shrub	2	28.6
	Montia sp.	Forb	2	28.6
	Phleum pratense	Graminoid	2	28.6
	Poa pratensis	Graminoid	2	28.6
	Potentilla argentea	Forb	2	28.6
	Potentilla sp.	Unknown	2	28.6
	Prunella vulgaris	Forb	2	28.6
	Ranunculus sp.	Forb	2	28.6
	Rhododendron malvaceus	Shrub	2	28.6
	Taraxacum sp.	Forb	2	28.6
	Adenocaulon bicolor	Forb	1	14.3
	Antennaria sp.	Forb	1	14.3
	Arnica cordifolia	Forb	1	14.3
	Arnica sp.	Forb	1	14.3
	Asparagus officinalis	Forb	1	14.3
	Brassica sp.	Forb	1	14.3
	Bromus inermis	Graminoid	1	14.3
	Bromus sp.	Graminoid	1	14.3
	Calochortus apiculatus	Forb	1	14.3
	Chimaphila umbellata	Forb	1	14.3
	Claytonia perfoliata	Forb	1	14.3
	Coptis occidentalis	Forb	1	14.3
	Cornus canadensis	Forb	1	14.3
	Elymus sp.	Graminoid	1	14.3
	Epilobium sp.	Forb	1	14.3
	Erythronium grandiflorum	Forb	1	14.3
	Eurybia sp.	Forb	1	14.3
	Fabaceae sp.	Unknown	1	14.3
	Fragaria sp.	Forb	1	14.3

Sample Timing	Taxon	Growth Form	Samples	Percent
	Galium triflorum	Forb	1	14.3
	Heuchera sp.	Forb	1	14.3
	Juncus sp.	Graminoid	1	14.3
	Liliaceae sp.	Forb	1	14.3
	Lotus sp.	Forb	1	14.3
	Malva neglecta	Forb	1	14.3
	Medicago sp.	Forb	1	14.3
	Melica sp.	Graminoid	1	14.3
	Myosotis discolor	Forb	1	14.3
	Orchidaceae sp.	Forb	1	14.3
	Osmorhiza sp.	Forb	1	14.3
	Phlox sp.	Forb	1	14.3
	Picea sp.	Tree	1	14.3
	Poa sp.	Graminoid	1	14.3
	Polygonum sp.	Forb	1	14.3
	Primula sp.	Forb	1	14.3
	Prunus avium	Shrub	1	14.3
	Pseudognaphalium sp.	Forb	1	14.3
	Pseudotsuga menziesii	Tree	1	14.3
	Raphanus sp.	Forb	1	14.3
	Sedum lanceolatum	Forb	1	14.3
	Spergula arvensis	Forb	1	14.3
	Spergularia rubra	Forb	1	14.3
	Stellaria crassifolia	Forb	1	14.3
	Taraxacum officinale	Forb	1	14.3
	Thlaspi arvense	Forb	1	14.3
	Vicia sativa	Forb	1	14.3
	Viola sp.	Forb	1	14.3
	Yucca glauca	Forb	1	14.3
Late summer	Moehringia lateriflora	Forb	7	100
	Onagraceae sp.	Forb	7	100
	Rosa sp.	Shrub	7	100
	Rosaceae sp.	Unknown	7	100
	Rubus sp.	Shrub	7	100
	Symphoricarpos occidentalis	Shrub	7	100
	Acer glabrum	Tree	6	85.7
	Acer sp.	Tree	6	85.7
	Asparagus officinalis	Forb	6	85.7
	Asteraceae sp.	Unknown	6	85.7
	Ceanothus sp.	Shrub	6	85.7
	Ceanothus velutinus	Shrub	6	85.7
	Chamerion angustifolium	Forb	6	85.7

Sample Timing	Taxon	Growth Form	Samples	Percent
	Coptis occidentalis	Forb	6	85.7
	Moehringia macrophylla	Forb	6	85.7
	Vaccinium myrtillus	Shrub	6	85.7
	Crataegus sp.	Shrub	5	71.4
	Galium triflorum	Forb	5	71.4
	Salix sp.	Shrub	5	71.4
	Vaccinium sp.	Shrub	5	71.4
	Viola sp.	Forb	5	71.4
	Adenocaulon bicolor	Forb	4	57.1
	Arnica latifolia	Forb	4	57.1
	Physocarpus malvaceus	Shrub	4	57.1
	Rhododendron malvaceus	Shrub	4	57.1
	Saxifragaceae sp.	Forb	4	57.1
	Thalictrum sp.	Forb	4	57.1
	Anthriscus cerefolium	Forb	3	42.9
	Clintonia uniflora	Forb	3	42.9
	Cornus sp.	Unknown	3	42.9
	Maianthemum racemosum	Forb	3	42.9
	Osmorhiza sp.	Forb	3	42.9
	Ribes sp.	Shrub	3	42.9
	Sambucus nigra	Shrub	3	42.9
	Trifolium sp.	Forb	3	42.9
	Alnus sp.	Shrub	2	28.6
	Apocynum androsaemifolium	Shrub	2	28.6
	Centaurea stoebe	Forb	2	28.6
	Chimaphila umbellata	Forb	2	28.6
	Circaea alpina	Forb	2	28.6
	Conimitella williamsii	Forb	2	28.6
	Cornus canadensis	Forb	2	28.6
	Eurybia sp.	Forb	2	28.6
	Festuca rubra	Graminoid	2	28.6
	Leucanthemum vulgare	Forb	2	28.6
	Liliaceae sp.	Forb	2	28.6
	Menziesia ferruginea	Shrub	2	28.6
	Paxistima myrsinites	Shrub	2	28.6
	Populus deltoides	Tree	2	28.6
	Rumex acetosella	Forb	2	28.6
	Spergularia rubra	Forb	2	28.6
	Tiarella trifoliata	Forb	2	28.6
	Trillium ovatum	Forb	2	28.6
	Amaranthaceae sp.	Forb	1	14.3
	Amaranthus sp.	Forb	1	14.3

Sample Timing	Taxon	Growth Form	Samples	Percent
	Anemone sp.	Forb	1	14.3
	Antennaria sp.	Forb	1	14.3
	Araliaceae sp.	Shrub	1	14.3
	Arnica sp.	Forb	1	14.3
	Asarum caudatum	Forb	1	14.3
	Bromus inermis	Graminoid	1	14.3
	Capsella bursa-pastoris	Forb	1	14.3
	Centaurea sp.	Forb	1	14.3
	Chenopodium album	Forb	1	14.3
	Claytonia sibirica	Forb	1	14.3
	Claytonia sp.	Forb	1	14.3
	Clematis sp.	Unknown	1	14.3
	Datiscaceae sp.	Forb	1	14.3
	Epilobium sp.	Forb	1	14.3
	Ericaceae sp.	Unknown	1	14.3
	Erodium cicutarium	Forb	1	14.3
	Fragaria sp.	Forb	1	14.3
	Fragaria vesca	Forb	1	14.3
	Goodyera oblongifolia	Forb	1	14.3
	Hedysarum alpinum	Forb	1	14.3
	Hedysarum sp.	Forb	1	14.3
	Hieracium albiflorum	Forb	1	14.3
	Holodiscus discolor	Shrub	1	14.3
	Lonicera sp.	Shrub	1	14.3
	Lotus corniculatus	Forb	1	14.3
	Lotus sp.	Forb	1	14.3
	Medicago lupulina	Forb	1	14.3
	Orobanchaceae sp.	Forb	1	14.3
	Phleum pratense	Graminoid	1	14.3
	Pinaceae sp.	Tree	1	14.3
	Plantago sp.	Forb	1	14.3
	Poa pratensis	Graminoid	1	14.3
	Polemonium sp.	Forb	1	14.3
	Polygonum aviculare	Forb	1	14.3
	Pseudotsuga menziesii	Tree	1	14.3
	Ranunculus acris	Forb	1	14.3
	Solidago sp.	Forb	1	14.3
	Taraxacum sp.	Forb	1	14.3
	Taxus brevifolia	Shrub	1	14.3
	Tsuga mertensiana	Tree	1	14.3
	Veronica officinalis	Forb	1	14.3

Objective #4: Integrate findings from the monitoring program into predictive models, such that predictions of elk population dynamics and hunting season distribution become more accurate in the future in northwest Montana and can be exported to other regions of Montana.

We will use new information from data collected as part of this study in an adaptive framework that will improve the previous elk IPM described in section 1 and facilitate management actions in Region 1 (Figure 37). However, given we are in the second year of the study, we have not yet fulfilled this objective.

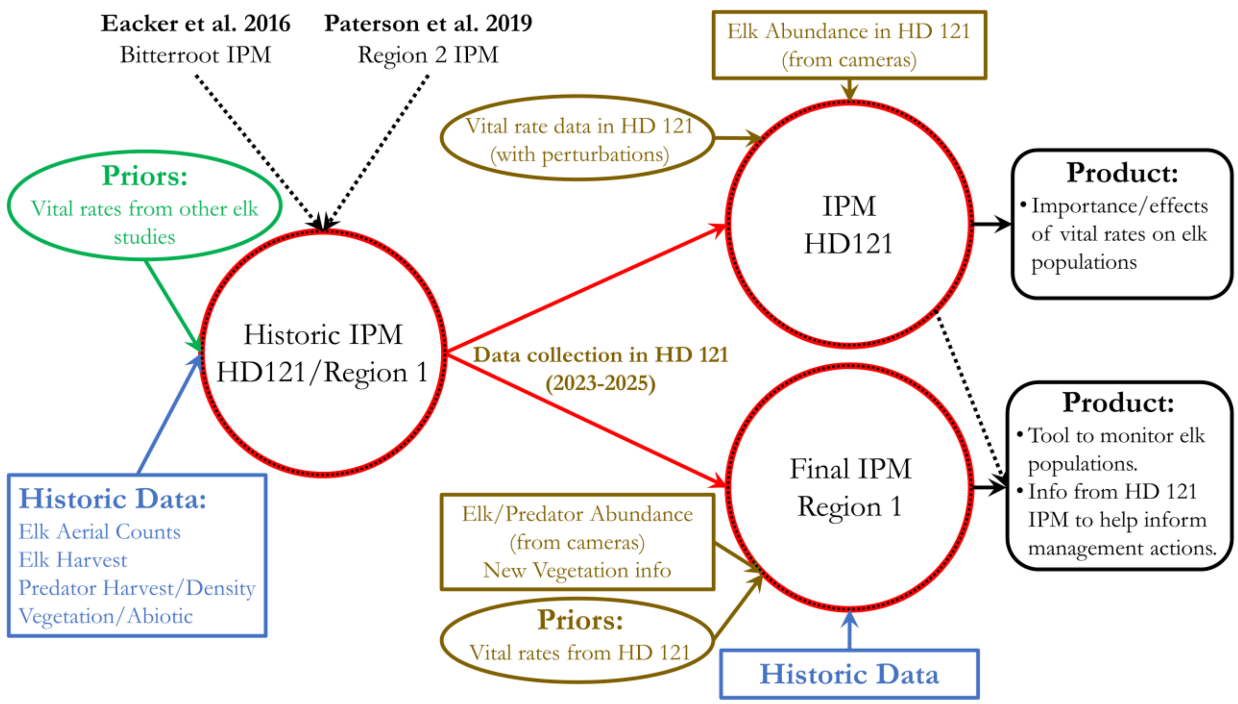

Figure 37. Diagram describing the workflow of our study as it relates to the population model(s) and desired outputs. Red areas represent integrated population models (IPM; all similar structure), green areas represent prior information from previous studies, blue areas represent historic datasets, gold areas represent new data from this study, and black areas represent desired products. In short, we will build upon the previous IPM (see Section 1) to create an IPM for hunting district 121 using only new data, which will be used to evaluate the importance of vital rates on elk populations. In concert with the HD 121 IPM, we will develop an IPM for Region 1 using both historic and new data, as well as information gained from sensitivity analyses with the HD 121, to produce a tool to monitor elk populations which will facilitate elk management throughout Region 1.

Acknowledgments

This research was a collaborative effort and would not have been possible without the cooperation amongst state and federal agency staff, University personnel, non-governmental organizations, and private citizens. We thank the private landowners for providing access and knowledge crucial to the development and implementation of the research. We thank the field technicians and hound handlers for their hard work towards making this project a success. We also thank agency staff across FWP Regions for providing helpful comments and suggestions during research development and for volunteering their time in the field. We thank Rocky Mountain Elk Foundation for providing funding and the U.S. Forest Service for providing housing for our winter crews, and for helping access sites across the Forest.

Appendix A: Percent change in resource use by elk between hunting periods

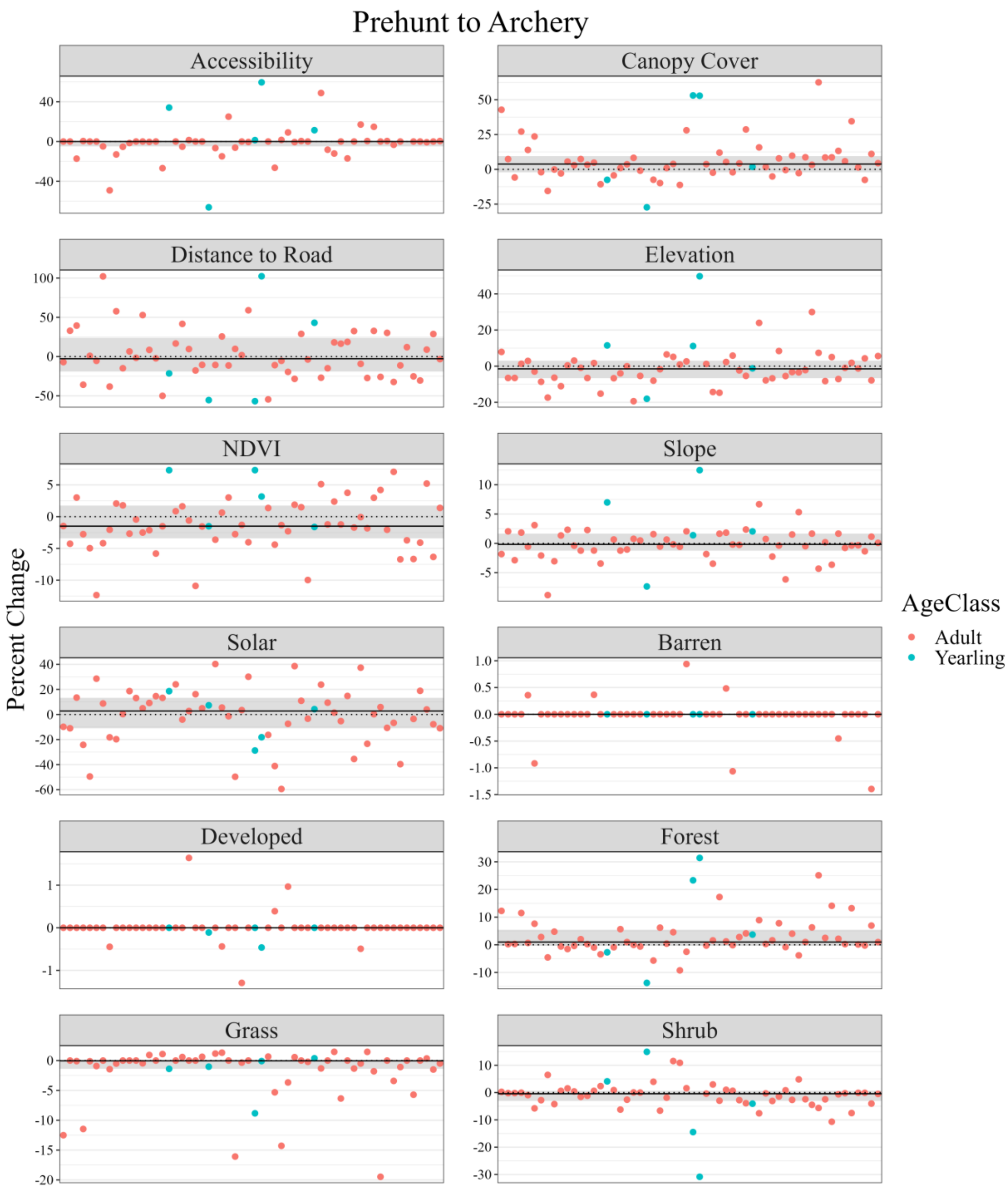

Figure A.1. Percent change in female elk use of resources between prehunt and archery periods in hunting district 121. Accessibility, Slope, Barren, Developed, Forest, Grass, and Shrub percentages are absolute changes, while other resources represent relative percent change. Each dot represents a unique elk, while the black line and gray ribbon represent the mean percent change and 50% quantile across elk. The horizontal dotted line highlights no change.

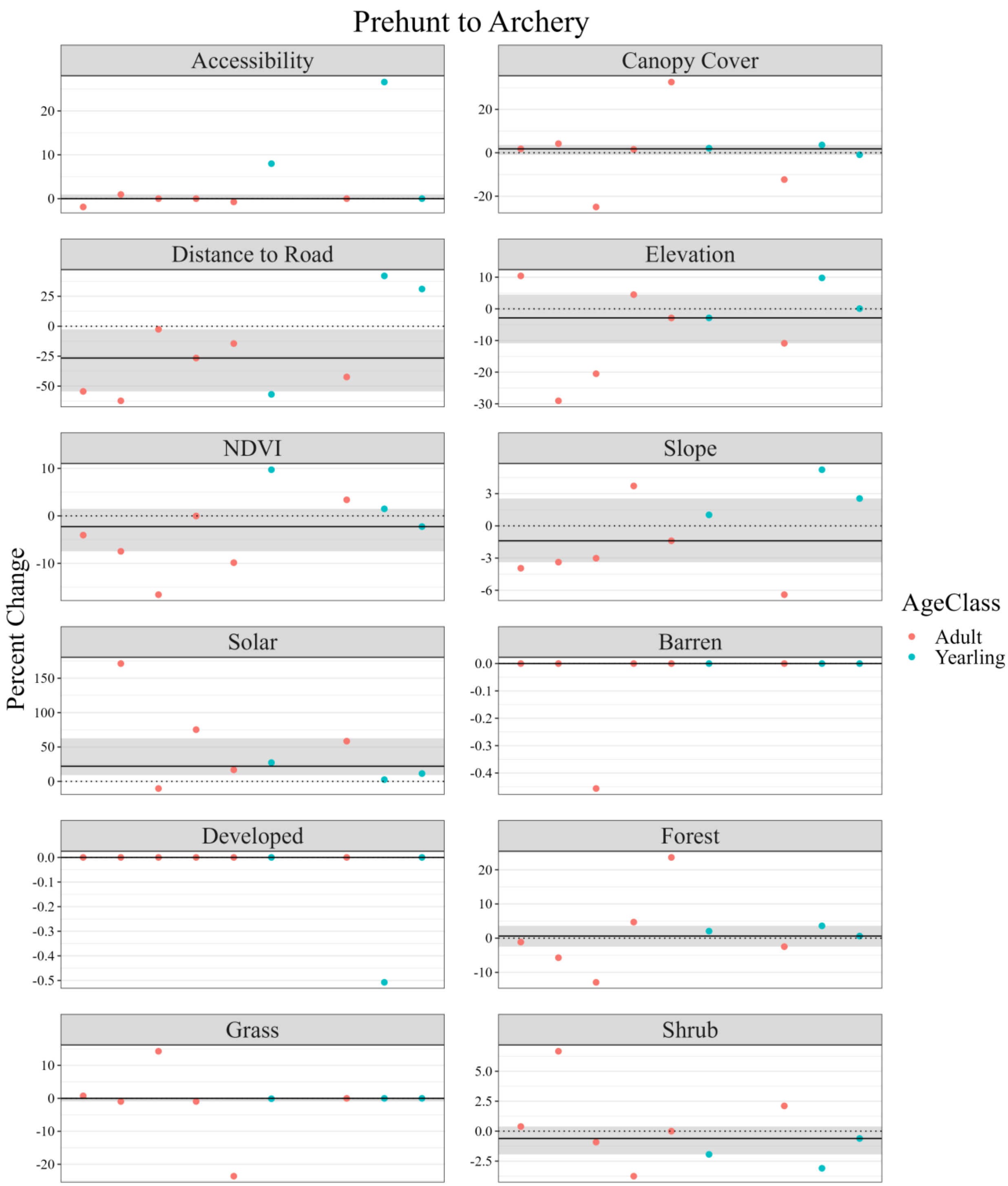

Figure A.2. Percent change in male elk use of resources between prehunt and archery periods in hunting district 121. Accessibility, Slope, Barren, Developed, Forest, Grass, and Shrub percentages are absolute changes, while other resources represent relative percent change. Each dot represents a unique elk, while the black line and gray ribbon represent the mean percent change and 50% quantile across elk. The horizontal dotted line highlights no change.

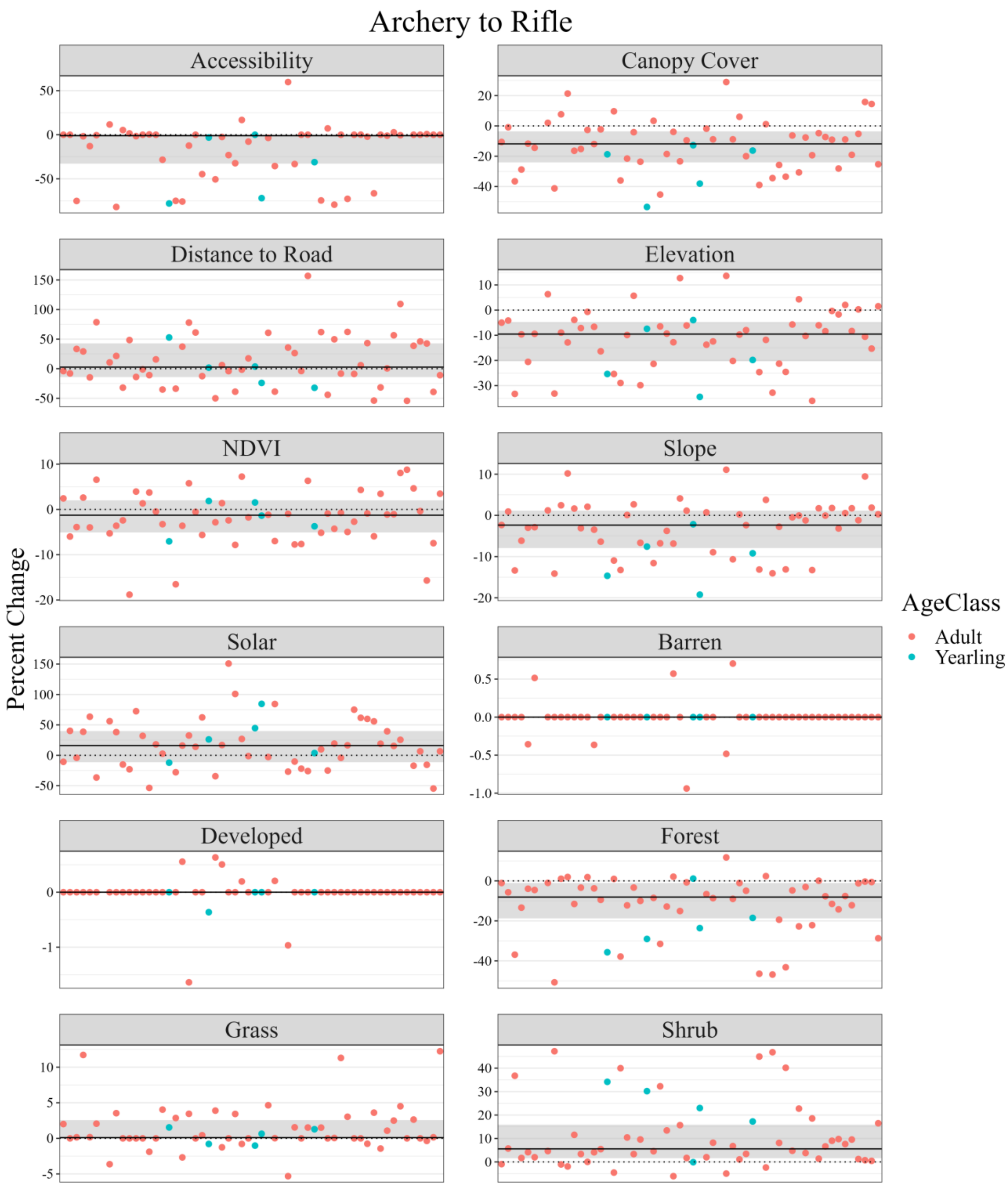

Figure A.3. Percent change in female elk use of resources between archery and rifle periods in hunting district 121. Accessibility, Slope, Barren, Developed, Forest, Grass, and Shrub percentages are absolute changes, while other resources represent relative percent change. Each dot represents a unique elk, while the black line and gray ribbon represent the mean percent change and 50% quantile across elk. The horizontal dotted line highlights no change.

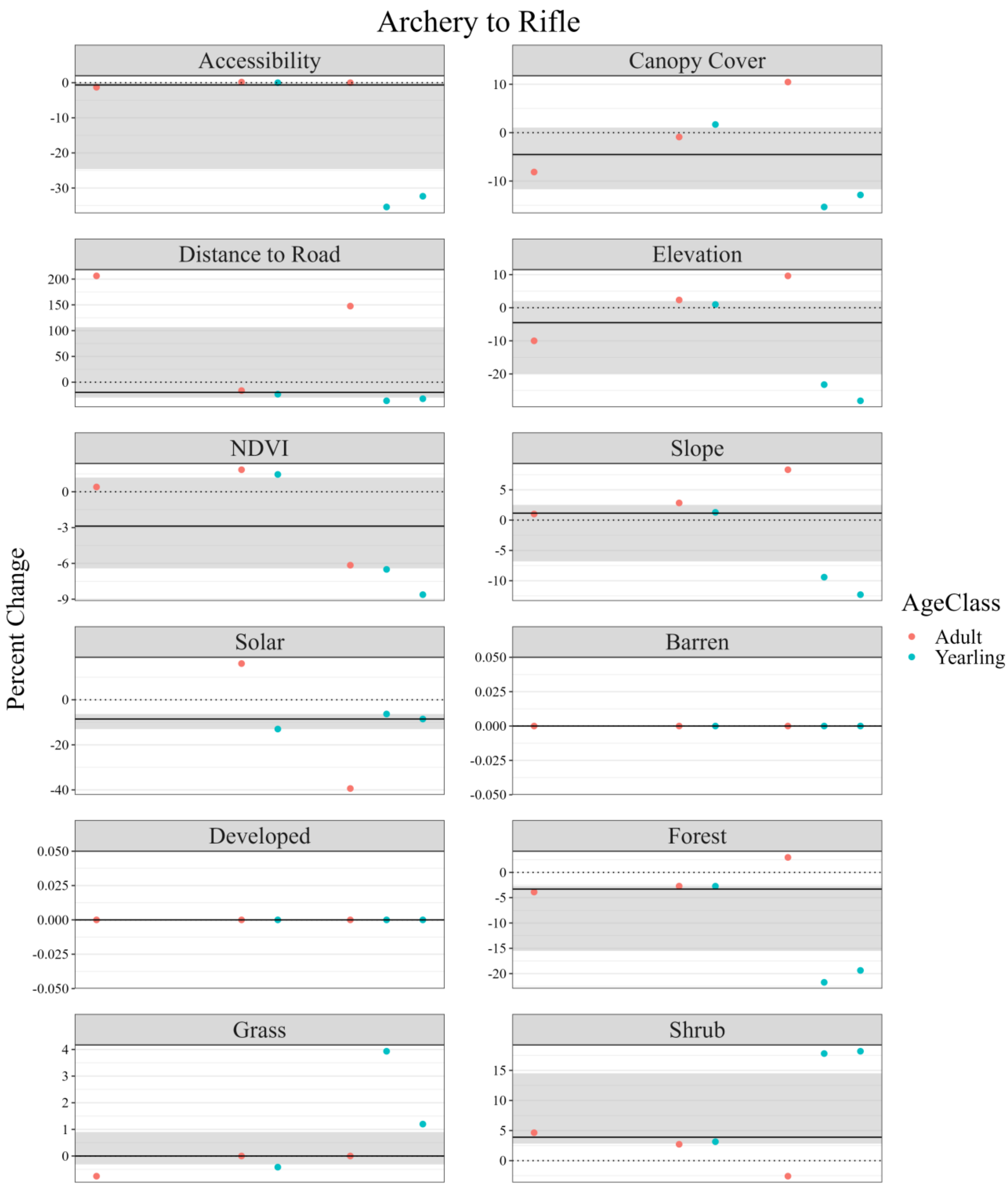

Figure A.4. Percent change in male elk use of resources between archery and rifle periods in hunting district 121. Accessibility, Slope, Barren, Developed, Forest, Grass, and Shrub percentages are absolute changes, while other resources represent relative percent change. Each dot represents a unique elk, while the black line and gray ribbon represent the mean percent change and 50% quantile across elk. The horizontal dotted line highlights no change.

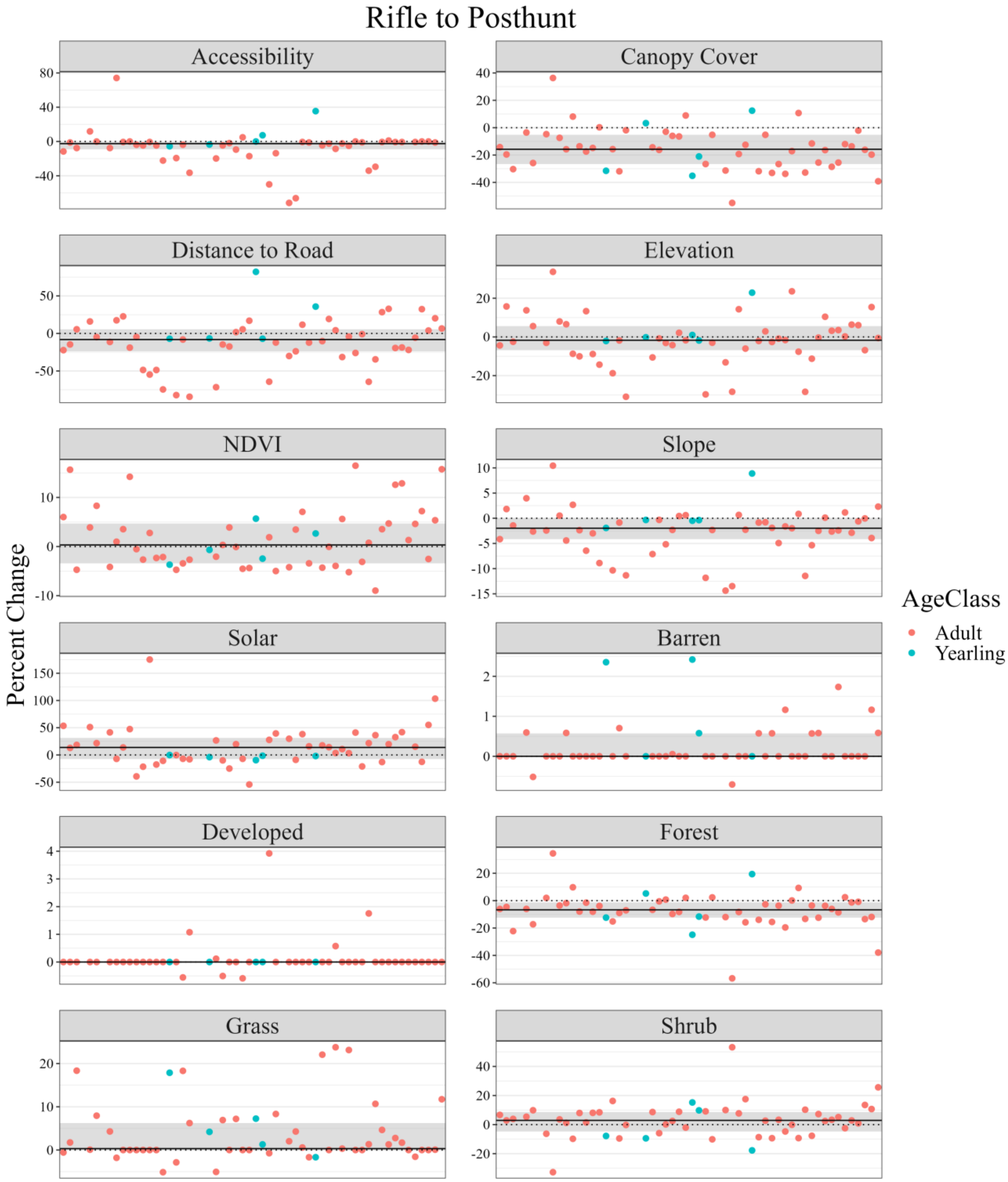

Figure A.5. Percent change in female elk use of resources between rifle and posthunt periods in hunting district 121. Accessibility, Slope, Barren, Developed, Forest, Grass, and Shrub percentages are absolute changes, while other resources represent relative percent change. Each dot represents a unique elk, while the black line and gray ribbon represent the mean percent change and 50% quantile across elk. The horizontal dotted line highlights no change.

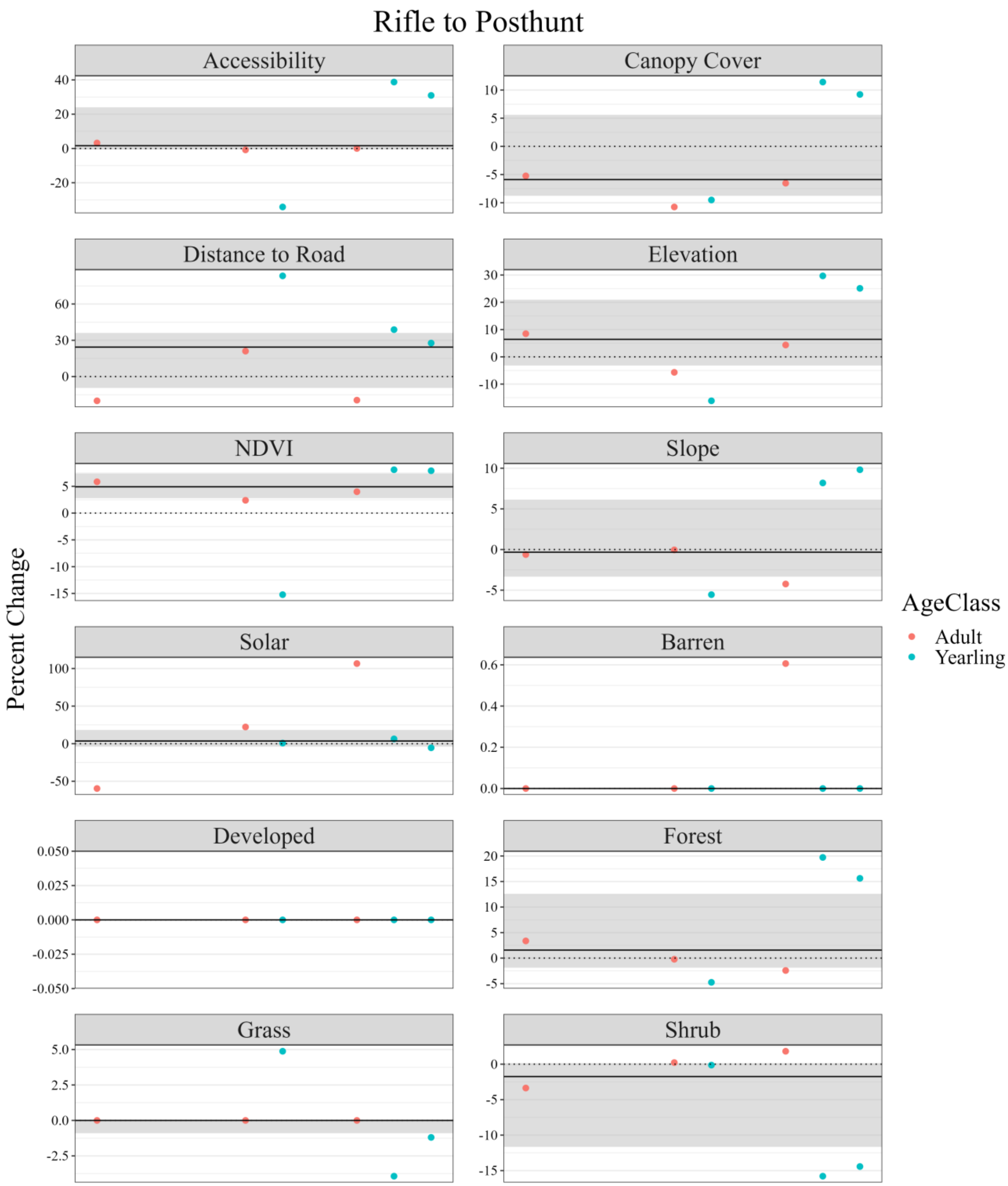

Figure A.6. Percent change in male elk use of resources between rifle and posthunt periods in hunting district 121. Accessibility, Slope, Barren, Developed, Forest, Grass, and Shrub percentages are absolute changes, while other resources represent relative percent change. Each dot represents a unique elk, while the black line and gray ribbon represent the mean percent change and 50% quantile across elk. The horizontal dotted line highlights no change.

Appendix B: Description of elk pathogens and their influence (if known) on individual or herd health.

Brucellosis--Brucellosis is an infectious disease caused by the *Brucella abortus* bacterium affecting some elk populations in the Greater Yellowstone Area. The presence of this disease in Montana elk herds is primarily a concern because infected elk can act as a reservoir for transmission to livestock. Naive elk and cattle may experience a high rate of abortion (Thorne et al. 1978); however, brucellosis is not considered a direct threat to the sustainability of elk populations in Montana.

Anaplasmosis--Anaplasmosis, a sickness caused by bacteria of the genus Anaplasma, is a vector-borne disease primarily affecting domestic cattle. *Anaplasma marginale*, the species most commonly involved with infections in cattle, affects red blood cells resulting in severe anemia and sometimes death. Elk are susceptible to Anaplasma infection; however, serious clinical signs have not been recorded and there is little evidence suggesting elk are important carriers or reservoirs of the disease (Kuttler 1984; Zaugg et al. 1996). The specific Anaplasma species that elk are exposed to are unknown because the test detects antibodies for multiple species. This pathogen is not expected to impact individual or herd health in elk.

Leptospirosis--Leptospira spp. are a group of several closely related bacteria that can infect nearly all mammals. Infection varies in severity from asymptomatic to fatal depending on the host and the serological variant of Leptospira. Naturally occurring Leptospira infections in wildlife are usually asymptomatic, but may result in renal failure, destruction of red blood cells, fever, inappetence, hemorrhages on mucous membranes, jaundice, dehydration, infertility, abortion, stillbirths, or weakened neonates. Leptospira infection is generally not considered to be of concern in populations of free-ranging elk, but has been widely studied in wildlife due to the possibility of transmission to domestic livestock (Thorne et al. 2002). Leptospira spp. infection may cause some mortality; however, clinical disease in wildlife is rare and not likely a major limiting factor in free-ranging elk populations (Thorne et al. 2002).

Parainfluenza-3--Parainfluenza-3 is a common virus that can be involved in respiratory disease in domestic ungulates. The disease associated with PI-3 is usually mild or subclinical, but under severe stress, the virus may predispose animals to coinfection with other respiratory pathogens resulting in development of secondary bacterial pneumonia. It is unknown whether exposure to this virus leads to clinical symptoms in free-ranging elk (Barber-Meyer et al. 2007). Evidence of exposure on serological testing is common in wildlife, but documented clinical cases of disease are not. Exposure to this virus is not expected to impact individual or herd health.

Bovine respiratory syncytial virus--Bovine respiratory syncytial virus can be a primary pathogen causing varying degrees of pneumonia, especially in young calves. Disease is often most severe when secondary bacterial infection occurs. Elk are susceptible to infection by the virus, which is most likely transmitted from cattle; however, serious clinical symptoms may not occur in wild elk (Barber-Meyer et al. 2007).

Bovine viral diarrhea (types 1 & 2)--Bovine viral diarrhea virus (types 1 & 2) can cause bloody diarrhea and can induce immunosuppression resulting in development of secondary bacterial pneumonia in domestic and wild ungulates. The different types (1 & 2) reflect differences in the antigens found on the viral surface protein and do not relate to the virulence of the virus. Elk are susceptible to infection with BVD, but there is little evidence of serious clinical effects (Tessaro et al. 1999). There is potential for wildlife populations to serve as reservoirs of this virus (Duncan et al. 2008).

Bovine herpes virus-1--Bovine herpes virus-1 is a common virus in cattle and can cause rhinotracheitis, fever, conjunctivitis, a drop in milk production, abortion, encephalitis, and lesions of the mucous membranes of the genital tract. The virus is transmitted most effectively by respiratory infections (Wentink et al. 1993). While most BHV-1 infections in cattle are mild, the virus can predispose animals to secondary bacterial pneumonia. BHV-1 can undergo long periods of latency before being reactivated, when it can again be shed and infect new hosts.

Epizootic hemorrhagic disease--Epizootic hemorrhagic disease (EHD) is caused by a virus that is transmitted by biting midges in the Culicoides genus and other arthropods. EHD can cause acute and frequently fatal hemorrhagic disease in domestic and wild ungulates. Recurrent outbreaks of EHD-associated mortality occur in white-tailed deer and mule deer, primarily in southeastern Montana (Montana Fish, Wildlife and Parks Wildlife Health Lab, unpublished data). Elk are susceptible to epizootic hemorrhagic disease, but generally do not suffer high rates of mortality or show clinical symptoms (Hoff and Trainer 1973; Nol et al. 2010). There is some concern that elk could act as reservoirs of EHD and transmit the virus to other wildlife (Thorne et al. 2002), but such relationships are not well studied.

Literature Cited

Barber-Meyer, S. M., P. J. White, and L. D. Mech. 2007. Survey of selected pathogens and blood parameters of Northern Yellowstone elk: wolf sanitation effect implications. The American Midland Naturalist 158(2):369-381.

Bocinsky, R. K. 2023. FedData: Functions to automate downloading geospatial data available from several federated data sources. R package version 3.0.4. https://CRAN.R-project.org/package=FedData.

Beery, S., Morris, D., Yang, S., 2019. Efficient pipeline for camera trap image review. ArXiv:1907.06772 Cs. http:arxiv.orgabs1907.06772.

Berg, J., D. R. Eacker, M. Hebblewhite, and E. H. Merrill. 2022. Summer elk calf survival in a partially migratory population. Journal of Wildlife Management 87:e22330.

Boertje, R. D., P. Valkenburg, and M. E. McNay. 1996. Increases in moose, caribou, and wolves following wolf control in Alaska. The Journal of Wildlife Management 60:474–489.

Boyd, R. J. 1970. Elk of the White River Plateau, Colorado. Colorado Division of Game, Fish and Parks. Technical Publication Number 25.

Brodie, J., H. Johnson, M. Mitchell, P. Zager, K. Proffitt, M. Hebblewhite, M. Kauffman, B. Johnson, J. Bissonette, C. Bishop, J. Gude, J. Herbert, K. Hersey, M. Hurley, P. M. Lukacs, S. McCorquodale, E. McIntire, J. Nowak, H. Sawyer, D. Smith, and P. J. White. 2013. Journal of Applied Ecology 50:295-305.

Burcham, L. T. 1956. Historical backgrounds of range land use in California. Journal of Range Management 9:81-86. doi:10.2307/3894555.

Cook, J. G., R. C. Cook, R. W. Davis, and L. L. Irwin. 2016. Nutritional ecology of elk during summer and autumn in the Pacific Northwest. Wildlife Monographs 195:1-81. doi:10.1002/wmon.1020.

Creel, S. and M. Creel. 2009. Density dependence and climate effects in Rocky Mountain elk: an application of regression with instrumental variables for population time series with sampling error. Journal of Animal Ecology 78:1291-1297.

Creel, S., D. Christianson, S. Liley, and J. A. Winnie Jr. 2007. Predation risk affects reproductive physiology and demography of elk. Science 315:960-960.

D'Eon, R., and D. Delparte. 2005. Effects of radio-collar position and orientation on GPS radio-collar performance, and the implications of PDOP in data screening. The Journal of Applied Ecology 42:383-388. doi:10.1111/j.1365-2664.2005.01010.x.

DeVoe, J. D., K. M. Proffitt, M. S. Mitchell, C. S. Jourdonnais, and K. J. Barker. 2019. Elk forage and risk tradeoffs during the fall archery season. The Journal of Wildlife Management 83:801–816.

Duncan, C., H. Van Campen, S. Soto, I. K. LeVan, L. A. Baeten, and M. W. Miller. 2008. Persistent *Bovine viral diarrhea virus* infection in wild cervids of Colorado. Journal of Veterinary Diagnostic Investigation 20:650-653.

Eacker, D. R., M. Hebblewhite, K. M. Proffitt, B. J. Jimenez, M. S. Mitchell, and H. S. Robinson. 2016. Annual elk calf survival in a multiple carnivore system. Journal of Wildlife Management 80(8): 1345-1359.

Eacker, D. R., P. M. Lukacs, K. M. Proffitt, and M. Hebblewhite. 2017. Assessing the importance of demographic parameters for population dynamics using Bayesian integrated population modeling. Ecological Applications 27:1280-1293.

Fennell, M., Beirne, C., and Burton, A. C. 2022. Use of object detection in camera trap image identification: Assessing a method to rapidly and accurately classify human and animal detections for research and application in recreation ecology. Global Ecology and Conservation. 35: e02104.

Fontaine, J. J., A. D. Fedele, L. S. Wszola, L. N. Messinger, C. J. Chizinski, J. J. Lusk, K. L. Decker, J. S. Taylor, and E. F. Stuber. 2019. Hunters and their perceptions of public access: A view from afield. Journal of Fish and Wildlife Management 10:589-601. doi:10.3996/082018-JFWM-077.

Garrott, R. A., L. L. Eberhardt, P. J. White, and J. Rotella. 2003. Climate-induced variation in vital rates of an unharvested large-herbivore population. Canadian Journal of Zoology 81:33-45.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some applications). No. 379. US Agricultural Research Service.

Gruntorad, M. P. and C. J. Chizinski. 2020. Constraints to hunting and harvesting elk in a landscape dominated by private land. Wildlife Biology 2020:1-9.

Hagerman, A. E. and L. G. Butler. 1978. Protein precipitation method for the quantitative determination of tannins. Journal of Agricultural and Food Chemistry 26: 809-812.

Haggerty, J. H., and W. R. Travis. 2006. Out of administrative control: Absentee owners, resident elk and the shifting nature of wildlife management in southwestern Montana. Geoforum 37:816-830.

Hayes, R. D., R. Farnell, R. M. Ward, J. Carey, M. Dehn, G. W. Kuzyk, A. M. Baer, C. L. Gardner, and M. O'Donoghue. 2003. Experimental reduction of wolves in the Yukon: ungulate responses and management implications. Wildlife Monographs 152:1–35.

Hebblewhite, M. 2004. Predation by wolves interacts with the North Pacific Oscillation (NPO) on a western North American elk population. Journal of Animal Ecology 74:226-233.

Hebblewhite, M., D. H. Pletscher, and P. C. Paquet. 2002. Elk population dynamics in areas with and without predation by recolonizing wolves in Banff National Park, Alberta. Canadian Journal of Zoology 80:789-799.

Hebblewhite, M., D. R. Eacker, S. Eggeman, H. Bohm, and E. H. Merrill. 2018. Density-independent predation affects migrants and residents equally in a declining partially migratory elk population. Oikos 127:1304-1318.

Hegel, T. M., C. C. Gates, and D. Eslinger. 2014. Survival and recovery estimates of male elk in a harvested inter-jurisdictional population. Wildlife Biology 20:57-63.

Hoff, L. and D. O. Trainer. 1973. Experimental infection in North American elk with epizootic hemorrhagic disease virus. Journal of Wildlife Diseases 9:129-132.

Horne, J. S., M. A. Hurley, C. G. White, J. Rachael. 2019. Effects of wolf pack size and winter conditions on elk mortality. Journal of Wildlife Management 83:1103-1116.

Hurley, M. A., J. W. Unsworth, P. Zager, M. Hebblewhite, E. O. Garton, D. M. Montgomery, J. R. Skalski, and C. L. Maycock. 2011. Demographic response of mule deer to experimental reduction of coyotes and mountain lions in southeastern Idaho. Wildlife Monographs:178:1–33.

Irwin, L. L. and J. M. Peek. 1983. Elk habitat use relative to forest succession in Idaho. Journal of Wildlife Management 47:664-672.

Johnson, H. E., L. S. Mills, T. R. Stephenson, and J. D. Wehausen. 2010. Population-specific vital rate contributions influence management of an endangered ungulate. Ecological Applications 20(6):1753-1765.

Keech, M. A., M. S. Lindberg, R. D. Boertje, P. Valkenburg, B. D. Taras, T. A. Boudreau, and K. B. Beckmen. 2011. Effects of predator treatments, individual traits, and environment on moose survival in Alaska. The Journal of Wildlife Management 75:1361–1380.

Keller, B. J., R. A. Montgomery, H. R. Campa III, D. E. Beyer Jr., S. R. Winterstein, L. P. Hansen, J. J. Millspaugh. 2015. A review of vital rates and cause-specific mortality of elk *Cervus elaphus* populations in eastern North America. Mammal Review 45:146-159.

Krausman, P. R., S. A. Christensen, J. E. McDonald, and B. D. Leopold. 2014. Dynamics and social issues of overpopulated deer ranges in the United States: a long term assessment. California Fish and Game 100:436-450.

Kuttler, K. L. 1984. Anaplasma infections in wild and domestic ruminants: a review. Journal Of Wildlife Diseases 20(1):12-20.

Lowrey, B., J. Devoe, K. M. Proffitt, and R. A. Garrott. 2020. Hiding without cover? Defining elk security in a beetle-killed forest. Journal of Wildlife Management 84:138–149.

Mattson, D. J. 1997. Use of ungulates by Yellowstone grizzly bears *Ursus arctos*. Biological Conservation 81:161-177.

Messer, M. A., R. A. Garrott, S. Cherry, P. J. White, F. G. R. Watson, and E. Merideth. 2009. Elk winter resource selection in a severe snowpack environment. Pages 137-156 *in* R. A. Garrott, P. J. White, and F. G. R. Watson, editors. The ecology of large mammals in central Yellowstone: sixteen years of integrated field studies. Elsevier, Academic Press, San Diego, California, USA.

Moeller, A. K., Lukacs, P. M., and Horne, J. S. 2018. Three novel methods to estimate abundance of unmarked animals using remote cameras. Ecosphere. 9(8): e02331.

Monzingo, D. S., J. G. Cook, R. C. Cook, J. S. Horne, and L. A. Shipley. 2023. Influences of succession and biogeoclimate on forage resources for elk in northern Idaho. Northwest Science 96:94-116.

Nol, P., C. Kato, W. K. Reeves, J. Rhyan, T. Spraker, T. Gidlewski, K. VerCauteren, and M. Salman. 2010. Epizootic hemorrhagic disease outbreak in a captive facility housing white-tailed deer (*Odocoileus virginianus*), bison (*Bison bison*), elk (*Cervus elaphus*), cattle (*Bos taurus*), and goats (*Capra hircus*) in Colorado, USA. Journal of Zoo and Wildlife Medicine 41(3):510-515.

Noyes, J. H., R. G. Sasser, B. K. Johnson, L. D. Bryant, and B. Alexander. 1997. Accuracy of pregnancy detection by serum protein (PSPB) in elk. Wildlife Society Bulletin 25:695-698.

Parker, K. L., P. S. Barboza, and M. P. Gillingham. 2009. Nutrition integrates environmental responses of ungulates. Functional Ecology 23:57-69.

Paterson, J. T., K. M. Proffitt, J. J. Rotella. 2022. Incorporating vital rates and harvest into stochastic population models to forecast elk population dynamics. Journal of Wildlife Management 86:e22189.

Paterson, J. T., K. M. Proffitt, J. J. Rotella, and R. Garrott. 2019. An improved understanding of ungulate population dynamics using count data: insights from western Montana. PLoS ONE 14:e0226492.

Powell, D. S. 1993. Forest resources of the United States, 1992. U. S. Department of Agriculture, Forest Service, Fort Collins, Co.

Proffitt, K. M., J. A. Cunningham, K. L. Hamlin, R. A. Garrott. 2014. Bottom-up and top-down influences on pregnancy rates and recruitment of northern Yellowstone elk. Journal of Wildlife Management 78:1383-1393.

Proffitt, K. M., J. A. Gude, K. L. Hamlin, and M. A. Messer. 2013. Effects of hunter access and habitat security on elk habitat selection in landscapes with a public and private land matrix. The Journal of Wildlife Management 77:514–524.

Proffitt, K. M., J. DeVoe, K. Barker, R. Durham, T. Hayes, M. Hebblewhite, C. Jourdonnais, P. Ramsey, and J. Shamhart. 2019. A century of changing fire management alters ungulate forage in a wildfire-dominated landscape. Forestry 92:523-537.

Proffitt, K. M., J. Millspaugh, C. Bishop, P. Lukacs, Z. Farley, J. DeVoe, C. Hansen. 2023. Evaluating habitat, carnivore abundance and elk vital rates in Pilgrim Creek. Federal Aid in Wildlife Restoration Grant W-188-R Annual Interim Report, September 2023. Montana Department of Fish, Wildlife and Parks.

Proffitt, K. M., M. Hebblewhite, W. Peters, N. Hupp, and J. Shamhart. 2016a. Linking landscape-scale differences in forage to ungulate nutritional ecology. Ecological Applications 26:2156-2174.

Proffitt, K. M., S. Thompson, D. Henry, B. Jimenez, and J. A. Gude. 2016b. Hunter access affects elk resource selection in the Missouri breaks, Montana. The Journal of Wildlife Management 80:1167–1176.

Proffitt, K. M., R. Garrott, J. A. Gude, M. Hebblewhite, B. Jimenez, J. T. Paterson, and J. Rotella. 2020. Integrated carnivore-ungulate management: a case study in west-central Montana. Wildlife Monographs 206:1–28.

Raithel, J. D., M. J. Kauffman, and D. H. Pletscher. 2007. Impact of spatial and temporal variation in calf survival on the growth of elk populations. Journal of Wildlife Management 71:795-803.

Ranglack, D. H., K. M. Proffitt, J. E. Canfield, J. A. Gude, J. Rotella, R. A. Garrott. 2022. Modeling broad-scale patterns of elk summer resource selection in Montana using regional and population-specific models. Ecosphere 13:e4311.

Ranglack, D. H., K. M. Proffitt, J. E. Canfield, J. A. Gude, J. Rotella, and R. A. Garrott. 2017. Security areas for elk during archery and rifle hunting seasons. Journal of Wildlife Management 81:778–791.

Robbins, C. T., S. Mole, A. E. Hagerman, and T. A. Hanley. 1987. Role of tannins in defending plants against ruminants: reduction in dry matter digestion?. Ecology 68:1606-1615.

Ruprecht, J., M. J. Wisdom, D. A. Clark, M. M. Rowland, and Taal Levi. 2023. Density-dependent changes in elk resource selection over successional time scales following forest disturbance. Ecological Applications e2891.

Schaub, M., and F. Abadi. 2011. Integrated population models: a novel analysis framework for deeper insights into population dynamics. Journal of Ornithology 152:227-237.

Schaub, M., R. Pradel, and J. D. Lebreton. 2004. Is the reintroduced white stork (Ciconia ciconia) population in Switzerland self-sustainable? Biological Conservation 119:105-114.

Schooler, S. L., N. J. Svoboda, S. P. Finnegan, J. Crye, K. F. Kellner, J. L. Belant. 2022. Maternal carryover, winter severity, and brown bear abundance relate to elk demographics. PLoS ONE 17:e0274359.

Schwartz, C. C., J. E. Swenson, and S. D. Miller. 2003. Large carnivores, moose, and humans: a changing paradigm of predator management in the 21st century. Alces 39:41–63.

Sergeyev, M., B. R. McMillan, K. R. Hersey, R. T. Larsen. 2021. How size and condition influence survival and cause-specific mortality of female elk. Journal of Wildlife Management 85:474-483.

Singer, F. J., A. Harting, K. K. Symonds, and M. B. Coughenour. 1997. Density dependence, compensation, and environmental effects on elk calf mortality in Yellowstone National Park. Journal of Wildlife Management 61:12-25.

Smith, B. L. and S. H. Anderson. 1998. Juvenile survival and population regulation of the Jackson elk herd. Journal of Wildlife Management 62:1036-1045.

Smith, B. L., E. S. Williams, K. C. McFarland, T. L. McDonald, G. Wang, and T. D. Moore. 2006. Neonatal mortality of elk in Wyoming: environmental, population, and predator effects. U.S Department of Interior, U.S. Fish and Wildlife Services, Biological Technical Publication, BTP-R6007-2006, Washington, D.C, USA.

Snobl, L. A., K. M. Proffitt, and J. J. Millspaugh. 2022. Wildfire extends the shelf-life of elk nutritional resources regardless of fire severity. Ecosphere 13:e4178. doi: 10.1002/ecs2.4178.

Snobl, L. A., K. M. Proffitt, C. P. Hansen, J. J. Millspaugh. 2024. Autumn resource selection by female elk in a recently burned landscape in western Montana. Journal of Wildlife Management 88:e22507.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262-278.

Tatman, N. M., S. G. Liley, J. W. Cain III, and J. W. Pitman. 2018. Effects of calf predation and nutrition on elk vital rates. Journal of Wildlife Management 82:1417-1428.

Tessaro, S. V., P. S. Carman, and D. Deregt. 1999. Viremia and virus shedding in elk infected with type 1 and virulent type 2 bovine viral diarrhea virus. Journal of Wildlife Diseases 35(4):671-677.

Thelen, T. H. 1991. Effects of harvest on antlers of simulated populations of elk. Journal of Wildlife Management 55:243-249.

Thompson M. J., Henderson R. E., Lemke T. O. & Sterling B. A. 1989. Evaluation of a collapsible clover trap for elk. Wildlife Society Bulletin 17:287-290.

Thorne, E. T., J. K. Morton, F. M. Blunt, and H. A. Dawson. 1978. Brucellosis in elk. II. Clinical effects and means of transmission as determined through artiĄcial infections. Journal of Wildlife Diseases 14:280-291.

Thorne, E. T., E. S. Williams, W.M. Samuel and T. P. Kistner. 2002. Diseases and parasites. Pages 351-387 in D. E. Toweill and J. W. Thomas, editors. North American Elk: Ecology and Management. Smithsonian Institution Press, Washington, D.C.

Trump, T., K. Knopff, A. Morehouse, and M. S. Boyce. 2022. Sustainable elk harvests in Alberta with increasing predator populations. PLoS ONE 17:e0269407.

Turnley, M. T., R. T. Larsen, K. R. Hersey, D. W. Sallee, M. S. Hinton, and B. R. McMillan. 2022. Optimizing methods for capturing neonate elk when using vaginal implant transmitters. Wildlife Society Bulletin 46(2): e1326.

Unsworth, J. W., L. Kuck, M. D. Scott, and E. O. Garton. 1993. Elk mortality in the Clearwater drainage of northcentral Idaho. Journal of Wildlife Management 57:495-502.

USGS. 2022a. Annual Disturbance Data. LANDFIRE 1.3.0. U.S. Department of Interior. https://www.landfire.gov.

USGS. 2022b. LANDFIRE 2020 Forest Canopy Cover. U.S. Department of Interior. https://www.landfire.gov.

Wade, D. A. and J. E. Bowns. 1993. Procedures for evaluating predation on livestock and wildlife. Publication B-1429: Texas Cooperative Extension Agency.

Wang, G., N. T. Hobbs, F. J. Singer, D. S. Ojima, and B. C. Lubow. 2002. Impacts of climate changes on elk population dynamics in Rocky Mountain National Park, Colorado, U.S.A. Climatic Change 54:205-223.

Wang, G., N. T. Hobbs, S. Twombly, R. B. Boone, A. W. Illius, I. J. Gordon, J. E. Gross. 2009. Density dependence in northern ungulates: interactions with predation and resources. Population Ecology 51:123-132.

Wentink, G. H., J. T. van Oirschot, and J. Verhoeff. 1993. Risk of infection with bovine herpes virus 1 (BHV1): a review. Veterinary Quarterly 15:30-33.

White, C. G., P. Zager, and M. W. Gratson. 2010. Influence of predator harvest, biological factors, and landscape on elk calf survival in Idaho. The Journal of Wildlife Management 74:355–369.

White, P. J., and R. A. Garrott. 2005. Yellowstone's ungulates after wolves- expectations, realizations, and predictions. Biological Conservation 125:141-152.

Wilmers, C. C., M. C. Metz, D. R. Stahler, M. T. Kohl, C. Geremia, and D. W Smith. 2020. How climate impacts the composition of wolf-killed elk in northern Yellowstone National Park. Journal of Animal Ecology 89:1511-1519.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009. Adaptive management: the U.S. Department of the Interior technical guide. U.S. Department of the Interior.

Zaugg, J. L., W. L. Goff, W. Foreyt, and D. L. Hunter. 1996. Susceptibility of elk (Cervus elaphus) to experimental infection with Anaplasma marginale and A. ovis. Journal of Wildlife Diseases 32:62-66.