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Evaluating Habitat, Carnivore Abundance and Elk Vital Rates in Pilgrim Creek

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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 for elk is to better understand what types of factors influence 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 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 over the past 10 years, with estimated total population sizes averaging approximately 1,760 individuals and a geometric mean growth rate of 1.010 (95% credible interval [CrI] = 0.984 – 1.037). Mean estimated annual natural survival (excluding harvest) of adult elk from 2013 – 2022 was 0.98 (95% CrI = 0.94 – 1.00), while mean annual natural survival of calves was 0.27 (95% CrI = 0.94 – 1.00). Estimated mean harvest rates of adult females, adult males, and calves was 0.066 (95% CrI = 0.050 – 0.087), 0.49 (95% CrI = 0.42 – 0.56), and 0.017 (95% CrI = 0.0000275 – 0.086), respectively. No factors, including indices of predator abundance, winter severity, or nutrition had strong associations with calf survival. While our 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 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 existing published data from southwest Montana to develop a model predicting elk distribution during archery and rifle hunting seasons in HD 121, as well as the effects of habitat conditions and hunter access on distributions. During both archery and rifle seasons, the model predicted elk were most likely to select areas with high canopy cover and limited public access. This pattern was accentuated during rifle season, when elk were also predicted to avoid high elevations with snow cover. While we expect to find similar patterns of selection in HD 121 once data is collected (e.g., elk selecting areas to avoid human harvest), we caution interpretation of these findings at this time, given the differences in landscapes between HD 121 and southwest Montana. This model will be refined and updated with data collected on elk locations, forage resources, and carnivore distributions within HD 121 during 2023 – 2025. This updated model will then be used to predict elk resource selection in HD 121 and across Region 1.

To improve our understanding of elk and carnivore 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. From December 21, 2022 to March 9, 2023, we captured and collared 71 elk (54 adult females, 6 female calves, 7 adult males, 4 male calves) with global positioning system (GPS) radio-collars programmed to record a location every 2 hours. From December 21, 2022 – July 31, 2023, we collected 132,157 locations from elk >6 months old. Only one collared female died due to natural causes attributed to poor body condition during this period. Using information from collared pregnant elk (42 individuals; 87.5% of collared female elk tested), we also captured and collared 25 elk neonates (16 males and 9 females) with expandable GPS collars in May and June 2023. As of July 31, 2023, 3 collared neonates died (one mountain lion predation, one black bear predation, and one unknown cause) and 5 collars fell off prematurely, resulting in unknown neonate status.

In summer 2022, FWP management staff captured one subadult male wolf and this individual emigrated from the study area in December 2022. During January and February 2023, we captured and collared 3 adult female mountain lions. As of July 31, 2023, we have collected a total of 3,181 locations from these individuals and all mountain lions are still alive with properly working collars. During summer 2023, we captured 1 female and 2 male black bears and collected 436 locations from these individuals. All bears are currently alive and collars are working properly.

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 1-1.5 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 will be serviced in September/October 2023.

To model the nutrition landscape for elk in HD 121, we first developed a landcover layer that included 25 unique strata combinations of landcover type, harvest strategy, and years-since-harvest. We generated 375 random sites 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. At each random 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 to determine important forage species for elk in HD 121. As of July 31, 2023, we measured vegetation at 172 sites and collected fecal pellet samples at 38 sites. These data will be used to estimate elk forage quantity and quality at each site, which will then be included in a model predicting 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.

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, 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. 2016), 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.

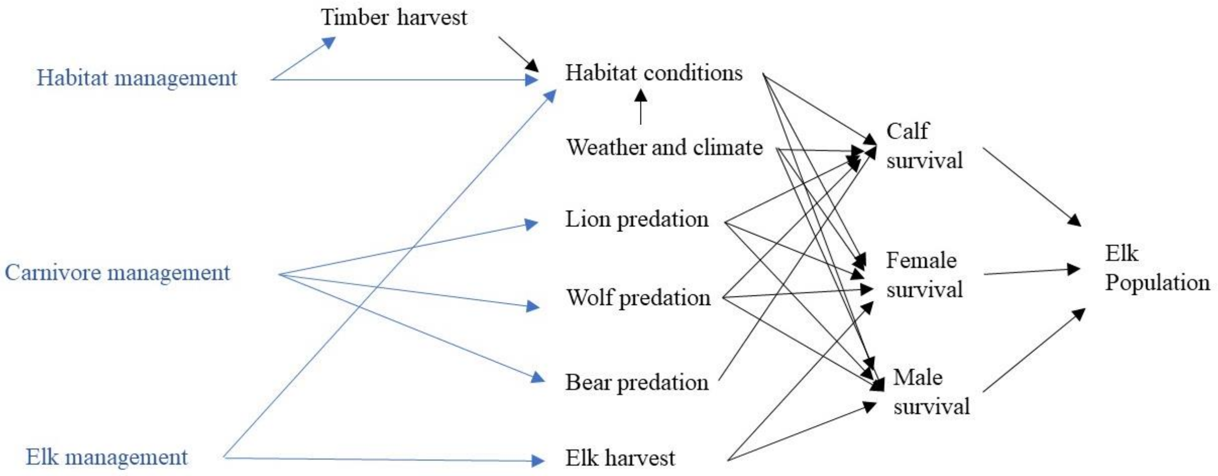


Figure 1. A conceptual model of factors influencing elk population dynamics.

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., 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. *in press*). 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.

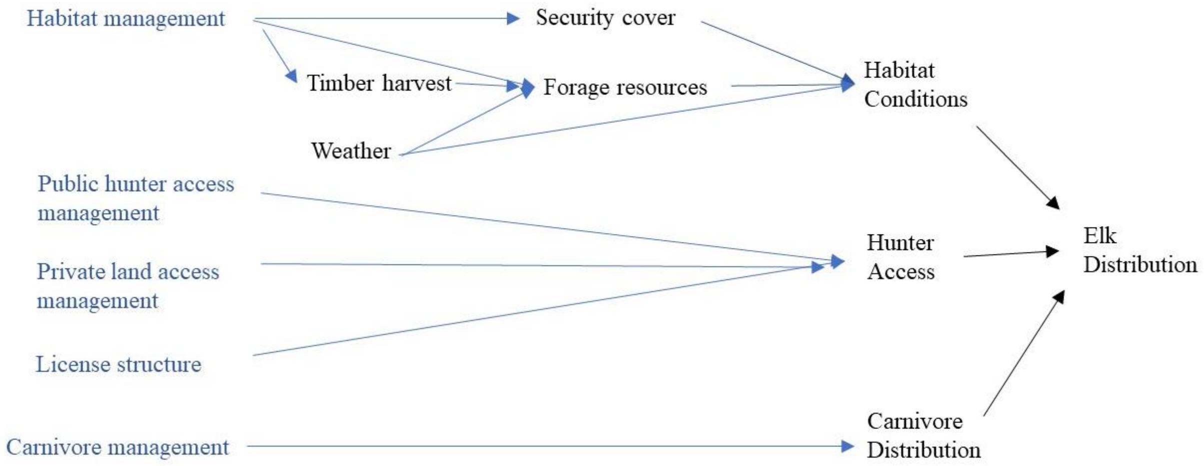
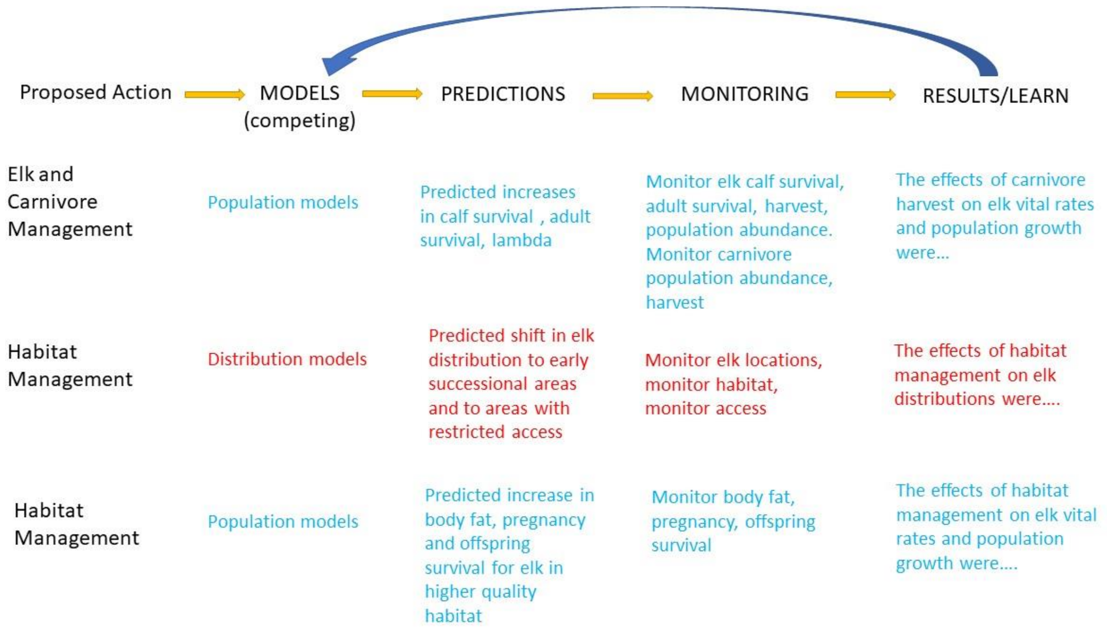


Figure 2. A conceptual model of factors influencing elk distributions during the fall hunting seasons.

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.



Proposed Action	MODELS (competing)	PREDICTIONS	MONITORING	RESULTS/LEARN
Elk and Carnivore Management	Population models	Predicted increases in calf survival , adult survival, lambda	Monitor elk calf survival, adult survival, harvest, population abundance. Monitor carnivore population abundance, harvest	The effects of carnivore harvest on elk vital rates and population growth were...
Habitat Management	Distribution models	Predicted shift in elk distribution to early successional areas and to areas with restricted access	Monitor elk locations, monitor habitat, monitor access	The effects of habitat management on elk distributions were....
Habitat Management	Population models	Predicted increase in body fat, pregnancy and offspring survival for elk in higher quality habitat	Monitor body fat, pregnancy, offspring survival	The effects of habitat management on elk vital rates and population growth were....

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 initiate 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 recruitment is approximately 22 calves per 100 adult females. Carnivores include black bear (*Ursus americanus*), mountain lion, and gray wolves.

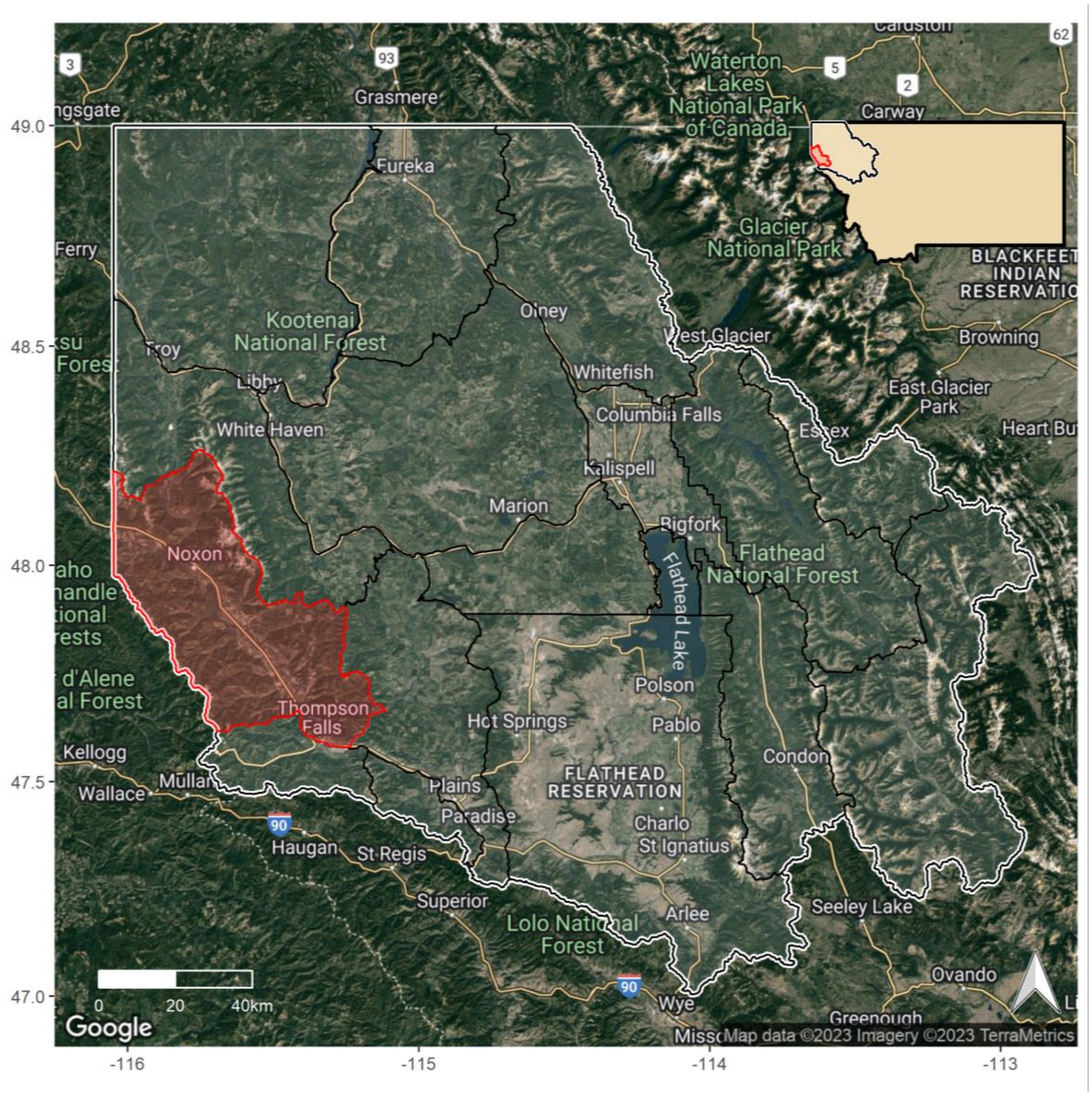


Figure 4. Location of the study area (hunting district 121; red area) within Region 1 (white area) in northwest Montana.

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 2005 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.

1.2 Data Collection and Description

We incorporated elk observation data, as well as biotic and abiotic covariates into an elk IPM to identify the state of elk populations for the past two decades.

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.

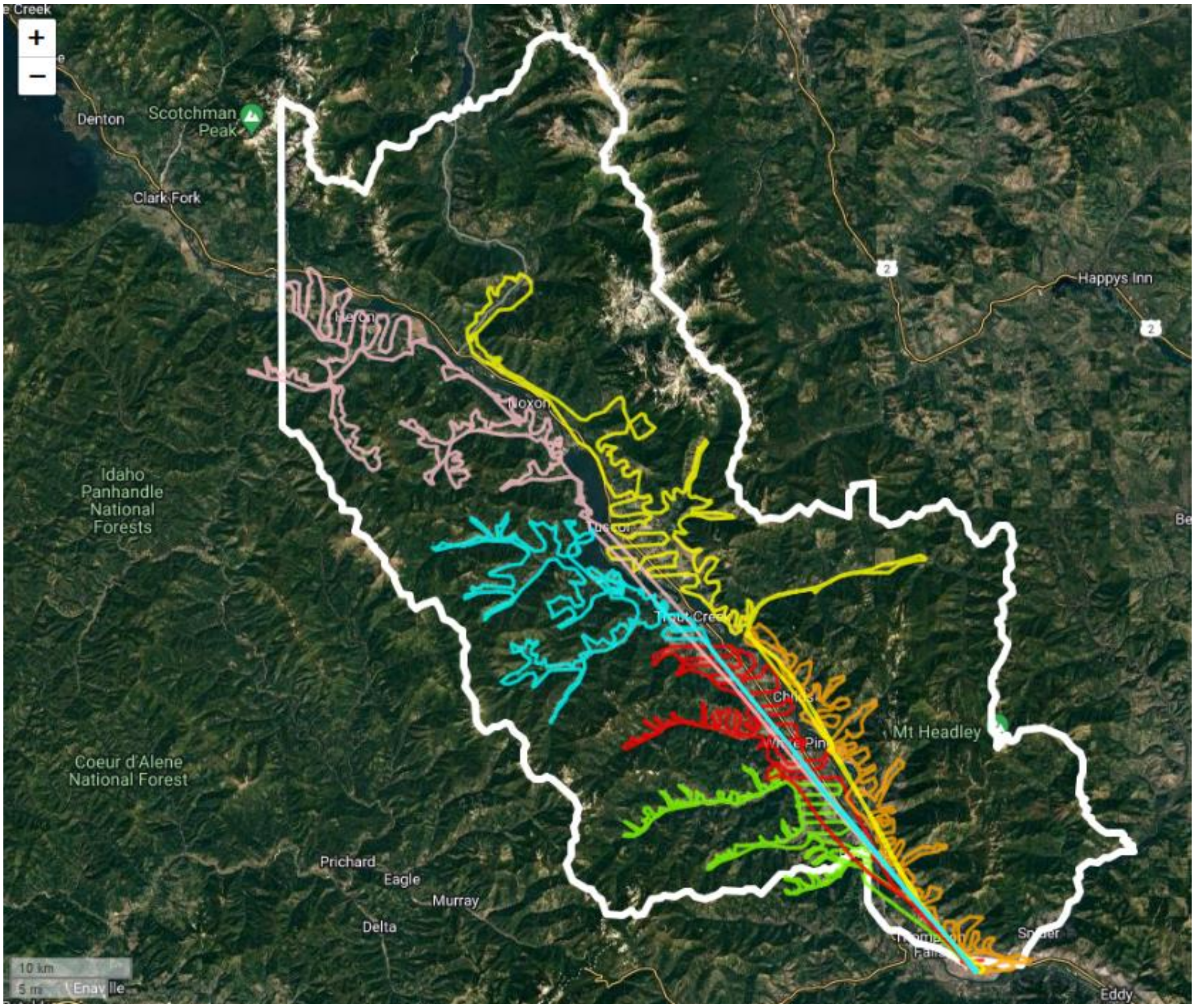


Figure 5. Aerial tracks from elk counts in hunting district 121 (white border) in April 2022. Colored lines represent tracks from each of six separate flights completed within approximately one week. Note, the yellow track up the Vermillion River is not typically surveyed on an annual basis.

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 (1,084 – 1,626) outlined in the 2005 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.

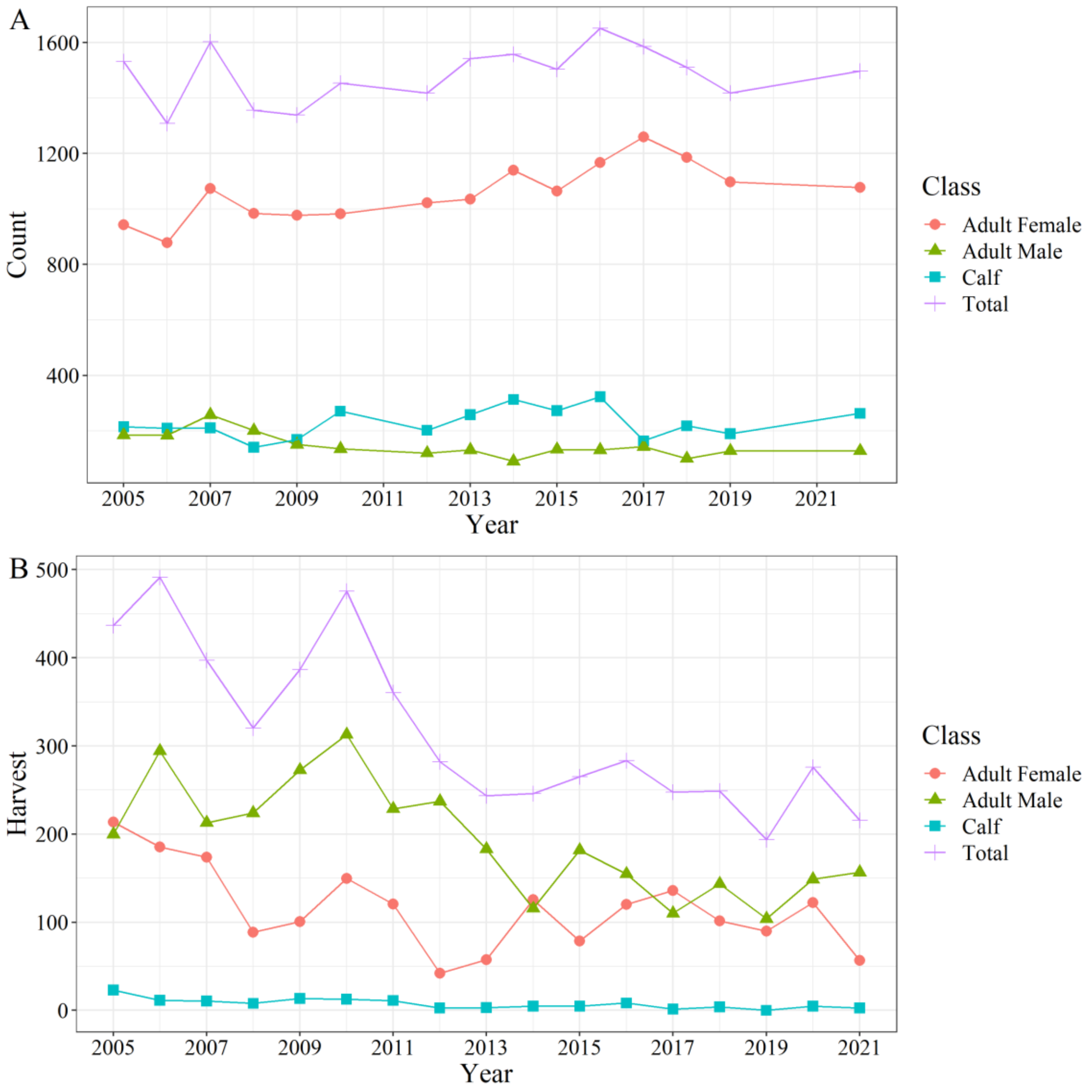


Figure 6. Elk population counts (panel A) and harvest estimates (panel B) for calves (<1 year old) and adult (>1 years old) females and males in hunting district 121 from 2005 – 2022. Note, limited aerial surveys were completed in 2011, 2014, 2018, 2020, and 2021 due either to poor conditions or COVID-19 restrictions.

1.2.2 Covariates

To evaluate how biotic and abiotic factors may have affected elk populations over the past two decades, we collected data related to predators, nutrition, and abiotic processes. We collected similar covariates as those used and described in Paterson et al. (2019), including indices of black bear, mountain lion, and wolf populations; Normalized Difference Vegetation Index (NDVI) as a measure of nutrition; spring and summer precipitation; and snow water equivalent (SWE) as a measure of winter severity. For indices of black bear and mountain lion populations, we used harvest information gathered by FWP, given all hunters are required to report harvest. For the wolf index, we used abundance estimates from an integrated patch occupancy model developed for Montana (Sells et al. 2022). Specifically, we summed abundance estimates across

600 km^2 pixels located within HD 121, divided this value by the total area of pixels included, then multiplied by the area of HD 121 (2,530.48 km^2) each year to arrive at annual wolf abundance values (Figure 7).

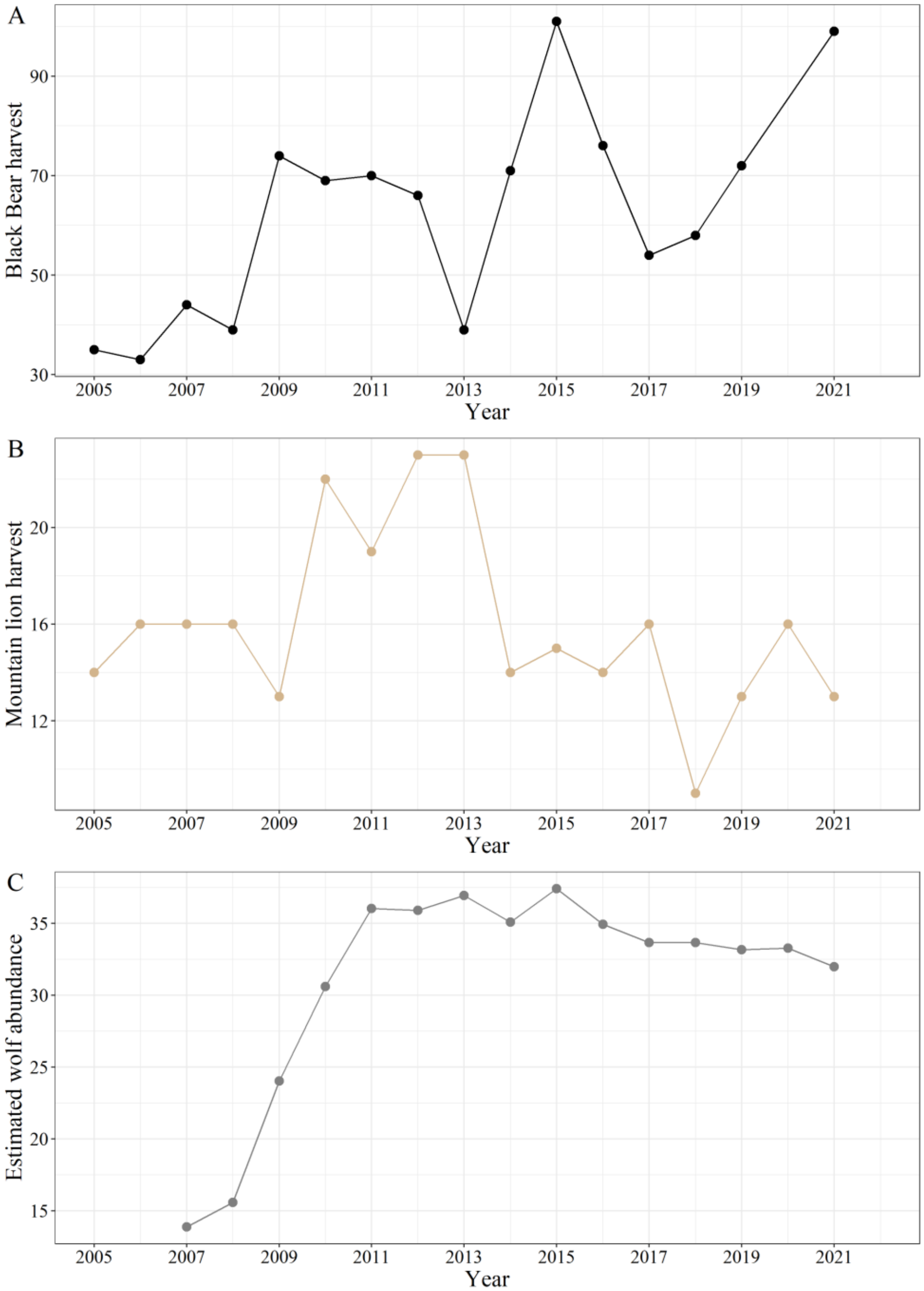


Figure 7. Black bear harvest (A), mountain lion harvest (B), and wolf abundance estimates (C) in hunting district 121 from 2005 – 2021. These values were used as indices for predator populations in integrated population models for elk.

We collected NDVI values in HD 121 at 1 km resolution every 16 days for the past 10 years from moderate resolution imaging spectroradiometer (MODIS) Terra satellites, accessed using the “MODIStsp” package in R (Busetto and Ranghetti 2016). We then calculated the average NDVI values across HD 121 for the “neonatal period” (late spring/early summer: May 1 – June 30) and “juvenile independence period” (late summer/early fall: July 1 – September 30) each year. Similarly, we collected winter (December 1 – April 30) daily SWE and spring and summer daily precipitation at 1 km resolution, then calculated mean annual values within HD 121 (Figure 8). We only included values for the past 10 years for these datasets because we decided to only interpret elk population dynamics over the past decade, given uncertainties in the dataset pre-2013 (see below).

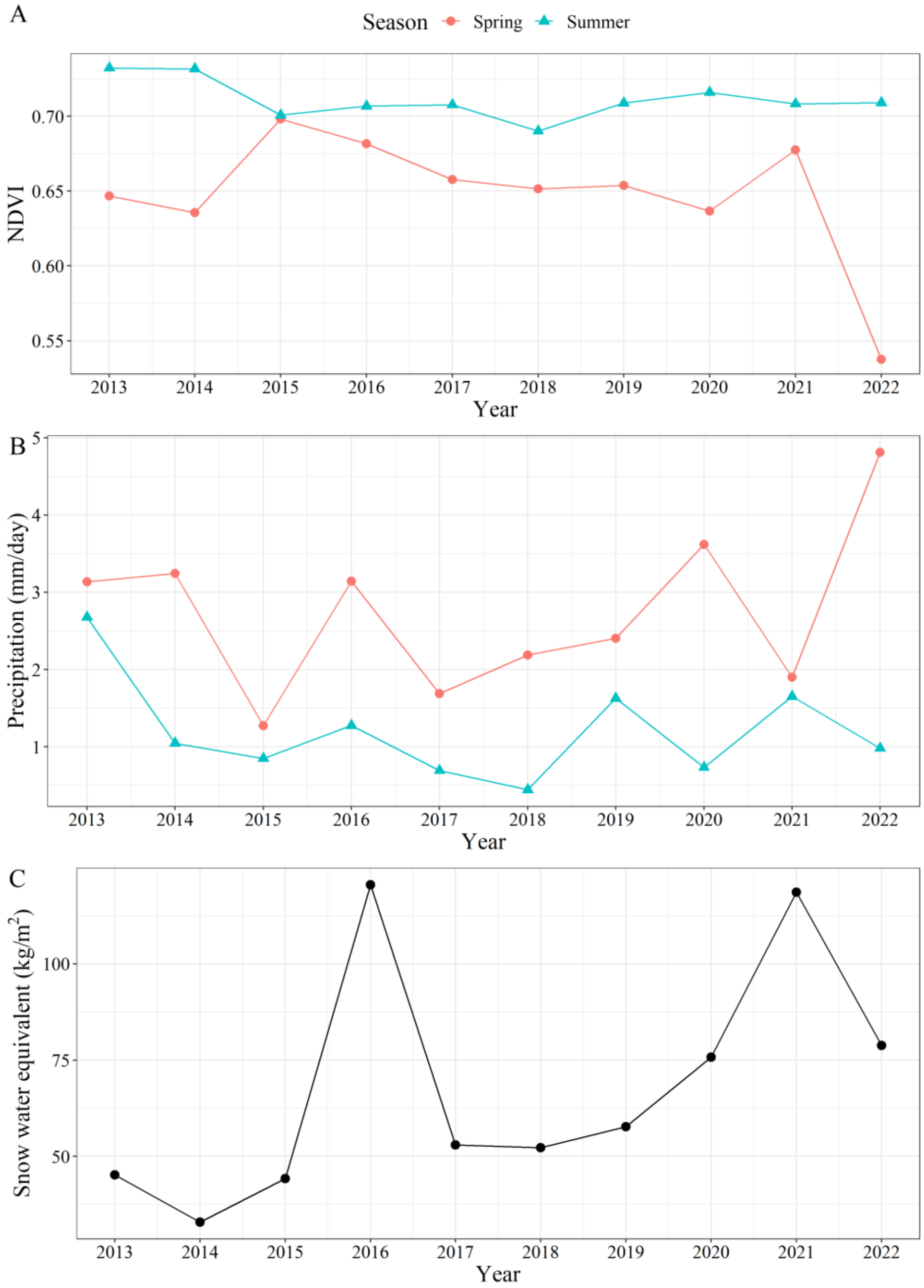


Figure 8. Mean daily spring (red circle) and summer (blue triangle) NDVI (A), precipitation (B), and mean daily winter snow water equivalent (C) across hunting district 121 from 2013 – 2022.

1.3 Integrated population model development

1.3.1 Population model

We developed an IPM with a similar structure as described in Paterson et al. (2019). 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. 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 9).

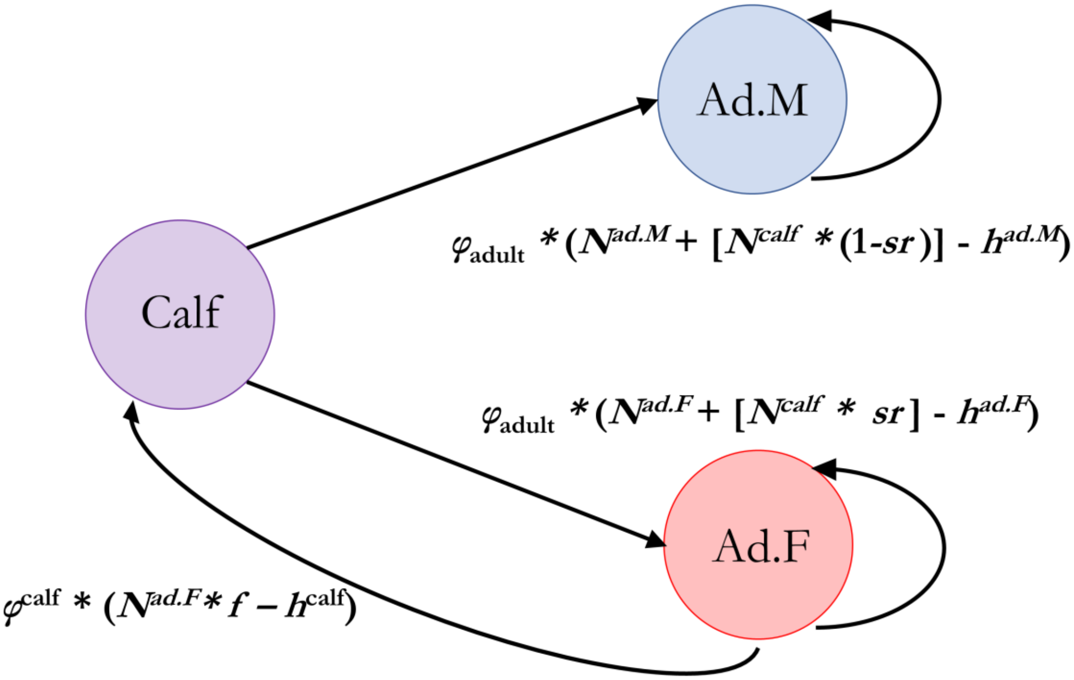


Figure 9. Life cycle diagram demonstrating transition probabilities among sex/age groups included in the integrated population model developed for hunting district 121. sr is the sex ratio at 1 year of age; φ^{adult} and φ^{calf} are annual natural survival of adults (≥ 1 year old) and calves (<1 year 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:

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

where φ is annual natural survival (excluding harvest), f is the number of calves produced per female, h is the number of individuals harvested, and sr is proportion of calves that were female at the time of observation (~10-11 months old). For simplicity, we assumed a 0.5 sex ratio and adult natural survival did not vary by age or sex.

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 structured count observation models to account for aerial elk counts that included both total counts and counts classified to age and sex. We were uncertain of the accuracy and representativeness of elk counts as it related to the true population size, so we tested modeling this observation process using a variety of distributions (e.g., Poisson, negative binomial, binomial, normal, lognormal). We describe only two of these models (Poisson and binomial) in this report to demonstrate the differences that arise in model estimates when different assumptions are made regarding the accuracy of counts. For Poisson models, we modeled the total count as a Poisson random variable with mean equal to the latent true population size and the variance equivalent to the mean:

$$\text{Count}_t^{\text{Total}} \sim \text{Poisson}\left(N_t^{\text{Total}}\right) \qquad \text{Eq. 3}$$

For binomial models, we modeled the total count as a binomial random variable with 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 $N^{Total} * p(1-p)$:

$$\text{Count}_t^{\text{Total}} \sim \text{Binomial}\left(N_t^{\text{Total}}, p_t\right) \qquad \text{Eq. 4}$$

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.

For elk classified to age and sex, we related the total number of classified individuals (Class) to the number of individuals in each age class using a multinomial distribution:

$$[\text{Count}^{calf}, \text{Count}^{ad.F}, \text{Count}^{ad.M}]_t \sim \text{Multinomial}(\boldsymbol{\pi}_t, \text{Class}_t) \qquad \text{Eq. 5}$$

where,

$$\boldsymbol{\pi}_t = \left[\frac{N^{calf}}{N^{Total}}, \frac{N^{ad.F}}{N^{Total}}, \frac{N^{ad.M}}{N^{Total}}\right]_t \qquad \text{Eq. 6}$$

assuming the proportion of each sex and age class classified was representative of the proportion in the true population.

We modeled harvest observations 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, and variance equal to the variance on harvest observations ($h\sigma^2$):

$$\begin{aligned} h_t^{calf} &\sim \text{Normal}\left(hr_t^{calf} * N_t^{ad.F} * f,\ h^{calf}\sigma_t^2\right) \\ h_t^{ad.F} &\sim \text{Normal}\left(hr_t^{ad.F} * \left[N_t^{ad.F} + N_t^{calf} * sr\right], h^{ad.F}\sigma_t^2\right) \\ h_t^{ad.M} &\sim \text{Normal}\left(hr_t^{ad.M} * \left[N_t^{ad.M} + N_t^{calf} * (1 - sr)\right], h^{ad.M}\sigma_t^2\right) \end{aligned} \qquad \text{Eq. 7}$$

1.3.3 Model fitting

We used a Bayesian framework to fit the IPM, given its hierarchical structure. We do not currently have data to inform estimation of most parameters in the IPM, so we assigned prior distributions for each parameter that were informed by past literature (Table 1). We also included pregnancy data from winter 2022-23 (see Section 3; 42 of 48 sampled adult elk were pregnant) in a binomial model within the IPM to facilitate estimation of pregnancy rate:

$$\begin{aligned} &\text{Prior: } f \sim \text{Unif}(0, 1) \\ &42 \sim \text{Binomial}(48,\ f) \end{aligned} \qquad \text{Eq. 8}$$

Table 1. Prior distributions and references for parameters included in elk integrated population models in hunting district 121 from 2005 – 2022. 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

Parameter	Prior Distribution	References
φ^{ad}	Unif(0.8, 1)	Unsworth et al. 1993; Raithel et al. 2007; Brodie et al. 2013; 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 developed link functions for each parameter, which allowed for the addition of covariates that explained variation in the response. Calf survival is known to be one of the most variable demographic rates in elk (e.g., Raithel et al. 2007); thus, we included the covariates described above in logit-link linear models to identify whether these factors affected calf survival (e.g., Paterson et al. 2019). Additionally, we included a temporal random effects structure for annual survival and harvest rate parameters, but left other parameters constant over time.

We 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. We determined that covariates influenced calf survival if 95% credible intervals (between 2.5% and 97.5% quantiles) of posterior distributions of parameter estimates did not overlap zero.

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

Results from the IPM that used the Poisson distribution to model count observations suggested elk populations did not differ greatly from counts, averaging approximately 1,534 individuals per year, with a geometric mean λ = 0.995 (95% CrI = 0.991 – 0.999) from 2005 – 2022 (Figure 10). In contrast, the IPM that used the binomial distribution to model count observations suggested elk populations dropped from approximately 3,300 individuals in 2005 to 1,876 individuals in 2013, with a geometric mean λ = 0.966 (95% CrI = 0.949 – 0.983) from 2005 – 2022 (Figure 10).

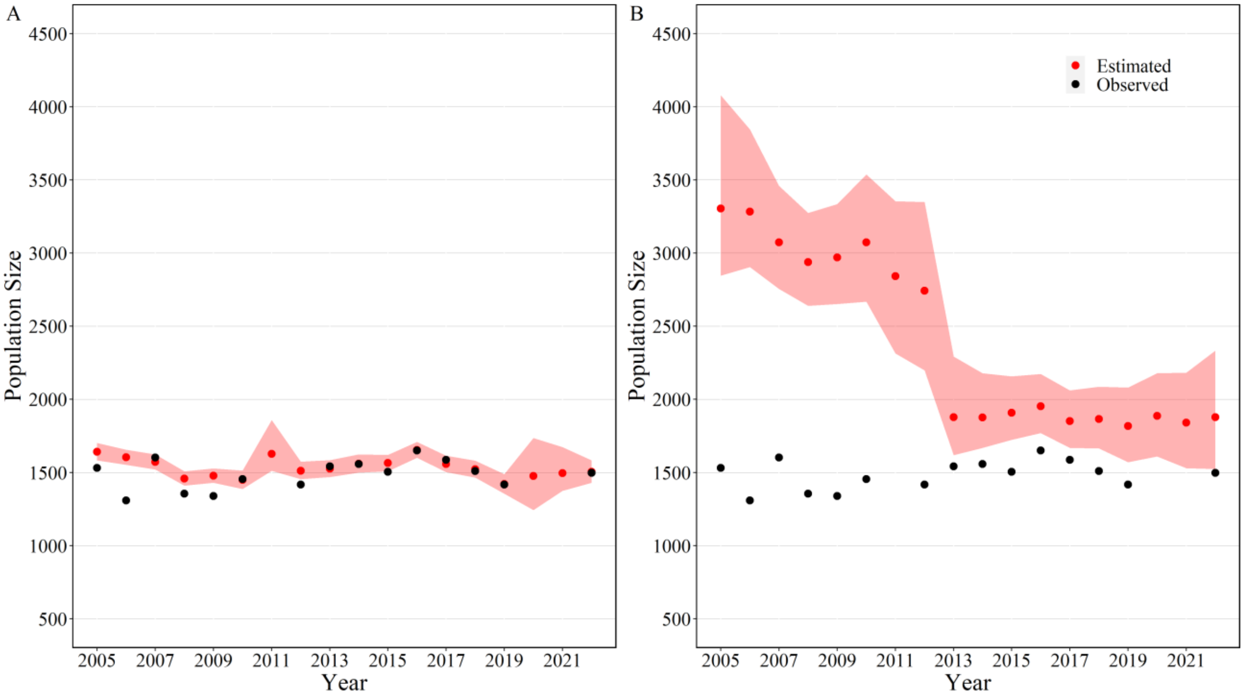


Figure 10. Elk population estimates and 95% credible intervals (red dots and ribbons) in hunting district 121 from integrated population models that used a Poisson distribution (A) and binomial distribution (B) to model total elk count data. Black dots represent total elk counts from aerial surveys.

Given aerial counts were completed in trend areas, suggesting counts represent a minimum estimate of the true elk population, we decided to use the IPM with a binomial observation model for all further analyses within HD 121. Further, 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 and factors affecting calf survival.

Using the binomial model with data after 2012, we found that elk populations have been relatively stable over the past 10 years, with estimated total population sizes averaging approximately 1,760 individuals (301 calves, 1,314 adult females, and 145 adult males) and arithmetic mean $\lambda = 1.010$ (95% CrI = 0.984 – 1.037; Figure 11). Model results suggested the annual proportion of individuals counted ranged from 0.82 (95% CrI = 0.67 – 0.98) to 0.92 (95% CrI = 0.82 – 0.99) with a 10-year mean of 0.87 (SD = 0.036).

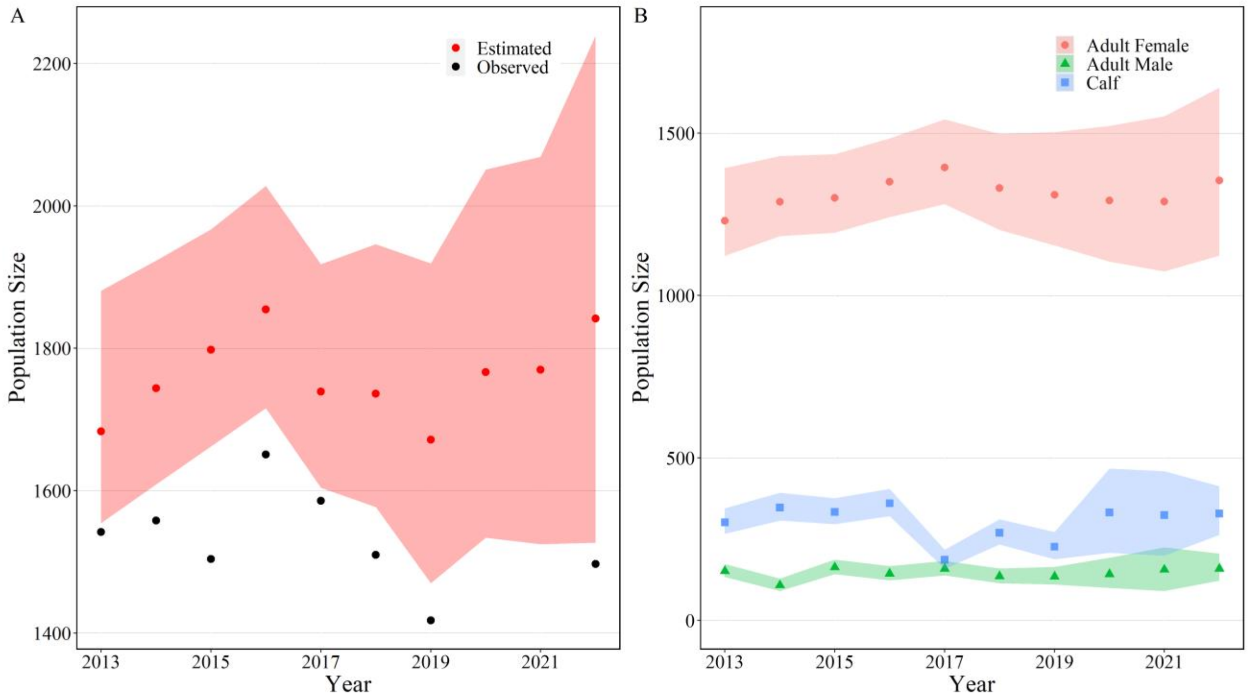


Figure 11. Total elk population estimates (A) and age/sex-specific estimates (B) in hunting district 121 from 2013 – 2022 based on a binomial count model. Red dots in panel A represent model estimates, while black dots represent observations from aerial counts. All values in panel B are model-estimated 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 – 2022 was 0.98 (95% CrI = 0.94 – 1.00), while mean annual natural survival of calves (<1 year old) was 0.27 (95% CrI = 0.94 – 1.00). Estimated mean harvest rates of adult females, adult males, and calves was 0.066 (95% CrI = 0.050 – 0.087), 0.49 (95% CrI = 0.42 – 0.56), and 0.017 (95% CrI = $2.75 * 10^{-5}$ – 0.086), respectively (Figure 12). The model-estimated pregnancy rate was 0.87 (95% CrI = 0.75 – 0.95).

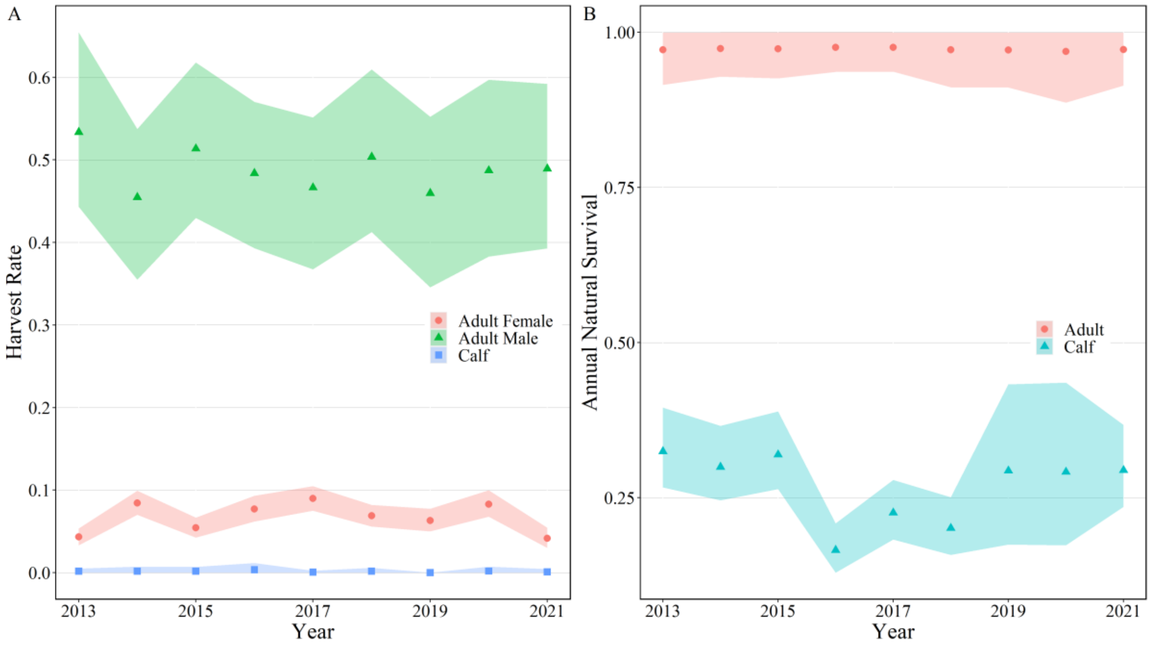


Figure 12. Estimated harvest rates of adult female, adult male, and calf elk (A) and estimated annual natural survival of adult and calf elk (B) from 2013 – 2021 in hunting district 121. Dots represent mean estimates and ribbons represent 95% credible intervals. Note: y-axis scales differ between panels to improve display.

We fit calf survival models with SWE, NDVI, and predator covariates, but removed precipitation covariates because they were highly correlated with NDVI. We also separated predator covariates into a separate model, given some correlations occurred between predator variables and NDVI/SWE, resulting in lack of model fit. Ultimately, calf survival models suggested there were not strong associations between abiotic/biotic covariates and calf survival over the past 10 years, given 95% credible intervals of all beta estimates eclipsed 0 (Figure 13).

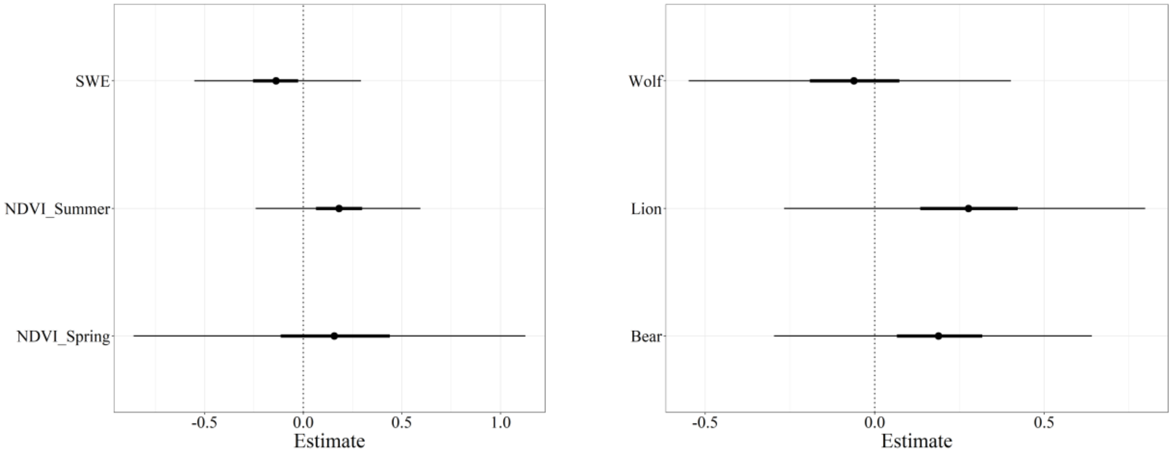


Figure 13. Beta coefficient estimates for covariates explaining annual natural calf survival in hunting district 121 from 2013 – 2022. Dots represent mean estimates, dark horizontal bars represent 50% credible intervals, and light horizontal bars represent 95% credible intervals. The vertical dotted line highlights a beta estimate of 0, suggesting no effect.

1.5 Discussion/Interpretation

Our results suggest that elk populations have been stable over the past decade and were approximately 13% higher than what was typically counted each year. Further, estimated elk demographic rates were consistent with rates documented in other elk literature; although, we did not find strong relationships between abiotic and biotic factors and calf survival like other studies (e.g., Eacker et al. 2016, Paterson et al. 2019). The lack of evidence for influential factors on calf survival is likely related to the relatively short time series we evaluated and the limited annual variability in calf survival and covariates during that period. Further, the discrepancy between annual counts and harvest estimates, as well as the current lack of data on calf survival in our study area, likely introduced additional uncertainty into estimates, ultimately making it difficult to identify any strong associations. The data we collect as part of this study in the coming years will hopefully reduce uncertainty in some of these parameters, making it possible to identify any factors associated with elk demographics and population dynamics.

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. As we demonstrated, interpretations of elk population trends over the past two decades differed significantly, depending on whether a Poisson or binomial distribution was used to describe the observation process. 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 (e.g., elk populations may be stable, but distributed in areas inaccessible to hunters in autumn) 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). Thus, we will wait to update the model with demographic information collected as part of this study (see Section 3) before making management recommendations.

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. 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 is to predict autumn elk distributions using information from past literature, then update the model with data collected as part of this study.

2.2 Data collection and analytical methods

Using existing published data, we developed a model predicting elk distribution during the autumn hunting seasons in HD 121, as well as the effects of habitat conditions and hunter access on distributions. First, we reviewed previous research evaluating factors affecting autumn elk distributions (e.g., Proffitt et al. 2013, 2016, Ranglack et al. 2017, DeVoe et al. 2019, Lowrey et al. 2020). Due to slight differences in covariates and analytical methods across studies, we decided to use results from Ranglack et al. (2017) in our predictive model, given the large sample size in that study (325 individual elk across 9 separate populations) and the relatively close proximity of their study area to ours (mostly southwest Montana).

We assembled the covariates included in the resource selection model from Ranglack et al. (2017) and produced rasters of each covariate for HD 121 (Table 2; Figure 14). Finally, we used covariate coefficient estimates from Ranglack et al. (2017; Table 3) to estimate the relative log-odds of elk selection during archery and rifle seasons across HD 121.

Table 2. Description of covariates used to predict elk resource selection during hunting seasons in hunting district 121.

Covariate	Description and Source
Access	Areas accessible to hunters (public lands and Block Management Areas [BMA]). Datasets come from Montana Cadastral ownership parcels and FWP BMA shapefiles.
Hunter effort	Hunter days/km^2 (hunting district-level). Obtained from FWP harvest reports (average from 2012-21).

Canopy cover	Percent forest canopy cover. Obtained from LANDFIRE 2020 Forest Canopy Cover (USGS 2022b).
Distance to road (archery)	Distance to open motorized routes during the archery season. Developed from a combination of FS and MDT roads layers.
Distance to road (rifle)	Distance to open motorized routes during the rifle season. Developed from a combination of FS and MDT roads layers.
Elevation	Elevation. Obtained from the National Elevation Dataset (using FedData package in R; Bocinsky 2023).
Slope	Percent slope. Calculated from elevation layer.
Snow water equivalent	Maximum snow water equivalent kg/m^2 during hunting seasons. Obtained from ORNL DAAC (using FedData package in R; Bocinsky 2023). Average from 2012-2022.
Solar radiation	Solar radiation. Calculated using the Area Solar Radiation tool and elevation layer in ArcMap (ESRI, Redlands, CA).
Time-integrated NDVI	Time-integrated normalized difference vegetation index. Obtained from USGS Remote Sensing Phenology (http://phenology.cr.usgs.gov/get_data_250w.php). Average from 2001 – 2015.

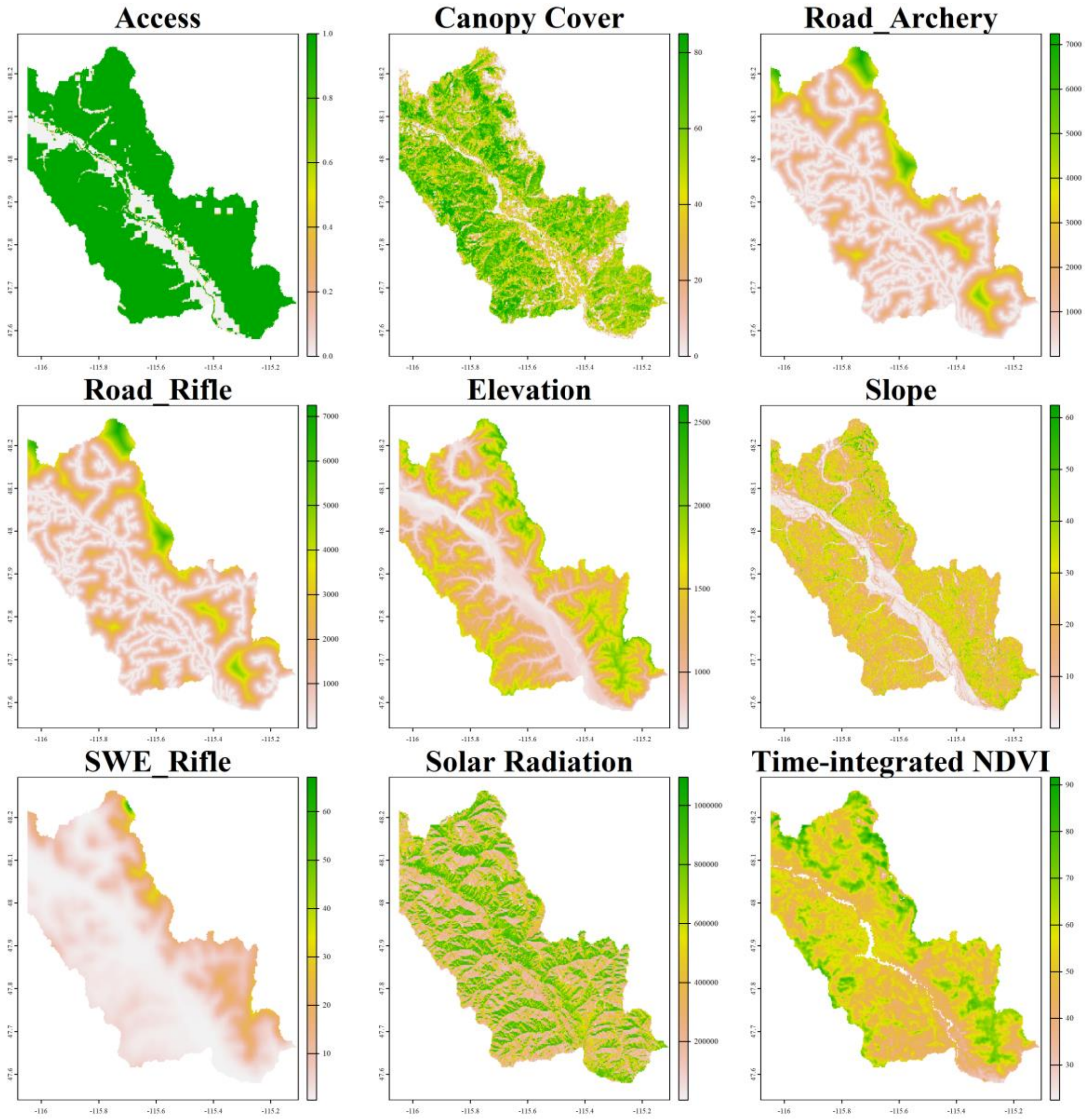


Figure 14. Rasters of covariates included in predictive models of elk resource selection during hunting seasons in hunting district 121.

Table 3. Functional form, spatial scale, standardized coefficient estimates, and 95% confidence intervals for the top regional model of archery season and rifle seasons female elk resource selection in southwestern Montana, USA, 2005 – 2014. Table adapted from Ranglack et al. (2017).

Season	Covariate	Functional Form Scale	Estimate	CI
Archery	Access	Binary; 30 m	−0.75	(−0.78, −0.72)
	Canopy cover	Pseudothreshold; 1km	0.55	(0.51, 0.60)
	Distance to road	Pseudothreshold; 30 m	0.43	(0.40, 0.47)
	Elevation	Quadratic; 30 m	−0.62	(−0.65, −0.59)

			0.87	(0.84, 0.90)
	Hunter effort	Linear; Hunting unit	−0.32	(−0.35, −0.30)
	Slope	Quadratic; 1 km	0.70	(0.67, 0.72)
			−0.51	(−0.55, −0.47)
	Solar radiation	Quadratic; 1 km	0.55	(0.53, 0.58)
			0.02	(0.00, 0.05)
	Time-integrated NDVI	Pseudothreshold; 250 m	0.63	(0.61, 0.66)
	Canopy cover × access		1.28	(1.20, 1.36)
	Distance to route × access		0.25	(0.21, 0.30)
	Distance to route × canopy cover		−0.42	(−0.51, −0.32)
	Distance to route × hunter effort		0.95	(0.91, 1.00)
	Distance to route × NDVI		−0.63	(−0.69, −0.58)
Rifle	Access	Binary; 30 m	−0.93	(−0.96, −0.91)
	Canopy cover	Pseudothreshold; 1 km	0.41	(0.37, 0.44)
	Distance to road	Pseudothreshold; 30 m	0.73	(0.68, 0.78)
	Elevation	Quadratic; 1,000 m	−1.14	(−1.19, −1.09)
			0.34	(0.31, 0.38)
	Hunter effort	Pseudothreshold; Unit	0.19	(0.16, 0.21)
	Slope	Quadratic; 1,000 m	1.11	(1.07, 1.15)
			−1.06	(−1.11, −1.02)
	Snow water equivalent	Linear; 1,000 m	−0.26	(−0.30, −0.23)
	Solar radiation	Quadratic; 1,000 m	0.66	(0.62, 0.71)
			−0.34	(−0.37, −0.30)
	Canopy cover × access		0.39	(0.34, 0.45)
	Distance to route × access		−0.46	(−0.52, −0.39)
	Distance to route × canopy cover		−0.29	(−0.38, −0.20)
	Distance to route × hunter effort		1.15	(1.11, 1.19)
	Distance to route × SWE		−0.47	(−0.50, −0.43)

2.3 Results and Discussion

During both archery and rifle seasons, the resource selection model predicted elk were most likely to select areas with high canopy cover and limited public access. This pattern was accentuated during rifle season, when elk were also predicted to avoid high elevations with snow cover (Figure 15).

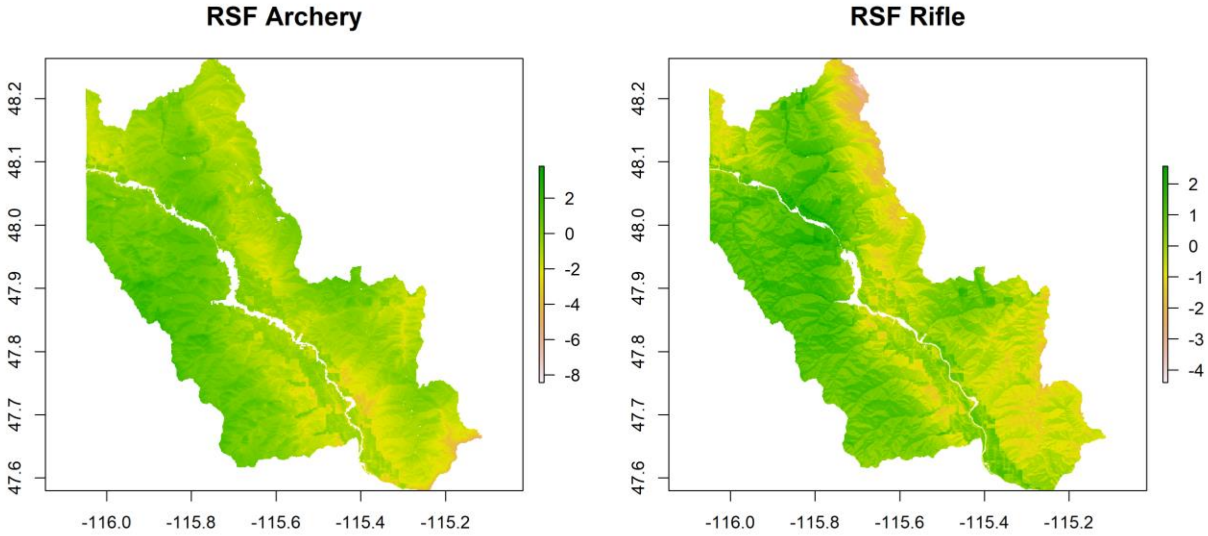


Figure 15. Relative log-odds of elk selection during archery and rifle seasons in hunting district 121, based on model coefficients from Ranglack et al. (2017). Green colors represent higher log-odds of selection.

While we expect to find similar patterns of selection in HD 121 once data is collected (e.g., elk selecting areas to avoid human harvest), we caution interpretation of these predictive maps at this time, given the differences in landscapes among study areas. For example, the average canopy cover across populations studied in Ranglack et al. (2017) was ~24% and elevations averaged ~2,077 m. In contrast, average canopy cover and elevation was ~47% and 1,251 m in HD 121, respectively. Resource selection is often a function of resource availability (Mysterud and Ims 1998, Gillies et al. 2006); thus, we could observe different selection patterns for these resources in our study area. Further, other attributes not included in Ranglack et al. (2017), such as timber harvest and predator use, may be important predictors of elk selection in HD 121. Thus, this model will be refined and updated with data collected on elk locations, forage resources, and carnivore distributions within HD 121 during 2023 – 2025 (see Section 3). This updated model will then be used to predict elk resource selection in HD 121 and across Region 1.

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 21, 2022 to March 9, 2023, we captured male and female elk >6 months old by a combination of Clover trapping (Thompson et al. 1989; Figure 16) 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, transmit a mortality notification 6 hours post-mortality, and drop off after 3 years.

Figure 16. Female elk captured and chemically immobilized in a Clover trap in winter 2022-23.

We calculated ingesta-free body fat (IFBF) for captured animals from measurements of chest girth and scaled estimates of maximum rump fat obtained using a portable ultrasound machine, when available (Cook et al. 2010, Cook et al. 2016). IFBF represents an index of nutritional resources acquired by individuals and reflects forage quality within individuals' ranges. We assessed lactation status of females during the December captures, but not during the February 2023 captures because some calves were weaned by that time. We assessed pregnancy of adult females at the time of capture by rectal palpation (Greer and Hawkins 1967). 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 collected 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.

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).

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, we located, captured, and collared neonatal elk calves following approved University of Montana animal capture protocols (003-23JMWB-011823). To locate and capture neonatal calf elk, we monitored VITs (see Section 3.2.1) for expulsion from the adult female elk during parturition, we monitored collars for evidence of a birthsite, and we opportunistically searched calving areas. Within 12 hours of being alerted of a VIT expulsion (Turnley et al. 2022), a capture crew of 2-4 people investigated the area around the expulsion, using telemetry to locate both the VIT/parturition site and the collared female. Not all collared females received VITs, so we also monitored GPS locations of collared pregnant elk without VITs daily and sent ground crews to investigate when elk locations started to "cluster", suggesting a parturition event. Finally, we used a helicopter for 5 days to help locate "opportunistic" neonates associated with uncollared females 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 will collect GPS location data for up to one year or until the collar breaks off (model VERTEX Mini Fawn-1C GLOBALSTAR; VECTRONIC Aerospace Inc.; Figure 17). All GPS collars had a mortality sensor that sent a mortality signal if the GPS collar remained motionless for ≥ 6 hours.

Figure 17. Capture and collaring of elk neonates in hunting district 121 in May and June 2023.

We searched neonate mortality sites and documented all signs of predation including tracks, scat, and hair samples (Smith et al. 2006, Eacker et al. 2016). We performed field necropsies and recorded measurements about puncture wounds, claw marks, bite marks, and patterns of consumption. We also swabbed bite mark locations to collect DNA samples from saliva for carnivore species identification. We classified mortality events as predation only if there was internal hemorrhaging and no possible non-predation cause of mortality.

3.2.3 Mountain Lion Capture and Monitoring

During winter 2022-23, 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 18).

Figure 18. Mountain lion capture and collaring in hunting district 121 in winter 2022-23.

3.2.4 Wolf Capture and Monitoring

During summer and fall 2022, 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, 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 19).

Figure 19. 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 1-1.5 meters off the ground at optimal angles for elk and target predator species (Figure 20). 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.

We will switch camera batteries and SD cards twice a year (autumn and spring) and will run all photos through an AI photo classifier that uses Microsoft's MegaDetector model in Python to identify empty photos (Beery et al. 2019, Fennell et al. 2022). We will accept photos that have at least 75% confidence of the photo being 'empty'. The photos classified as potentially having an animal present will then be reviewed and classified to species, and the total number of each species present in each photo will be counted.

Figure 20. Trail camera deployment in hunting district 121 during May and June 2023.

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

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 (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 21). 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 21), with the intention to visit each location once from May-August 2023.

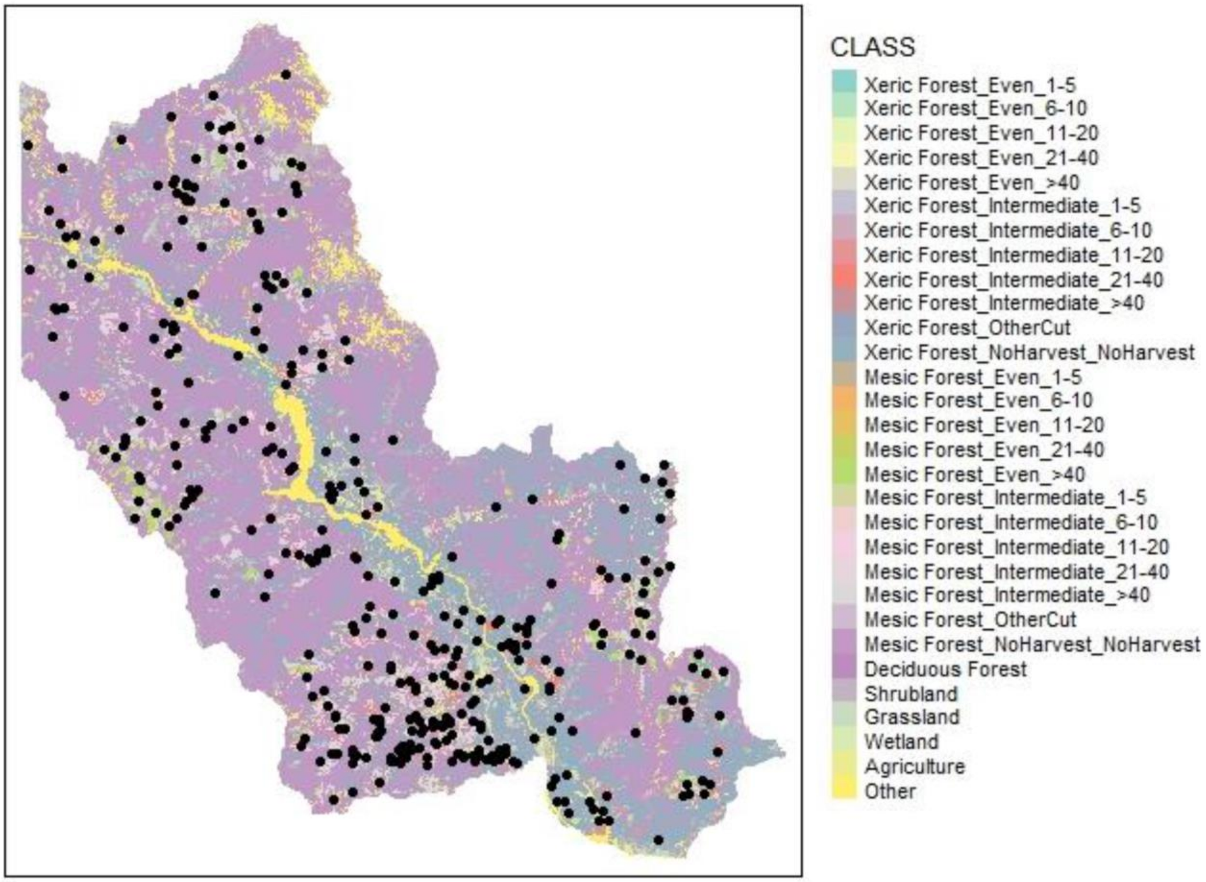


Figure 21. Reclassified landcover strata in hunting district 121 incorporating generalized landcover category, timber harvest strategy, and time-since-harvest. Black dots represent potential vegetation sites randomly selected by strata. The Xeric Forest_OtherCut, Mesic Forest_OtherCut, Deciduous Forest, Wetland, and Other strata were not included in the sampling stratification because of their low prevalence and/or inability to be sampled.

We measured forage quantity and quality at each random 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 (Figure 22). 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 22. Vegetation sampling in hunting district 121 in summer 2023.

To evaluate forage quality, we recorded phenology (emergent, flowering, fruiting, and cured/mature) at these plots and collected 5-10 g (dried) samples of each understory forage species in each stage of phenology for lab analysis. We dried samples for 24-48 hours at 40-60 °C within 24 hours of collection. Forage species will be identified via DNA metabarcoding of elk fecal pellets (see below). In lieu of those data, our initial forage species lists were informed by data collected in nearby systems in recent years (Proffitt et al 2016, Snobl et al 2022). The results from the vegetation analysis lab will be combined with the estimated cover percentages of each species in each phenological stage at a plot to estimate the mean digestible energy (kcal/g) at each sampling point.

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 homogenized and froze composite samples in a liquid salt-based RNA stabilizer. Samples will be sent to the Species From Feces – Bat Ecology and Genetics Lab at Northern Arizona University, where they will use DNA metabarcoding to determine the plant species composition within the pellets.

Using these data, we will create separate predictive models for early (May-June) and late (July-August) summer forage quantity and quality, given the nutritional needs of elk vary greatly by season (Toweill and Thomas 2002).

3.3 Results as of July 31, 2023

3.3.1 Adult Elk Capture and Monitoring

In winter 2022-23, we captured and collared 71 elk (54 adult females, 6 female calves, 7 adult males, 4 male calves; Figure 23). 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 = 77.1% - 95.8%), which is similar to the state-wide average (87%). We have not yet received cementum aging results.

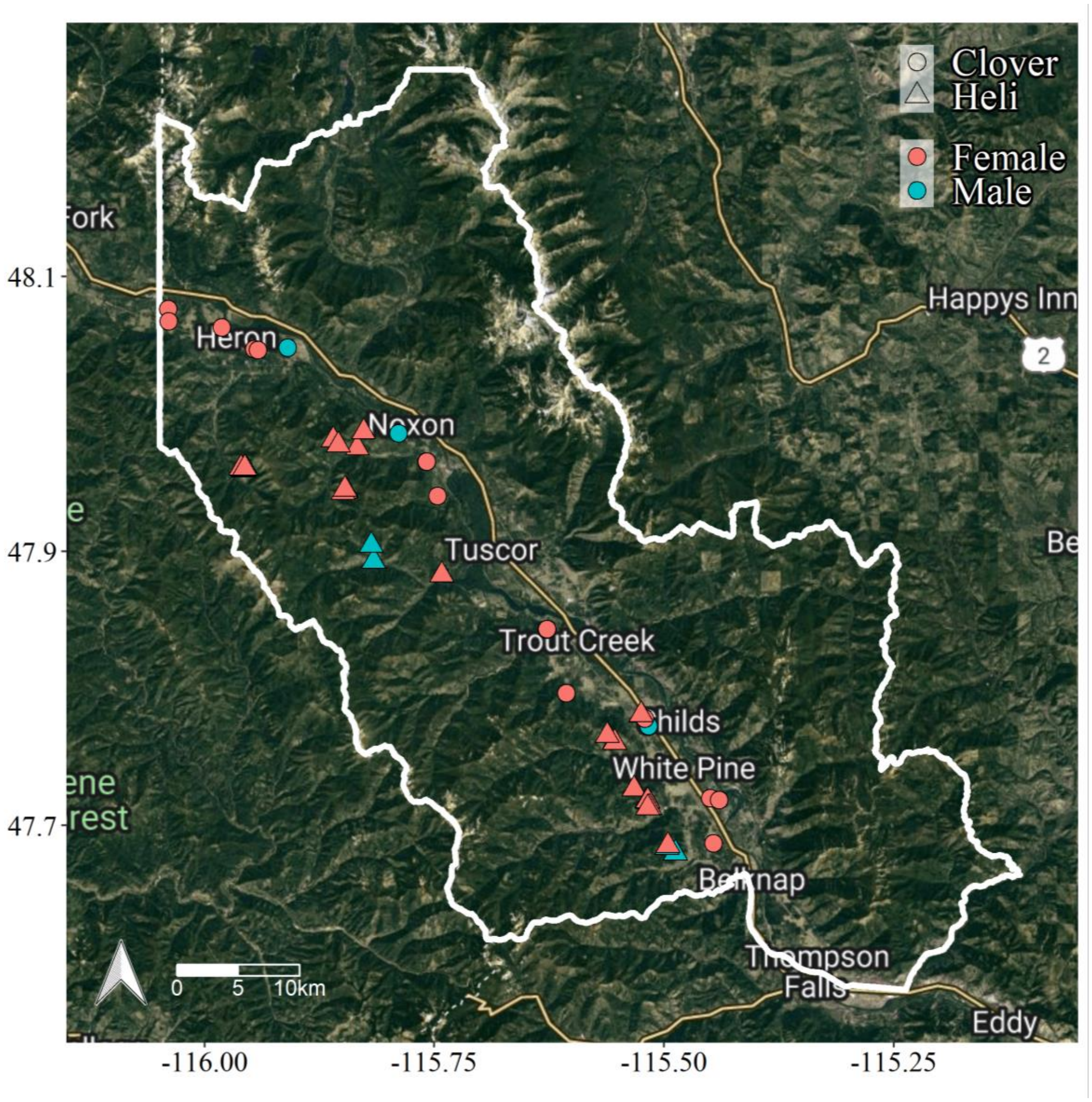


Figure 23. Locations of female (red) and male (blue) elk captures in hunting district 121 (white outline) in winter 2022-23. Elk were captured via Clover trap (circles) and helicopter (triangles) methods. Some captures occurred close together, so locations are difficult to differentiate on the map.

The serology screening 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 4). 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 I.

Table 4. 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

After removing locations with dilution of precision >10, suggesting poor accuracy (~2.3% of locations; D’Eon and Delparte 2005), we collected a total of 33,557 locations from 60 female elk and 5,545 locations from 11 male elk in winter (December 21, 2022 – March 31, 2023); 59,721 locations from 58 female elk and 10,911 locations from 11 male elk in spring (April 1 – June 30, 2023); and 18,995 locations from 58 female elk and 3,428 locations from 10 male elk in summer (July 1 – July 31, 2023; Figure 24).

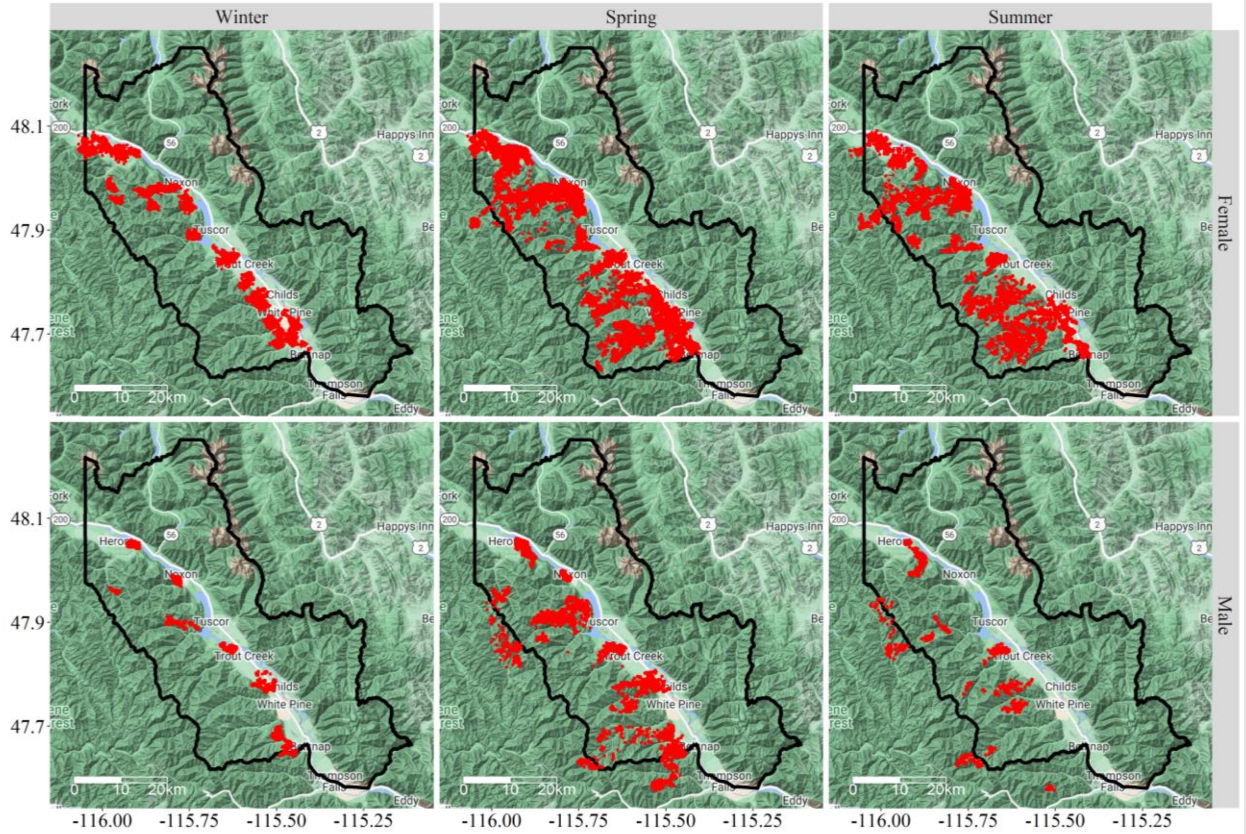


Figure 24. Winter (December 21, 2022 – March 31, 2023), spring (April 1 – June 30, 2023), and summer (July 1 – July 31, 2023) locations (red dots) of male and female elk captured in hunting district 121 (black outline). Winter locations included 60 females and 11 males; spring locations included 58 females and 11 males; and summer locations included 58 females and 10 males.

As of July 31, 2023, 1 female calf mortality occurred due to natural causes attributed to poor body condition. Two mortalities (1 adult female and 1 female calf) occurred during Clover trapping due to capture myopathy, but these individuals were never included in the sample. Two collars (one male and one female) have malfunctioned after deployment (stopped collecting and transmitting locations).

3.3.2 Neonate Elk Capture and Monitoring

We captured and collared 25 elk neonates (16 males and 9 females) in May and June 2023 (Figure 25). Most neonates collared were associated with collared females (*n* = 16); however, we also collared 9 opportunistic neonates not associated with a collared female. Neonate weights averaged 18.4 kg (SD = 4.5) for males and 17.1 kg (SD = 2.7) for females, and average age at capture was ~1.7 days (range = 0 – 4 days).

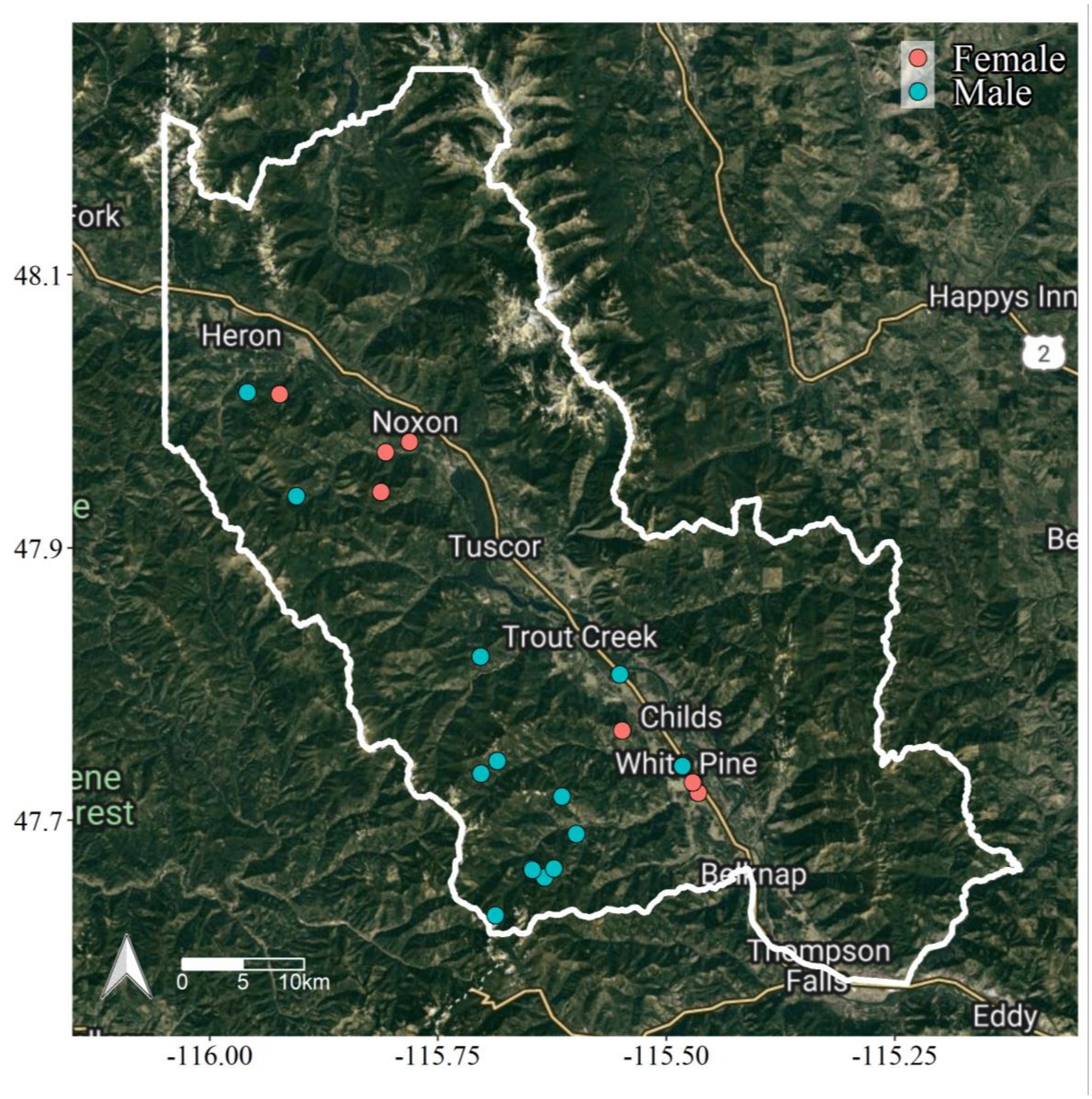


Figure 25. Locations of female (red) and male (blue) elk neonate captures in hunting district 121 (white outline) in May and June 2023.

As of July 31, 2023, we were monitoring 17 neonates. Three collared neonates died (one mountain lion predation, one black bear predation, and one unknown cause) and five collars fell off prematurely, resulting in unknown neonate status. All other collared neonates are alive and collars are functioning properly.

3.3.3 Mountain Lion Capture and Monitoring

During January and February, 2023, we captured and collared 3 adult female mountain lions. As of July 31, 2023, we have collected a total of 1,131 locations from these individuals in winter, 1,541 locations in spring, and 509 locations in summer (Figure 26). All tagged mountain lions are alive and no collars have malfunctioned.

These data will be used to provide information regarding space use and survival of mountain lions in the region.

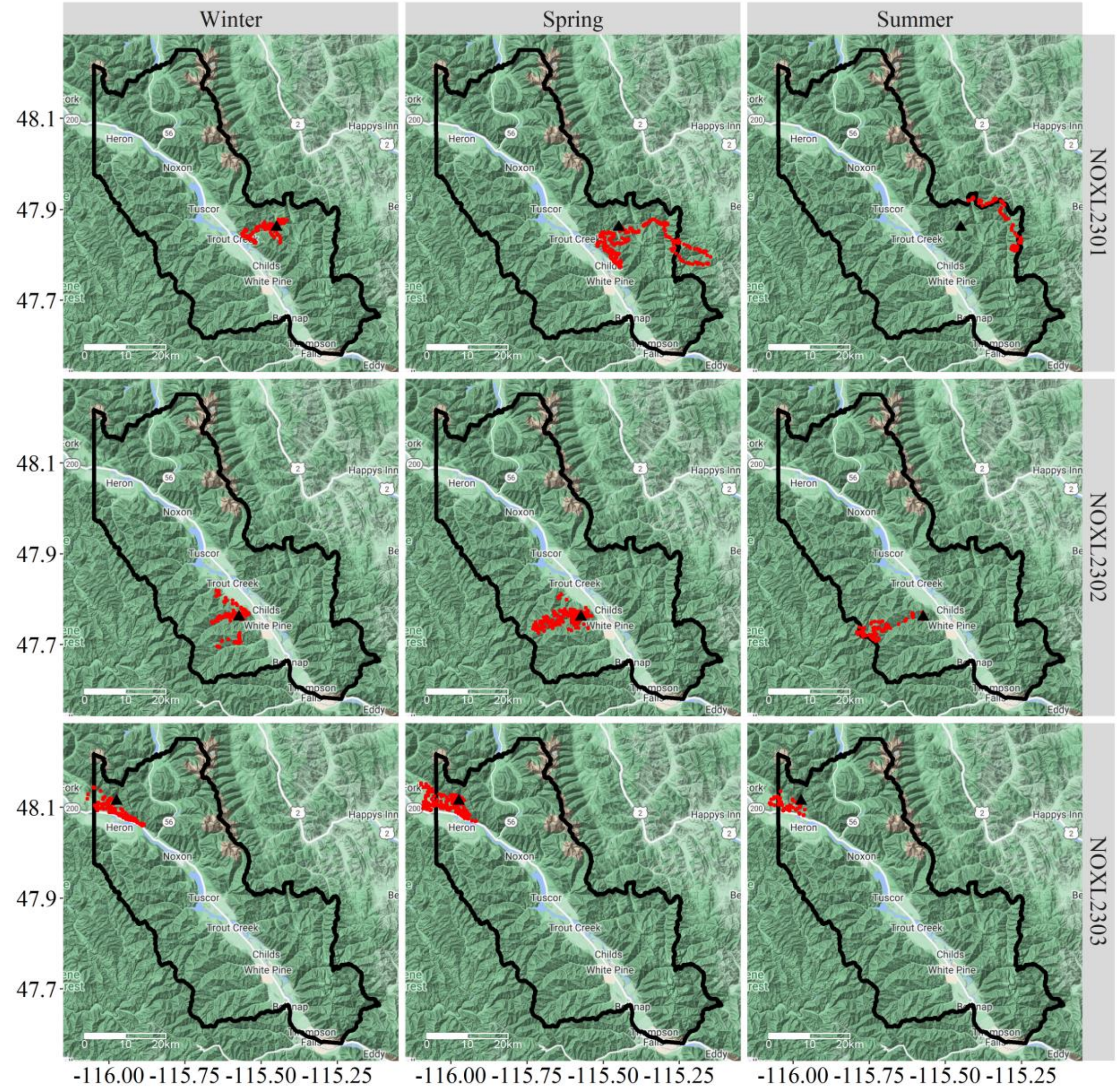


Figure 26. Winter (January 6 – March 31, 2023), spring (April 1 – June 30, 2023), and summer (July 1 – July 31, 2023) locations (red dots) of the 3 adult female mountain lions captured in hunting district 121 (black outline). Black triangles represent the capture location for each individual.

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. We were unable to locate and capture wolves aerially.

3.3.5 Black Bear Capture and Monitoring

As of July 31, 2023, we captured 1 female and 2 male black bears and collected 436 locations (96 in spring and 340 in summer) from these individuals (Figure 27). All bears are currently alive and collars are working properly. These data will be used to provide information regarding space use and survival of black bears in the region.

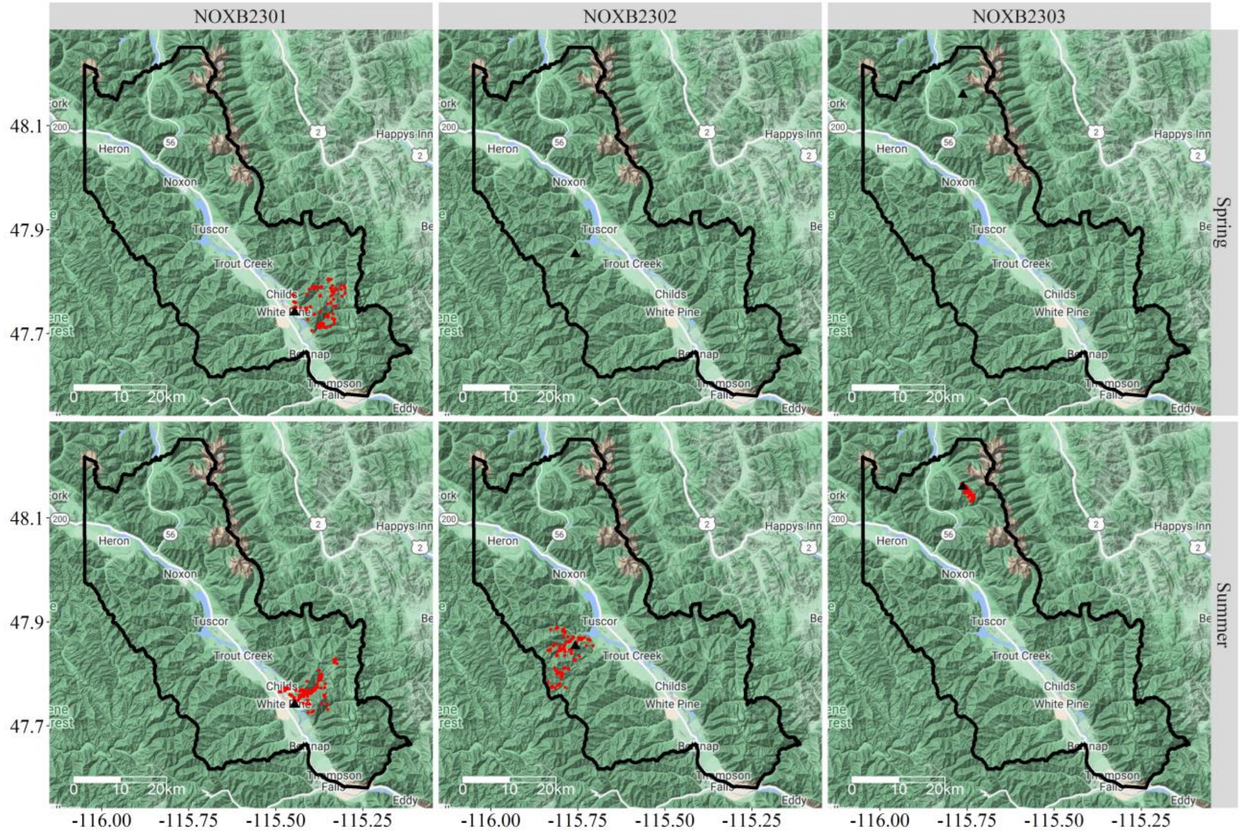


Figure 27. Spring (April 1 – June 30, 2023) and summer (July 1 – July 31, 2023) locations (red dots) of the 3 black bears captured in hunting district 121 (black outline). Black triangles represent the capture location for each individual.

3.3.6 Trail Camera Placement

In May and June 2023, we deployed 80 random cameras and 39 predator cameras paired with the random cameras across HD 121 (Figure 28). These cameras will be serviced and the remaining cameras deployed in September/October 2023. We will use photo data to estimate abundance of elk, mountain lions, black bears, and wolves in HD 121 using "space to event" methods (Moeller et al. 2018).

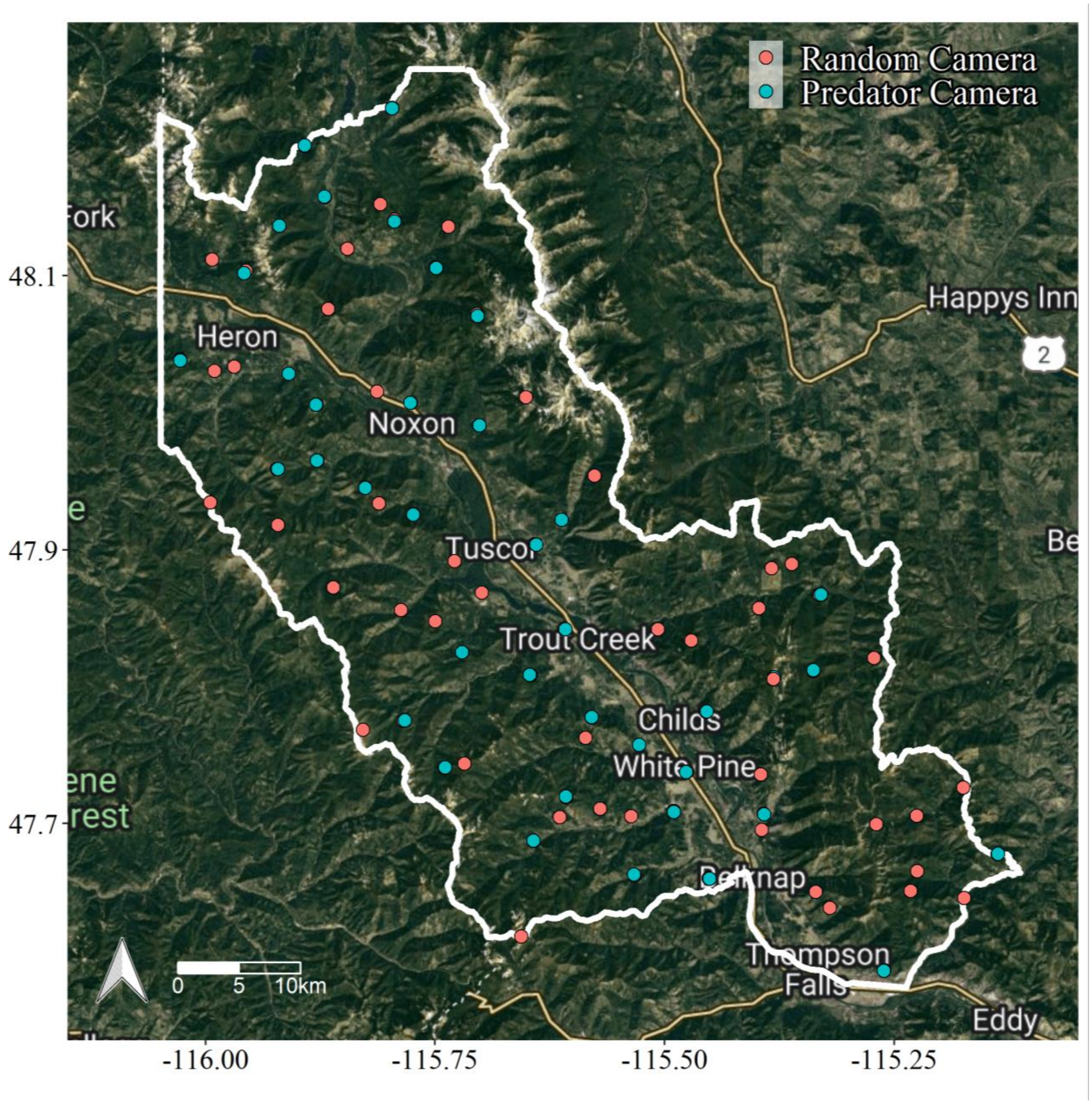


Figure 28. Location of random (red) and predator trail cameras (blue) in hunting district 121 in summer 2023. Each predator camera was paired with a random camera within 250 m, so these locations are largely overlapping in the map.

3.3.7 *Vegetation Surveys*

From May – July 31, 2023, we measured vegetation at 172 sites (ranging from 2 – 14 sites per landcover strata) and collected fecal pellet samples at 38 sites (ranging from 2 – 5 samples per week; Figure 29). These data will be analyzed in winter 2023-24.

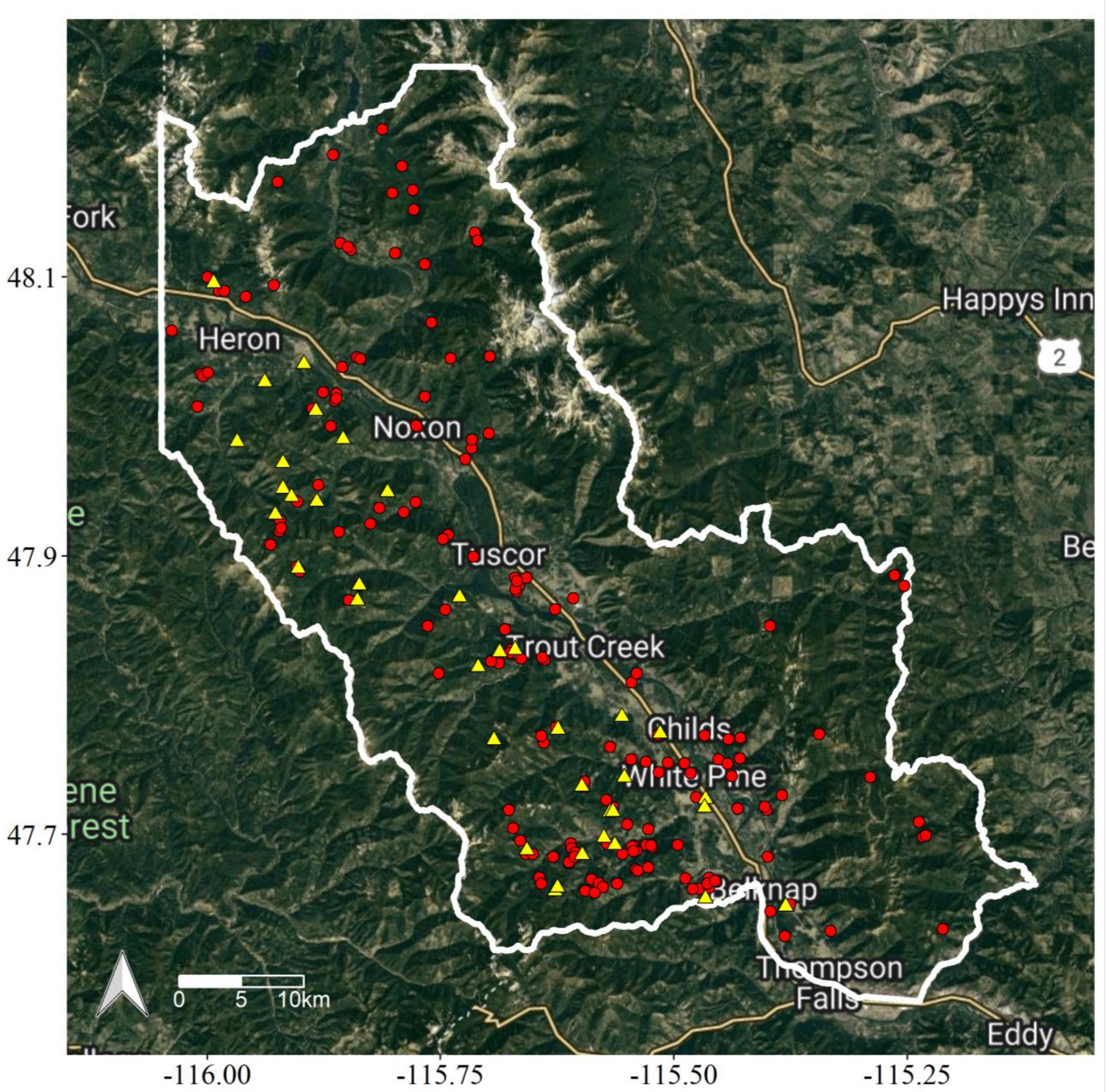


Figure 29. Locations of vegetation (red circles) and fecal pellet samples (yellow triangles) collected within hunting district 121 (white outline) from May – July 31, 2023.

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 historic IPM described in section 1 and facilitate management actions in Region 1 (Figure 30). However, given we are in the first year of the study, we have not yet fulfilled this objective.

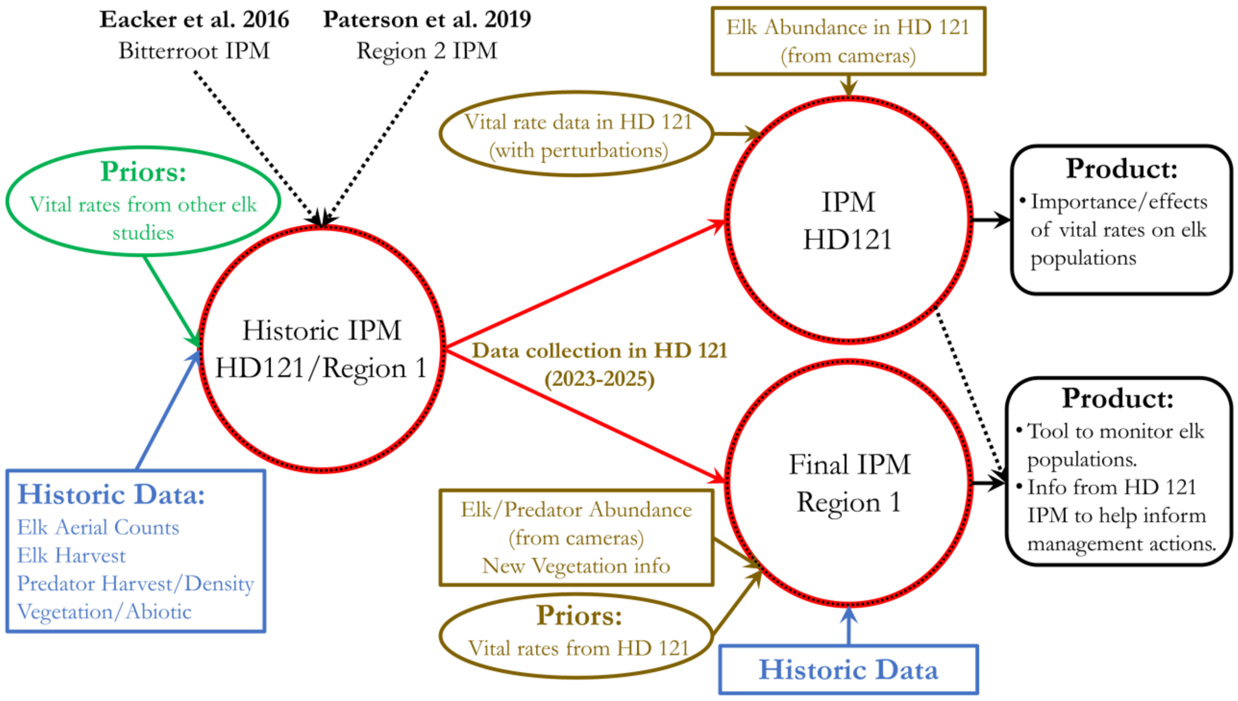


Figure 30. Diagram describing the workflow of our study as it relates to the population model(s) and desired outputs. Red areas represent integrated population models (IPM; all similar structure), green areas represent prior information from previous studies, blue areas represent historic datasets, gold areas represent new data from this study, and black areas represent desired products. In short, we will build upon the historic IPM 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 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 I: 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.

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