C O L O R A D O   P A R K S   &   W I L D L I F E

Wildlife Research Reports

MAMMALS – JANUARY 2024

WILDLIFE RESEARCH REPORTS

JANUARY–DECEMBER 2023

MAMMALS RESEARCH PROGRAM

COLORADO PARKS AND WILDLIFE
Research Center, 317 W. Prospect, Fort Collins, CO 80526

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EXECUTIVE SUMMARY

This Wildlife Research Report represents summaries (≤5 pages each with tables and figures) of wildlife research projects conducted by the Mammals Research Section of Colorado Parks and Wildlife (CPW) during 2023. These research efforts represent long-term projects (4–10 years) in various stages of completion addressing applied questions to benefit the management and conservation of various mammal species in Colorado. In addition to the research summaries presented in this document, more technical and detailed versions of most projects (Annual Federal Aid Reports) and related scientific publications that have thus far been completed can be accessed on the CPW website at http://cpw.state.co.us/learn/Pages/ResearchMammalsPubs.aspx or from the project principal investigators listed at the beginning of each summary.

Current research projects address various aspects of wildlife management and ecology to enhance understanding and management of wildlife responses to habitat alterations, human-wildlife interactions, and investigating improved approaches for wildlife population monitoring and management. The Nongame Mammal Conservation Section addresses ongoing monitoring of lynx in the San Juan mountain range and preliminary results addressing influence of forest management practices on snowshoe hare density in Colorado. The Ungulate Management and Conservation Section includes a pilot evaluation of moose and elk behavioral response to recent wolf establishment in North Park, Colorado, an evaluation of factors influencing elk calf recruitment, two studies addressing elk response to human recreation, and a summary of publication results addressing Colorado moose ecology and management from 2013–2020. The Predatory Mammal Management and Conservation Section describes onging research addressing bobcat population dynamics and density estimation, mule deer survival and cougar conflict response to cougar population manipulation, and evaluation of accelerometer collars and methods development for domestic cattle to eventually address cattle response to wolf activity during wolf establishment. The Support Services section provides annual updates from the CPW Research Library and ongoing database development from the Research and Species Conservation Database Analyst/Manager.

In addition to the ongoing project summaries described above, Appendix A includes publication abstracts (<1 page summaries) completed by CPW research staff since December 2022. These scientific publications provide results from recently completed CPW research projects and other collaborations with universities and wildlife management agencies. Topics addressed include small mammal species ecology and conservation (impacts of spruce beetle outbreaks on showshoe hares and red squirrels), ungulate ecology and management (genomic correlates for migratory direction in mule deer and plant and mule deer responses to 3 mechanical treatment methods), and approaches for wildlife population monitoring (multistage hierarchical capture–recapture models, evaluation of camera model and alignment for paired-camera stations, an approach to select surrogate species for connectivity conservation, and an assessment of intensity of use to understand animal movement behavior).

We have benefitted from numerous collaborations that support these projects and the opportunity to work with and train wildlife technicians and graduate students that will likely continue their careers in wildlife management and ecology in the future. Research collaborators include the CPW Wildlife Commission, statewide CPW personnel, Federal Aid in Wildlife Restoration, Colorado State University, University of Wyoming, Western Illinois University, Southern Illinois University, Trent University, University of Rhode Island, U.S. Bureau of Land Management, U.S. Forest Service, CPW big game auction-raffle grants, Species Conservation Trust Fund, Great Outdoors Colorado, CPW Habitat Partnership Program, Rocky Mountain Elk Foundation, and numerous private land owners providing access to support field research projects.

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TABLE OF CONTENTS
MAMMALS WILDLIFE RESEARCH REPORTS

NONGAME MAMMAL CONSERVATION

CANADA LYNX MONITORING IN COLORADO 2022-2023 by J. Ivan, T. Brtis, and L. McCurdy…………………………………………………………………………………………... 2

INFLUENCE OF FOREST MANAGEMENT ON SNOWSHOE HARE DENSITY IN LODGEPOLE AND SPRUCE-FIR SYSTEMS IN COLORADO by J. Ivan……………………..7

UNGULATE MANAGEMENT AND CONSERVATION

PILOT EVALUATION OF PREY DISTRIBUTION AND MOOSE RECRUITMENT FOLLOWING EXPOSURE TO WOLF PREDATION RISK IN NORTH PARK, COLORADO by E. Bergman and E. Brandell……………………………………………………………..... 11

EVALUATING FACTORS INFLUENCING ELK RECRUITMENT IN COLORADO by N. Rayl, M. Alldredge, and C. Anderson…..…………………………………………………... 14

RESPONSE OF ELK TO HUMAN RECREATION AT MULTIPLE SCALES: DEMOGRAPHIC SHIFTS AND BEHAVIORALLY MEDIATED FLUCTUATIONS IN ABUNDANCE by E. Bergman and N. Rayl………………………………………………….. 19

SPATIOTEMPORAL EFFECTS OF HUMAN RECREATION ON ELK BEHAVIOR: AN ASSESSMENT WITHIN CRITICAL TIME STAGES by N. Rayl, E. Bergman, and J. Holbrook………………………………………………………………………………………. 22

EVALUATION AND INCORPORATION OF LIFE HISTORY TRAITS, NUTRITIONAL STATUS, AND BROWSE CHARACTERISTICS IN SHIRA'S MOOSE MANAGEMENT IN COLORADO by E. Bergman………………………………………………………………… 25

PREDATORY MAMMAL MANAGEMENT AND CONSERVATION

BOBCAT POPULATION DYNAMICS AND DENSITY ESTIMATION by S. Frank, J. Ivan, M. Vieira, and J. Runge.…..31

MULE DEER POPULATION RESPONSE TO COUGAR POPULATION MANIPULATION by M. Alldredge, A. Vitt, B. Lamont, T. Woodward, J. Grigg, and C. Anderson…………………...33

EVALUATION OF ACCELEROMETER COLLARS AND METHODS DEVELOPMENT FOR DOMESTIC CATTLE by E. Brandell…………………………………………………………36

SUPPORT SERVICES

RESEARCH LIBRARY ANNUAL REPORT 2023 by K. Hertel………………………………40

RESEARCH DATABASE SUPPORT SERVICES by B. Wasserstein…………………………41

APPENDIX A. MAMMALS RESEARCH PUBLICATION ABSTRACTS

SMALL MAMMAL ECOLOGY AND CONSERVATION……………………………………. 45

UNGULATE ECOLOGY AND MANAGEMENT.. 46

APPROACHES FOR WILDLIFE POPULATION MONITORING... 47

NONGAME MAMMAL CONSERVATION

CANADA LYNX MONITORING IN COLORADO 2022-2023

INFLUENCE OF FOREST MANAGEMENT ON SNOWSHOE HARE DENSITY IN LODGEPOLE AND SPRUCE-FIR SYSTEMS IN COLORADO

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Canada lynx monitoring in Colorado 2022 – 2023

Period Covered: December 1, 2022 – April 30, 2023

Principal Investigators: Jake Ivan, Jake.Ivan@state.co.us; Tim Brtis; Lori McCurdy

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In an effort to restore a viable population of Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999−2006. In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success and that the population of Canada lynx in the state was apparently viable and self-sustaining. In order to track the persistence of this new population and thus determine the long-term success of the reintroduction, a minimally-invasive, statewide monitoring program is required. From 2014−2023 CPW initiated a portion of the statewide monitoring scheme described in Ivan (2013) by completing surveys in a random sample of monitoring units (n = 50) from the San Juan Mountains in southwest Colorado (n = 179 total units; Figure 1).

During the 2022−2023 winter, personnel from CPW and USFS completed the ninth year of monitoring work on this same sample. Thirteen units were sampled via snow-tracking surveys conducted between December 1 and March 31. On each of 1–3 independent occasions, survey crews searched roadways (snow-covered paved roads and logging roads) and trails for lynx tracks. Crews searched the maximum linear distance of roads possible within each survey unit given safety and logistical constraints. Each survey covered a minimum of 10 linear kilometers (6.2 miles) distributed across at least 2 quadrants of the unit. Thirty-five units could not be surveyed via snow tracking. Instead, survey crews deployed 4 passive infrared motion cameras in each of these units during fall 2022. Cameras were lured with visual attractants and scent lure to enhance detection of lynx in the area. Cameras were retrieved during summer or fall 2023 and all photos were archived and viewed by at least 2 observers to determine species present in each. Camera data were then binned such that each of 10 15-day periods from December 1 through April 30 was considered an 'occasion,' and any photo of a lynx obtained during a 15-day period was considered a 'detection' during that occasion.

Surveyors covered 730 km during snow tracking surveys and detected 10 lynx tracks at 5 units (Table 1). This is a slight increase over the program-low of 6 tracks in 4 units observed in 2021–22. Lynx were detected via camera sampling in only one unit during the 2023–23 survey season, which is two fewer units than the previous program low for cameras, which was observed in 2020–21. Snow depths during the 2022–23 season were among the highest ever recorded and a number of cameras were buried for days to weeks, which could have resulted in fewer lynx detections. Also, after 9 seasons of sampling, perhaps resident individuals are developing fatigue to the lures used on the project. In response to the potential for lure fatigue, 117 cameras were passively (i.e., no lure) deployed along roads, trails, and other potential travel routes during fall 2023 in 16 camera units that have had lynx detections in the past. Deployments followed protocols established by (King et al. 2020) and (Anderson et al. 2023). These cameras will be retrieved in summer 2024. Detections at these deployments, and not at traditional camera stations in the same unit, would support the notion that lynx are exhibiting lure fatigue, and future sampling could switch to passive sampling to capture lynx moving along natural travel routes rather than luring them to a predetermined camera set. Given the program-low in snowtracking detections in 2021–22, and program-low in camera detections this season (2022–23), it is also possible that lynx distribution declined sharply over the past two survey seasons, which would indicate a decline in the population as well.

Lynx were once again detected during snowtrack surveys at Molas Pass and South Mineral, after having gone undetected there in 2021–22. Cameras picked up lynx near Wolf Creek Pass for only the 3rd time in 9 years of sampling, but failed to detect lynx at Rio Grand Reservoir, Lizard Head Pass, and Conejos Peak for only the 2nd or 3rd time since the monitoring program began (Figure 1).

We used the R package (R Development Core Team 2018) 'RMark' (Laake 2018) to fit multiple-season (i.e., "dynamic") occupancy models (MacKenzie et al. 2006) to our survey data using program MARK (White and Burnham 1999). Thus, we estimated the derived probability of a unit being occupied (ψ), or used, by lynx over the course of the winter, along with the probability of detecting a lynx (*p*) given that the unit was occupied, the probability a unit that was unused in one year was used the next (i.e., "local colonization," γ), and the probability a used unit became unused from one year to the next (i.e., "local extinction," ε). For each model we fit for the analysis, we specified that the initial ψ in the time series should be a function of the proportion of the unit that is covered by spruce/fir forest – the single most important and consistent predictor of ψ in past analyses. For sake of comparison we fit a base model in which *p* was specified to be constant for the duration of the survey. However, based on previous work, we considered several other structures for *p* we anticipated would fit better. We fit models that specified 1) *p* could vary by survey method (i.e., detection could be different for cameras compared to snowtracking), 2) *p* could be higher during breeding season when lynx tend to move more and are therefore more likely to be detected by track or at a camera, and 3) *p* for cameras deployed from 2017–21 could be different than *p* for other years due to the lure substitution. Additionally we fit a model in which the effect of breeding season was only allowed to act on cameras, not snowtracking. We allowed annual estimates of ε and γ to be different each year (i.e., assuming occupancy dynamics were not random but instead dependent on the year previous and the population is not at equilibrium), which allowed derived ψ to vary as freely as possible given the data. We used Akaike's Information Criterion (AIC), adjusted for small sample size (Burnham and Anderson 2002) to identify the best-fitting model from this small set. Ultimately, we fit a linear model through the time series of ψ estimates to estimate the slope of the trend in occupancy through time. Ideally we would test other predictions of lynx occupancy to see, for instance, if colonization or extinction were influenced by bark beetles, fire, or the presence of competitors or prey species. However, we do not currently have enough data to test these predictions in addition to assessing trend, which is the highest priority.

As has been the case since the inception of our monitoring program, the proportion of the sample unit covered by spruce-fir forest was positively associated with the initial occupancy estimate in the time series. Even though local colonization and extinction were allowed to vary freely from year to year, annual estimates were near zero and varied little (ε = 0.00–0.11; γ = 0.00–0.10) up until the most recent 2 seasons when extinction probability was high ($\varepsilon_{21\text{–}22}$ = 0.36, SE = 0.18; $\varepsilon_{22\text{–}23}$ = 0.73, SE = 0.17). Accordingly, derived occupancy was relatively stable across years (ψ = 0.25–0.34), but dropped to the lowest level observed to date this past season (ψ = 0.11, SE = 0.05). The slope of the trend in occupancy through time was slightly negative but not statistically different from zero (β = -0.007, SE = 0.01; Figure 2). Similar to previous years, detection probability was relatively high for snow tracking surveys (*p* = 0.65, SE = 0.06), lower for camera surveys (*p* = 0.22, SE = 0.03) using Pikauba, and lowest for camera surveys utilizing Violator 7 (*p* = 0.06, SE = 0.02). We estimated that 11% of the sample units in the San Juan's were occupied by lynx (95% confidence interval: 2–20%) during 2022–23 (Figure 2).

Table 1. Summary statistics from snow tracking effort.

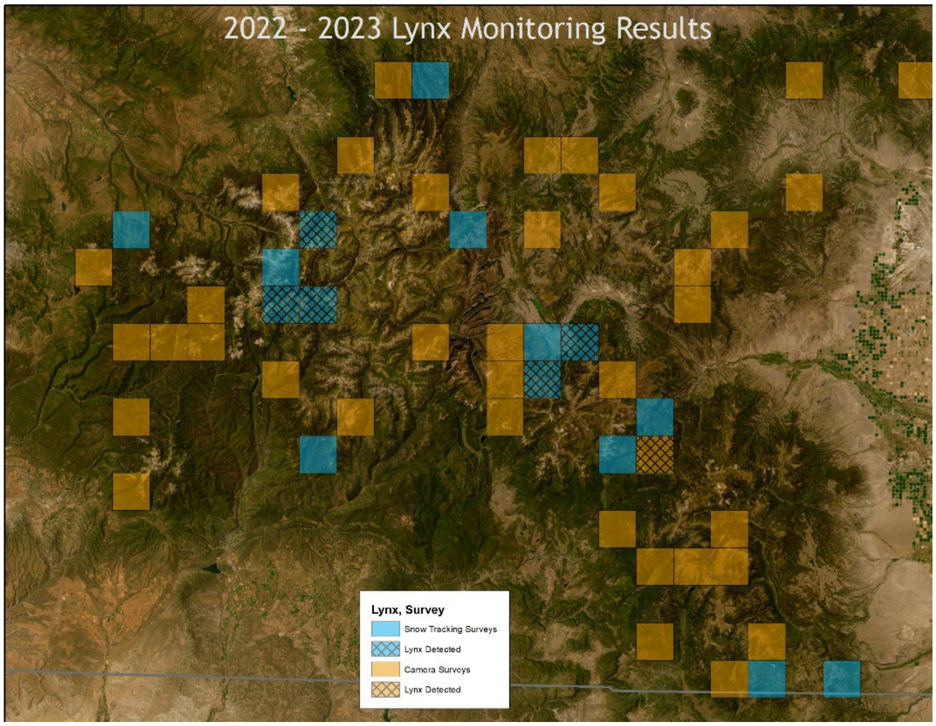
Season	#Units Surveyed	#Units with Lynx	#Lynx Tracks	#Genetic Samples[a]	Lynx DNA[b]	Km Surveyed (Total)	Mean Km Surveyed per Visit	#CPW Personnel[c]	#USFS Personnel[c]
2014-2015	18	7	12	8	8	884	20.1	30	13
2015-2016	17	7	14	9	6	987	21.9	23	6
2016-2017	16	8	13	7	5	703	18.0	20	8
2017-2018	14	7	9	3	1	578	19.3	14	5
2018-2019	14	6	8	2	1	510	19.6	16	5
2019-2020	14	7	11	3	2	640	19.4	15	3
2020-2021	15	9	14	12	7	790	18.8	17	3
2021-2022	13	4	6	5	4	692	18.7	11	3
2022-2023	15	5	10	9	7	730	18.3	15	2

[a] Number of genetic samples (scat, hair, or eDNA) collected via backtracking putative lynx tracks
[b] Number of genetic samples that came back positive for Lynx
[c]Number of staff that participate in the annual effort

Table 2. Summary statistics from camera effort.

Season	#Units Surveyed	#Units With Lynx	#Photos (Total)	#Photos (Lynx)	#Cameras With Lynx	#CPW Personnel	#USFS Personnel
2014-2015	31	7	133,483	184	11	46	12
2015-2016	31	7	101,534	455	10	33	9
2016-2017	33	6	168,705	251	10	29	9
2017-2018	35	5	173,279	90	8	35	8
2018-2019	35	6	201,782	59	9	31	7
2019-2020	36	4	706,074	36	4	29	6
2020-2021	35	3	347,868	36	3	23	5
2021-2022	35	5	576,288	116	7	23	4
2022-2023	35	1	531,083	4	1	31	3

a)



b)

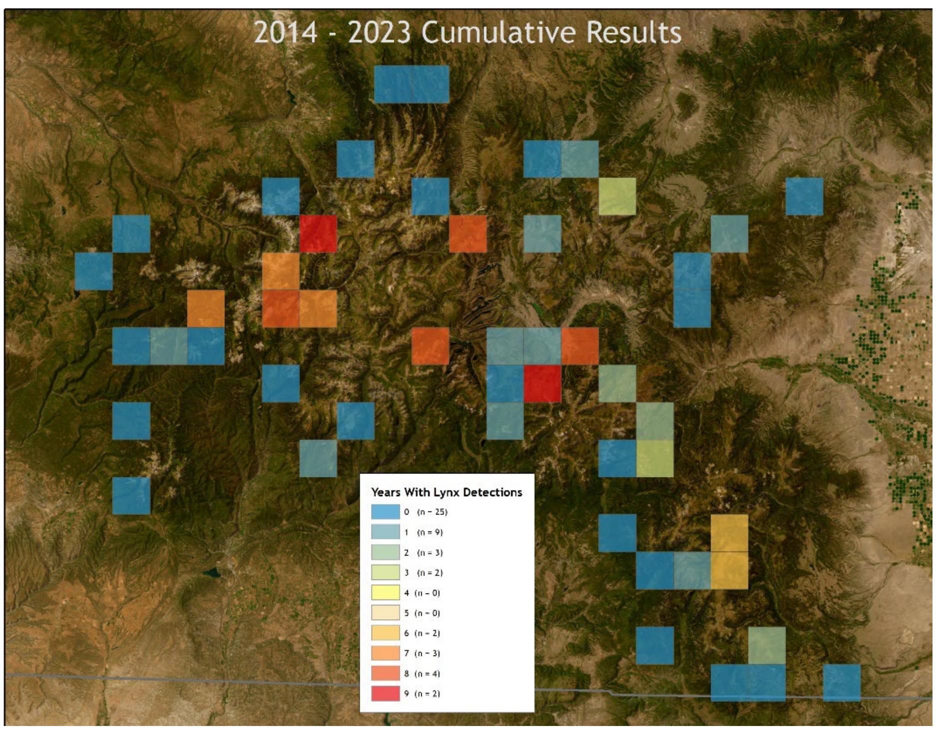


Figure 1. Lynx monitoring results for a) the current sampling season (2022–2023) and b) the cumulative monitoring effort (2014–2023), San Juan Mountains, southwest Colorado. Colored units (*n* = 50) depicted here are those selected at random from the population of units (*n* = 179) encompassing lynx habitat in the San Juan Mountains. Lynx were detected in 6 units in 2022−2023 and 25 units cumulatively since monitoring began in 2014−2015.

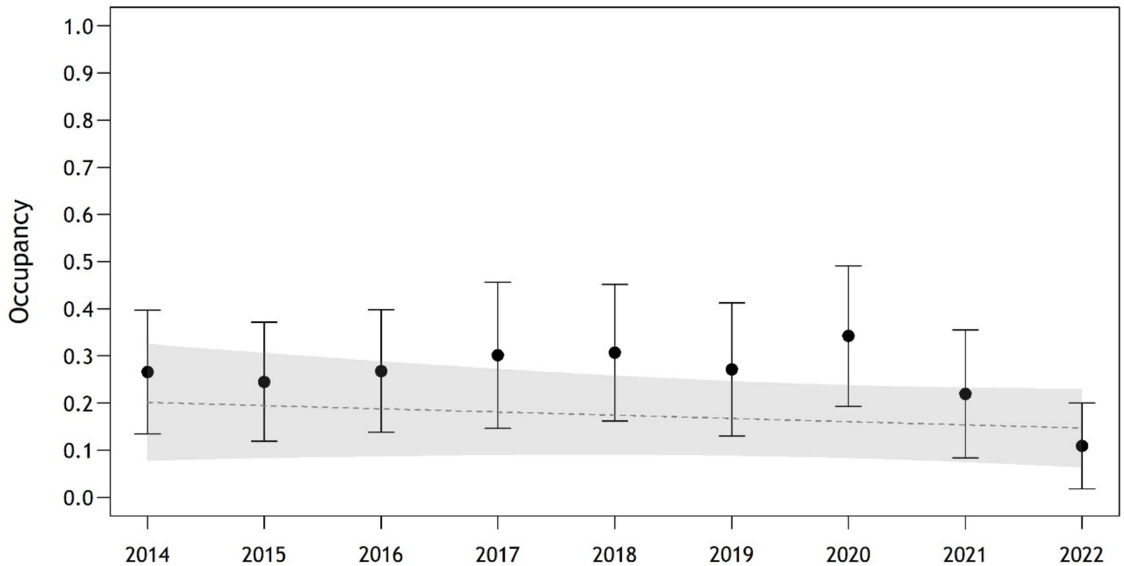


Figure 2. Occupancy estimates (Ψ) and trend (including 95% CI) for Canada lynx in the San Juan Mountains, southwest Colorado.

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Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Influence of forest management on snowshoe hare density in lodgepole and spruce-fir systems in Colorado

Period Covered: January 1, 2022 – December 31, 2023

Principal Investigators: Jake Ivan, Jake.Ivan@state.co.us;

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Understanding and monitoring snowshoe hare (*Lepus americanus*) density in Colorado is imperative because hares comprise 70% of the diet of the state-endangered, federally threatened Canada lynx (*Lynx canadensis*; U.S. Fish and Wildlife Service 2000, Ivan and Shenk 2016). Forest management is an important driver of snowshoe hare density, and all National Forests in Colorado are required to include management direction aimed at conservation of Canada lynx and snowshoe hare as per the Southern Rockies Lynx Amendment (SRLA; https://www.fs.usda.gov/detail/r2/landmanagement/planning/?cid= stelprdb5356865). At the same time, Forests in the Region are compelled to meet timber production obligations. Such activities may depress snowshoe hare density, improve it, or have mixed effects dependent on the specific activity and the time elapsed since that activity was initiated. Here I describe a sampling scheme to assess impacts of common forest management techniques on snowshoe hare density in both lodgepole pine (*Pinus contorta*) and spruce-fir (*Picea engelmannii – Abies lasiocarpa*) systems in Colorado.

To select forest stands for sampling, I first used U. S. Forest Service (USFS) spatial data to delineate all spruce-fir and lodgepole pine stands (stratum 1) on USFS land in Colorado, and identified all of the management activities that have occurred in each stand over time. With consultation from the USFS Region 2 Lynx-Silviculture Team and USFS Rocky Mountain Research Station, I then grouped relevant forest management activities (stratum 2) into 4 broad categories: even-aged management, uneven-aged management, thinning, and unmanaged controls. I wanted to assess both the immediate and long-term impacts of management on hare densities. Therefore, when selecting stands for sampling, I took the additional step of binning the date of the most recent management activity into 2-decade intervals (i.e., 0-20, 20-40, and 40-60 years before 2018). I then selected a spatially balanced random sample of 5 stands within each combination of forest type × management activity × time interval. This design ensured that I sampled the complete gradient of time since implementation for each management activity of interest in each forest type of interest. There is no notion of "completion date" for unmanaged controls, so I simply sampled 10 randomly selected stands from this combination. Also, uneven-aged lodgepole pine treatments are rare, so I did not sample that combination (Figure 1).

During summer 2018, I established $n = 50$ 1-m^2 permanent circular plots within each of the stands selected for sampling. Plot locations within each stand were selected in a spatially balanced, random fashion. Technicians cleared and counted snowshoe hare pellets in each plot as they established them. These same plots were re-visited and re-counted during summers 2019 and 2023. In addition to sampling the previously cleared plots from 2018, technicians were able to install plots at 2 more replicate sites for each combination of forest type × management activity × time interval during 2019. In 2021 and 2022, we sampled vegetation metrics in each stand to help account for extraneous noise in the data and allow us to better assess the effects of the treatments themselves. A handful of initially selected stands were re-classified or excluded during 2019–2022 because ground-truthing and/or vegetation metrics revealed they did not actually fit in the stratum for which they were selected. New stands were sampled in their place by pulling the next one from the spatially balanced list. Similarly, 12 new stands were selected to replace those that burned during the 2020 fire season. Currently, inference is based on $n = 130$ total stands. Finally, prior to the 2023 field season, I computed the sampling variance of the pellet count for each time interval within each treatment. We sampled additional stands in the 3 most variable bins in an effort to reduce variability and improve our understanding of snowshoe hare response to these treatments.

Pellet information from cleared plots is more accurate than that from uncleared plots because uncleared plots usually include pellet accumulation across several years (Hodges and Mills 2008). The degree to which previous years are represented can depend on local weather conditions, site conditions at the plot, and variability in actual snowshoe hare density over previous winters. Data from cleared plots necessarily reflects hare activity from the previous 12 months, and tracks true density more closely. Therefore, I focused the current analysis on the 2019–23 data from previously cleared plots. For each forest type × management activity combination, I plotted mean pellet counts against "year since activity," then fit a curve (e.g., quadratic function) through the data (Figure 2).

Results from this preliminary analysis suggest that on average the highest snowshoe hare densities typically occur in unmanaged spruce-fir forests, and that unmanaged spruce-fir forests are estimated to have more than twice the relative hare density of unmanaged lodgepole pine forests (Figure 2). For both forest types, the fitted line suggests that even-aged management (e.g., clearcutting), immediately depresses relative hare density to near zero, but density rebounds and peaks 20-40 years after management before declining again (lodgepole systems) or leveling off (sprue-fir systems) 40-60 years after. Estimated peak hare densities after even-aged management in lodgepole systems tend to be higher than the control condition. However, in spruce-fir systems the estimated fitted line is flatter and peak densities fell short of the control condition. In both forest types, thinning (which often occurs 20-40 years after stands undergo even-aged management, especially in lodgepole) immediately depresses hare densities. In spruce-fir stands, densities were estimated to slowly recover through time in nearly linear fashion. However, they follow a peaked response in lodgepole pine, similar to the response to even-aged management. Uneven-aged management of spruce-fir forests results in immediate depression of relative hare density, which then recovers back to pre-treatment levels approximately 40 years after the treatment.

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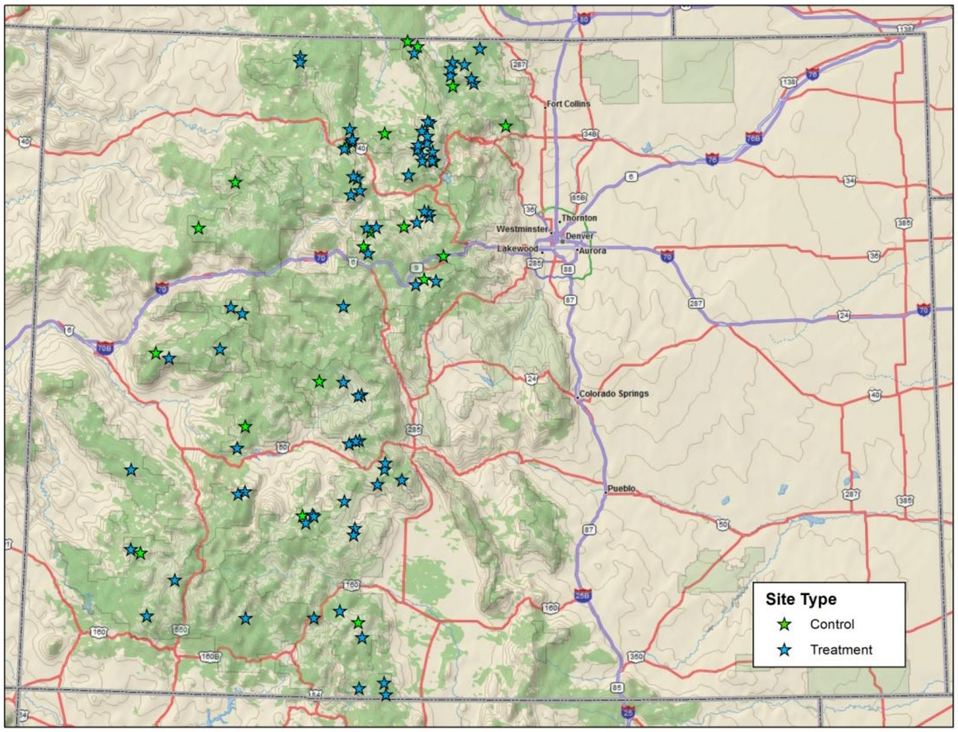

Figure 1. Location of all stands (*n* = 130) resampled for snowshoe hare pellets, June-September 2023.

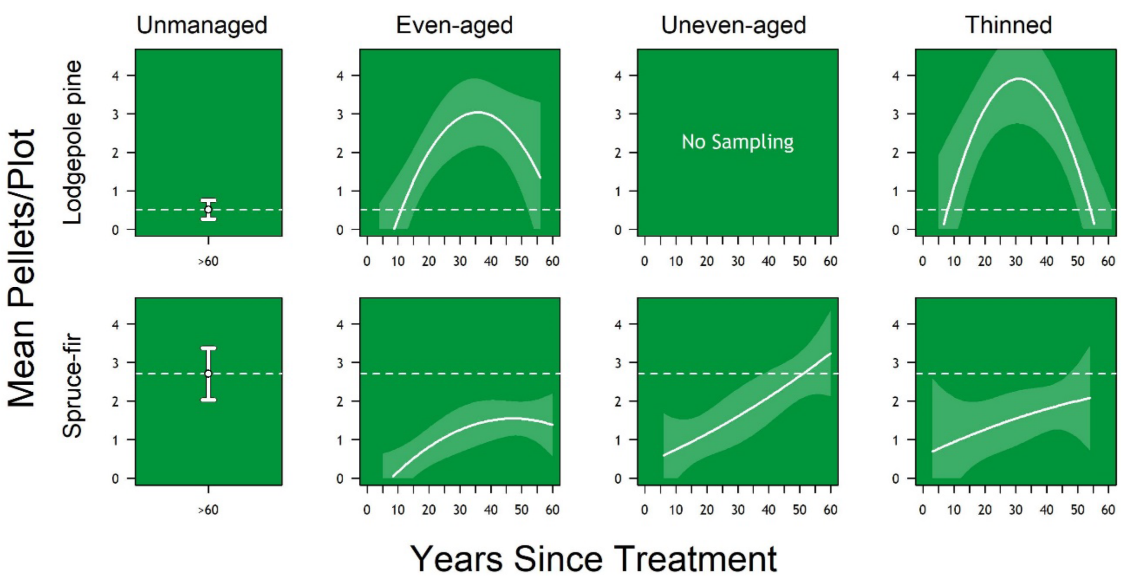

Figure 2. Fitted quadratic function (white line) and 95% CI (shaded polygon) relating pellet counts (i.e., relative snowshoe hare density) to time elapsed since treatment for each forest type × management activity combination. Dotted lines indicate the mean pellets/plot for the unmanaged controls for each forest type.

UNGULATE MANAGEMENT AND CONSERVATION

PILOT EVALUATION OF PREY DISTRIBUTION AND MOOSE RECRUITMENT FOLLOWING EXPOSURE TO WOLF PREDATION RISK IN NORTH PARK, COLORADO

EVALUATING FACTORS INFLUENCING ELK RECRUITMENT IN COLORADO

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EVALUATION AND INCORPORATION OF LIFE HISTROY TRAITS, NUTRITIONAL STATUS, AND BROWSE CHARACTERISTICS IN SHIRA'S MOOSE MANAGEMENT IN COLORADO

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Pilot evaluation of prey distribution and moose recruitment following exposure to wolf predation risk in North Park, Colorado

Period Covered: January 1, 2023 – December 31, 2023

Principal Investigators: Eric Bergman, eric.bergman@state.co.us; Ellen Brandell, ellen.brandell@state.co.us

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During November 2020, Colorado voters passed Proposition 114 (subsequently codified as Colorado Revised Statue 33-2-105.8), which directed Colorado Parks and Wildlife (CPW) and the CPW Wildlife Commission to develop a gray wolf (*Canis lupus*) reintroduction and management plan for Colorado by the end of 2023 (CPW 2023). Wolves are a native species to Colorado and prior to westward European expansion they occurred throughout the Rocky Mountains and into Colorado's eastern plains (Feldhamer et al. 2003). Since the 1940s, wolf presence in Colorado has been sporadic (Warren 1942, Lechleitner 1969, Armstrong et al. 2011, CPW 2023). Beginning in the early 2000s, CPW documented occasional wolf presence in Colorado (Colorado Parks and Wildlife 2021), primarily in North Park. During the summer of 2021, a pack comprised of 2 adults and 6 pups was observed in North Park. In December 2023, CPW introduced 10 wolves into the state from Oregon, fulfilling the December 31, 2023 deadline set in CRS 33-2-105.8. Between immigration, reintroduction, and reproduction, wolves will become a consistent feature on Colorado's landscape, and specifically in North Park. The return of wolves to Colorado's landscape has already generated interest in future research projects.

Between the 1940s and present day, and largely in the absence of wolves, Colorado's ungulate prey populations (i.e., elk (*Cervus americanus*), mule deer (*Odocoileus hemionus*), and moose (*Alces alces*) adapted to many changes. These changes included successional change in vegetation, increases and reductions in competition with other native herbivores and livestock, novel diseases, predation from mountain lions (*Puma concolor*), black bears (*Ursus americanus*), bobcats (*Lynx rufus*) and coyotes (*Canis latrans*), but also increased human activity, human disturbance, and large increases in human infrastructure. Moose experienced deliberate management transplants between the late 1970s (Denney 1976) and mid-2000s. By 2022, Colorado's moose population was estimated to be 3,000–3,500 animals (CPW, unpublished data). Similarly, during the 1940s it was believed there were 45,000 elk in Colorado (Swift 1945) and population growth during the next 6–7 decades led to a peak of ~300,000 animals during the late 1990s and early 2000s (CPW, unpublished data).

This research is generally focused on predator-prey dynamics and how wolves will influence wild prey. Specifically, this research will measure prey survival, productivity, and distribution. To supplement survival and spatial data collected from moose during 2013–2019 (Bergman 2022), we initiated capture and collaring efforts of cow and calf moose during the winter of 2021–2022. These efforts demonstrated that moose calf abundance and subsequent moose calf density in North Park were insufficient to accommodate the necessary sample size for the initial study design of this project. Historically modeled estimates for the North Park moose herd suggest it is comprised of 600–800 animals. Sex and age distribution data from this herd simultaneously indicate there are ~70 bulls/100 cows and ~52 calves/100 cows, thereby lending evidence that there are ~140–190 moose calves in North Park. However, it is likely that >50% of these calves reside on private lands during winter, making their access for capture purposes logistically difficult. Accordingly, there are likely only ~70–95 calves available on public land, of which CPW would need to capture 65%-85% to meet sample size requirements. Capturing such a large proportions of this calf population is both logistically and financially difficult and preliminary efforts in North Park provided evidence that it would be infeasible to capture 60 moose calves each winter. However, capture efforts of cow moose between 2013–2019 (Bergman 2022) and again during the winter of 2021–2022 provided evidence of adequate densities to accommodate robust capturing and collaring efforts, thereby presenting alternative opportunities to estimate calf survival.

Advancements in satellite collar technology make it feasible for researchers to attain location data from moose that were collected only a few hours earlier. When coupled with VHF capabilities, researchers have the ability to quickly relocate and observe animals. For the purposes of this study, this technology will allow researchers to observe cow moose, but also observe if cow moose are accompanied by a calf (<12 months old). Repeated observations of cows and calves in this manner, and gathered at key points in time, will allow researchers to approximate calf survival by quantifying the decay in calf/cow ratios from birth to the yearling age class (Lukacs et al. 2004). While these data will not provide cause-specific calf mortality estimates, they will improve population models that inform moose ecology and harvest management decision making for the North Park moose herd.

To implement this alternative approach to estimating calf survival, a total of 80 cow moose will be collared in North Park. In addition to the previously collared moose, 65 moose were collared for the first time in February 2023. Collars were be deployed in a spatially balanced manner, with approximately 40 collars on both the northern and southern halves of North Park. Calf-at-heel surveys were conducted in June and December 2023. 92% and 71% of moose with active collars were observed in the June and December surveys, respectively. Preliminary calf-at-heel ratios were 0.63 and 0.43 calves/cow during the first two surveys. Further analysis and estimation of monthly and annual calf survival rates will be done in the future when all data have been collected.

There was some collar failure over the year, which effectively reduces sample size due to inability to locate collared moose during surveys. We plan to collar an additional 5–10 moose in the winter 2023–2024 to meet our desired sample size for calf-at-heel surveys. Data collected from cow moose during 2022 did not deviate from data collected during 2013–2019. Between 2012–2022 survival of cow moose ranged from 91.2%–94.8%. During the same period, pregnancy rates of moose ranged from 54.8%–88.0%.

To expand this research to include additional prey species, 40 cow elk were collared in February 2023. These elk will serve as sentinel animals that will allow researchers to quantify group size behavior, spatial distribution, and habitat use, relative to any known wolf activity. To collect these data, we aimed to obtain aerial visual observations of all collared elk on a monthly basis and record the habitat type they occurred in and the size of the elk group they resided in. In addition to estimating group size from the air, we took photographs, allowing us to count elk in groups. We conducted seven aerial surveys from March to December, 2023, and located 50% of collared elk per flight on average. This resulted in 9–19 unique elk groups observed per survey.

We will continue approximately monthly elk surveys in addition to the continual locational data collection on GPS collars. Six collared elk died over the year, therefore we plan to collar elk in the winter 2023–2024 to retain our desired sample size of 40 elk.

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Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Evaluating factors influencing elk recruitment in Colorado

Period Covered: January 1, 2023-December 31, 2023

Principal Investigators: Nathaniel Rayl, nathaniel.rayl@state.co.us; Mat Alldredge, mat.alldredge@state.co.us; Chuck Anderson, chuck.anderson@state.co.us

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In Colorado, elk (*Cervus canadensis*) are an important natural resource that are valued for ecological, consumptive, aesthetic, and economic reasons. In 1910, less than 1,000 elk remained in Colorado (Swift 1945), but today the state population is estimated to be the largest in the country, with more than 290,000 elk. Over the last two decades, however, wildlife managers in Colorado have become increasingly concerned about declining winter elk calf recruitment (estimated using juvenile/adult female ratios) in the southern portion of the state. Although juvenile/adult female ratios are often highly correlated with juvenile elk survival, they are an imperfect estimate of recruitment because they are affected by harvest, pregnancy rates, juvenile survival, and adult female survival (Caughley 1974, Gaillard et al. 2000, Harris et al. 2008, Lukacs et al. 2018). Thus, there is a need for elk research in Colorado based upon monitoring of marked individuals to evaluate factors affecting each stage of production and survival. In 2016, we began a study to investigate factors influencing elk recruitment in 2 elk Data Analysis Units (DAUs; E-20, E-33) with low juvenile/adult female ratios (Fig. 1). In 2019, we expanded this study into a 3rd DAU with high juvenile/adult female ratios (E-2), to better determine how predators, habitat, and weather conditions are impacting elk recruitment in Colorado (Fig. 2). In 2021, we concluded collaring efforts in E-33.

Since study initiation, we have collared 513 pregnant females in February-March, 799 neonates in May-August, and 246 6-month-old calves in December (Table 1). Averaged across years, we estimated that the annual pregnancy rate of adult female elk was 94% in the Bear's Ears herd (excluding 2019 data where $n = 3$; range = 90-97%), 91% in the Trinchera herd (range = 85-94%), and 92% (range = 88-95%) in the Uncompahgre Plateau herd (Fig. 3). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013). From 2017-2023, we estimated that the mean ingesta-free body fat (IFBF) of adult female elk was 6.89% in the Bear's Ears Herd, 7.60% in the Trinchera herd, and 7.57% in the Uncompahgre Plateau herd (Fig. 4). When late-winter IFBF values are <8-9% for adult female elk that have lactated through the previous growing season, this suggests that there may be nutritional limitations, but it does not identify whether limitations are a result of summer-autumn or winter nutrition (R. Cook, personal communication). Averaged across years, we estimated that the median date of calving was June 1 in the Bear's Ears, Trinchera, and Uncompahgre Plateau herds (Fig. 5). We estimated that the mean weight of 6-month old elk calves was 221.1 lb (95% CI = 215.4-226.7 lb) from the Bear's Ears herd and 235.5 lb (95% CI = 229.7-241.3 lb) from the Uncompahgre Plateau elk herd.

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Table 1. The number of elk collared in each age class from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds from 2017-2023.

	Herd							
	E-2 Bear's Ears			E-20 Uncompahgre Plateau			E-33 Trinchera	
Year	Adult	Neonate	6-month	Adult	Neonate	6-month	Adult	Neonate
2017				23	40		23	57
2018				25	48		21	53
2019	2	49	25	30	49	25	30	46
2020	40	54	25	40	52	25	19	21
2021	40	53	25	40	52	25	20	21
2022	40	54	21	40	53	25		
2023	40	43	25	40	54	25		

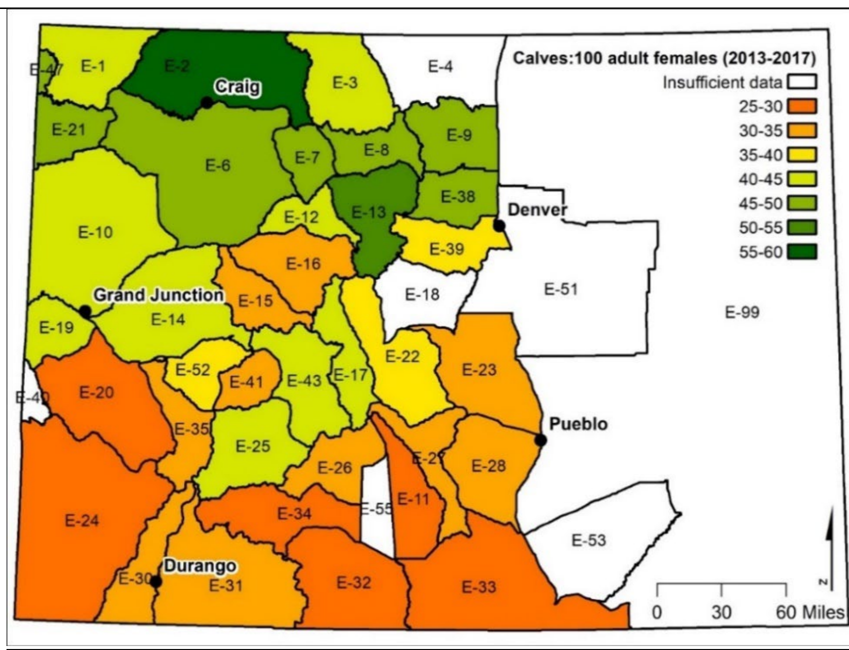

Figure 1. The number of elk calves per 100 adult females observed during December-February aerial surveys (5-year average from 2013-2017) within elk Data Analysis Units (DAUs; labeled with black text).

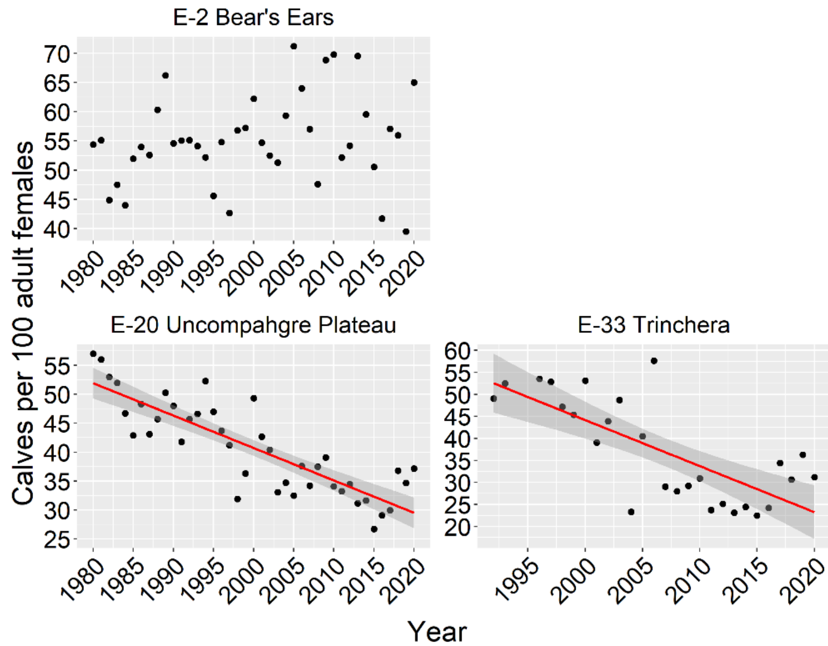

Figure 2. The estimated number of calves per 100 adult females observed annually during winter classification surveys in the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) elk herds from 1980-2020 (1992-2020 for the Trinchera herd). Red lines and shaded bands represent linear regression trends with 95% confidence intervals, and indicate an average decrease of 0.56 and 1.05 calves per 100 adult females per year in the Uncompahgre Plateau and Trinchera herds, respectively.

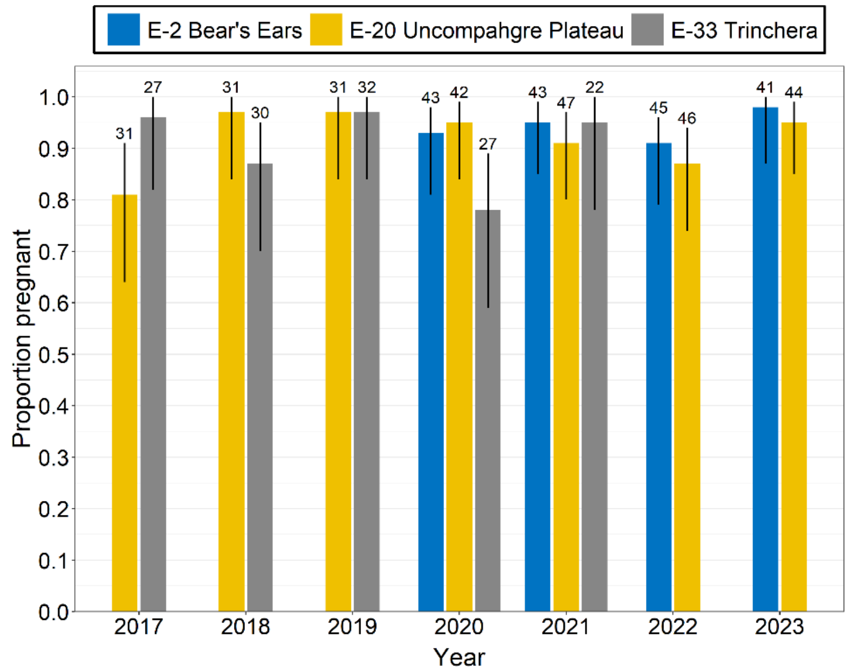

Figure 3. Estimated average pregnancy rates of adult female elk from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds sampled during late winter 2017-2023. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

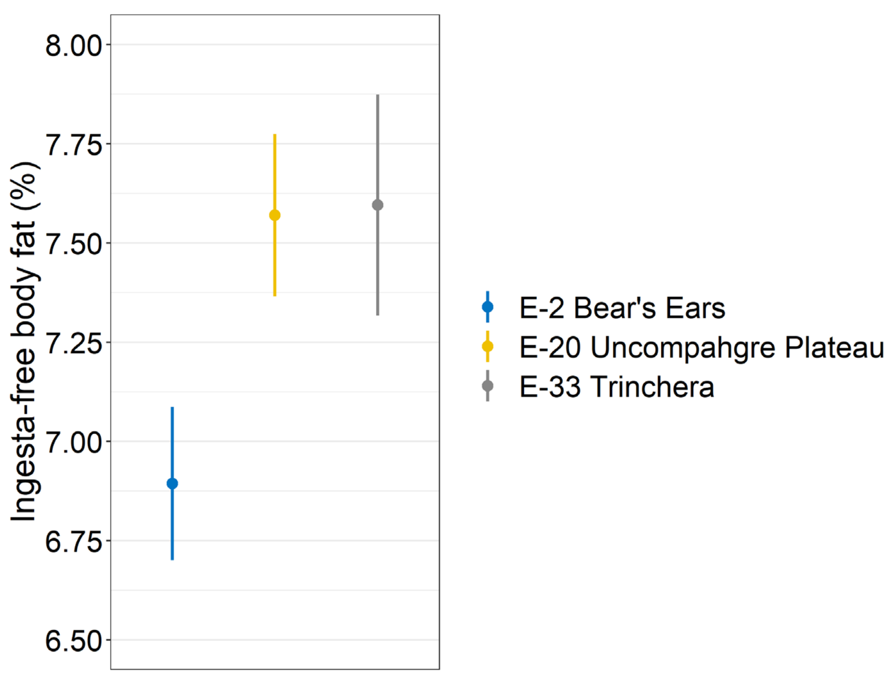

Figure 4. The estimated ingesta-free body fat (%) of adult female elk with 95% confidence intervals from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds sampled during late winter 2017-2023.

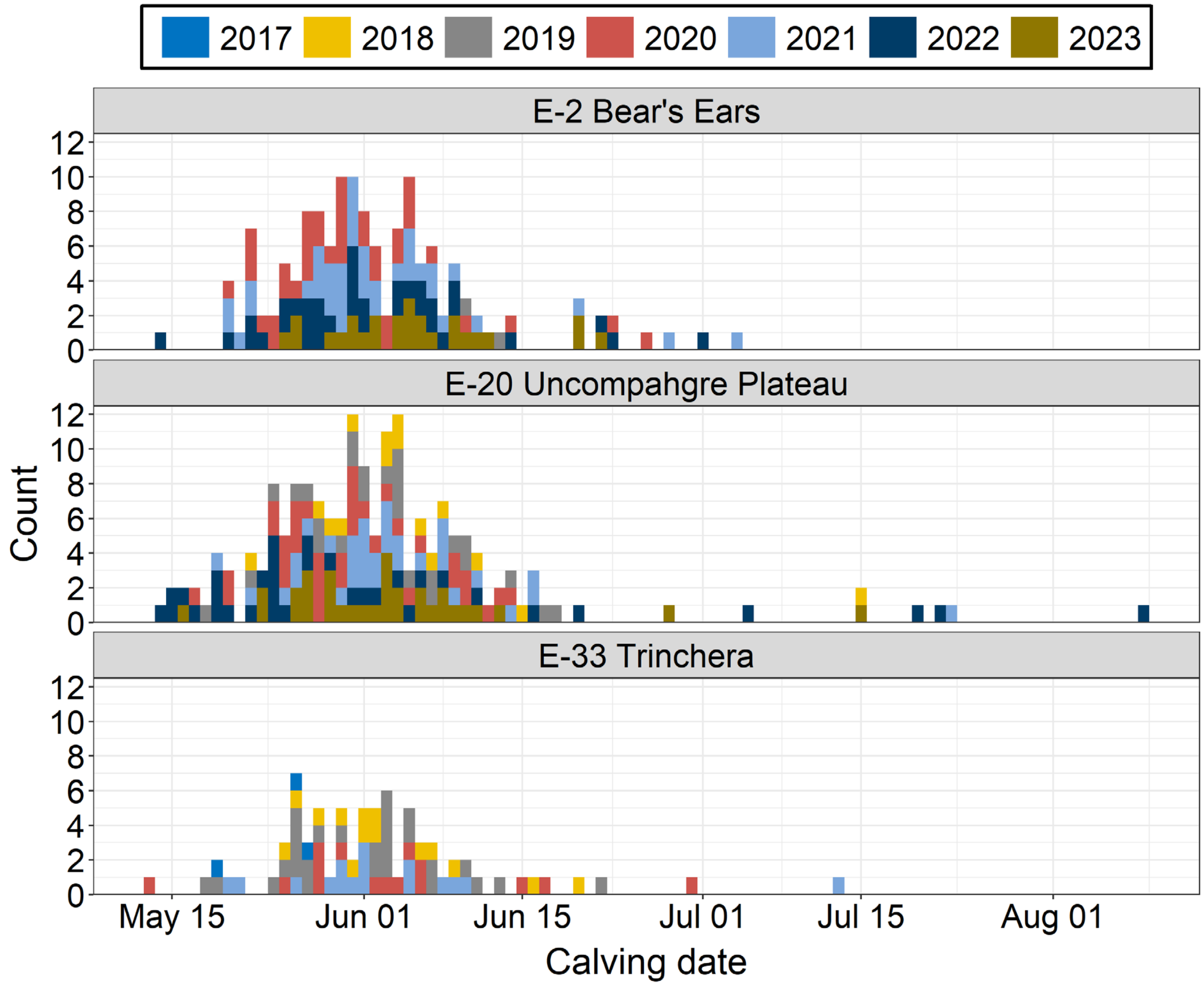

Figure 5. The estimated calving dates of collared adult female elk from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds from 2017-2023.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Response of elk to human recreation at multiple scales: demographic shifts and behaviorally-mediated fluctuations in local abundance

Period Covered: January 1, 2023-December 31, 2023

Principal Investigators: Eric Bergman, eric.bergman@state.co.us; Nathaniel Rayl, nathaniel.rayl@state.co.us

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This project has objectives on 2 scales. At the broad, elk herd-level scale, we are estimating pregnancy rates, calf survival rates, and cause-specific mortality rates to evaluate the importance of mortality sources for elk calf survival. More specifically, we are evaluating the influence of biotic (birth date, birth mass, gender, maternal body condition, habitat conditions), abiotic (previous and current weather conditions), and human-induced factors (i.e., relative exposure to recreational activities) on seasonal mortality risk of elk calves from birth to age 1 and on pregnancy rates of mature female elk. At the narrower geographic and temporal scale, we are using changes in elk abundance within small study units (<65 km^2 [25 mi^2]) as a tool to evaluate the influence of human recreation on elk distribution. At this narrower scale, the primary objective is to evaluate the role that human recreation (e.g., hiking, mountain biking, horseback riding, trail running, hunting, etc.) has on the behavioral distribution of elk on spring calving, summer, and fall transition ranges. Coupled to the objective of detecting behaviorally influenced changes in abundance and density, we are evaluating the effectiveness of current recreational closures maintained by ski areas, counties, and federal land management agencies.

From 2019-2023, we have collared 184 pregnant females in March, 244 neonates in May-July, and 125 6-month-old calves in December from the Avalanche Creek elk herd (Data Analysis Unit E-15; Table 1). Averaged across years, we estimated the annual pregnancy rate of adult female elk was 92% (95% CI = 87-95%; Fig. 1). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013). We estimated that the mean ingesta-free body fat (IFBF) of adult female elk was 8.23 (95 CI = 7.90-8.57%). When late-winter IFBF values are <8-9% for adult female elk that have lactated through the previous growing season, this suggests that there may be nutritional limitations, but it does not identify whether limitations are a result of summer-autumn or winter nutrition (R. Cook, personal communication). Averaged across years, we estimated that the median date of calving was June 1 (Fig. 2). We estimated that the mean weight of 6-month old elk calves was 246.3 lb (95% CI = 240.3-252.3).

During the summers of 2019, 2020, and 2021 a total of 384,455, 5,313,367, and 4,856,973 photos were taken, respectively, by cameras that were deployed across 8 study units. Photos taken during 2022 and retrieved from cameras during 2023 are being archived. During 2023 a formal process to facilitate automated (AI) photo recognition, led by a post-doctoral researcher, was initiated. Initial aspects of this process evaluated numerous AI options and quickly identified Pytorch-Wildlife (formerly called Megadetector) as the most efficient and effective tool that is currently available. Data collected during 2019 has been evaluated using Pytorch-Wildlife and quantification of error rates (both Type I and Type II) is currently underway.

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Table 1. The number of elk collared in each age class from the Avalanche Creek elk herd (DAU E-15) from 2019-2023.

	Age class		
Year	Adult	Neonate	6-month
2019	24	26	25
2020	40	54	25
2021	40	51	25
2022	40	53	25
2023	40	60	25

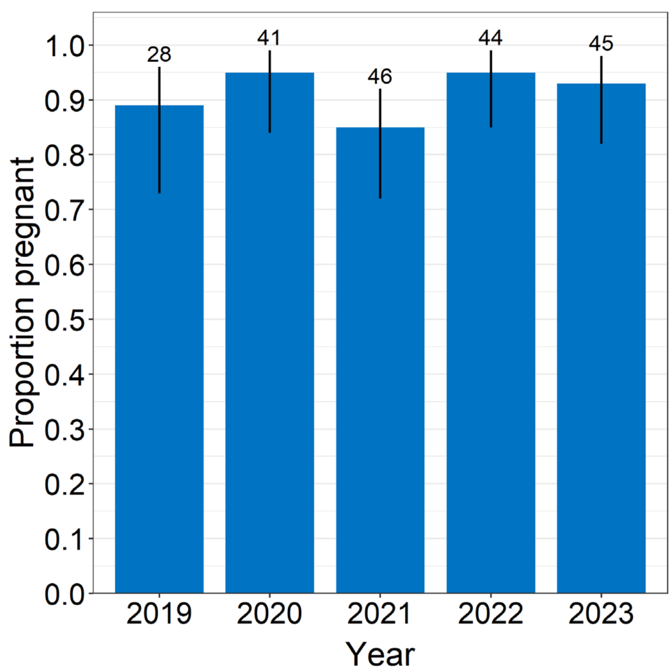

Figure 1. Estimated average pregnancy rates of adult female elk from the Avalanche Creek (DAU E-15) herds sampled during late winter 2019-2023. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

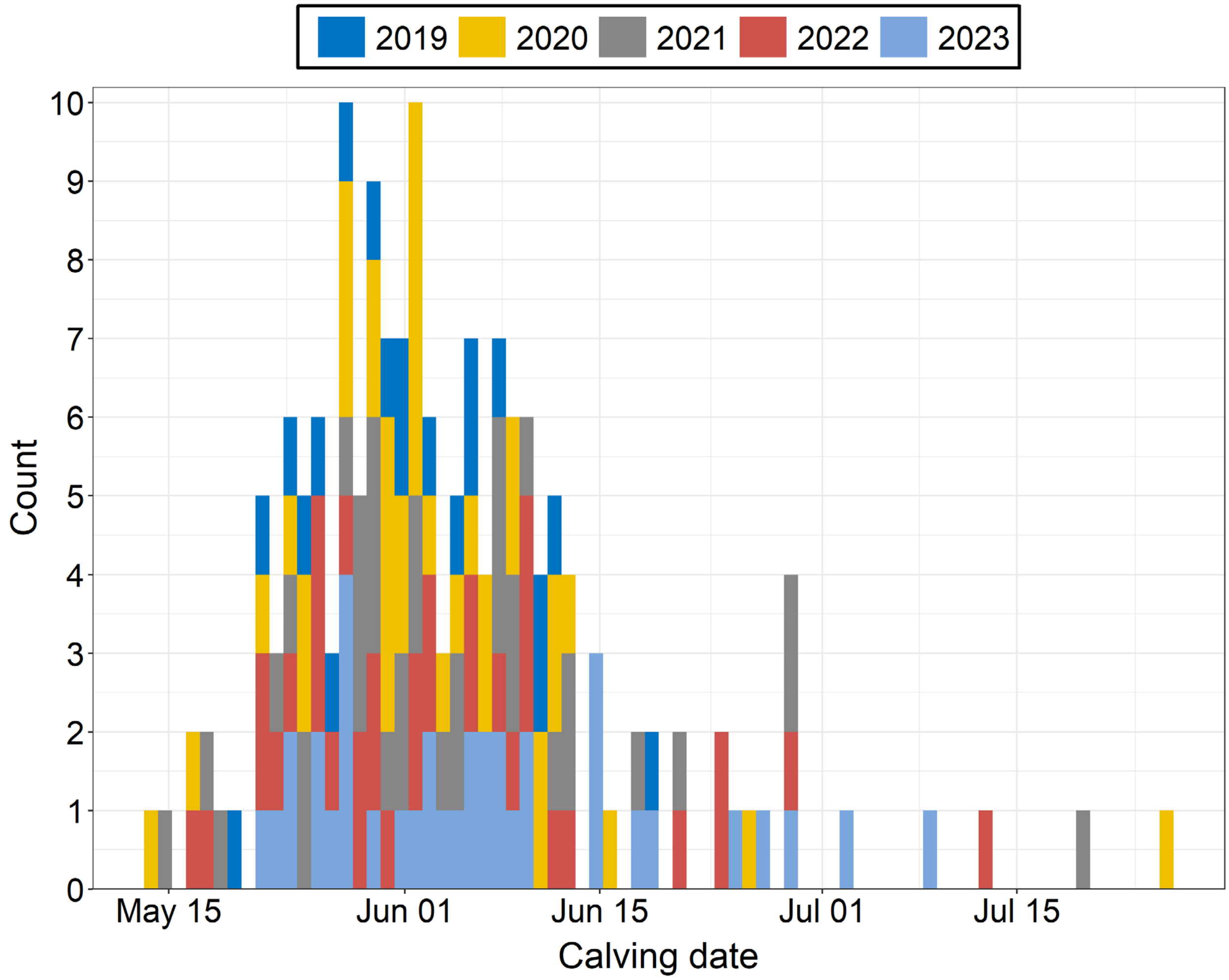

Figure 2. The estimated calving dates of collared female elk from the Avalanche Creek (DAU E-15) herd from 2019-2023.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Spatiotemporal effects of human recreation on elk behavior: an assessment within critical time stages

Period Covered: January 1, 2023-December 31, 2023

Principal Investigators: Nathaniel Rayl, nathaniel.rayl@state.co.us; Eric Bergman, eric.bergman@state.co.us; Joe Holbrook, Joe.Holbrook@uwyo.edu

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The influence of recreational disturbance on ungulate populations is of particular interest to wildlife managers in Colorado, as there is growing concern about its potential impacts within the state. Currently, the western United States is experiencing some of the highest rates of human population growth in the country, with growth in rural and exurban areas frequently outpacing growth in urban areas. Additionally, participation in outdoor recreation is also increasing. In Colorado, the number of individuals participating in recreational activities, and the associated demand for recreational opportunities, appear to be increasing. Understanding potential impacts of recreational activity on elk spatial ecology in Colorado is critical for guiding management actions, as altered movements may result in reduced foraging time and higher energetic costs, which may decrease fitness.

We are studying elk from the resident portion of the Bear's Ears elk herd (DAU E-2) in Colorado to determine potential impacts of recreational activities on this population. This research project is a collaboration between Colorado Parks and Wildlife (CPW) and the Haub School of Environment and Natural Resources at the University of Wyoming, and forms the basis of an M.S. thesis for a graduate student (Eric VanNatta, also CPW Area 10 Terrestrial Biologist) enrolled at the Haub School.

In January 2020 and January 2021, we collared 30 and 26 adult female elk, respectively, from the resident portion of the Bear's Ears elk herd on U.S. Forest Service (USFS) land near Steamboat Springs. We estimated pregnancy rates of 93% (95% CI: 79-98%) in 2020 and 96% (95% CI: 81-100%) in 2021.

From May-October 2020 we deployed trail counters at 22 trailheads in the Routt National Forest (Fig. 1). We recorded roughly 100,000 people departing and returning from these trailheads. Among individual trailheads, we documented average daily traffic counts ranging from 2-325 people (Fig. 2). Most traffic was recorded on weekends with noticeable lulls in traffic frequency observed during weekdays. During the 2021 field season, we again deployed trail counters at the 22 trailheads, and also added additional trail counters at 1-km intervals along each trail for up to 5-km from the trailhead. These additional trail counters are being deployed on a rotating basis to sample each trail. Data collected from these additional trail counters will provide an estimate of the decay of traffic along trails.

During the 2020 and 2021 field season, we distributed handheld GPSs to recreationists (hikers, bikers, hunters) to record detailed tracks of human use within this trail system (Fig. 3). In 2020, we collected over 100 GPS tracks. These tracks from recreationists and hunters will allow us to better quantify human recreation on the landscape and evaluate how elk respond to recreationists. In fall 2023, Eric VanNatta successfully completed and defended his M.S. proposal at the University of Wyoming and finished processing and cleaning the trail counter dataset.

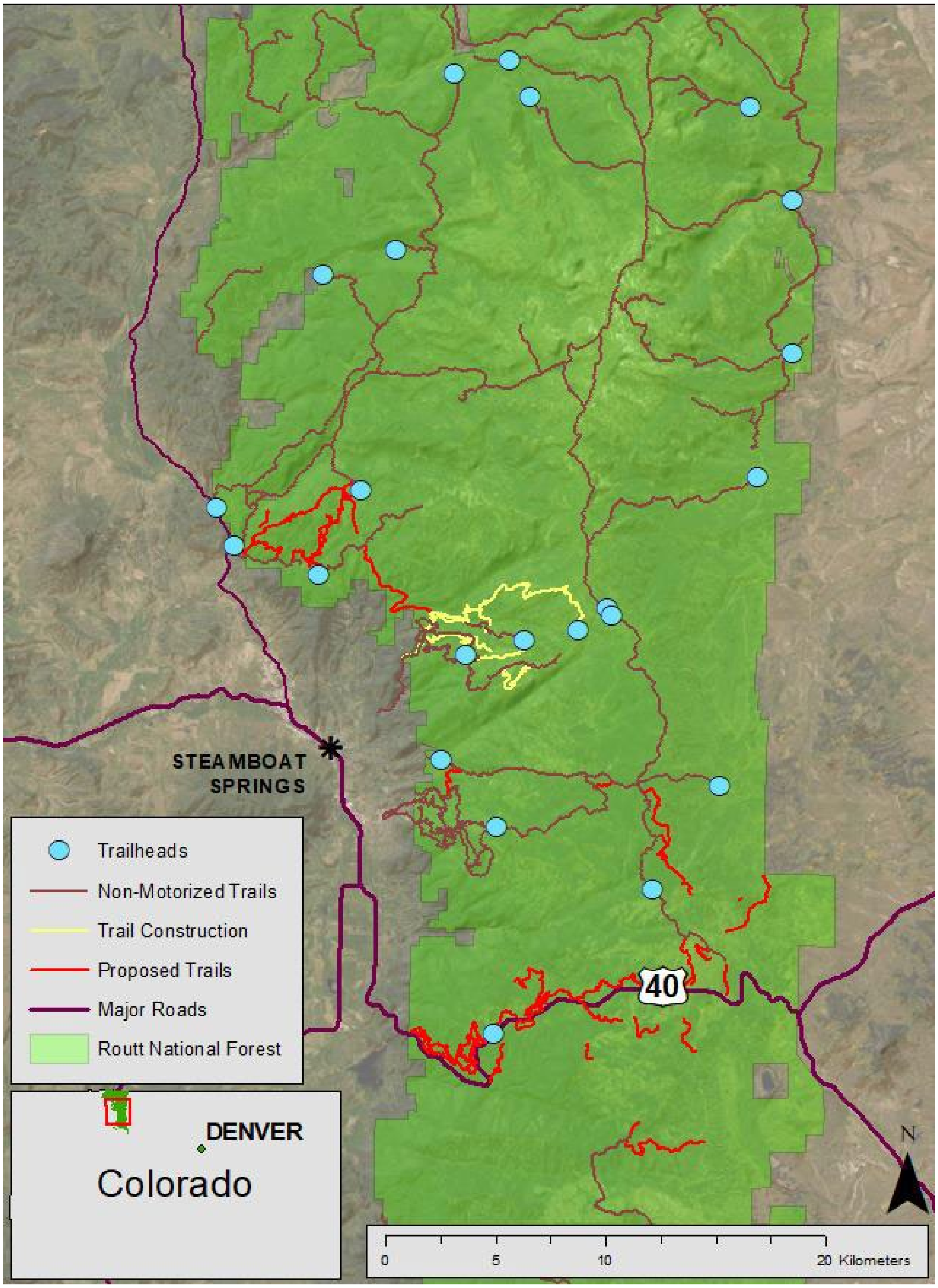

Figure 1. Routt National Forest study area located in northwest Colorado, USA.

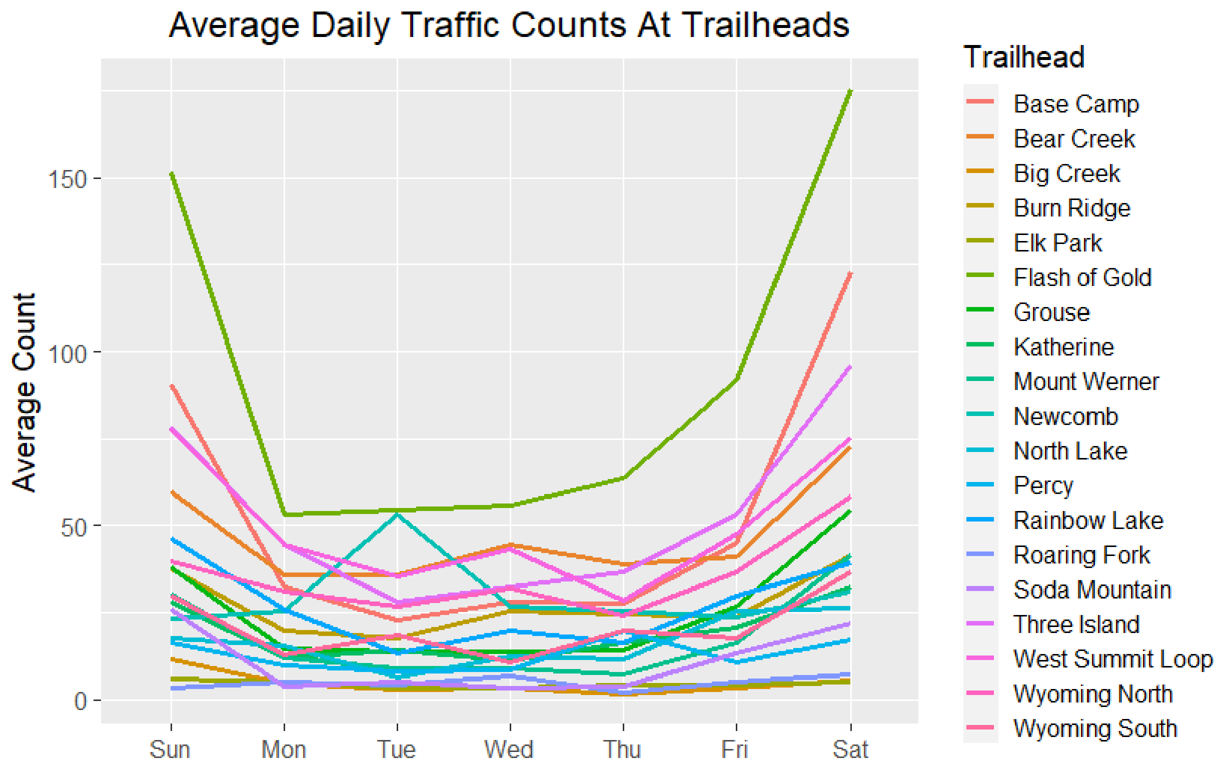

Figure 2. Daily trends in trailhead traffic documented with trail counters from June through October 2020, excluding Fish Creek Falls, Mad Creek, and Red Dirt trailheads, which received average daily counts >200.

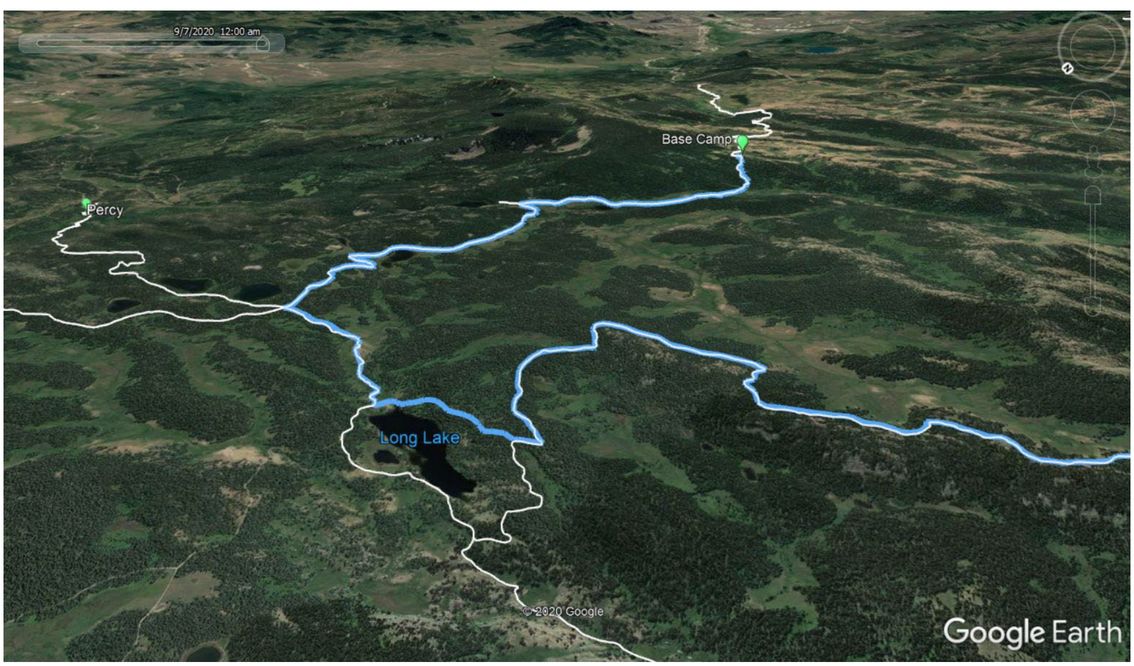

Figure 3. GPS track (blue) recorded from recreational mountain biker on trail system (white) in August 2020. Note the off-trail use near Long Lake.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Evaluation and incorporation of life history traits, nutritional status, and browse characteristics in Shira's moose management in Colorado

Period Covered: January 1, 2023 – December 31, 2023

Principal Investigator: Eric J. Bergman, eric.bergman@state.co.us

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During November of 2013 Colorado Parks and Wildlife (CPW) initiated a large scale moose research project. Fieldwork for this project was completed during 2019–2020, and analysis and publication of results occurred from 2020–2024. The impetus for CPW's moose research program was many-fold, but some of the most important objectives included: assessment of Colorado's moose herd dynamics relative to other states, estimation of survival rates and reproductive parameters, documentation of prevalence and the impacts of various mortality sources including human harvest, evaluation of the effects of carotid worm (*Elaeophora schneideri*) and winter ticks, and evaluation of the potential role of vegetation monitoring in long-term moose management processes. Abstracts of this published research are included below (Appendix 1).

Research published by Nadeau et al. (2017) concluded that during the 21st century, moose populations in Colorado had grown, but much of that growth likely occurred via range expansion as moose colonized unoccupied areas. During this study, adult female survival averaged 93% but declined to 88% when human harvest was included as a mortality source (Bergman et al. 2024). Evaluation of field methods to quantify spring and summer calf-at-heel ratios estimated that detection probabilities of calves was 0.80 and that calf-at-heel ratios ranged from 0.54–0.84 (Bergman et al. 2020*b*). Incorporation of this detection probability into the expected parturition dates for moose calves reduced the variation in expected dates and shifted the mean date to an earlier time period, suggesting 90% of calves were born by 27th of May (Bergman et al. 2020*a*). Research completed by LeVan et al. (2013) documented very high prevalence (83%) of carotid worm infections in harvested moose, suggesting infection is common within Colorado's moose population, but also that infection is not lethal for animals. Recent research (DeCesare et al. 2024) on the relationship between climate and regional weather patterns and winter tick parasitism of moose suggests that while Colorado's colder winters and deeper snow depths likely reduce average annual tick infestation, a warming environment would increase snowpack variability and tick presence may increase. This project did not identify a strong nexus between moose productivity and surrounding habitat characteristics, although a positive correlation between calf-at-heel counts, willow height and willow cover was identified (Hayes et al. 2022). Finally, while outside the primary objectives of this project, genetic comparison with data from other western states, western Canada, and Alaska suggested a high degree of overlap among the currently identified subspecies of moose, suggesting further distinction of moose subspecies is not genetically supported, nor is threatened or endangered species status warranted for any existing subspecies (DeCesare et al. 2020).

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DeCesare, N. J., R. B. Harris, M. P. Atwood, E. J. Bergman, A. B. Courtemanch, P. C. Cross, G. L. Fralick, K. R. Hersey, M. A. Hurley, T. M. Koser, R. L. Levine, K. L. Monteith, J. R. Newby, C. J. Peterson, S. Robertson, and B. L.Wise. 2024. Warm places, warm years and warm season increase parasitizing of moose by winter ticks. Ecosphere 15:In Press.

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LeVan, I. K., K. A. Fox, and M. W. Miller. 2013. High elaeophorosis prevalence among harvested Colorado moose. Journal of Wildlife Diseases 49:666-669.

Nadeau, M. S., N. J. DeCesare, D. G. Brimeyer, E. J. Bergman, R. B. Harris, K. R. Hersey, K. K. Huebner, P. E. Matthews, and T. P. Thomas. 2017. Status and trends of moose populations and hunting opportunity in the western United States. Alces: A Journal Devoted to the Biology and Management of Moose 53:99-112.

Appendix 1. Moose research publication abstracts.

Status and trends of moose populations and hunting opportunity in the western United States

M. Steven Nadeau, Nicholas J. DeCesare, Douglas G. Brimeyer, Eric J. Bergman, Richard B. Harris, Kent R. Hersey, Kari K. Huebner, Patrick E. Matthews, and Timothy P. Thomas

ABSTRACT: We review the state of knowledge of moose (Alces alces shirasi) in the western US with respect to the species' range, population monitoring and management, vegetative associations, licensed hunting opportunity and hunter harvest success, and hypothesized limiting factors. Most moose monitoring programs in this region rely on a mixture of aerial surveys of various formats and hunter harvest statistics. However, given the many challenges of funding and collecting rigorous aerial survey data for small and widespread moose populations, biologists in many western states are currently exploring other potential avenues for future population monitoring. In 2015, a total of 2,263 hunting permits were offered among 6 states, with 1,811 moose harvested and an average success rate per permit-holder of 80%. The spatial distribution of permits across the region shows an uneven gradient of hunting opportunity, with some local concentrations of opportunity appearing consistent across state boundaries. On average, hunting opportunity has decreased across 56% of the western US, remained stable across 17%, and increased across 27% during 2005–2015. Generally, declines in hunting opportunity for moose are evident across large portions (62–89%) of the "stronghold" states where moose have been hunted for the longest period of time (e.g., Idaho, Montana, Utah, and Wyoming). In contrast, increases in opportunity appear more common at peripheries of the range where populations have expanded, including most of Colorado, northeastern Washington, southern Idaho, and eastern Montana. There are many factors of potential importance to moose in this region, including parasites, predators, climate, forage quality, forage quantity, and humans. State wildlife agencies are currently conducting a variety of research focused on population vital rates, the development of monitoring techniques, forage quality, trace mineral levels, and evaluation of relative impacts among potential limiting factors.

ALCES 53:99–112 (2017)

Management considerations of moose life-history characteristics in Colorado, USA.
Eric J. Bergman, Jonathan P. Runge, Mark C. Fisher, and Lisa L. Wolfe
ABSTRACT: Wildlife management agencies are obliged to provide evidence-based management recommendations to stakeholders. However, allocation of resources towards the management of species cannot be uniform. The consideration of life history characteristics of moose offers wildlife managers a more robust understanding of population ecology, while also providing insight into potential limiting factors for long-term management. From 2014-2020 we simultaneously measured survival of adult moose, as well as calf productivity, in relation to the nutritional condition of adult females, in Colorado. Mean annual adult survival was high (93%, 95% confidence interval: 91%–95%). Human hunter harvest was the leading source of mortality and lowered annual adult survival to 88%. Malnutrition was the leading source of natural mortality. Mean annual pregnancy rates were low (77%) and highly variable (95% confidence interval: 65%–88%). However, low pregnancy rates were compensated for by high apparent calf survival. The best predictor of moose pregnancy was nutritional condition. Our data suggest that bottom-up ecological processes were affecting moose population growth, but populations were likely increasing during our study, with a population growth rate for the period of our study between 1.03–1.11.
Wildlife Biology *In Review* (2024)

Moose calf detection probabilities: quantification and evaluation of a ground-based survey technique
Eric J. Bergman, Forest P. Hayes, Paul M. Lukacs, and Chad J. Bishop
ABSTRACT: Survey data improve population management, yet those data often have associated bias. We quantified one source of bias in moose survey data (observer detection probability, p), by using repeated ground-observations of calves-at-heel of radio-collared moose in Colorado, USA. Detection probabilities, which varied both spatially and temporally, were estimated using an occupancy-modelling framework. We provide an efficient offset for modelled calf-at-heel occupancy (ψ) estimates that accommodates summer calf mortality. Detection probabilities were most efficiently modelled with seasonal variation, with the lowest probability of detecting calves-at-heel occurring during parturition (i.e. May) and later autumn periods (after August). Our most efficiently modelled detection probability estimate for summer was 0.80 (SE = 0.05). During the four years of this study, ψ estimates ranged from 0.54–0.84 (SE = 0.08–0.11). Accounting for 91.7% monthly calf survival corrected ψ estimates downward (ψ = 0.42–0.65). Our results suggest that repeated ground-based observations of individual cow moose, during summer months, can be can a cost-effective strategy for estimating a productivity parameter for moose. Ground survey results can be further improved by accounting for calf mortality.
Wildlife Biology 2:1-9 (2020)

Estimation of moose parturition dates in Colorado: incorporating imperfect detections
Eric J. Bergman, Forest P. Hayes, and Kevin Aagaard
ABSTRACT: Researchers and managers use productivity surveys to evaluate moose populations for harvest and population management purposes, yet such surveys are prone to bias. We incorporated detection probability estimates (*p*) into spring and summer ground surveys to reduce the influence of observer bias on the estimation of moose parturition dates in Colorado. In our study, the cumulative parturition probability for moose was 0.50 by May 19, and the probability of parturition exceeded 0.9 by May 27. Timing of moose calf parturition in Colorado appears synchronous with parturition in more northern latitudes. Our results can be used to plan ground surveys in a manner that will reduce bias stemming from unobservable and yet-born calves.
ALCES 56:127-135 (2020)

High elaeophora prevalence among harvested moose in Colorado
Ivy K. LeVan, Karen A. Fox, and Michael W. Miller
ABSTRACT: Infection with *Elaeophora schneideri*, a filarial parasite, occurs commonly in mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus nelsoni*), but seemingly less so in moose (*Alces alces*). Of 109 carotid artery samples from moose harvested throughout Colorado, USA, in 2007, 14 (13%; 95% binomial confidence interval [bCI]=7–21%) showed gross and 91 (83%; 95% bCI=75–90%) showed histologic evidence of elaeophorosis. Although neither blindness nor other clinical signs associated with elaeophorosis were reported among the harvested moose we examined, the pervasiveness of this parasite may motivate further study of the potential effects of elaeophorosis on moose survival and population performance in the southern Rocky Mountains. Our data suggest histopathology may be more sensitive than gross examination in detecting elaeophorosis in harvested moose.
Journal of Wildlife Disease 49:666-669 (2013)

Warm places, warm years and warm seasons increase parasitizing of moose by winter ticks
Nicholas J. DeCesare, Richard B. Harris, M. Paul Atwood, Eric J. Bergman, Alyson B. Courtemanch, Paul C. Cross, Gary L. Fralick, Kent R. Hersey, Mark A. Hurley, Troy M. Koser, Rebecca L. Levine, Kevin L. Monteith, Jesse R. Newby, Collin J. Peterson, Samuel Robertson, and Benjamin L. Wise
ABSTRACT: Observed links between parasites, such as ticks, and climate change have aroused concern for human health, wildlife population dynamics, and broader ecosystem effects. The one-host life history of the winter tick (*Dermacentor albipictus*) links each annual cohort to environmental conditions during three specific time periods when they are predictably vulnerable: spring detachment from hosts, summer larval stage, and fall questing for hosts. We used mixed-effects generalized linear models to investigate drivers of tick loads carried by moose (*Alces alces*) relative to these time periods and across 750 moose, 10 years, and 16 study areas in the western United States. We tested for effects of biotic factors (moose density, shared winter range, vegetation, migratory behavior) and weather conditions (temperature, snow, humidity) during each seasonal period when ticks are vulnerable and off-host. We found that warm climatic regions, warm seasonal periods across multiple partitions of the annual tick life cycle, and warm years relative to long-term averages each contributed to increased tick loads. We also found important effects of snow and other biotic factors such as host density and vegetation. Tick loads in the western United States were, on average, lower than those where tick-related die-offs in moose populations have occurred recently, but loads carried by some individuals may be sufficient to cause mortality. Lastly, we found inter-annual variation in tick loads to be most correlated with spring snowpack, suggesting this environmental component may have the highest potential to induce change in tick load dynamics in the immediate future of this region.
Ecosphere ***Accepted In Press*** **(2024)**

Effects of willow nutrition and morphology on calving success of moose
Forest P. Hayes, Joshua J. Millspaugh, Eric J. Bergman, Ragan M. Callaway, and Chad J. Bishop
ABSTRACT: Across much of North America, populations of moose (*Alces alces*) are declining because of disease, predation, climate change, and anthropogenic-driven habitat loss. Contrary to this trend, populations of moose in Colorado, USA, have continued to grow. Studying successful (i.e., persistent or growing) populations of moose can facilitate continued conservation by identifying habitat features critical to persistence of moose. We hypothesized that moose using habitat with higher quality willow (*Salix* spp.) would have a higher probability of having a calf-at-heel (i.e., calving success). We evaluated moose calving success using repeated ground observations of collared individuals with calves in an occupancy model framework to account for detection probability. We then evaluated the impact of willow habitat quality and nutrition on moose calving success by studying 2 spatially segregated populations of moose in Colorado. Last, we evaluated correlations between willow characteristics (browse intensity, height, cover, leaf length, and species) and willow nutrition (dry matter digestibility [DMD]) to assess the

utility of using those characteristics to assess willow nutrition. We found willow height and cover had a high probability of being positively associated with higher individual-level calving success. Willow DMD, browse intensity, and leaf length were not predictive of individual moose calving success; however, the site with higher mean DMD consistently had higher mean estimates of calving success for the same year. Our results suggest surveying DMD is likely not a useful metric for assessing differences in calving success of individual moose but may be of use at population levels. Further, the assessment of willow morphology and density may be used to identify areas that support higher levels of moose calving success.
The Journal of Wildlife Management 86:e22175 (2022)

Phylogeography of moose in western North America
Nicholas J. DeCesare, Byron V. Weckworth, Kristine L. Pilgrim, Andrew B. D. Walker, Eric J. Bergman, Kassidy E. Colson, Rob Corrigan, Richard B. Harris, Mark Hebblewhite, Brett R. Jesmer, Jesse R. Newby, Jason R. Smith, Rob B. Tether, Timothy P. Thomas, and Michael K. Schwartz
ABSTRACT: Subspecies designations within temperate species' ranges often reflect populations that were isolated by past continental glaciation, and glacial vicariance is believed to be a primary mechanism behind the diversification of several subspecies of North American cervids. We used genetics and the fossil record to study the phylogeography of three moose subspecies (*Alces alces andersoni*, *A. a. gigas*, and *A. a. shirasi*) in western North America. We sequenced the complete mitochondrial genome (16,341 base pairs; $n = 60$ moose) and genotyped 13 nuclear microsatellites ($n = 253$) to evaluate genetic variation among moose samples. We also reviewed the fossil record for detections of all North American cervids to comparatively assess the evidence for the existence of a southern refugial population of moose corresponding to *A. a. shirasi* during the last glacial maximum of the Pleistocene. Analysis of mtDNA molecular variance did not support distinct clades of moose corresponding to currently recognized subspecies, and mitogenomic haplotype phylogenies did not consistently distinguish individuals according to subspecies groupings. Analysis of population structure using microsatellite loci showed support for two to five clusters of moose, including the consistent distinction of a southern group of moose within the range of *A. a. shirasi*. We hypothesize that these microsatellite results reflect recent, not deep, divergence and may be confounded by a significant effect of geographic distance on gene flow across the region. Review of the fossil record showed no evidence of moose south of the Wisconsin ice age glaciers ≥ 15,000 years ago. We encourage the integration of our results with complementary analyses of phenotype data, such as morphometrics, originally used to delineate moose subspecies, for further evaluation of subspecies designations for North American moose.
Journal of Mammalogy 101:10-23 (2020)

PREDATORY MAMMAL MANAGEMENT AND CONSERVATION

BOBCAT POPULATION DYNAMICS AND DENSITY ESTIMATION

MULE DEER POPULATION RESPONSE TO COUGAR POPULATION MANIPULATION

EVALUATION OF ACCELEROMETER COLLARS AND METHODS DEVELOPMENT FOR DOMESTIC CATTLE

Colorado Parks and Wildlife
WILDLIFE RESEARCH PROJECT SUMMARY

Bobcat population dynamics and density estimation

Period Covered: January 01, 2023 – December 31, 2023

Principal Investigators: Shane Frank, shane.frank@state.co.us; Jake Ivan, jake.ivan@state.co.us; Mark Vieira, mark.vieira@state.co.us; Jon Runge, jon.runge@state.co.us

Personnel: Johnathan Lambert, Tom Knowles, Mike Swaro, Darby Finley, Garrett Smith, Brian Holmes, J.C. Rivale, Erin Sawa, Rachel Baker, Chris Martin, Kirsten Terkildsen, Nick Ragucci, David Starzenski

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To enhance our understanding of bobcat (*Lynx rufus*) population dynamics and the relative influence of bobcat harvest on bobcat densities in Colorado, a pilot study was started late September 2022 and data collection continued through fall of 2023. The major field objectives of the pilot study were (1) to capture and mark bobcats with ear tags and GPS collars to be used in mark-resight analysis for population density estimation in two study areas and (2) to determine whether successful bobcat trapping rate is sufficient to build toward an adequately sized sample population in subsequent years for population density estimation within a longer-term bobcat population dynamics research project. An updated study plan was submitted and accepted late fall/early winter of 2023.

We selected two study areas, 'Piceance' and 'Skull Creek,' in the northwest region within Game Management Units 10 and 22 (Figure 1). Each area was 20 x 20 km (400 km^2 area) in extent, with similar topography and habitat composition. Piceance had higher historical bobcat harvest (>2.55 bobcats/100 km^2) than Skull Creek (nearly 0 bobcats/100 km^2). Habitat type composition was predominated by pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) and sagebrush (*Artemisia* spp.) communities in both study areas. CPW personnel continued live-trapping bobcats that started 11/18/2022 through 04/06/2023. As of 12/31/2023, CPW captured 29 unmarked bobcats with 13 recaptures. On average, an unmarked bobcat required approximately 64 trap nights for capture, rendering a rate acceptable to reach the eventual desired sample size of 30 bobcats per study area. There were 119 individual camera detections of bobcats recorded from November 2022-April 2023 within the Piceance, of which 9 were marked, 93 unmarked, and 17 unknown. More than 30% of the collared bobcats in Piceance were detected on the cameras. Population estimation was possible for the Piceance study area, but was not for the Skull Creek study area due to severe winter conditions precluding access and fieldwork necessary to set up the full camera trap array and live traps. The population estimate for the Piceance for the 2022-2023 field data is preliminary, due to incomplete coverage of the study area from the severe winter. In fall of 2023, CPW personnel checked and refreshed 100 camera traps within the Piceance study area and finished deploying the remaining 65 camera traps within the Skull Creek study area (Figure 1). Camera trap checks and set-ups included initially placing or replacing visual and scent lure to draw bobcats for photo detections or 'resights' in the case of marked bobcats. Live-trapping efforts in both study areas and camera image collection will continue through spring of 2024, at which point photo identification and mark-resight analysis will commence for the new data set (2023-2024). Images collected in the fall of 2023 have been photo-identified and population estimation models will be performed by spring 2024 alongside photo identification of the new images collected in spring. Information from the pilot study data will be included in the longer-term study plan addendum that was approved late 2023, which addresses bobcat density-habitat relationships, survival, diet, prey base, and associations between bobcat density, harvest, and primary prey, cottontails and jackrabbits.

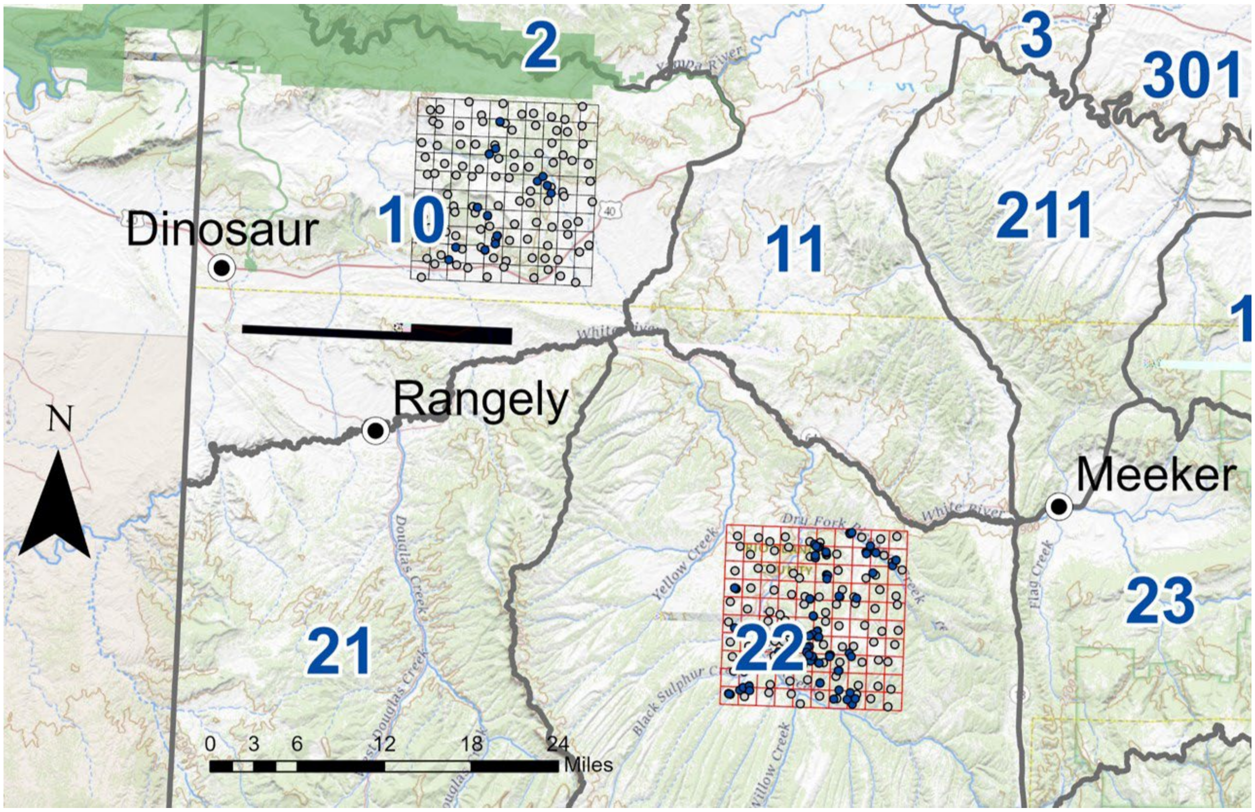

Figure 1. The bobcat study areas (20 x 20 km) in northwest Colorado include the Piceance grid, shown in red (lower), within Game Management Unit (GMU) 22 and the Skull Creek grid, shown in gray (upper), within GMU 10, which is bordered to the north by Dinosaur National Monument (green shaded area). Bobcat study areas are subdivided into 100 2 x 2 km cells, each containing a camera trap (gray dot). Dark blue dots depict live trap location/efforts.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Mule deer population response to cougar population manipulation

Period Covered: January 1, 2023 – December 31, 2023

Principal Investigators: Mat Alldredge, mat.alldredge@state.co.us; Allen Vitt, allen.vitt@state.co.us; Bryan Lamont, bryan.lamont@state.co.us; Ty Woodward, tyrel.woodward@state.co.us; Jamin Grigg, jamin.grigg@state.co.us; Chuck Anderson, chuck.anderson@state.co.us

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The adopted Colorado mule deer (*Odocoileus hemionus*) strategy identified predation as one of the potential factors limiting Colorado mule deer populations. Since the adoption of the mule deer strategy by the Colorado Parks and Wildlife (CPW) Commission, members of the CPW Leadership Team developed a plan to implement the strategy. To inform predator harvest and management decisions, staff examined existing data sets related to predator and deer relationships. In June 2015, CPW personnel from the SE Region, Terrestrial, and Research branches met to explore the concept for a project that examines how deer demographic parameters may change following cougar population suppression. Deer Data Analysis Unit (DAU) D-16 had experienced significant deer mortality from cougars. This study initiated in 2017 in D-16 and the adjacent D-34 as a manipulative study to examine the effects of cougar predation on mule deer and simultaneously examine the effects of cougar harvest on the cougar population.

To assess the effect of management manipulations, it was necessary to develop an experimental framework including a control and treatment study area. Otherwise, the magnitude of the effect would be unknown as other limiting factors fluctuate. D-34 is an adjacent mule deer DAU to the south of D-16, which has a similar mule deer population size and habitat. Using D-16 and D-34 in a crossover design allowed for the manipulation of a potential limiting factor for mule deer population growth or survival and examine similarities in the response as the control and treatment are switched between the areas. The study's first objective was to assess the impact of cougar predation on mule deer survival and determine if this impact could be manipulated by altering cougar densities. The second objective was to assess how this manipulation would affect the cougar population in terms of intraspecific mortality and human conflict.

The manipulation involved increasing cougar harvest in D-16 for the first 3 years of the study and then reducing harvest to a low level for the following 6 years and doing the reverse in D-34 with a reduced harvest for the first 6 years and increased harvest in the last 3 years. During this time we would monitor deer mortality from cougars, measure cougar density, and assess intraspecific cougar mortality and cougar/human conflict in both study areas.

To date, deer survival has been relatively high (86% average doe survival D-16 and D-34; 64% average winter fawn survival D-16; 84% average winter fawn survival D-34) in both study areas across years and deer mortality associated with cougars has been low (5.6% does D-16; 7.2% does D-34; 4.2% fawns D-16; 2.1% fawns D-34). Because deer survival was relatively high in the area and mortality associated with cougars was relatively low during the first 6 years of the study, <u>we stopped investigating the impact of cougar predation on deer survival</u>. The remaining treatment was to increase cougar harvest in D34, which presumably would increase deer survival. However, it was decided that it would not be possible to measure an effect if it did occur with relatively high deer survival evident during the period of low cougar harvest/relatively high cougar density.

Graduate student, Annie Hart, at Colorado State University is continuing her Master's project examining the deer data. The first part of her project examines how variation in natural forage abundance influences mule deer selection of agricultural resources. The other part of her project will model adult and juvenile survival to help understand the costs and benefits of migration. This is using a state uncertainty modeling approach to estimate survival of migrant and resident fawns, which incorporates the survival of individuals that die before their movement strategy is classified.

The cougar population component of the study is continuing with assessing impacts of cougar harvest in D-16 and D-34. We continue to estimate cougar density in both study areas and are monitoring intraspecific effects and cougar/human conflict. As this continues, we will maintain a low cougar harvest (quota of 12) in D-16 but need to increase the cougar quota in D-34. The quota in D-34 had been reduced to 15 since the study started, but we proposed an increase in the quota to 35 cougars to start in the 2023-2024 hunting season, which was approved by the CPW Wildlife Commission in 2023.

During the study we have captured and collared 108 cougars in D-16 and 120 in D-34. Last year we captured 11 in D-16 and 20 in D-34. The higher captures in D-34 were related to increased sample size requirements for the cougar survey in D-34 that year. Over the last couple of years collars have been failing sooner than expected, presumably because collar batteries are not lasting as long as they used to.

To date, we have completed 3 density estimates in each D-16 and D-34 with preliminary estimates ranging from 2.7 to 3.1 independent cougars per 100 km^2. This does not account for any cougars that may have been harvested prior to the initiation of the survey each year. We have not detected a significant change in density relative to changes in harvest quotas or achieved harvest. In 2023 the density estimate was conducted in D-34.

Cougar mortality has been relatively low throughout the study, with the majority of this attributable to hunting mortality. Other sources of mortality include disease, intraspecific killing, human conflict removal and unknown. Intraspecific mortality has ranged from 1 to 2 incidences yearly in D-16 and 1 to 3 in D-34 for collared cougars.

Cougar/human conflict is variable between years and study areas. This conflict may include livestock depredation, pet depredation, being in unacceptable locations, or aggressive behaviors toward humans. We show conflict rates from 2000-2023 (Figure 1) which shows the variability across time. There may also be variability in these data from how it was reported and recorded, most notably the switch to an electronic/online approach of the conflict app in 2019. D-34 had some of the highest conflict, especially in 2021 and 2023, but historical conflict rates also had occasional high years as well.

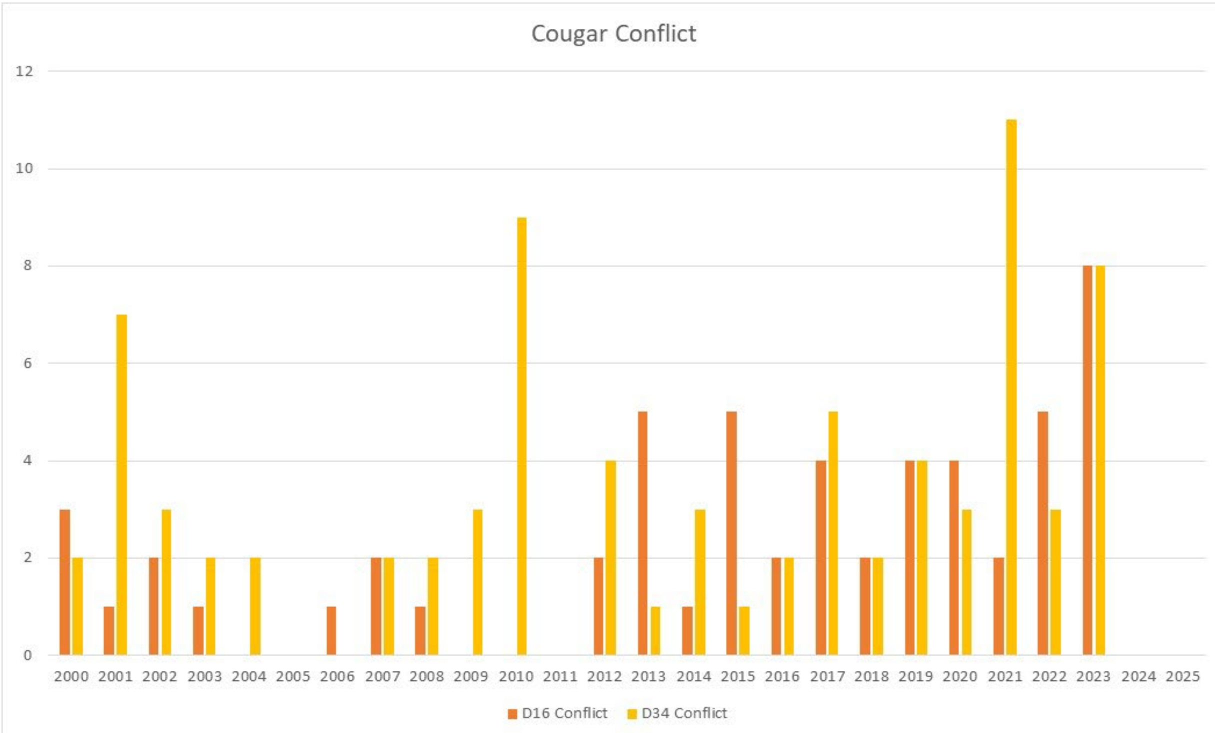

Figure 1: Number of human/cougar conflicts in DAUs D-16 and D-34 by year. This does not include sightings.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Evaluation of accelerometer collars and methods development for domestic cattle

Period Covered: January 1, 2023-December 31, 2023

Principal Investigators: Ellen Brandell, ellen.brandell@state.co.us

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Livestock production is an important component of Colorado's economy (University of Arkansas accessed 2023, Bureau of Land Management accessed 2023), as well as ingrained in the state's culture and heritage – cattle production in particular. Colorado citizens are concerned about the effects of re-establishing gray wolves (*Canis lupus*) on livestock (Niemiec et al. 2022), and given the geographic constraints of CRS 33-2-105.8 (Colorado General Assembly 2020, CPW 2023) and suitable wolf habitat in Colorado (Ditmer et al. 2022), wolves and livestock will spatially overlap in western Colorado. Wolves may affect livestock both directly and indirectly; direct effects include depredation, which has already occurred in the state. Indirect effects, such as increased stress or vigilance behavior, are much more difficult to observe and quantify.

Indirect effects of wolves on cattle have been documented in other western states or laboratory experiments, such as decreased weight gain (Ramler et al. 2014) and increased stress (Cooke et al. 2013). However, these negative effects are not ubiquitous across studies, and the majority of published literature on this topic lacks a mechanistic understanding. For example, cattle movement rates (Laporte et al. 2010, Bailey et al. 2018) and physiology (Cooke et al. 2013) in response to wolf presence have been studied, but unless changes in movement rates or physiology have direct implications for weight gain, pregnancy rates, or animal health, it might not be important to a producer or impact the operation's economics.

In a future research project, we aim to link cattle behavior and movement in response to wolf presence to cattle stress levels, weight gain, and pregnancy rates. Quantifying the mechanisms of changes in cattle stress, weight gain, and pregnancy rates is critical for identifying whether a causal relationship exists between wolf exposure and cattle responses, the magnitude of this effect, and subsequent consequences for producers' bottom line. However, before we can launch a research project, we need to test the field equipment and develop data collection methods.

In spring 2023, we began a methods testing project to evaluate GPS and accelerometer collars on beef cattle. We had three goals of this methods testing project: (1) assess proper fit of GPS/accelerometer collars on both adult female cows and calves throughout the grazing season; (2) develop methods to calibrate accelerometer data to common cattle behaviors; (3) test field equipment, and improve equipment as needed.

We outfitted 20 cows with collars in May and June 2023. More specifically, we collared and monitored 10 cow-calf pairs from two cattle operations (one in Northeast Colorado, one in Northwest Colorado). Cow-calf pairs are of interest as calves are the most vulnerable to predation. Data collection ranged from approximately 1-5 months while cattle were grazing on allotments (e.g., USFS, BLM). We obtained a high-quality visual observation of all collared animals at least twice per month, and often multiple times a week. Visual observations were obtained by CPW staff, the livestock owner, or ranch personnel. Animal condition and collar fit was assessed visually, and with associated photos and video where possible. We used this information to determine if collars needed to be periodically adjusted. Calf collars had a section of elastic to allow for growth in between adjustments.

Accelerometers collect triaxial data (x, y, and z axes) 8 times per second (8 Hz). Accelerometers have been used on cattle and other grazing species to identify behaviors and quantify time budgets (Riaboff et al. 2020, Riaboff et al. 2022). We will create time budgets by specifying cattle behaviors such as feeding, resting, ruminating, moving, acting vigilant, and grooming. We will calibrate cattle behavior by performing focal follows, where an individual cow or calf is observed for a predetermined amount of time (20 minutes), and the timing of different behaviors is recorded (Riaboff et al. 2022). One adult female cow per operation was outfitted with a camera collar as well to provide constant behavioral validation data. The observation data is compared with the triaxial data patterns, and unique data patterns are labeled as specific behaviors using machine learning algorithms (Riaboff et al. 2020, Riaboff et al. 2022). Collars will also collect geospatial data at short, regular intervals to calculate distance moved and movement rates (Bailey et al. 2018). We are currently organizing and analyzing these data.

Experiences from this methods testing project will help guide equipment decisions, data collection methods, and fieldwork as we develop a larger-scale research project focusing on indirect effects of predators on livestock.

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SUPPORT SERVICES

RESEARCH LIBRARY ANNUAL REPORT 2023

RESEARCH DATABASE SUPPORT SERVICES

Colorado Parks and Wildlife

RESEARCH LIBRARY ANNUAL REPORT 2023

Period Covered: January 1, 2023 – December 31, 2023

Author: Karen Hertel, Karen.Hertel@state.co.us

The Colorado Parks and Wildlife Research Center Library, in existence since the 1960s in the Fort Collins office, serves all CPW staff regardless of location. Primary functions of the library are to 1) support wildlife research and management by providing research assistance and full-text information resources, and 2) serve as an institutional repository by archiving and providing access to documents produced by agency staff.

Karen Hertel was hired as the new librarian in December of 2022; primary focuses in 2023 were:

- Collection analysis, resulting in the withdrawal of 2,135 obsolete, duplicate, or seldom-used items.
- Updating of bibliographic records in the catalog to correct call numbers to match shelf location.
- Continued digitization of CPW documents, adding 392 CPW documents and 91 theses to the pdf collection.

As of December 2023, the CPW Library Catalog contains 8,233 records (unique titles) and 20,734 items (many titles have more than one item; for example, a report that is produced multiple years). CPW Digital Collections, part of the Plains to Peaks Collective, grew to 347 items, accessible through the catalog or the public-facing website. There are 253 registered patrons (CPW staff).

Approximately 90% of the library budget was used for electronic journal and database subscriptions. To facilitate access to all library resources, including the journals and databases, the decision was made to return to Ebsco (cancelled in 2020) as the vendor for the public-facing discovery layer of the catalog and retain the underlying Integrated Library System (ILS) with the current AspenCat consortium. The primary rationale is to enhance access to costly journal and database resources while retaining a cost-effective ILS. The transition to the Ebsco service was initiated in December of 2023.

Current databases include BioOne, Birds of North America, ProQuest Dissertations and Theses, ProQuest Natural Science, JSTOR Life Sciences, and curated collections from Wiley Online Library and Canadian Science Publishing.

A major role of the librarian is to assist CPW staff with document delivery and research assistance. Document requests are filled through CPW subscriptions, interlibrary loan privileges at the University of Wyoming Library, and on-site only (not remote) access at CSU Morgan Library. This year, 310 reference requests were received. The majority were document delivery requests; other assistance included compiling literature reviews, utilizing databases, accessing state and federal documents, etc.

In 2023, the library received two large donations of materials from retired CPW staff. These were accessioned and organized for further processing.

Contacts were made with Colorado State Library (CSL) staff to facilitate sharing of print and digital items and utilize their cataloging records for CPW items when feasible. Procedures for distributing CPW reports in both print and digital format to CSL for inclusion in their collection and distribution to depository libraries were established.

Colorado Parks and Wildlife

RESEARCH DATABASE SUPPORT SERVICES

Period Covered: January 1, 2023 – December 31, 2023

Author: Benjamin Wasserstein, Research & Species Conservation Database Analyst/Manager, Benjamin.Wasserstein@state.co.us

The Research & Species Conservation Database Analyst/Manager serves as CPW's operational professional for statewide activities on research, wildlife health, species conservation, and terrestrial data analysis and summarization. Duties and goals for this role involve developing and maintaining custom database solutions for research and management projects, providing custom applications for analysis and reporting, and administering data and database systems in an organized and efficient manner. This annual report serves to highlight this role's work in the 2023 calendar year with the caveat that the position was unstaffed from January 1 through June 16, 2023. A detailed summary of managed database systems serves as a snapshot of totals at the end of the 2023 calendar year (Figure 1).

USGS NABat Data Call

CPW provided data to the U.S. Geological Survey's North American Bat Monitoring Program (NABat) to assist with the USGS' nationwide bat status and trends analysis. The NABat Program utilizes multiple lines of evidence to understand where, when, and how bat populations have changed over time. CPW was able to provide nearly 30,000 bat observation records stemming from multiple decades worth of data that were compiled and collected by CPW staff. CPW's historical bat records date back to the 1930s, and through record-keeping, data digitization, and data management, these data were provided to the USGS' NABat Program to allow for statewide and nationwide occupancy and abundance modeling. This work has also pointed CPW and other researchers to new portions of the state being used by bat species.

Results from the NABat Program can be found at *https://sciencebase.usgs.gov/nabat/#/results*.

ACUC Forms Going Digital

CPW's Animal Care and Use Committee (ACUC) has historically relied on a variety of hard copy forms to ensure the requirements of the Animal Welfare Act are applied to management and research projects. Recognizing the need for a more efficient and accessible system, we initiated a significant shift towards a digital workflow in 2023. This transition began with developing a custom web form that enables the submission of training records for individuals working under specific projects. This approach not only streamlines the submission process but also ensures the instantaneous creation of a digital training records document while automating data storage into a centralized system. The digital form also implements automated email notifications, which immediately notify the ACUC Program Assistant and supervisor when training records are submitted for a particular trainee.

This effort aims to simplify data management and reduce time spent on manual data entry, document scanning, and retrieval. A digital data solution for ACUC also helps facilitate real-time data and information sharing among relevant staff, which in turn helps streamline the ACUC process as a whole. Work to bring other ACUC forms and documents into a fully digital workflow will continue into 2024.

Custom Applications

The Research Database Analyst develops custom database applications for Mammals/Avian Research, Wildlife Health, and Species Conservation staff. These applications offer data management and analysis solutions that are tailored to specific research and management projects. Software programs and platforms such as Microsoft Access, Tableau, ArcGIS, and R Shiny web applications are utilized to provide users with tailored views into CPW research and management data. A select few custom applications are highlighted below.

Seed Mix Data Entry R Shiny Web Application

The Seed Mix Data Entry R Shiny web application is tailored to allow for data entry into the "SeedMix" SQL Server database. This database serves as the central point for the data behind CPW's "Colorado Seed Tool" phone application. The web application is coded in R – a free, open source programming language, and the application itself is hosted on a cloud-based server that utilizes a portable installation of R. The Seed Mix Data Entry App allows CPW habitat experts to populate the database with information from reclamation and seeding professionals regarding seeding success across Colorado. Download the "Colorado Seed Tool" app from the Apple or Google Play app stores to tap into the wealth of data within this database and to increase your seeding success.

Chronic Wasting Disease (CWD) R Shiny Web Application

The CWD R Shiny web application provides CPW's Wildlife Health staff with access to raw data and data summaries involving CWD monitoring across the state. Staff may use the application to view estimates of CWD prevalence across different species, years, Game Management Units (GMUs), and Data Analysis Units (DAUs). The application is updated on a weekly basis to account for new CWD test submissions. Similar to the Seed Mix R shiny app, the CWD web application utilizes a portable version of R hosted alongside the application on a cloud server.

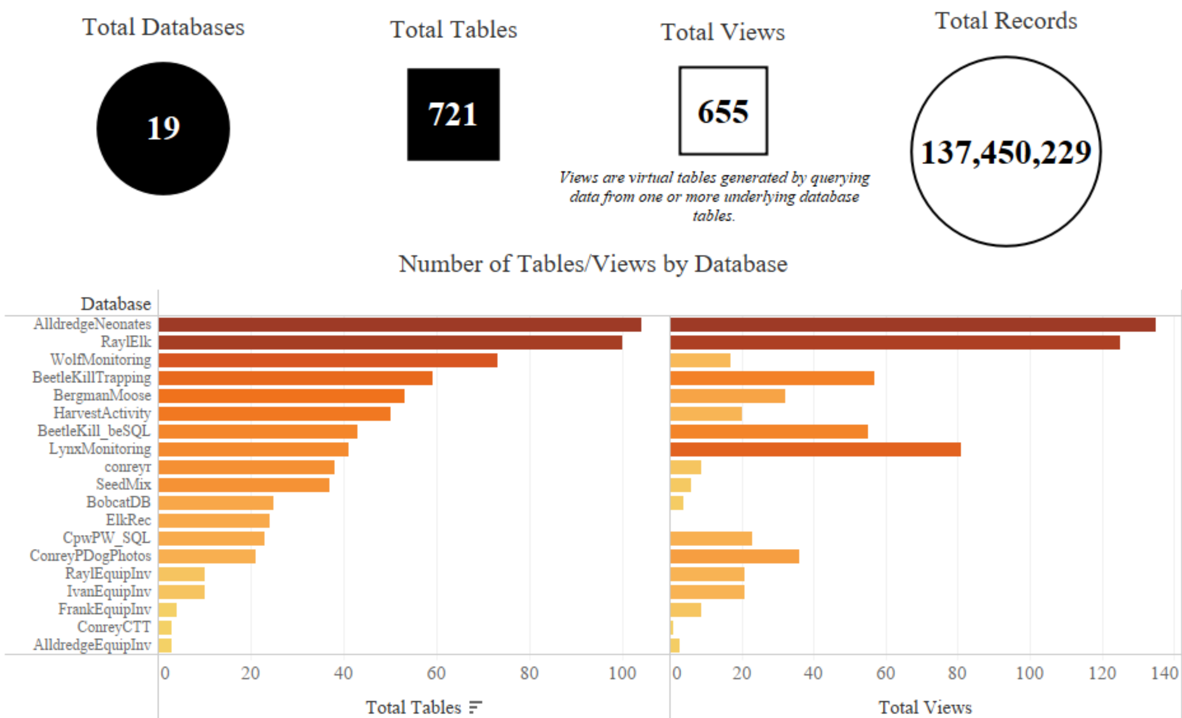
Gray Wolf Monitoring Database and Dashboards

Initial development of CPW's "WolfMonitoring" research database concluded in 2023. This involved developing all back-end SQL Server database tables, views, functions, and stored procedures to allow for standardized data management involving gray wolf research and species conservation efforts. A custom front-end Microsoft Access database allows for data entry, and Tableau dashboards are currently in development to allow for information sharing with CPW staff. Discussions are also underway involving public information sharing regarding gray wolf activity in Colorado; keep an eye on the CPW website's "Stay Informed" page for more details on this note: https://cpw.state.co.us/learn/Pages/Wolves-Stay-Informed.aspx

Research Databases In-development

Development is underway for databases that will house research data related to Greater Sage-grouse, Bobcat, and Pronghorn. This involves full-stack database development which includes developing the back-end database (raw tables, views, stored procedures, etc.) as well as developing front-end applications that provide access to the data. Once development is complete, these new databases will be published to the production server and captured in next year's database summary. For more information regarding the size and growth of research databases, keep an eye on the annual mammals/avian research database summary (Figure 1).

CPW Mammals/Avian Research SQL Server Database Summary - January 2023



Database	# Records (Tables)	# Records (Views)	Total Record Count
RaylElk	15,183,402	36,990,015	52,173,417
ConreyPDogPhotos	10,506,215	22,843,589	33,349,804
AlldredgeNeonates	3,707,902	21,072,887	24,780,789
LynxMonitoring	7,526,046	12,238,151	19,764,197
BergmanMoose	499,238	1,742,462	2,241,700
BeetleKill_beSQL	848,302	1,240,986	2,089,288
ElkRec	1,211,849	0	1,211,849
HarvestActivity	635,474	241,599	877,073
SeedMix	191,593	136,892	328,485
CpwPW_SQL	58,291	123,815	182,106
conreyr	167,097	1,301	168,398
BeetleKillTrapping	56,307	32,877	89,184
ConreyCTT	44,118	44,096	88,214
WolfMonitoring	8,415	28,260	36,675
IvanEquipInv	7,534	23,433	30,967
BobcatDB	13,765	13,510	27,275
RaylEquipInv	1,927	7,153	9,080
FrankEquipInv	336	1,324	1,660
AlldredgeEquipInv	65	3	68
Grand Total	*40,667,876*	*96,782,353*	*137,450,229*

Total # of Records by Database

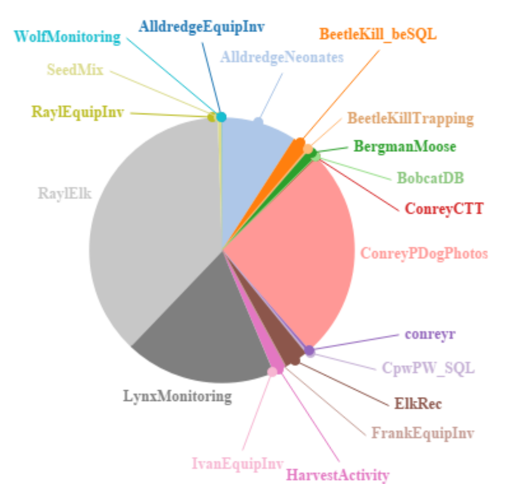


Figure 1. The 2023 end of year summary from all managed SQL Server databases and their associated tables/views.

APPENDIX A. CPW mammal research abstracts accepted for publication since December 2022.

Small Mammal Ecology and Conservation – page 46

- Differential impacts of spruce beetle outbreaks on snowshoe hares and red squirrels in the southern Rocky Mountains

Ungulate Ecology and Management – page 47

- Genomic correlates for migratory direction in a free-ranging cervid
- Plant and mule deer responses to pinyon-juniper removal by three mechanical methods

Approaches for Wildlife Population Monitoring – pages 48-50

- Multistage hierarchical capture–recapture models
- Influence of camera model and alignment on the performance of paired camera stations
- An objective approach to select surrogate species for connectivity conservation
- A multi-property assessment of intensity of use provides a functional understanding of animal movement

SMALL MAMMAL ECOLOGY AND CONSERVATION

Differential impacts of spruce beetle outbreaks on snowshoe hares and red squirrels in the southern Rocky Mountains

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Citation: Ivan, J. S., E. S. Newkirk, and B. D. Gerber. 2023. Differential impacts of spruce beetle outbreaks on snowshoe hares and red squirrels in the southern Rocky Mountains. Forest Ecology and Management 544:121147; https://doi.org/10.1016/j.foreco.2023.121147

ABSTRACT Spruce beetles (*Dendroctonus rufipennis*) have impacted millions of acres of Engelmann spruce (*Picea engelmannii*) – subalpine fir (*Abies lasiocarpa*) forest in North America over the past decade, resulting in the most extensive outbreak in recorded history. This dramatic alteration of forest composition and structure has precipitated numerous changes to forest ecology and ecosystem services. Among the least studied of these changes are impacts to wild mammals, including snowshoe hares (*Lepus americanus*) and red squirrels (*Tamiasciurus hudsonicus*). We sampled a chronosequence of spruce-fir stands along a gradient of 'years elapsed since spruce beetle outbreak' (YSO) in order to estimate impacts to abundance of these two species in the southern Rocky Mountains. Snowshoe hare abundance was not related to YSO, at least in the first decade post-outbreak. Instead, hare abundance during this period was positively related to horizontal cover, especially that due to stem density of small diameter subalpine fir. Notably, snowshoe hare abundance was negatively related to stem density of small diameter Engelmann spruce, suggesting that elements of horizontal cover may not be uniformly beneficial to hares. Hare abundance was also negatively related to ground cover, which could help explain the lack of relationship to YSO, assuming reduction in overstory canopy would lead to increases in ground cover. Red squirrel abundance was negatively related to YSO and outbreak severity (i.e., basal area of large diameter dead trees). This was likely due to diminished cone crops in impacted areas, which red squirrels cache and rely on heavily to sustain them through the winter. Basal area of remaining large live fir trees was not related to squirrel abundance, suggesting that regeneration of spruce and associated cone crops may be necessary for recovery of red squirrels, which may take several decades. Published September 2023.

UNGULATE ECOLOGY AND MANAGEMENT

Genomic correlates for migratory direction in a free-ranging cervid

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Citation: Bonar, M., S. J. Anderson, C. R Anderson Jr, G. Wittemyer, J. M. Northrup and A. B. A. Shafer. 2022. Genomic correlates for migratory direction in a free-ranging cervid. Prodeedings of the Royal Society B 289: 20221969: https://doi.org/10.1098/rspb.2022.1969

ABSTRACT Animal migrations are some of the most ubiquitous and one of the most threatened ecological processes globally. A wide range of migratory behaviours occur in nature, and this behaviour is not uniform among and within species, where even individuals in the same population can exhibit differences. While the environment largely drives migratory behaviour, it is necessary to understand the genetic mechanisms influencing migration to elucidate the potential of migratory species to cope with novel conditions and adapt to environmental change. In this study, we identified genes associated with a migratory trait by undertaking pooled genome-wide scans on a natural population of migrating mule deer. We identified genomic regions associated with variation in migratory direction, including FITM1, a gene linked to the formation of lipids, and DPPA3, a gene linked to epigenetic modifications of the maternal line. Such a genetic basis for a migratory trait contributes to the adaptive potential of the species and might affect the flexibility of individuals to change their behaviour in the face of changes in their environment. Published December 2022.

Plant and mule deer responses to pinyon-juniper removal by three mechanical methods

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Citation: Johnston, D. B., and C. R. Anderson Jr. 2023. Plant and mule deer responses to pinyon-juniper removal by three mechanical treatment methods. Wildlife Society Bulletin 47(2):1–21; DOI: 10.1002/wsb.1421

ABSTRACT Land managers in western North America often reverse succession by removing pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) trees to reduce fire risk and increase forage for wildlife and livestock. Because prescribed fire carries inherent risks, mechanical methods such as chaining, roller-chopping, and mastication are often used. Mechanical methods differ in cost and the size of woody debris produced, and may differentially impact plant and animal responses. We implemented a randomized, complete block, split-plot experiment in December 2011 in the Piceance Basin, northwestern Colorado, USA, to compare mechanical methods and to explore seeding (subplot) interactions. We assessed vegetation 1-, 2-, 5-, and 6-years post-treatment, and mule deer (*Odocoileus hemionus*) response via GPS locations 3–8 years post-treatment. By 2016, treated plots had 3–5 times higher perennial grass cover and ~10 times higher cheatgrass (*Bromus tectorum*) cover than untreated control plots. Rollerchopped plots had both the highest non-native annual forb cover, and when seeded, the highest density of bitterbrush (*Purshia tridentata*), a nutritious shrub used by mule deer. Masticated plots had higher bitterbrush use during summer and fall, leaving less forage available for winter. Days of winter mule deer use from GPS point locations in chained and rollerchopped plots was ~70% higher than in control plots, while winter use in masticated plots was similar to control plots. Mule deer use appears related to a combination of hiding cover, resulting from residual woody debris, and winter forage availability. Roller-chopped plots provide the best combination of hiding cover and winter forage, but mastication or chaining, applied leaving dispersed security cover, may be better options at large scales or when invasive species concerns exist. Published February 2023.

APPROACHES FOR WILDLIFE POPULATION MONITORING

Multistage hierarchical capture–recapture models

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Citation: Hooten, M. B., M. R. Schwob, D. S. Johnson, and J. S. Ivan. 2023. Multstage hierarchical capture–recapture models. Enviornmetrics 34(6):1–14; https://doi.org/10.1002/env.2799

ABSTRACT Ecologists increasingly rely on Bayesian methods to fit capture–recapture models. Capture–recapture models are used to estimate abundance while accounting for imperfect detectability in individual-level data. A variety of implementations exist for such models, including integrated likelihood, parameter-expanded data augmentation, and combinations of those. Capture–recapture models with latent random effects can be computationally intensive to fit using conventional Bayesian algorithms. We identify alternative specifications of capture–recapture models by considering a conditional representation of the model structure. The resulting alternative model can be specified in a way that leads to more stable computation and allows us to fit the desired model in stages while leveraging parallel computing resources. Our model specification includes a component for the capture history of detected individuals and another component for the sample size which is random before observed. We demonstrate this approach using three examples including simulation and two datasets resulting from capture–recapture studies of different species. Published March 2023.

Influence of camera model and alignment on the performance of paired camera stations

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Citation: Swearingen, T. C., R. W. Klaver, C. R. Anderson Jr., and C. N. Jaques. 2023. Influence of camera model and alignment on the performance of paired camera stations. Wildlife Society Bulletin 47(2):e1422; https://doi.org/10.1002/wsb.1422

ABSTRACT The probability of obtaining images of target species may vary across camera models or relative position of cameras at survey locations. Alignment of cameras within paired camera stations (hereafter, stations) could affect species detection due to issues with image exposure. We quantified effects of 3 camera models and alignment (staggered, offset by a perpendicular distance of 4.6 m, and aligned, directly facing one another) on camera performance in a station design. Mean exposure events (flash from one camera overexposes or underexposes pictures) at aligned stations was 3.93 (SE = 1.01; $n = 40$), whereas no exposure events were documented at staggered ($n = 36$) stations. Overall frequency of exposure events of mammal images at aligned cameras was 44% (68 exposure events/153 images). On average, 8% (range 0−35%) of mammal images from aligned stations were exposure events. We detected no difference ($P = 0.88$) in exposure events among paired camera models. Further, we detected no overall differences ($P \geq 0.07$) in paired camera performance (i.e., number of mammal images over survey interval) between aligned or staggered stations, though reliability (i.e., percentage of camera stations that lasted entire survey interval) varied ($P \leq 0.001$) between model types. Research deploying 2 cameras within a camera station framework can eliminate exposure events by using a staggered camera alignment without affecting the number of usable mammal photos. Rigorous field testing prior to deployment of stations is warranted to optimize reliability. One of our low-cost models performed as well as a more expensive model within our paired camera stations at collecting mammal images, and thus could be incorporated into study designs without compromising quality of camera photo data. We suggest a pilot study before large-scale deployment to evaluate reliability and performance of cameras, particularly when deploying multiple models. Published June 2023

An objective approach to select surrogate species for connectivity conservation

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Citation: Dutta, T., M. De Barba, N Selva, A. C. Fedorca, L Maiorano, W. Thuiller, A. Zedresser, J. Signer, F. Pfluger, S. Frank, P M. Lucas, and N. Balkenholl. 2023. An objective approach to select surrogate species for connectivity conservation. Frontiers in Ecology and Evolution 11:1078649; doi: 10.3389/fevo.2023.1078649

Introduction: Connected landscapes can increase the effectiveness of protected areas by facilitating individual movement and gene flow between populations, thereby increasing the persistence of species even in fragmented habitats. Connectivity planning is often based on modeling connectivity for a limited number of species, i.e., "connectivity umbrellas", which serve as surrogates for co-occurring species. Connectivity umbrellas are usually selected a priori, based on a few life history traits and often without evaluating other species.
Methods: We developed a quantitative method to identify connectivity umbrellas at multiple scales. We demonstrate the approach on the terrestrial large mammal community (24 species) in continental Europe at two scales: 13 geographic biomes and 36 ecoregions, and evaluate the interaction of landscape characteristics on the selection of connectivity umbrellas.
Results: We show that the number, identity, and attributes of connectivity umbrellas are sensitive to spatial scale and human influence on the landscape. Multiple species were selected as connectivity umbrellas in 92% of the geographic biomes (average of 4.15 species) and 83% of the ecoregions (average of 3.16 species). None of the 24 species evaluated is by itself an effective connectivity umbrella across its entire range. We identified significant interactions between species and landscape attributes. Species selected as connectivity umbrellas in regions with low human influence have higher mean body mass, larger home ranges, longer dispersal distances, smaller geographic ranges, occur at lower population densities, and are of higher conservation concern than connectivity umbrellas in more human-influenced regions. More species are required to meet connectivity targets in regions with high human influence (average of three species) in comparison to regions with low human influence (average of 1.67 species).
Discussion: We conclude that multiple species selected in relation to landscape scale and characteristics are essential to meet connectivity goals. Our approach enhances objectivity in selecting which and how many species are required for connectivity conservation and fosters well-informed decisions, that in turn benefit entire communities and ecosystems. Published July 2023

A multi-property assessment of intensity of use provides a functional understanding of animal movement

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Citation: Bastille-Rousseau, G., S. A. Crews, E. B. Donovan, M. E. Egan, N. T. Gorman, J. B. Pitman, A. M. Weber, E. M. Audia, M. R. Larreur, H. Manninen, S. Blake, M. W. Eihholz, E. Bergman, and N. D. Rayl. 2023. A multi-preperty assessment of intensity of use provides a functional understanding of animal movement. Methods in Ecology and Evolution First available online December 2023, DOI: 10.1111/2041-210X.14274

ABSTRACT
1. The intensity of use of a location is one of the most studied properties of animal movement, yet movement analyses generally focus on the overall use of a location without much consideration of how patterns in intensity of use emerge. Extracting properties related to intensity of use, such as the number of visits, the average and variation in time spent and the average and variation in time between visits, could help provide a more mechanistic understanding of how animals use landscape. Combining and synthesizing these properties into a single spatial representation could inform the role that a location plays for an animal.
2. We developed an R package named 'UseScape' that allows the extraction of these metrics and then clustered them using mixture modelling to create a spatial representation of the type of use an animal makes of the landscape. We illustrate applications of the approach using datasets of animal movement from four taxa and highlight species-specific and cross-species insights.
3. Our framework highlights properties that functionally differ in how animals use them, contrasting, for example, heavily used locations that emerge because they are frequented for long durations, locations that are repeatedly and regularly visited for shorter durations of time or locations visited irregularly. We found that species generally had similar types of use, such as typical low, mid and high use, but there were also species-specific clusters that would have been ignored when only focusing on the overall intensity of use.
4. Our multi-system comparison highlighted how the framework provided novel insights that would not have been directly obtainable by currently available approaches. By making the framework available as an R package, these analyses can be easily applicable to a myriad of systems where relocation data are available. Published Dec. 2023

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