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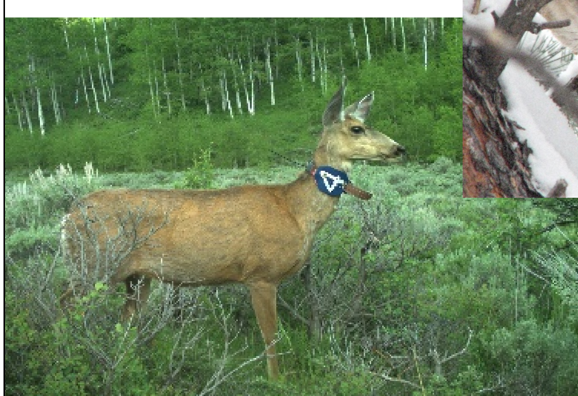
Wildlife Research Reports

MAMMALS – JULY 2021



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WILDLIFE RESEARCH REPORTS

JULY 2020–JUNE 2021

MAMMALS RESEARCH PROGRAM

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

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 2020 and 2021. 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 management. The Nongame Mammal Conservation Section addresses ongoing monitoring of lynx in the San Juan mountain range and preliminary results addressing influences of forest management practices on snowshoe hare density in Colorado. The Ungulate Conservation Section includes 6 projects addressing mule deer/energy development interactions to inform future development planning, related research addressing vegetation and mule deer responses to 3 mechanical treatment methods, evaluation of moose demographic parameters that will inform future moose management in Colorado, an evaluation of factors influencing elk calf recruitment, and 2 recent studies addressing elk response to human recreation. The Support Services Section describes the CPW library services to provide internal access of CPW publications and online support for wildlife and fisheries management related publications.

In addition to the ongoing project summaries described above, Appendix A includes 12 publication abstracts (<2 page summaries) under 5 subject headings completed by CPW research staff since July 2020. These scientific publications provide results from recently completed CPW research projects and other collaborations with universities and wildlife management agencies. Topics addressed include nongame species ecology and conservation (lynx associations with beetle killed forests, and a collaborative modelling effort to address lynx distribution in the southern extent of their range), carnivore ecology and management (mountain lion population response to hunter harvest), ungulate ecology and management (mule deer response to energy development activity, applying memory covariates to enhance assessment of mule deer habitat use patterns, developing an approach to estimate timing of moose calf births, addressing the influence of willow nutrition and morphology on moose calving rates, and investigation of potential disease spread from migratory elk to livestock), university collaborations addressing wildlife genetics and disease research (evaluation of how human altered landscapes influence viral transmission in cougars, characteristics of anelloviruses in domestic and various wild cat species, and reconstructing statewide viral phylogenies from commonly collected mountain lion tooth samples), and a *Journal of Wildlife Management* editorial representing an evaluation of the journal from senior and mid-career scientists to provide suggestions for future improvement.

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, Montana State University, University of Wyoming, 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, Safari Club International, Boone and Crocket Club, Colorado Mule Deer Association, The Mule Deer Foundation, Muley Fanatic Foundation, EnCana Corp., ExxonMobil/XTO Energy, Marathon Oil, Shell Exploration and Production, WPX Energy, and numerous private land owners providing access to support field research projects.

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Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Canada lynx monitoring in Colorado

Period Covered: July 1, 2019 – June 30, 2020

Principal Investigators: Eric Odell, Eric.Odell@state.co.us; Jake Ivan, Jake.Ivan@state.co.us; Scott Wait, Scott.Wait@state.co.us; Morgan Hertel, Morgan.Hertel@state.co.us

Personnel: Brad Weinmeister, Evan Phillips, Nate Seward, Brent Frankland

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. 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. During 2014−2020 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 2019−2020 personnel from CPW and USFS completed the sixth year of monitoring work on this same sample. Specifically, 14 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 (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. The remaining 36 units could not be surveyed via snow tracking. Instead, survey crews deployed 4 passive infrared motion cameras in each of these units during fall 2019. Cameras were baited with visual attractants and scent lure to enhance detection of lynx living in the area. Cameras were retrieved during summer or fall 2020 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 650 km during snow tracking surveys and detected lynx at 6 units (Table 1). These results are among the lowest recorded for the project, but mirror those recorded during the past 3 years (Table 1). Surveyors collected more than 3 times the photos during 2019–2020 than have been collected in any other year. This can be mostly attributed to the use of new, more sensitive cameras along with new, high capacity memory cards. However, for the third year in a row we collected <50% of the number of lynx photos taken during the initial years of the monitoring effort (Table 2). In fact, the 36 lynx photos collected during the 2019−20 season was the fewest recorded since the inception of the project. We initially considered at least 3 possible explanations for the lack of photos collected in recent years. First, we hypothesized that abnormal snow patterns (lack of snow in 2017–18, record snow in

2018–19) could have impacted detection probability. Second, lack of detections could have been due to the new lure (Caven's Violator 7; Minnesota Trapline Products, https://www.minntrapprod.com/Bobcat-and-Lynx/products/829/) we used in 2017–18, 2018–19, and 2019−20 after the lure we used previously (Pikauba; Luerres Forget's Lures, http://www.leurresforget.com/product.php?id_product=15) became unavailable. Finally, it could be that lynx have disappeared from a number of camera units. Unfortunately, the changes in snow and lure were confounded for a few years, thus making it difficult to determine which factor resulted in fewer detections. However, 2019−20 was a normal snow year, yet the number of lynx photos was still low. This indicates that abnormal snow was not the cause of the pattern we observed. Also, the number of snow tracking units with lynx has remained fairly steady throughout the project; we can think of no reason why snow track units would remain occupied while lynx blinked out of camera units, unless just by chance. Thus, we suggest that the new lure is less effective than the original. Fortunately the original formulation is again available and will be deployed for the 2020−21 survey. We plan to utilize this lure for the remainder of the survey efforts, provided it remains available. We obtained lynx detections for only the second time at a camera unit near Wolf Creek Pass. Lynx were again detected at Lizard Head Pass after no detections last year, and in all four snow tracking units along the Hwy 550 corridor after two of the four went without detections in 2018−19. However, we failed to detect lynx in at the Table Mountain Unit northwest of Creede, at Lemon Reservoir, at Little Squaw Creek west of Creede, and at Trujillo Meadows near the New Mexico border, where they had been detected the previous two seasons (Figure 1).

We used the R (R Development Core Team 2018) package '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 (i.e., used) by lynx over the course of the winter (ψ), 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). Based on previous work, we treated 'survey method' as a group variable so that we could allow p to vary by method. Additionally, we allowed p for 2017–18, 2018–19, and 2019–20 to differ from other years due to the new lure, and we included a breeding season effect for detection at cameras (lynx tend to move more in late winter when they begin to breed, and thus should encounter cameras more often). Also based on previous work, we specified initial ψ in the time series to be a function of the proportion of the unit that was covered by spruce/fir forest. We then allowed annual estimates of ε to be constant or a function of average years since bark beetle infestation, proportion of the unit impacted by bark beetles, proportion of the unit that was burned during Summer 2013, and the number of photos of other species that could potentially impact presence of lynx (e.g., snowshoe hares as a food source; coyotes, bobcats, foxes, and cougars as potential competitors). We allowed annual estimates of γ to be constant or a function of snowshoe hares. We limited our model set by first setting a general structure for ψ while assessing fit of various combinations of variables expected to affect p. We then fixed the best-fitting structure for p, and assessed combinations of the covariates expected to influence ε or γ, allowing up to 2 of these covariates at a time, in addition to the covariates on detection. We made inference from the best-fitting model as selected via Akaikie's Information Criterion (AIC), adjusted for small sample size (Burnham and Anderson 2002).

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. Local colonization probability was estimated to be low (γ = 0.03, SE = 0.01) and constant; local extinction was also low, but in some years twice that of colonization (ε = 0.03 to 0.06, SE = 0.03 to 0.05). Furthermore, in all of the top models, ε was negatively (but weakly) associated with the number of coyote photos collected on the year indicating that the probability of extinction of a unit in any given year goes up as the index of coyote abundance goes down (Appendix 1). Local extinction was also significantly, positively associated with the number of fox photos in the top model, suggesting that extinction is more likely in units in which we detected fox more often. Other models for ε that performed better than a constant structure included a negative relationship with number of snowshoe hare photos (less likely to go extinct as hare index increases), a positive relationship with the number of bobcat photos (more likely to go extinct as bobcat index increases), and a positive association with proportion of a unit impacted by beetles. However, the hare, bobcat, and beetle models were not as well supported as those including coyotes and foxes. The five occupancy growth rates (λ) estimated between surveys were all near 1.0, indicating a stable distribution with little to no growth (Figure 2). Similar to previous years, detection probability was relatively high for snow tracking surveys ($p = 0.59$, SE=0.05), and relatively low for camera surveys ($p = 0.23$, SE = 0.04) during December–February and April, although detection at cameras increased to 0.34 (SE = 0.07) during breeding season (March) as expected. We found a significant, negative effect on p during winters when Violator 7 was used as lure ($p = 0.08$, SE = 0.02 for December–February and April; $p = 0.13$, SE = 0.05 for breeding season). We estimated that 29% of the sample units in the San Juan's were occupied by lynx (95% confidence interval: 15–43%) during 2019–20 (Figure 2). The spatial distribution of lynx in the San Juans remained largely unchanged (Figure 1).

Table 1. Summary statistics from snow tracking effort.

Season	#Units Surveyed	#Units with Lynx	#Lynx Tracks	#Genetic Samples[a]	Km Surveyed (Total)	Mean Km Surveyed per Visit	#CPW Personnel	#USFS Personnel
2014-2015	24	8	13	10[b]	1,088	20.1	30	13
2015-2016	17	7	14	9[c]	987	21.9	23	6
2016-2017	16	8	13	7[d]	703	18.0	20	8
2017-2018	14	7	9	3[e]	578	19.3	14	5
2018-2019	14	6	7	2[e]	510	19.6	16	5
2019-2020	15	6	10	2[b]	650	19.7	15	3

[a] Number of genetic samples (scat or hair) collected via backtracking putative lynx tracks
[b]DNA analysis confirms that all samples collected from putative lynx tracks were lynx
[c]DNA analysis confirms that 6 of 9 samples were lynx (1 coyote, 1 either mule deer or human, 1undetermined)
[d]DNA analyses confirmed that 5 of 7 samples were lynx (1 coyote, 1 snowshoe hare)
[e]DNA analysis confirms 1 sample was lynx; remaining samples were not analyzed

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	32	8	134,694	301	14	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	36	6	204,243	59	9	31	7
2019-2020	36	4	701,724	36	4	29	6

a)

b)

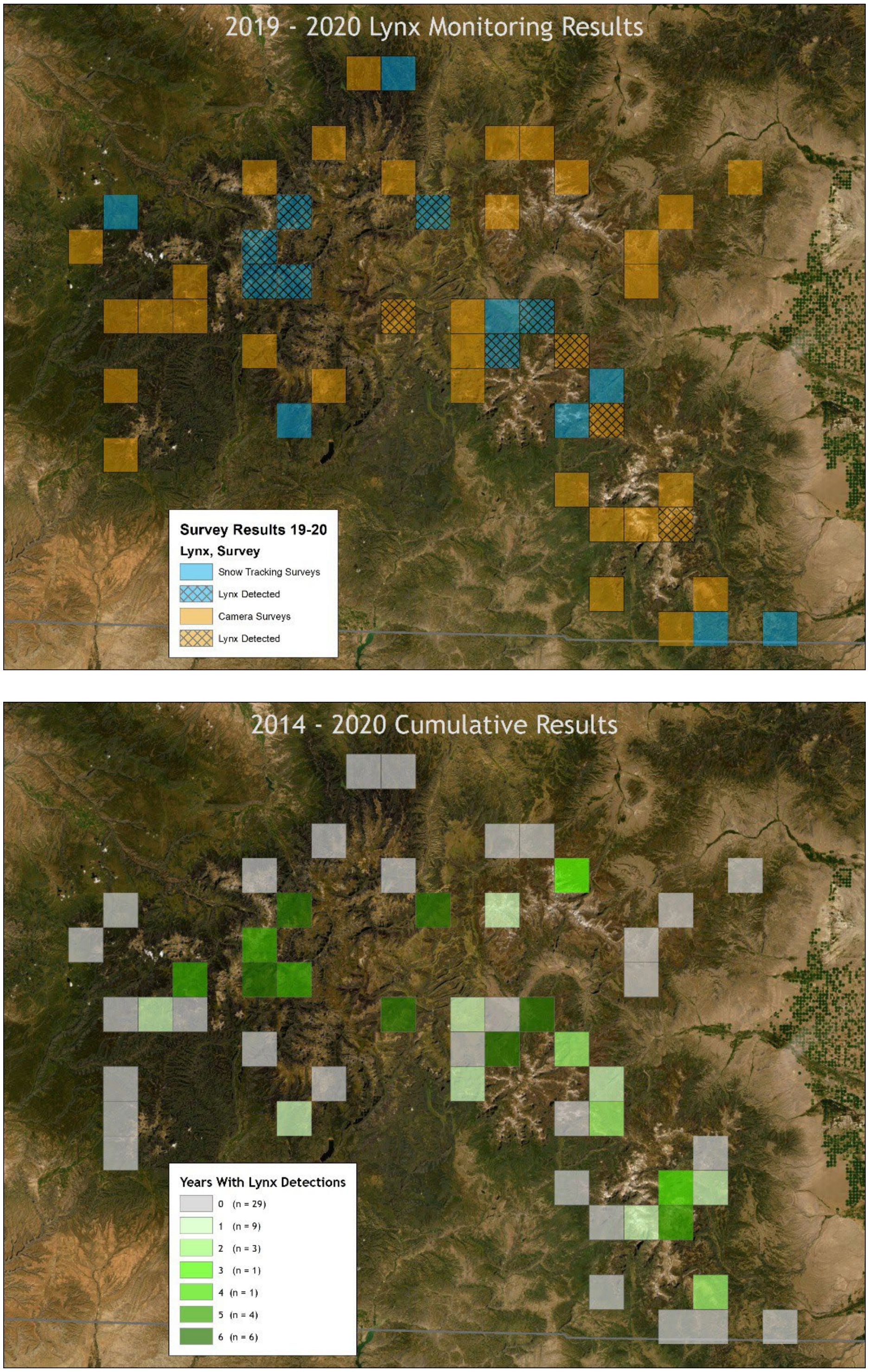

Figure 1. Lynx monitoring results for a) the current sampling season (2019–2020) and b) the cumulative monitoring effort (2014–2020), San Juan Mountains, southwest Colorado. Colored units (*n* = 50) depicted here are those selected at random from the population of units (*n* = 179) encompassing lynx habitat in the San Juan Mountains. Lynx were detected in 11 units in 2019−2020 and 23 units cumulatively since monitoring began in 2014−2015.

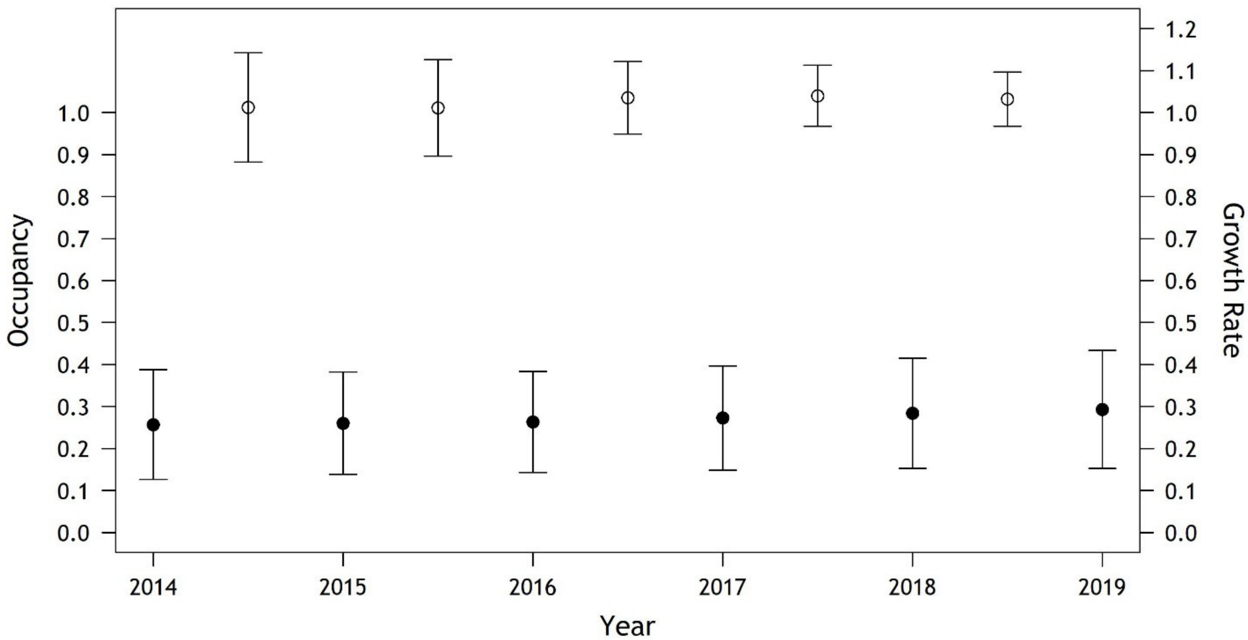

Figure 2. Occupancy estimates (Ψ, filled circles, left axis) and annual growth rate (λ) in occupancy between surveys (open circles, right axis) for Canada lynx in the San Juan Mountains, southwest Colorado. 'Year' indicates when the efforts were initiated (e.g., winter 2014−15, winter 2019−20). Growth rates less than 1.0 indicate a decline in occupancy; those >1.0 indicate an increase.

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Appendix 1. Model selection results for lynx monitoring data collected in the San Juan Mountains, Colorado, 2014–2020. Rankings are based on Akaike's Information Criterion adjusted for small sample size (AIC_c). Eight variables were considered as covariates to inform estimation of local extinction (ε); one was considered for local colonization (γ). The complete model set (n = 46) included all combinations of two of these covariates, in addition to modeling detection (*p*) as a function of survey method, breeding season, and alternate lure used during the 2017–18, 2018–19, and 2019–2020 seasons. Only the best 10 models are shown.

Model	AIC_c	ΔAIC_c	AIC_c Wts	No. Par.
ψ (Prop Spruce/Fir) ε (Coyote + Fox) γ (.) *p* (Best)	574.54	0.00	0.19	10
ψ (Prop Spruce/Fir) ε (Coyote) γ (.) *p* (Best)	576.43	1.89	0.08	9
ψ (Prop Spruce/Fir) ε (Coyote + PropBeetle) γ (.) *p* (Best)	576.50	1.96	0.07	10
ψ (Prop Spruce/Fir) ε (Coyote + Hare) γ (.) *p* (Best)	576.61	2.07	0.07	10
ψ (Prop Spruce/Fir) ε (Bobcat + Coyote) γ (.) *p* (Best)	577.17	2.63	0.05	10
ψ (Prop Spruce/Fir) ε (.) γ (.) *p* (Best)	578.01	3.47	0.03	8
ψ (Prop Spruce/Fir) ε (Coyote + PropBurn) γ (.) *p* (Best)	578.12	3.58	0.03	10
ψ (Prop Spruce/Fir) ε (BKAvg + Coyote) γ (.) *p* (Best)	578.21	3.67	0.03	10
ψ (Prop Spruce/Fir) ε (Cougar + Coyote) γ (.) *p* (Best)	578.30	3.76	0.03	10
ψ (Prop Spruce/Fir) ε (Bobcat) γ (.) *p* (Best)	578.50	3.96	0.03	9

[a]Best-fitting structure for detection probability included effects for survey method, breeding season, and an effect for the 2017–18, 2018–19, and 2019–20 survey seasons when Violator 7 was used for lure rather than Pikauba.

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: July 1, 2019 – June 30, 2020

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

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Understanding and monitoring snowshoe hare (*Lepus americanus*) density in Colorado is important 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 we 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, we 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, we then grouped relevant forest management activities (stratum 2) into 4 broad categories: even-aged management, uneven-aged management, thinning, and unmanaged controls. We wanted to assess both the immediate and long-term impacts of management on hare densities. Therefore, when selecting stands for sampling, we 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). We then selected a spatially balanced random sample of 5 stands within each combination of forest type × management activity × time interval. This design ensured that we 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 we simply sampled 10 randomly selected stands from this combination. Also, uneven-aged lodgepole pine treatments are rare, so we did not sample that combination (Figure 1).

During summer 2018, we 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 2020. 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. Also, a handful of stands visited in 2019 and 2020 were re-classified or tossed because ground-truthing 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, a handful more stands were replaced during the 2021 field season, and 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, in 2021, we sampled vegetation metrics in each stand that will hopefully account for the considerable noise we have observed (highly variable results for some strata) and allow us to better assess the effects of the treatments themselves. This vegetation sampling will be completed during the 2022 field season.

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, we focused the current analysis on the 2019-21 data from previously cleared plots. For each forest type × management activity combination, we 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 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 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 well 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 30 years after the treatment.

Note the outlier on the right side of the even-aged lodgepole panel (Figure 2). This "high density" site is an even-aged lodgepole stand that happens to be surrounded by high quality spruce-fir forest on at least two sides. Thus, the high relative hare density observed at this site may be due to the quality habitat in adjacent stands rather than by the quality of the sampled stand itself. While we left the point on the figure for transparency, we excluded it when fitting the curve as it appears to be a true outlier (including it "flattens" the curve somewhat such that it crosses the control line at about 55 years).

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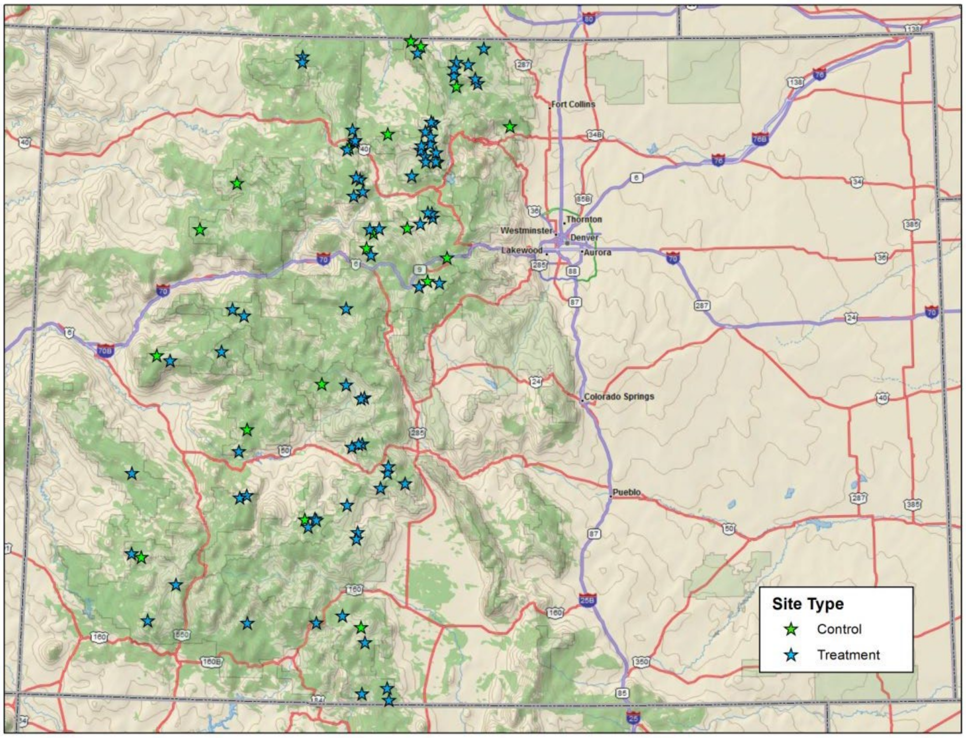

Figure 1. Location of all stands (n = 130) resampled for snowshoe hare pellets, June-September 2020.

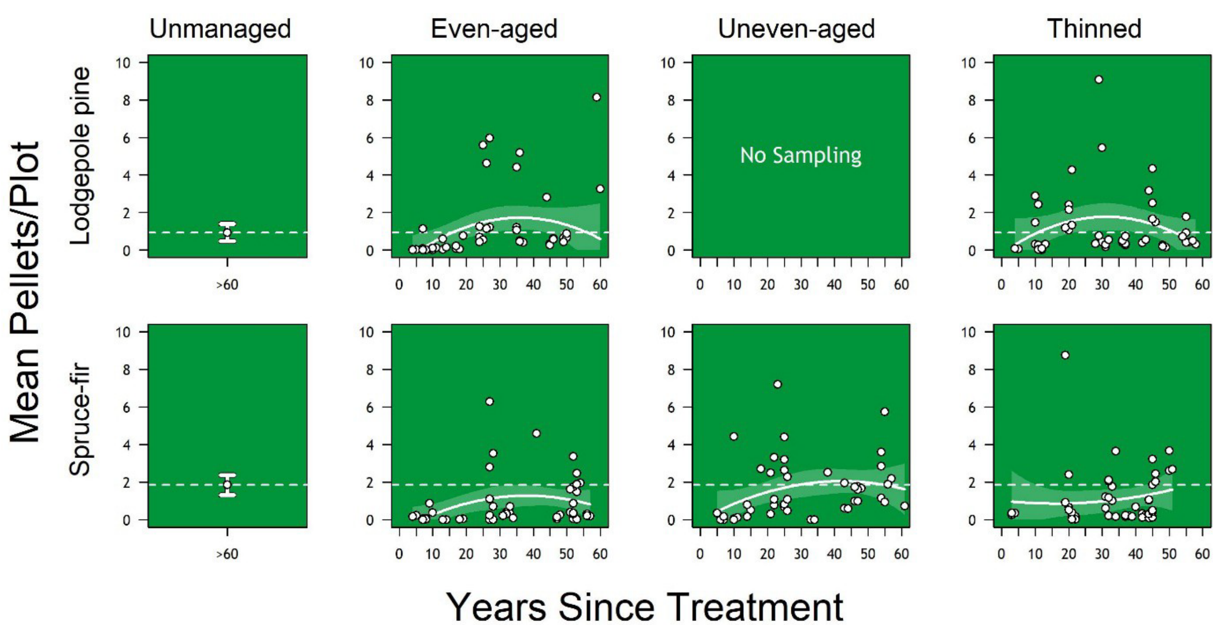

Figure 2. Fitted quadratic function (white line) and 95% CI (shaded polygon) relating pellet counts (i.e., relative snowshoe hare density) to time elapsed since treatment for each forest type × management activity combination. Dotted lines indicate the mean pellets/plot for the unmanaged controls for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

UNGULATE MANAGEMENT AND CONSERVATION

POPULATION PERFORMANCE OF PICEANCE BASIN MULE DEER IN RESPONSE TO NATURAL GAS RESOURCE EXTRACTION AND MITIGATION EFFORTS TO ADDRESS HUMAN ACRIVITY AND HABITAT DEGRADATION

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

EVALUATING FACTORS INFLUENCING ELK RECRUITMENT IN COLORADO

RESPONSE OF ELK TO HUMAN RECREATION AT MULTIPLE SCALES: DEMOGRAPHIC SHIFTS AND BEHAVIORALLY MEDIATED FLUCTUATIONS IN ABUNDANCE

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Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation

Period Covered: July 1, 2020 – June 30, 2021

Principal Investigator: C. R. Anderson, Jr.

Personnel: D. Bilyeu-Johnston, K. Aagaard, CPW; J. Northrup, Ontario Ministry of Natural Resources and Forestry; B. Gerber, University of Rhode Island; G. Wittemyer, Colorado State University. Project support received from Federal Aid in Wildlife Restoration, Colorado Mule Deer Association, Colorado Mule Deer Foundation, Muley Fanatic Foundation, Colorado State Severance Tax Fund, Caerus Oil and Gas LLC, EnCana Corp., ExxonMobil Production Co./XTO Energy, Marathon Oil Corp., Shell Petroleum, Williams and WPX Energy.

We propose to experimentally evaluate winter range habitat treatments and human-activity management alternatives intended to enhance mule deer (*Odocoileus hemionus*) populations exposed to energy-development activities. The Piceance Basin of northwestern Colorado was selected as the project area due to ongoing natural gas development in one of the most extensive and important mule deer winter and transition range areas in Colorado. The data presented here represent preliminary and final results of a 10-year research project addressing habitat improvements as mitigation and evaluation of deer responses to energy development activities to inform future development planning options on important seasonal ranges.

From 2008–2019, we monitored deer on 4 winter range study areas representing relatively high (Ryan Gulch, South Magnolia) and low (North Magnolia, North Ridge) levels of development activity (Figure 1) to address factors influencing deer behavior and demographics and to evaluate success of habitat treatments as a mitigation option. We recorded adult female habitat use and movement patterns; estimated neonatal, overwinter fawn and annual adult female survival; estimated annual early and late winter body condition, pregnancy and fetal rates of adult females; and estimated annual mule deer abundance among study areas. Winter range habitat improvements completed spring 2013 resulted in 604 acres of mechanically treated pinion-juniper/mountain shrub habitats in each of 2 treatment areas (Figure 2) with minor (North Magnolia) and extensive (South Magnolia) energy development, respectively.

During this research segment, we finalized publication of mule deer behavioral and demographic responses to energy development activity (Northrup et al. 2021; Appendix A) and submitted results addressing vegetation and mule deer responses to 3 mechanical treatment methods (Johnston and Anderson, in review; see next research summary) for publication (Wildlife Society Bulletin). Based on final (migration, mule deer behavioral and demographic responses, reproductive success and neonate survival; see Anderson 2019 for detailed methods and results and Appendix A for publication abstracts) and preliminary data analyses (vegetation and herbivore response to habitat treatments, next research summary) for this 10-year project: (1) annual adult female survival was consistent among areas averaging 79-87% annually, but overwinter fawn survival was variable, ranging from 31% to 95% within study areas, with annual and study area differences primarily due to early winter fawn condition, annual weather conditions, and factors associated with predation on winter range; (2) mule deer body condition early and late winter was generally consistent within areas, with higher variability among study areas early winter, primarily due to December lactation rates, and late winter condition related to seasonal moisture and winter severity; (3) late winter mule deer densities increased through 2016 in all study areas, ranging from 50% in North Ridge to 103% in North Magnolia, but have stabilized recently in 3 of the 4 study areas with recent decline evident in North Ridge (Figure 3); (4) migratory mule deer selected for areas with increased cover and increased their rate of travel through developed areas, and avoided negative influences through behavioral shifts in timing and rate of migration, but did not avoid development structures (Figure 4); (5) mule deer exhibited behavioral plasticity in relation to energy development, without evidence of demographic effects, where disturbance distance varied relative to diurnal extent and magnitude of development activity (Figure 5), which provide for useful mitigation options in future development planning; and (6) energy development activity under existing conditions did not influence pregnancy rates, fetal rates or early fawn survival (0-6 months), but may have reduced fetal survival (March until birth) during 2012 when drought conditions persisted during the third trimester of doe parturition (Figure 6).

Final results are pending to address vegetation and mule deer responses to assess habitat treatment mitigation options for energy development planning, and to develop a spatial planning tool to guide future energy development. Final data collection efforts for this project were completed by spring 2020. Collaborative research with agency biologists, graduate students, and university professors has produced 22 scientific publications (see Anderson 2021, Appendix A) addressing improved monitoring techniques for neonate mule deer captures; development and evaluation of a remote mule deer collaring device; mule deer migration relative to energy development; improved approaches to address animal habitat use patterns; mule deer response to helicopter capture and handling; potential effects of male-biased harvest on mule deer productivity; mule deer genetics in relation to body condition and migration; acoustic monitoring to investigate spatial and temporal factors influencing mule deer vigilance and foraging behavior; the relationship of plant phenology with mule deer body condition; approaches to identify cause-specific mortality in mule deer from field necropsies; the influence of individual and temporal factors affecting late winter body condition estimates of adult female mule deer; and mule deer behavioral and demographic responses to energy development activities to inform future development planning. Publications describing these results are summarized in Anderson 2021, Appendix A, and preliminary results describing vegetation and herbivore responses to habitat treatments are reported in the next research summary. We anticipate the opportunity to work cooperatively toward developing solutions for allowing the nation's energy reserves to be developed in a manner that benefits wildlife and the people who value both the wildlife and energy resources of Colorado and elsewhere.

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Anderson, C. R., Jr. 2019. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Federal Aid in Wildlife Restoration Annual Report W-243-R3, Ft. Collins, CO USA.

Anderson, C. R., Jr. 2021. Population performance of Piceance Basin mule deer in response to natural gas resource extraction and mitigation efforts to address human activity and habitat degradation. Federal Aid in Wildlife Restoration Annual Report W-243-R4, Ft. Collins, CO USA.

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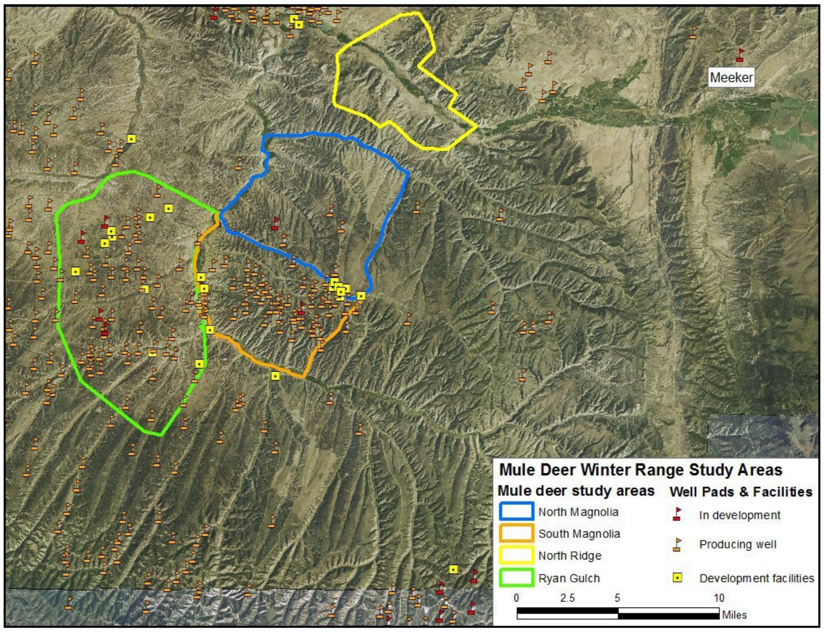

Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, winter 2013/14 (Accessed http://cogcc.state.co.us/ December 31, 2013; energy development activity has been minor since 2013).

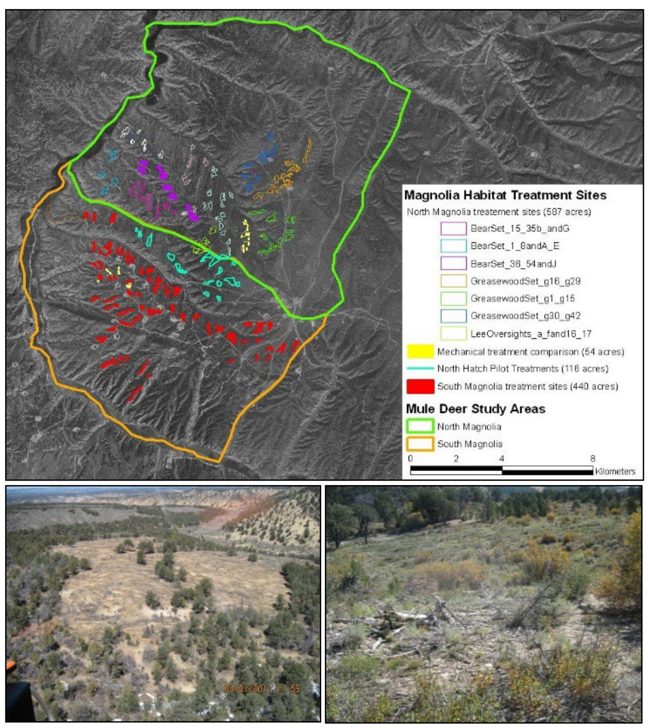

Figure 2. Habitat treatment site delineations in 2 mule deer study areas (604 acres each) of the Piceance Basin, northwest Colorado (Top; cyan polygons completed Jan 2011 using hydro-axe; yellow polygons completed Jan 2012 using hydro-axe, roller-chop, and chaining; and remaining polygons completed Apr 2013 using hydro-axe). January 2011 hydro-axe treatment-site photos from North Hatch Gulch during April (Lower left, aerial view) and October, 2011 (Lower right, ground view).

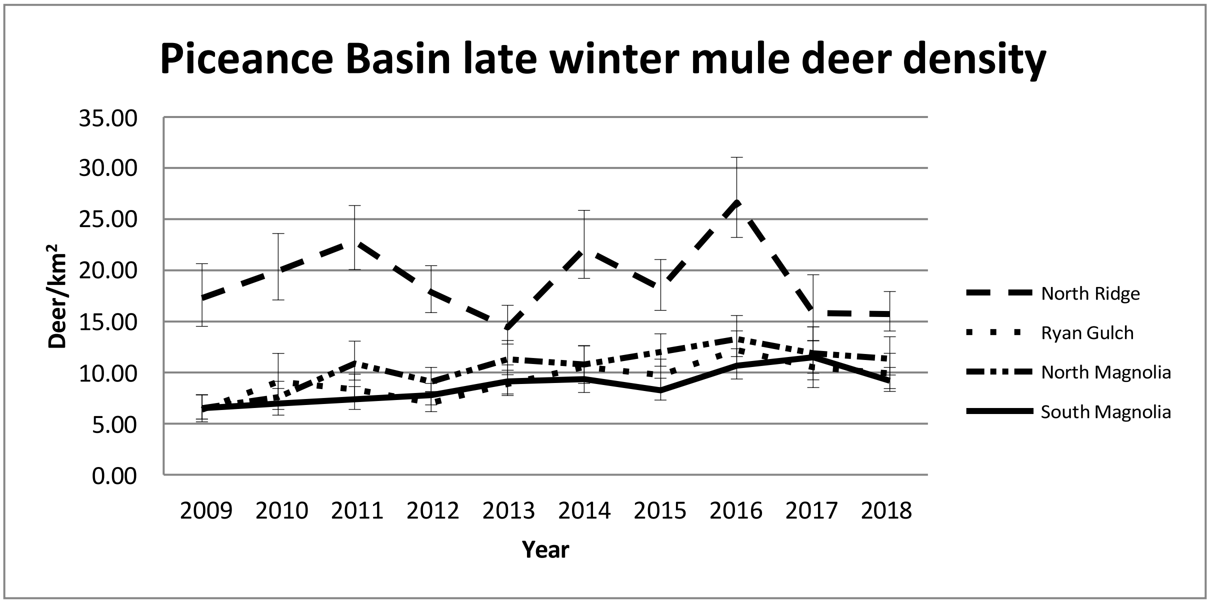

Figure 3. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009–2018.

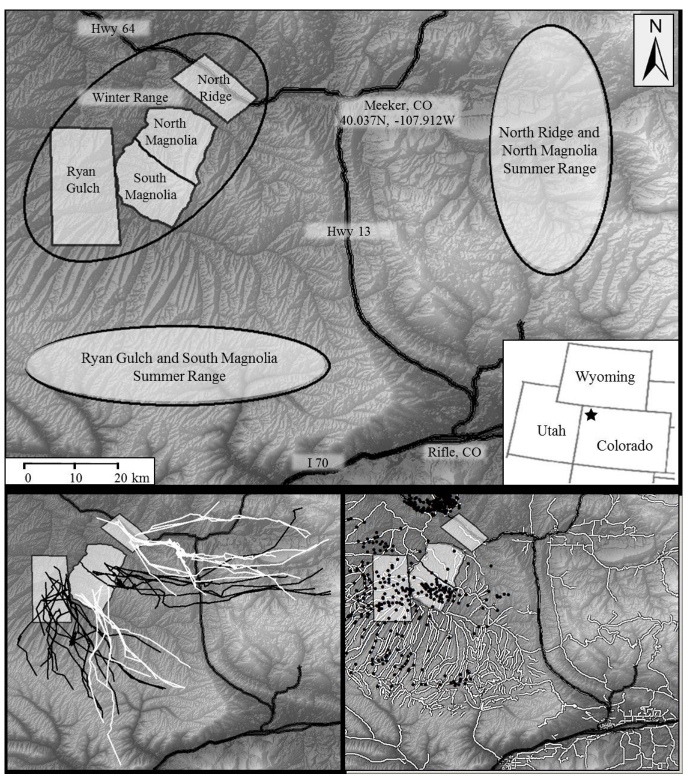

Figure 4. Mule deer study areas in the Piceance Basin of northwestern Colorado, USA (Top), spring 2009 migration routes of adult female mule deer (*n* = 52; Lower left), and active natural-gas well pads (black dots) and roads (state, county, and natural-gas; white lines) from May 2009 (Lower right; from Lendrum et al. 2012; http://dx.doi.org/10.1890/ES12-00165.1).

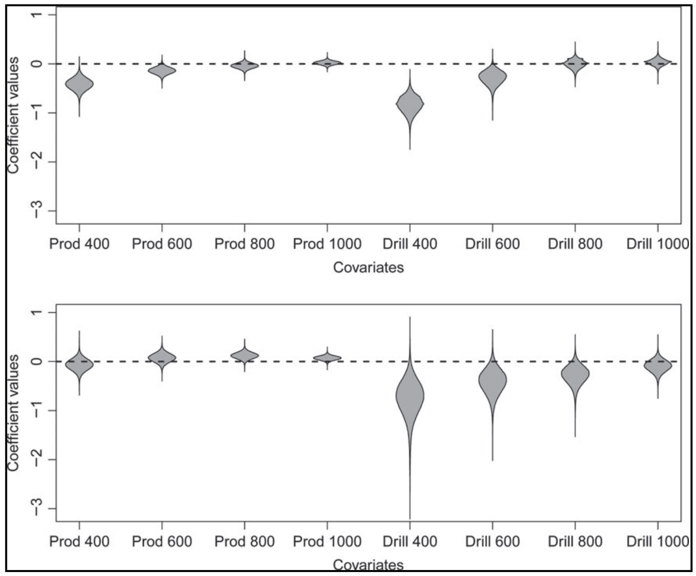

Figure 5. Posterior distributions of population-level coefficients related to natural gas development for RSF models during the day (top) and night (bottom) for 53 adult female mule deer in the Piceance Basin, northwest Colorado. Dashed line indicates 0 selection or avoidance (below the line) of the habitat features. ‘Drill’ and ‘Prod’ represent drilling and producing well pads, respectively. The numbers following ‘Drill’ or ‘Prod’ represent the distance from respective well pads evaluated (e.g., ‘Drill 600’ is the number of well pads with active drilling between 400–600 m from the deer location; from Northrup et al. 2015; http://onlinelibrary.wiley.com/doi/10.1111/gcb.13037/abstract). Road disturbance was relatively minor (~60–120 m, not illustrated above).

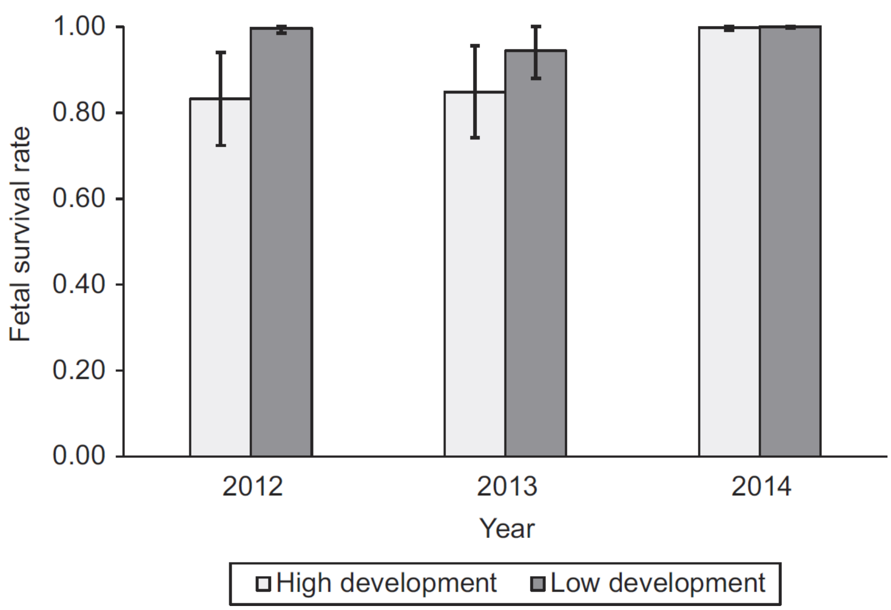

Figure 6. Model averaged estimates of mule deer fetal survival from early March until birth (late May–June) in high and low energy development study areas of the Piceance Basin, northwest Colorado, 2012–2014 (from Peterson et al. 2017; http://www.bioone.org/doi/pdf/10.2981/wlb.00341).

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Plant and mule deer responses to pinyon-juniper removal by three mechanical methods (*follow-up to:* Examining the effectiveness of mechanical treatments as a restoration technique for mule deer habitat)

Period Covered: July 1, 2020 – June 30, 2021

Principal Investigators: Danielle Johnston (Danielle.bilyeu@state.co.us), Chuck Anderson (chuck.anderson@state.co.us)

Personnel: C. Bishop, D. Collins, K. Kain, S. VanNortwick, B. deVergie, D. Finley, L. Gepfert, T. Knowles, B. Petch, J. Rivale, Z. Swennes, M. Way, CPW; L. Belmonte, E. Hollowed, BLM; M. Paschke, G. Stephens, B. Wolk, J. Northrup, B. Gerber, G. Wittemyer, Colorado State University; L. Coulter, Coulter Aviation. Project support received from Federal Aid in Wildlife Restoration, Colorado Mule Deer Association, Colorado Mule Deer Foundation, Muley Fanatic Foundation, Colorado State Severance Tax Fund, Caerus Oil and Gas LLC, EnCana Corp., ExxonMobil Production Co./XTO Energy, Marathon Oil Corp., Shell Petroleum, and WPX Energy.

Land managers in western North America often reverse succession by removing pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) trees to reduce fire risk and/or increase forage for wildlife or livestock (Monaco and Gunnell 2020). Because prescribed fire is risky, mechanical methods such as chaining, rollerchopping, and mastication are often used (Figure 1). Mechanical methods differ in cost and in the size of woody debris produced, and may also differ in 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 chaining, rollerchopping, mastication and control (whole plots, $n = 7$) and to explore seeding (subplot) interactions (Figure 2). We assessed plants 1, 2, 5, and 6 years post-treatment, and mule deer (*Odocoileus hemionus*) response via GPS locations 3-8 years post-treatment. Early results were published previously (Stephens et al. 2016); this effort combines follow-up vegetation data with mule deer responses.

By 2016, treated plots had 3-5 times higher perennial grass cover and ~10 times higher cheatgrass (*Bromus tectorum*) cover than controls (Figure 3). Rollerchopped plots had both the highest annual species cover, and when seeded, also the highest density of bitterbrush (*Purshia tridentata*), a nutritious shrub for mule deer (Figure 4). Winter deer GPS point detections in chained and rollerchopped plots were almost twice as high as control ($P < 0.001$), while detections in masticated plots were about 20% higher than control ($P \leq 0.042$; Figure 5). Deer detections appear related to a combination of relative hiding cover, resulting from residual woody debris, and winter forage availability. Masticated plots received higher bitterbrush use during summer/fall than chained or rollerchopped plots ($P < 0.05$; Figure 6). This may have made masticated plots less attractive the following winter, as ungulates tend to browse the most palatable plants and plant parts first (Armstrong and Macdonald 1992). Rollerchopped and chained plots appeared to provide the best combination of mule deer cover and winter forage, but mastication, applied leaving dispersed security cover, may be a viable option where invasive species concerns exist.

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Figure 1. Equipment, residual structure, and vegetation response 9 years post-treatment for a) chaining, b) rollerchopping, and c) mastication.

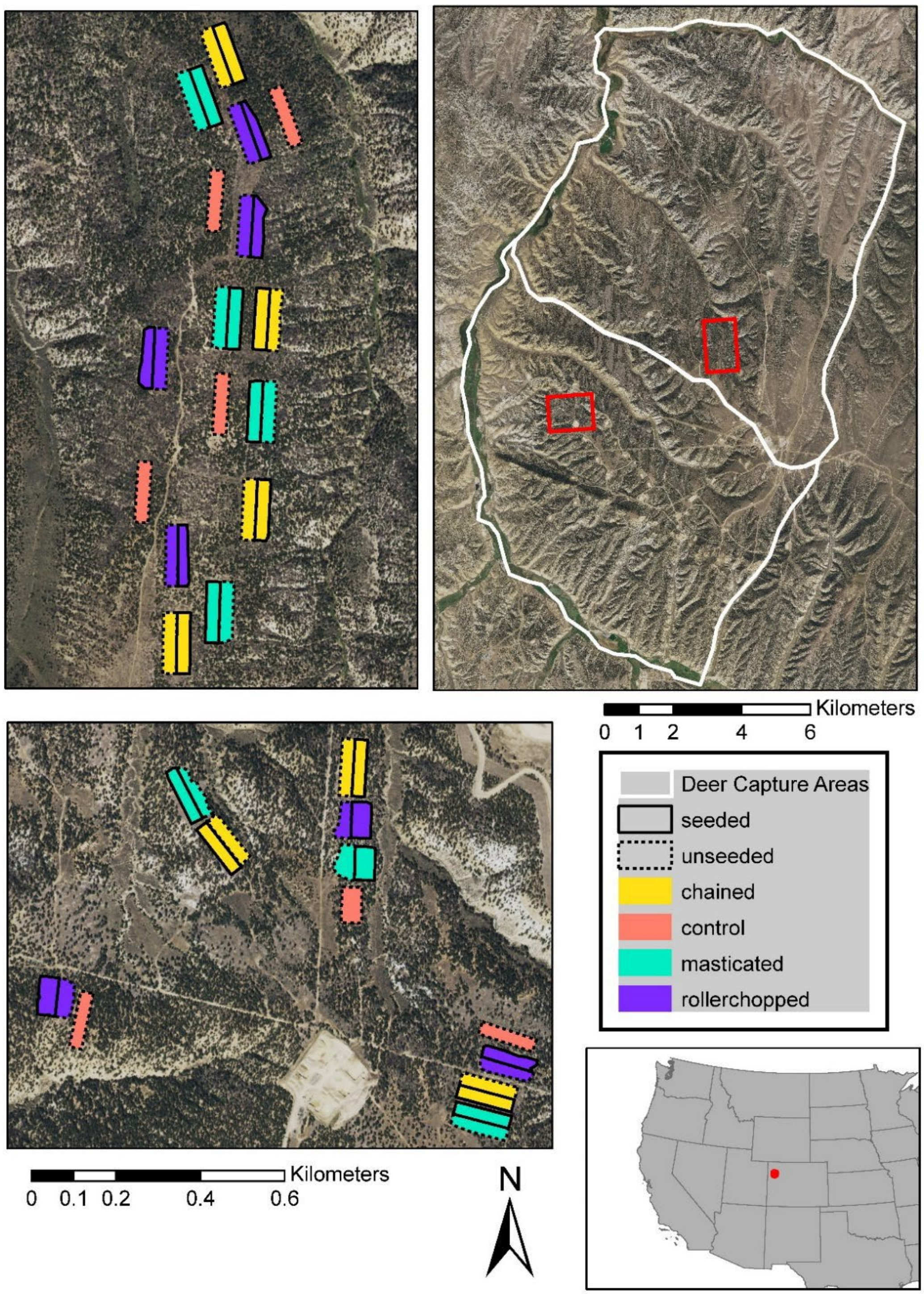

Figure 2. Location of tree removal and control plots within north and south Magnolia winter range study areas in the Piceance Basin, Rio Blanco County, Colorado, USA.

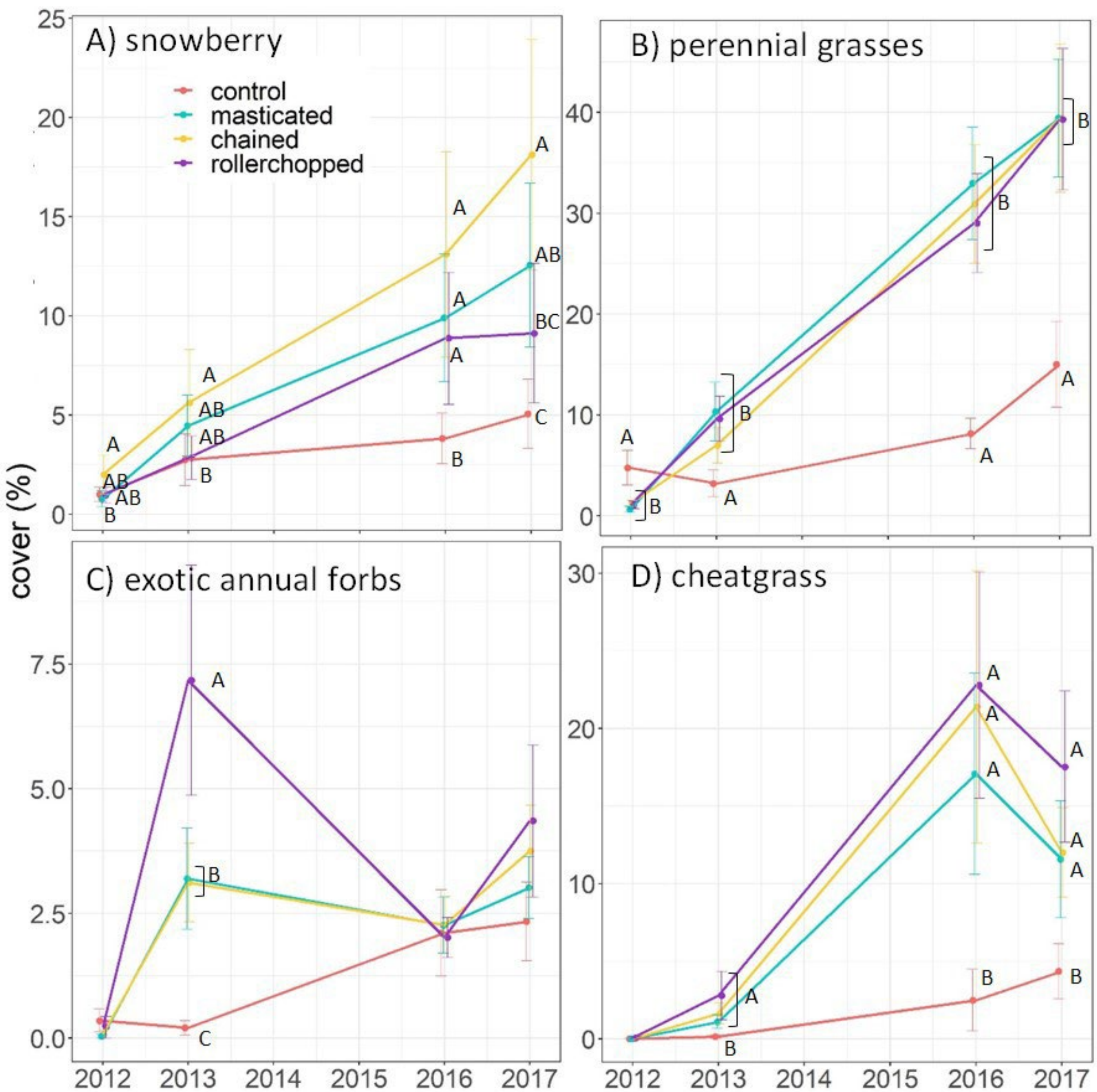

Figure 3. Percent cover of A) snowberry, B) perennial grasses, C) exotic annual forbs, and D) cheatgrass 1-6 years following implementation of 3 pinyon and juniper removal methods, unseeded subplots only. Points not sharing letters are significantly different at $\alpha = 0.05$ for within-year contrasts between treatments. Error bars = 95% CIs.

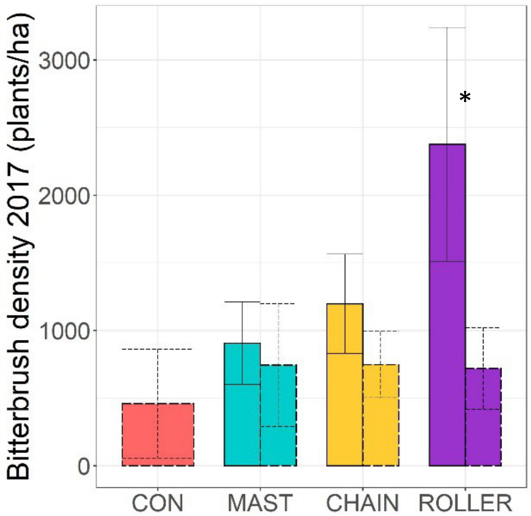

Figure 4. 2017 bitterbrush density within seeded (solid outline) and unseeded (dashed outline) subplots 6 years after implementation of 3 pinyon and juniper removal methods: CON (control), MAST (masticated), CHAIN (chained, and ROLLER (rollerchopped). Star indicates a significant contrast between seeded and unseeded subplots at α = 0.05. Error bars
= 95% CIs.

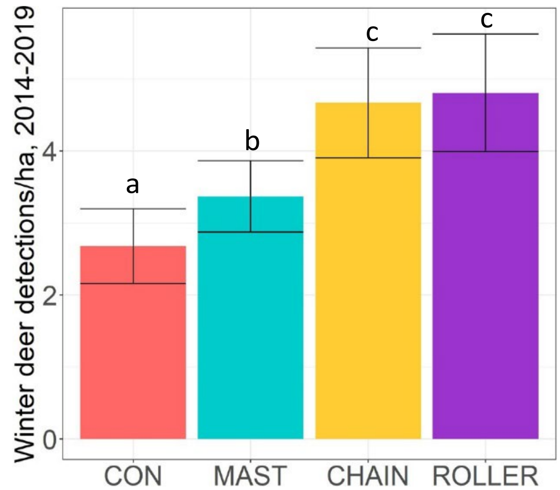

Figure 5. Mule deer GPS locations (points/ha) in winter over a 5-year period in control plots and plots treated to remove pinyon and juniper trees by 3 different methods: CON (control), MAST (masticated), CHAIN (chained), and ROLLER (rollerchopped). Bars not sharing letters are significantly different at α = 0.056. Error bars = 95% CIs.

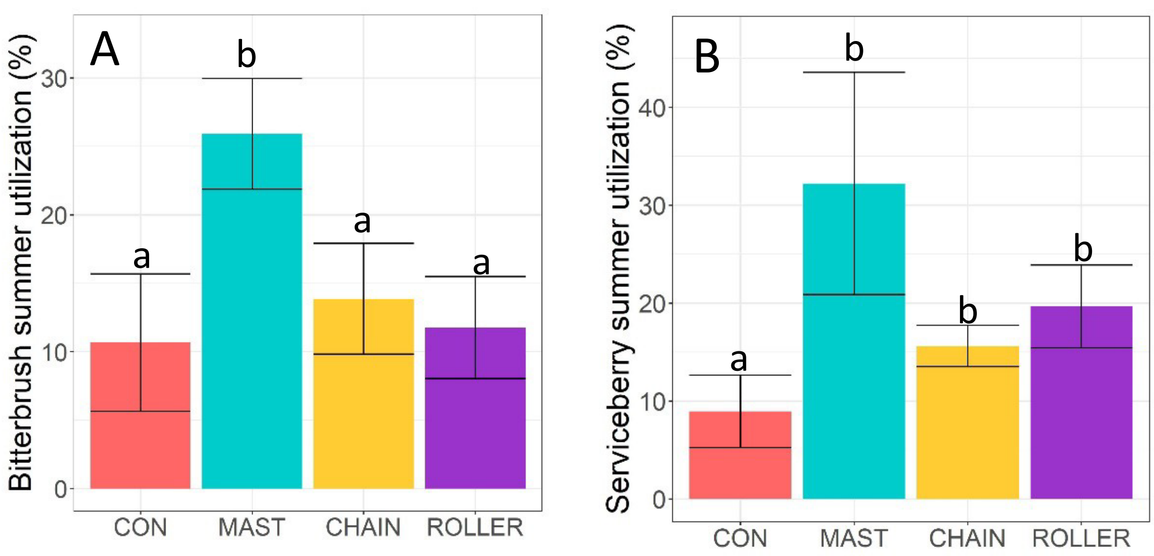

Figure 6. Percent of current year growth removed by herbivory during the growing season for A) bitterbrush and B) serviceberry 6 years following implementation of 3 pinyon and juniper removal methods: CON (control), MAST (masticated), CHAIN (chained), and ROLLER (rollerchopped), unseeded subplots only. Bars not sharing letters are significantly different at $\alpha = 0.05$. Error bars = 95% CIs.

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: July 1, 2020 – June 30, 2021

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

During November of 2013 we initiated a large scale moose research project in 3 of Colorado Parks and Wildlife's 4 geographical regions (NE, NW, and SW; Figure 1). After 3 field seasons this research was scaled back and became focused on moose herds in the NW (North Park) and NE (Laramie River) Regions. During FY 20-21 this research project will be completed. The primary objectives during all years of this project were the capture of adult female moose for the purposes of deploying VHF and GPS collars, collecting pregnancy data via blood serum, evaluating body condition via ultrasonography, and collecting early winter calf-at-heel ratios. Beginning in 2014–2015 and continuing through the summer of 2019, summer field efforts focused on estimation of parturition rates. Between November 2013 and January 2019, 255 moose were captured. These 255 capture events were comprised of 178 unique individuals and 78 recaptures. A total of 214 observations of radio collared moose were made during parturition, and a total of 319 willow measurements were collected.

Initial analyses and publications from this project focused on quantification of moose calf-at-heel detection probabilities, but also estimation of moose parturition timing. Subsequent analyses and publication focused on relationships between willow community diversity, digestibility, and moose productivity. Final analyses and publications will focus on adult female survival, pregnancy, and apparent calf survival.

Between 2013-2019 annual survival of radio collared animals was 90.3% (range: 84.2%-93.0%). During that period, we observed that the probability of moose being pregnant was best predicted by maximum loin depth (Figure 2), whereas regional and annual effects in pregnancy rates were not discernible. Pregnancy rates averaged 75%, and were similar between areas (70% in NW Colorado, 60% in NE Colorado), although a high degree of annual variation in pregnancy was observed and strong inference was limited by samples size. Over the course of this study, average calf-at-heel estimates at the time of parturition were 67 calves/100 cows, but these estimates deteriorated to 52 calves/100 cows at the time of capture (mid-December). The observed decay in calf-at-heel ratios during the 7-month window between parturition and winter capture suggested monthly calf survival was 96.7% (Figure 3).

Overall, data collected during this project met expectations. In particular, survival rates were consistently high in all study areas. Observed pregnancy rates were lower and more variable that other ungulates in Colorado. Twinning rates ranged from 5%-10% during this study. Observed winter calf-at-heel rates suggest that moose calf survival during the first 7 months of life was 79%. However, anecdotal information throughout Colorado suggests moose populations are stable or increasing. The merger of low and variable pregnancy rate data with average survival rate data during the first 7-months of life suggests moose calf survival during the subsequent 5-months, leading to 1-year recruitment, is high. If indeed true, novel sources of mortality to moose calves during the overwinter period may impose a disproportionate impact on overall moose herd performance.

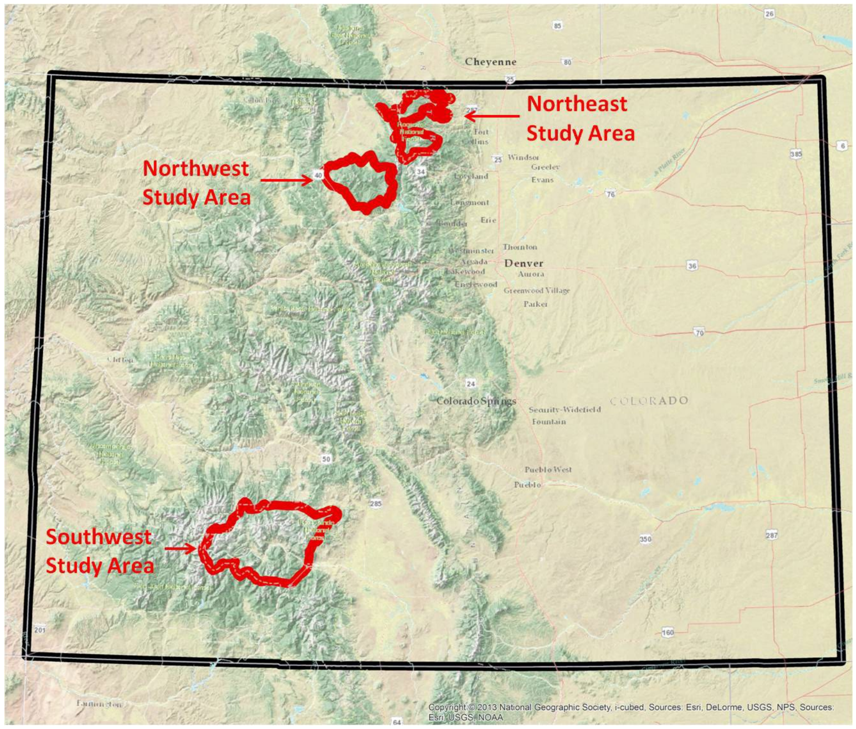

Figure 1. Moose research study areas, located in 3 regions in Colorado. A total of 255 moose were captured during winters between 2013–2014 and 2018–2019.

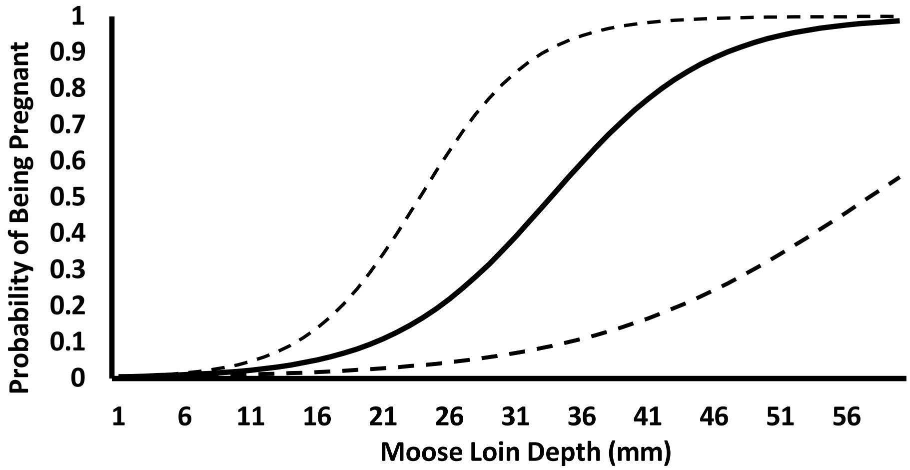

Figure 2. During the course of this study, probability of moose pregnancy has been best predicted by measured loin depth. The relationship between body condition and pregnancy status is reflected by the solid black line and from data collected during the all 5 years of the study (dotted lines represent 95% CIs). No regional effects were found in our data, and the lack of significance of annual effects in our best performing models is likely driven by small sample sizes.

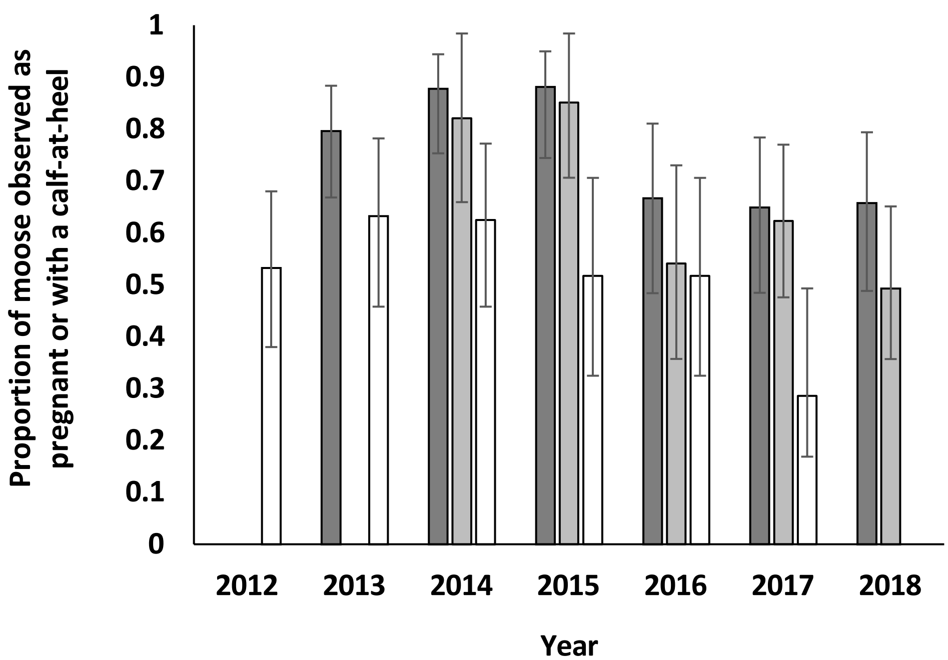

Figure 3. Summary of moose reproduction and 6-month recruitment data. White bars reflect observed calf-at-heel data collected in December during annual moose capture efforts. Winter data are associated with reproduction from the previous year. Dark gray bars reflect pregnancy rates derived from Pregnancy Specific Protein B (PSPB) concentrations in blood collected during December each year. Light gray bars reflect calf-at-heel ratios (CPW unpublished data) collected at the time of parturition in early summer each year. Error bars = 95% confidence intervals for winter pregnancy and December calf-at-heel ratios and 95% credible intervals for spring calf-at-heel ratios.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Evaluating factors influencing elk recruitment in Colorado

Period Covered: July 1, 2020 – June 30, 2021

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

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 2-year pilot study to investigate factors influencing elk recruitment in 2 elk Data Analysis Units (DAUs; E-20, E-33) with low juvenile/adult female ratios (Figure 1). In 2019, we expanded this pilot study work 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 (Figure 2).

Since study initiation, we have collared 354 pregnant female elk in February and March by helicopter net-gunning (Table 1). Averaged across years, we estimated that annual pregnancy rates of adult female elk were 93% in the Bear's Ears herd (excluding 2019 data where $n = 3$), 88% in the Trinchera herd (range = 78-95%), and 90% (range = 77-97%) in the Uncompahgre Plateau herd (Figure 3). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013). From 2019-2021, we estimated that annual mean ingesta-free body fat (IFBF) of adult female elk was 6.74% in the Bear's Ears Herd, 7.20% in the Trinchera herd, and 7.10% in the Uncompahgre Plateau herd (Figure 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).

From 2017–2021, we collared 595 neonate elk calves in May-August and 100 6-month old elk calves in December (Table 2). In 2019, the estimated mean date of calving was June 1 in the Trinchera herd, and June 3 in the Uncompahgre Plateau herd. In 2020, the estimated mean date of calving was May 31 in the Bear's Ears and Uncompahgre Plateau herds, and June 3 in the Trinchera herd. In 2021, the estimated mean date of calving was June 1 in the Bear's Ears herd, June 3 in the Trinchera herd, and June 4 in the Uncompahgre Plateau herd. In 2019, the mean weight of 6-month old calves was 101.8 kg (224.4 lb) (95% CI = 96.5-107.2 kg [212.7-236.3 lb]) from the Bear's Ears herd and 113.9 kg (251.1 lb) (95% CI = 108.4-119.4 kg [239.0-263.2 lb]) from the Uncompahgre Plateau elk herd. In 2020, the mean weight of calves from the Bear's Ears herd was 97.9 kg (215.8 lb) (95% CI = 90.9-104.9 kg [200.4-231.3 lb]) and 102.8 kg (226.6 lb) (95% CI = 96.6-108.9 kg [213.0-240.1 lb]) from the Uncompahgre Plateau elk herd.

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Table 1. The number of pregnant adult female elk collared in March in in the Bear's Ears (DAU E-2), Trinchera (DAU E-33), and Uncompahgre Plateau (DAU E-20) elk herds from 2017-2021 in Colorado, USA.

	Herd		
Year	Bear's Ears	Trinchera	Uncompahgre Plateau
2017		22	23
2018		17	30
2019	2	30	30
2020	40	20	40
2021	40	20	40

Table 2. The number of neonate and 6-month old elk calves (6-month old calf totals are displayed in parentheses) collared from in the Bear's Ears (DAU E-2), Trinchera (DAU E-33), and Uncompahgre Plateau (DAU E-20) elk herds from 2017-2021 in Colorado, USA.

	Herd		
Year	Bear's Ears	Trinchera	Uncompahgre Plateau
2017		57	40
2018		53	48
2019	49 (25)	46	49 (25)
2020	54 (25)	21	52 (25)
2021	53	21	52

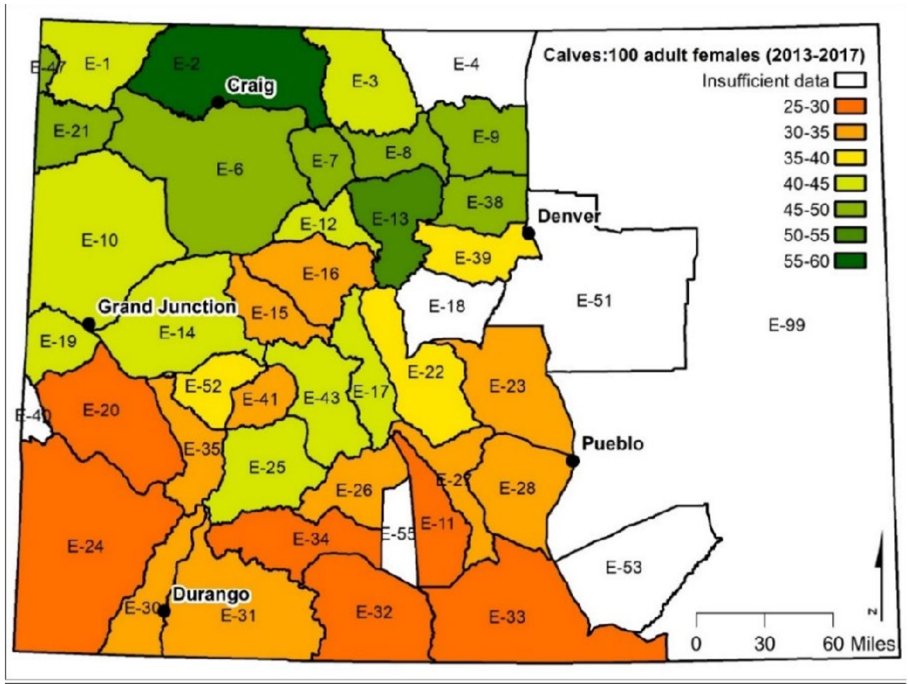

Figure 1. The number of elk calves per 100 adult females observed during December-February aerial surveys (5-year average from 2013-2017) within elk Data Analysis Units (DAUs; labeled with black text) in Colorado, USA.

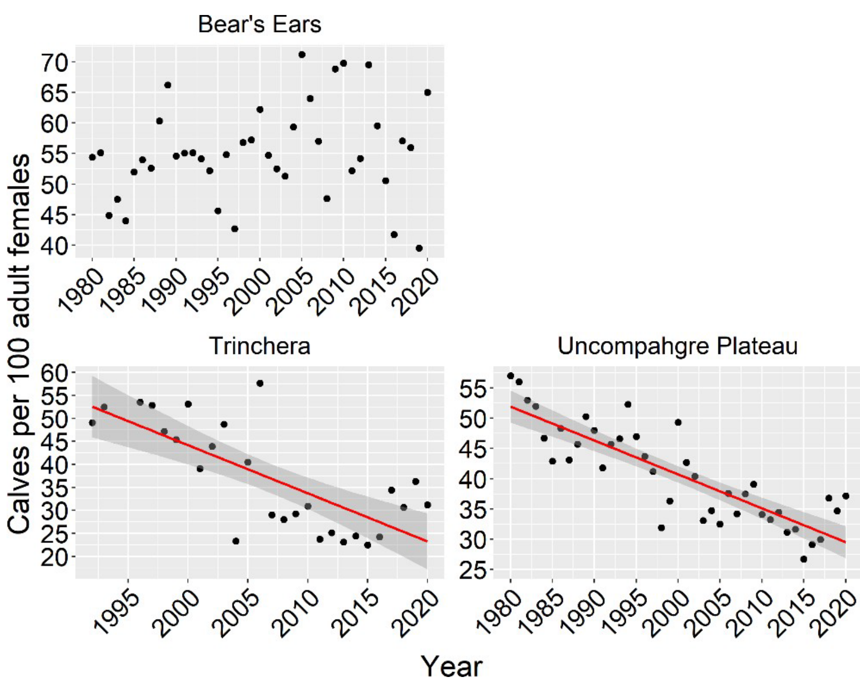

Figure 2. The estimated number of calves per 100 adult females observed annually during winter classification surveys in the Bear's Ears (DAU E-2), Trinchera (DAU E-33), and Uncompahgre Plateau (DAU E-20) elk herds from 1980-2020 (1992-2020 for the Trinchera herd) in Colorado, USA. Red lines and shaded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

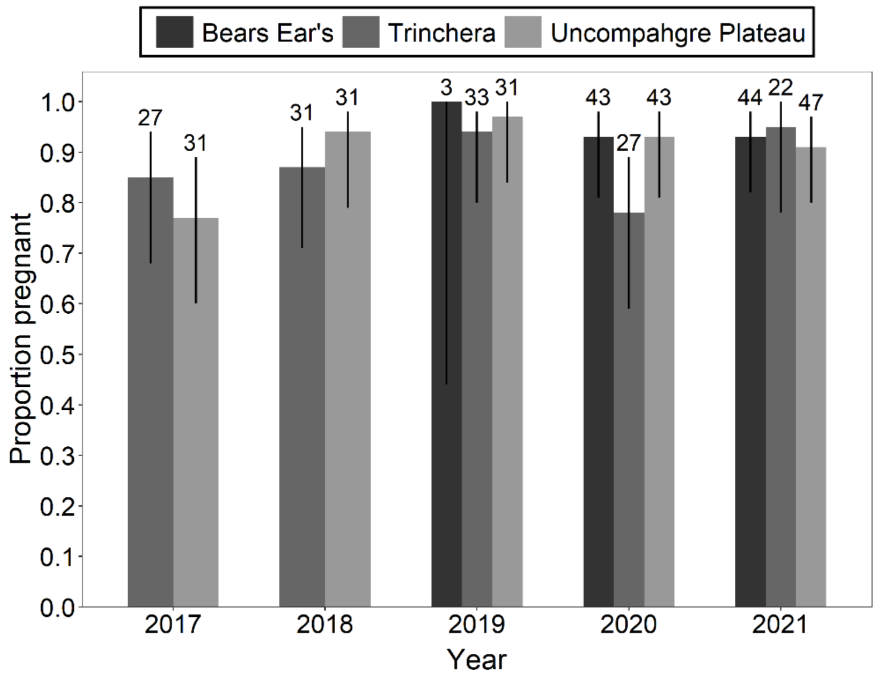

Figure 3. Estimated average pregnancy rates of adult female elk from the Bear's Ears (DAU E-2), Trinchera (DAU E-33), and Uncompahgre Plateau (DAU E-20) herds sampled during late winter 2017-2020 in Colorado, USA. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

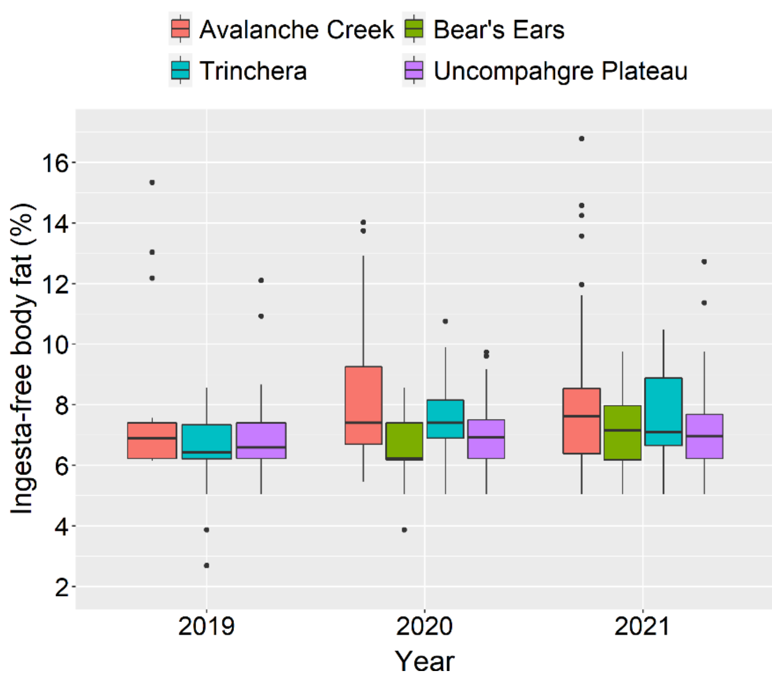

Figure 4. The estimated ingesta-free body fat (%) of adult female elk from the Bear's Ears (DAU E-2), Trinchera (DAU E-33), and Uncompahgre Plateau (DAU E-20) herds during late-winter 2019-2021 in Colorado, USA.

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: July 1, 2020 – June 30, 2021

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

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 short-term (~3-4 weeks) 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.

Since study initiation, we have collared 104 pregnant female elk, 24 in March 2019, 40 in March 2020, and 40 in March 2021. We estimated the pregnancy rate of adult female elk was 89% (95% CI = 73-96%; $n = 28$) in 2019, 95% (95% CI = 84-99%; $n = 41$) in 2020, and 85% (95% CI = 72-93%; $n = 47$) in 2021. Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013). We estimated the mean percent ingesta-free body fat (IFBF) of adult female elk to be 7.4% (95% CI = 6.5-8.3%; $n = 28$) in 2019, 8.1% (95% CI = 7.5-8.8%; $n = 38$) in 2020, and 8.2% (95% CI = 7.4-9.0%; $n = 47$) in 2021. 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).

From May-July 2019–2021, we collared 131 neonate elk calves, 26 in 2019, 54 in 2020, and 51 in 2021. The estimated mean date of calving was May 31 ($n = 20$) in 2019, June 3 ($n = 40$) in 2020, and June 3 ($n = 38$) in 2021. We also collared 25 6-month old elk calves in December of 2019 and 2020. The mean weight of 6-month old calves was 115.8 kg (255.3 lb) (95% CI = 110.8-120.8 kg [244.3-266.3 lb]) in 2019 and 109.0 kg (240.3 lb) (95% CI: 103.3-114.8 kg [227.7-253.1 lb]) in 2020.

During the summer of 2019, a total of 384,455 photos were taken by the 118 cameras deployed across 8 study units. During the summer of 2020, approximately 4.6 million photos were taken by the 238 cameras deployed across 8 study units. These photos are actively being archived. Automated photo recognition software continues to be developed and will be applied to these photos to expedite future analyses.

Literature Cited:

Cook, R. C., J. G. Cook, D. J. Vales, B. K. Johnson, S. M. McCorquodale, L. A. Shipley, R. A. Riggs, L. L. Irwin, S. L. Murphie, B. L. Murphie, K. A. Schoenecker, F. Geyer, P. B. Hall, R. D. Spencer, D. A. Immell, D. H. Jackson, B. L. Tiller, P. J. Miller, and L. Schmitz. 2013. Regional and seasonal patterns of nutritional condition and reproduction in elk. Wildlife Monographs 184:1–44.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

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

Period Covered: July 1, 2020 – June 30, 2021

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

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 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. In both years, the estimated pregnancy rate was 93% (95% CI: 79-98%).

From May-October 2020 we deployed trail counters at 22 trailheads in the Routt National Forest (Figure 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 (Figure 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 (Figure 3). In 2020, we collected over 100 GPS tracks. GPS tracks from recreationists and hunters will allow us to better quantify human recreation on the landscape and evaluate how elk respond to recreationists.

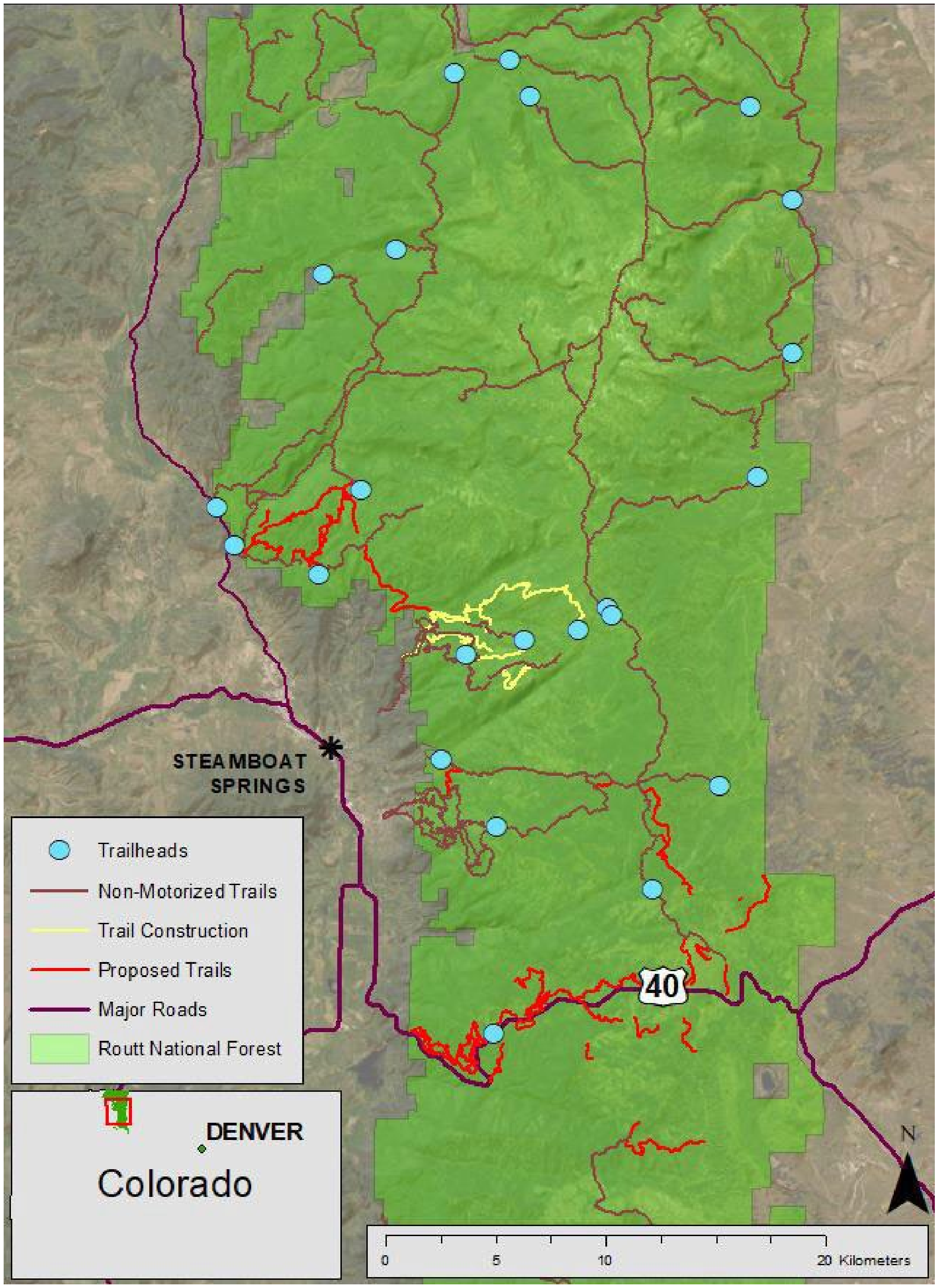

Figure 1. Routt National Forest study area located in northwest Colorado, USA.

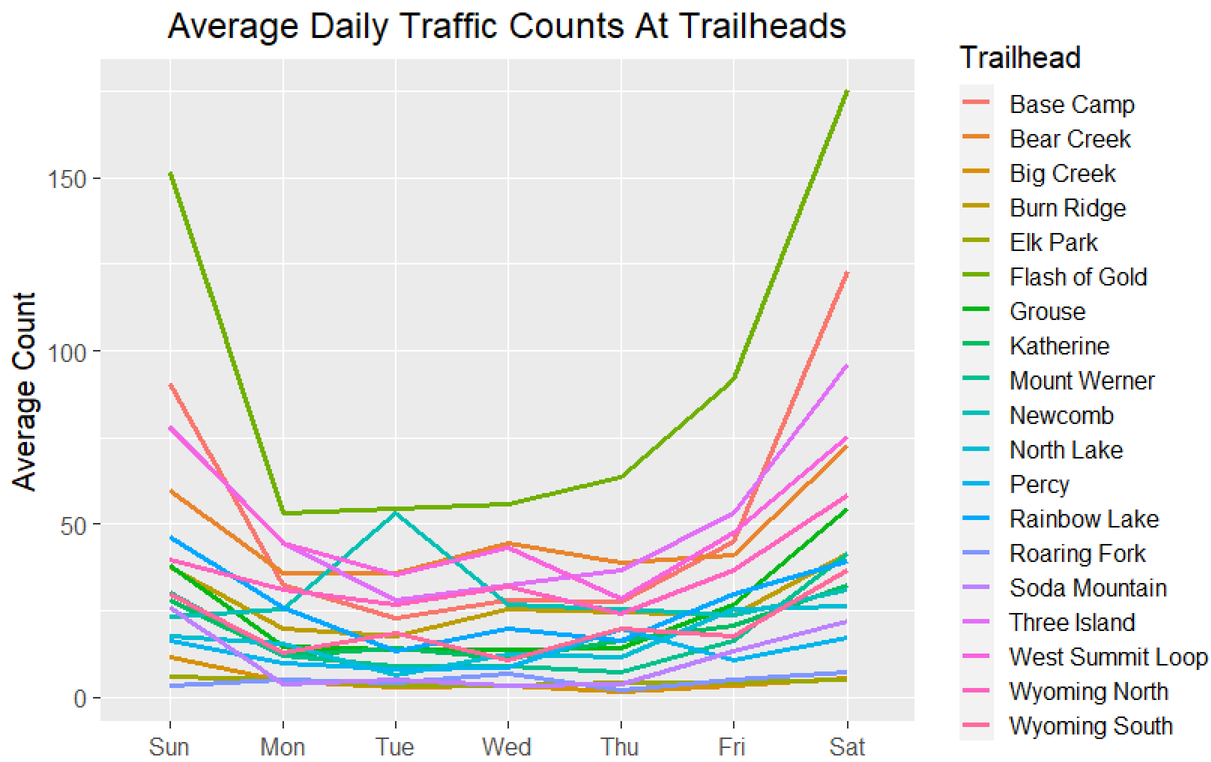

Figure 2. Daily trends in trailhead traffic documented with trail counters from June through October 2020, excluding Fish Creek Falls, Mad Creek, and Red Dirt trailheads, which received average daily counts >200.

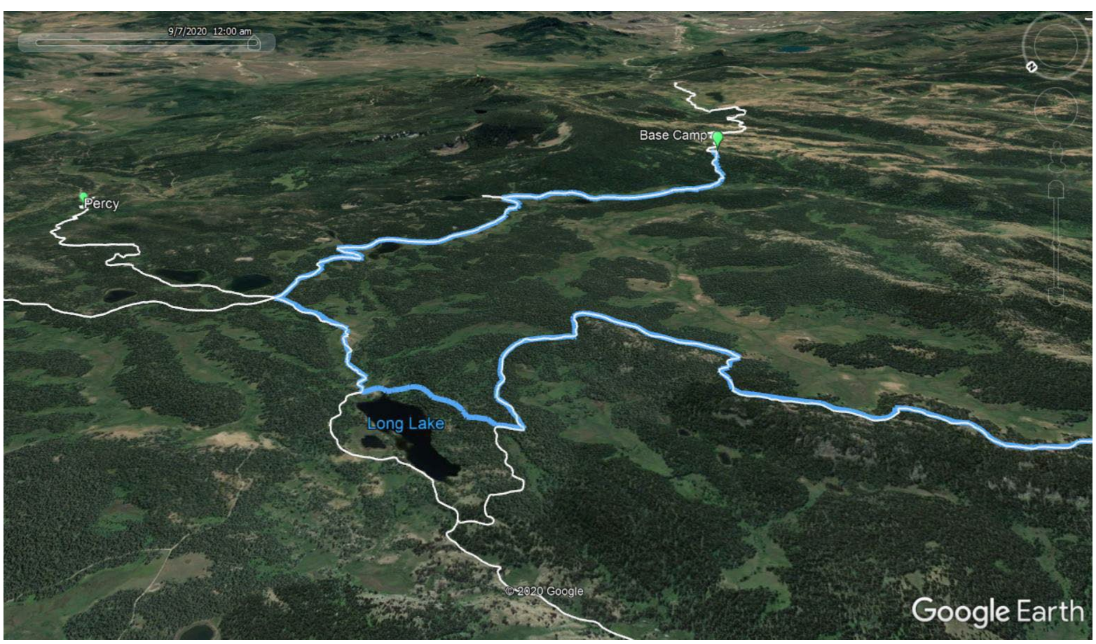

Figure 3. GPS track (blue) recorded from recreational mountain biker on trail system (white) in August 2020. Note the off-trail use near Long Lake.

SUPPORT SERVICES

RESEARCH LIBRARY ANNUAL REPORT

ANNUAL REPORT

COLORADO PARKS & WILDLIFE
RESEARCH LIBRARY

JULY 1, 2020-JUNE 30, 2021

alexandria.austermann@state.co.us
https://cpw.catalog.aspencat.info/

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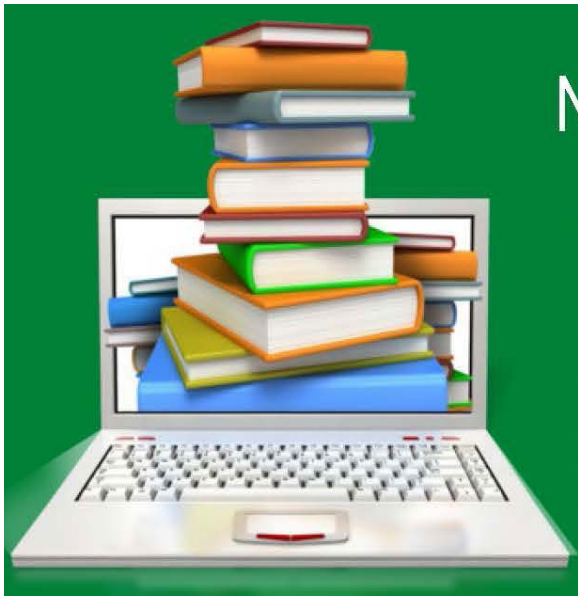
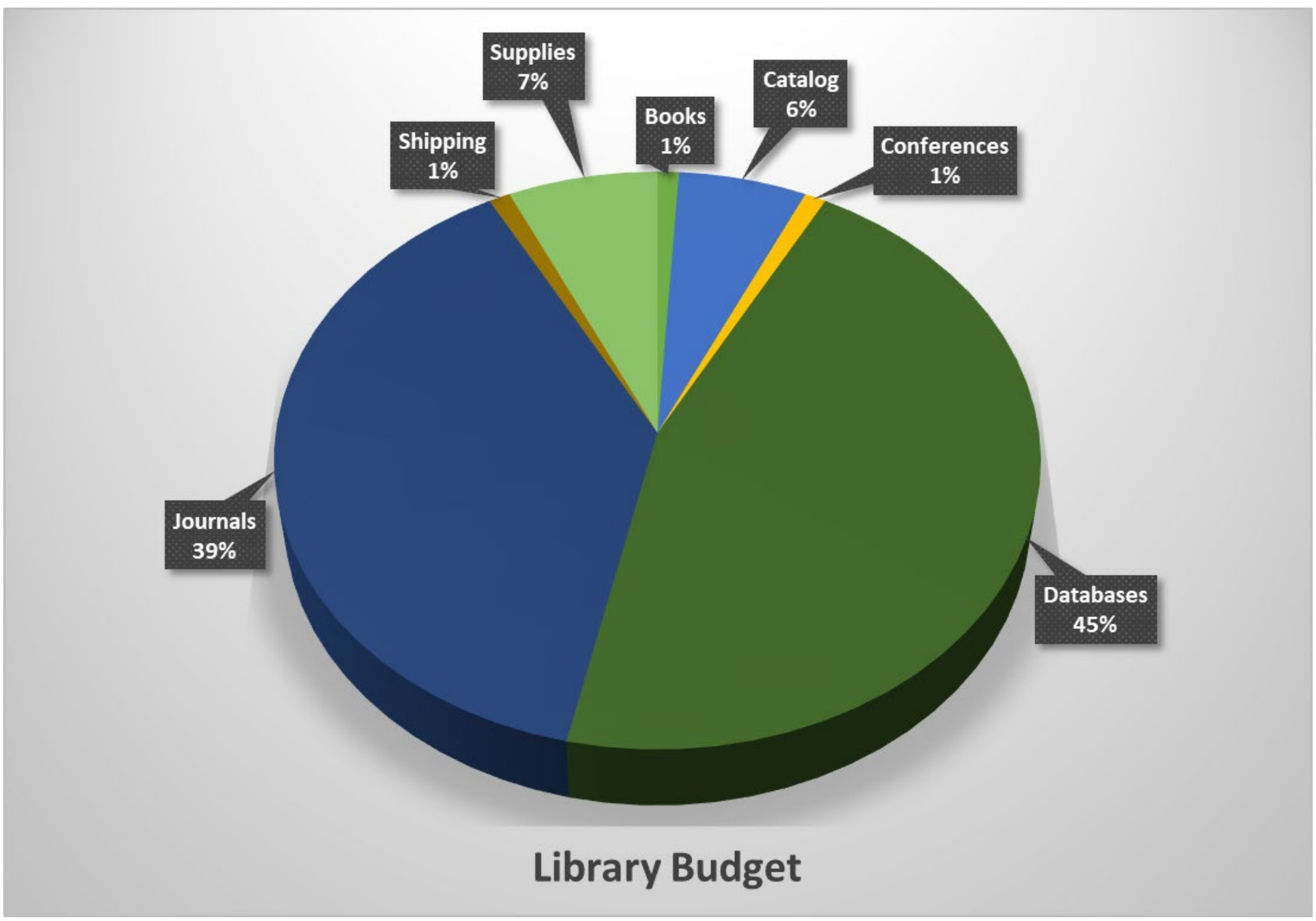
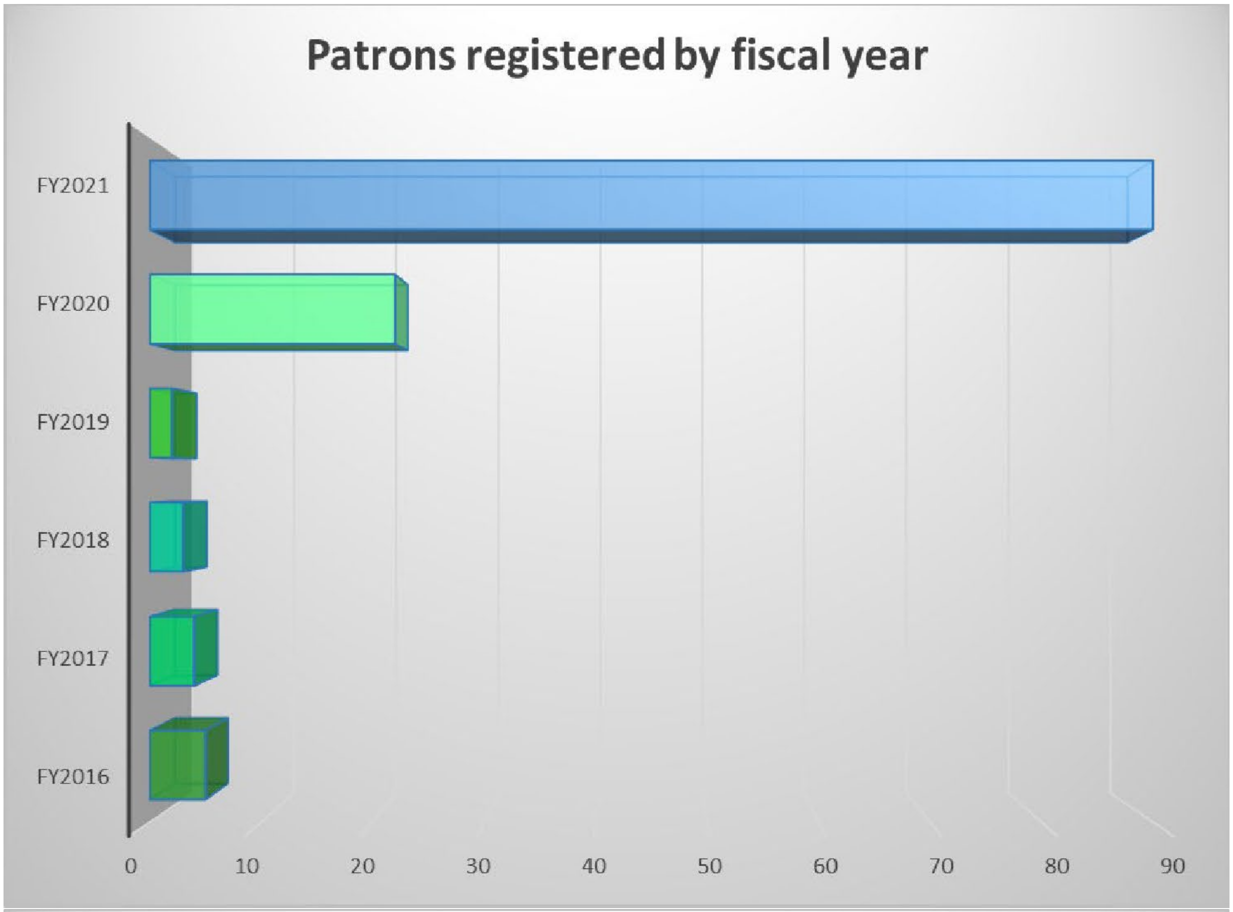


New Database for Digital Items

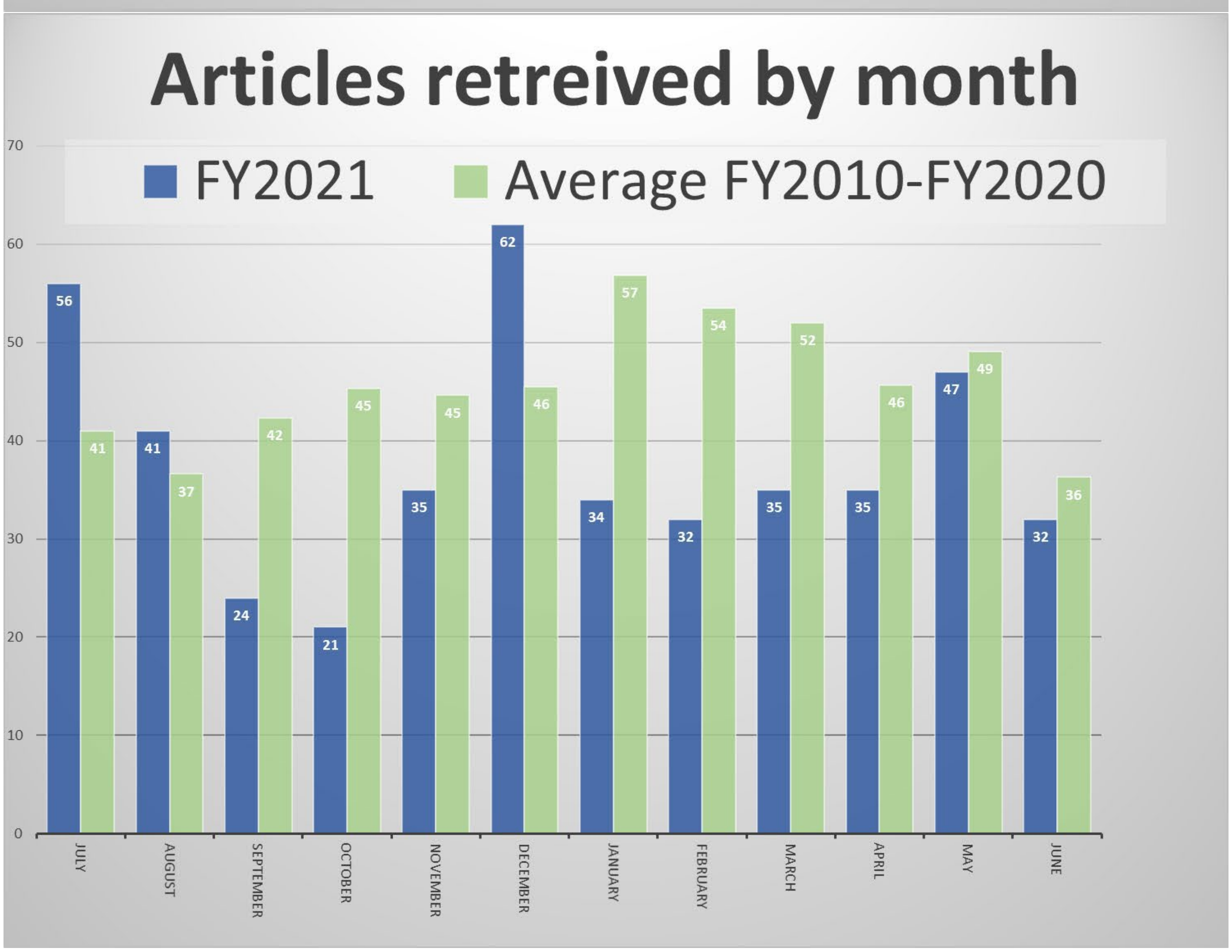
The library has added a new database for hosting digital collections. Photos, journal articles, streaming videos and other digital items that don't fit into the traditional library catalog can be hosted in the new database. The new database can be searched from the library catalog, so patrons don't have to search two different systems for digital items.


90 new patrons were signed up
102 items were added to the new database
454 articles were sent to patrons
652 new items were added to the catalog. 5725 items were updated
FY2021


Supplies 7%
Catalog 6%
Books 1%
Shipping 1%
Conferences 1%
Journals 39%
Databases 45%
Library Budget



Patrons registered by fiscal year
FY2021
FY2020
FY2019
FY2018
FY2017
FY2016
0
10
20
30
40
50
60
70
80
90



Articles retreived by month
FY2021
Average FY2010-FY2020
0
10
20
30
40
50
60
70
56
41
41
37
24
42
21
45
35
45
62
46
34
57
32
54
35
52
35
46
47
49
32
36
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE

Colorado Parks & Wildlife Research Library

COLLECTION DEVELOPMENT POLICY

Mission Statement

The Colorado Parks & Wildlife (CPW) Research Library serves two functions.

1. The library supports wildlife-related research and management by providing needed information, including books, full-text articles, publications from other government agencies, and literature searches.
2. The library serves as an institutional repository for documents written by Division staff and makes those freely available to the public.

Evaluation of collection and maintenance policies

The research library was created in the late 1960s primarily to provide support to the wildlife research sections, Avian, Mammals and Aquatic, and has evolved over the years to serve the broader information needs of CPW staff. The library's print collection–which consists mainly of books, journals and Division publications–has been assembled through purchase, donation and contributions from Division staff. The collection is an excellent historic record of Division publications dating back to 1877, when the first fish commissioner was appointed. The collection also holds original print Federal Aid reports dating back to the late 1930s, written shortly after the Pittman-Robertson Federal Aid in Wildlife Restoration Act was passed in 1937.

Two copies of all printed Division publications are cataloged and any extra copies the library receives are available for distribution upon request. The library maintains a mailing list of institutions and individuals that receive copies of printed reports. The Colorado State library receives and hosts PDF copies of Division publications that are then linked in the CPW library catalog. A digitization project for older CPW publications is underway and PDFs of publications are added to the library catalog or the State Library catalog as they are scanned.

The following guidelines have been established by the librarian:

- The library will collect items to support wildlife-related research and management. Items of a more general nature, fiction or sports books for example, will not be added to the collection. Purchase of new material is generally made at the request of, or in consultation with, CPW staff. Retention of non-wildlife subject material–i.e., computer manuals–will be based on space and usage. All items will be judged on the following factors:
    - relevance and use,
    - redundancy,
    - relationship to existing collections at another library,
    - accuracy and impartiality,

    - authority of author/publisher,
    - physical condition,
    - suitability of subject and style,
    - language,
    - availability of an electronic format,
    - timeliness, and
    - unique features of the material.
- Under normal circumstances, only two copies of an item will be held in the Library collection due to space considerations. Exceptions may be made for items in high demand or those often in long-term check-out to CPW staff. Extra copies of internal, un-cataloged CPW publications will be kept as space permits. Only one copy of each journal issue will be held, with the exception of additional issues of Colorado Outdoors.
- In general, only English language material will be added to the collection. A book in a foreign language may be added at the request of a CPW employee. Translations of CPW publications, currently Spanish versions of some brochures, should be retained.
- When possible, CPW publications will be preserved in print format for long-term archiving. Since all current publications start as a PDF, the librarian will request enough print copies for cataloging and distribution if copies are printed. If physical copies of the report are not printed, the librarian will send a copy of the PDF to the State Library for archiving. The librarian will make every effort to obtain "white paper" publications from CPW staff and the CPW web site to add as many CPW publications to the library collection as possible. The recent addition of a suitable database for photos, journal articles, streaming videos and other digital items not suitable for the library catalog, widens the scope of items that can be collected, preserved and accessed.
- Non-print formats–such as DVDs–will only be purchased by special request and will be shelved in the Library collection by subject.
- Journals are purchased from the publisher on a fixed-fee basis to avoid mid-year price increases. Online access is preferred and print subscriptions are being phased out where possible. Annual review of the journals subscriptions is undertaken by the librarian with assistance from the research managers.
- Theses and dissertations are added to the collection as donated.
- Gifts to the library are accepted on a no-strings-attached basis. The individual donating the material will not dictate inclusion or retention. The librarian will follow standard guidelines for subject and format to decide what is added to the collection. Anything not added to the collection will be donated or recycled.
- The physical condition of a book may influence inclusion in the collection. If water damaged with subsequent mold, the item will be discarded to prevent spread of mold. If repair of a damaged

item (torn pages, broken spine) is possible, the book will be repaired. Damaged items are judged using the same criteria as other material with the additional possibility of replacement if warranted.

Weeding policy

Weeding, withdrawal of items that no longer meet collection criteria, is conducted as an ongoing or special project to evaluate items already in the library collection. Decisions are made on an item-by-item basis as to retention or withdrawal. Weeding is often started due to space considerations but should always follow the collection development guidelines. As in adding to the collection, withdrawal of material should be made with the entire collection in mind. The added availability of an electronic version will often spur selected weeding of print copies. Within the CPW collection, publication date considerations will generally only apply to specific subjects; a 3-year limit on retention of computer manuals, for example. Usage statistics are also not as relevant as in other libraries in determining what to keep and what to discard. Initial weeding is conducted by the librarian and may involve the subject specialists in the final retention decisions. In addition to physically removing the material from the shelf, time and labor must be allocated for disposal (recycling, sending to another library, etc.) and updating holdings in the library catalog database.

Currently, the print journal collection is not subject to weeding. There is plenty of space on the shelves for the current holdings and future need for physical copies is declining with electronic conversions. At some point, the print journals may be discarded but for the time being, there are journals and issues of journals that are not available online and so the physical copies are necessary to fulfill article requests. The non-Colorado state wildlife magazines (Montana Outdoors, South Dakota Conservation Digest, etc.) are a special subset of the journal collection and are subject to different rules. The issues of those journals will be displayed for a month or two and then discarded when new issues come in.

Electronic resources

Selection of electronic resources should follow the same collection development guidelines outlined above. However, the review process before purchase may be expanded due to the greater expenditure of funds and the wider audience that the e-resource may reach. For example, a trial or demonstration of a database may be scheduled to obtain staff input on relevance and use before the purchase is made. The addition of online journal access to our print subscription is made with input from the research managers if it will greatly increase our periodical subscription budget. As technology advances and the budget allows, review of products such as e-book collections and e-journal packages as well as additional features for the library catalog will be considered.

Interlibrary Loan

No library can acquire every resource needed by its patrons. This is especially true with our ever developing subject diversity within wildlife-related topics. It is inevitable CPW staff will request items that are not owned by the research library. These requests will include articles from scholarly journals not covered in either our print subscriptions or online databases or books not in our collection. The librarian will then make use of local academic or federal libraries or the nationwide interlibrary loan (ILL) network to borrow or obtain a full-text version of the request. If the librarian finds numerous requests from the same journal or book, it may prompt purchase of a copy for the library. It is often more efficient to purchase a book than to borrow it from another institution, especially if the material fills a gap in the library collection.

Conclusion

Due to the constant change in the information needs of CPW staff and the rapid growth of electronic media, this collection development policy should serve as a guideline for decision-making. It should not become a static document, but should be reviewed and updated periodically and revised as conditions change.

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Kay Horton Knudsen, Research Librarian, November 10, 2010
Alexandria Austermann, Research Librarian, October 05, 2021

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APPENDIX A. CPW mammal research abstracts published since July 2020.

A Specialized Forest Carnivore Navigates Landscape-level Disturbance: Canada Lynx in Spruce-Beetle Impacted Forests

John R. Squires,[a] Joseph D. Holbrook,[b] Lucretia E. Olson,[a] Jacob S. Ivan,[c] Randal W. Ghormley,[d] Rick L. Lawrence[e]
[a] USDA Forest Service, Rocky Mountain Research Station, Missoula, MT, USA
[b] Haub School of Environment and Natural Resources, Department of Zoology and Physiology, University of Wyoming, Laramie, WY, USA
[c] Mammals Research Section, Colorado Parks and Wildlife, Fort Collins, CO, USA
[d] Rio Grande National Forest (retired), Monte Vista, CO, USA
[e] Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, USA

Citation: Squires, J. R., J. D. Holbrook, L. E. Olson, J. S. Ivan, R. W. Ghormley, and R. L. Lawrence. 2020. A specialized forest carnivore navigates landscape-level disturbance: Canada lynx in spruce-beetle impacted forests. Forest Ecology and Management 475:118400.

ABSTRACT Canada lynx (*Lynx canadensis*) occupy cold wet forests (boreal and subalpine forest) that were structured by natural disturbance processes for millennia. In the Southern Rocky Mountains, at the species' southern range periphery, Canada lynx habitat has been recently impacted by large-scale disturbance from spruce beetles (Dendroctonus rufipennis). This disturbance poses a challenge for forest managers who must administer this novel landscape in ways that also facilitate timber salvage. To aid managers with this problem, we instrumented Canada lynx with GPS collars to document their selection of beetle impacted forests at spatial scales that spanned from landscapes to movement paths. We used a use-availability design based on remotely-sensed covariates to evaluate landscape- and path-level selection. We evaluated selection at the home-range scale in beetle-kill areas based on vegetation plots sampled in the field to quantify forest structure and composition. We found that across all scales of selection, Canada lynx selected forests with a higher proportion of beetle-kill trees that were generally larger in diameter than randomly available. Within home ranges, Canada lynx selected forests with greater live components of subalpine fir and live canopy of Engelmann spruce. During winter, Canada lynx exhibited functional responses, or disproportionate use relative to availability, for forest horizontal cover, diameter of beetle killed trees, live canopy of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*), and additive use (and consistent selection) for relative density of snowshoe hares and density of subcanopy subalpine fir 3–4.9 in. (7.6–12.4 cm) in diameter. We discuss our results in the context of balancing resource needs of Canada lynx with the desire to salvage timber in beetle-impacted forests. Published July 2020

Improved Prediction of Canada Lynx Distribution Through Regional Model Transferability and Data Efficiency

Lucretia E. Olson[1], Nichole Bjornlie[2], Gary Hanvey[3], Joseph D. Holbrook[4], Jacob S. Ivan[5], Scott Jackson[3], Brian Kertson[6], Travis King[7], Michael Lucid[8], Dennis Murray[9], Robert Naney[10], John Rohrer[10], Arthur Scully[9], Daniel Thornton[7], Zachary Walker[2], and John R. Squires[1]
[1] Rocky Mountain Research Station, U. S. Forest Service, Missoula, MT, USA
[2] Wyoming Game and Fish Department, Lander, WY, USA
[3] U. S. Department of Agriculture, Northern Region, U. S. Forest Service, Missoula, MT, USA
[4] Dept. of Zoology and Physiology, Haub School of Environment and Natural Resources, University of Wyoming, Laramie, WY, USA
[5] Colorado Parks and Wildlife, Fort Collins, CO, USA
[6] Washington Department of Fish and Wildlife, Snoqualmie, WA, USA
[7] School of the Environment, Washington State University, Pullman, WA, USA
[8] Idaho Department of Fish and Game, Coeur d'Alene, ID, USA
[9] Environmental and Life Sciences, Biology Department, Trent University, Peterborough, ON, Canada
[10] U. S. Forest Service, Okanogan-Wenatchee National Forest, Winthrop, WA, USA

Citation: Olson, L. E., N. Bjornlie, G. Hanvey, J. D. Holbrook, J. S. Ivan, S. Jackson, B. Kertson, T. King, M. Lucid, D. Murray, R. Naney, J. Rohrer, A. Scully, D. Thornton, Z. Walker, and J. R. Squires. 2021. Improved prediction of Canada lynx distribution through regional model transferability and data efficiency. Ecology and Evolution 11:1667–1690; doi.org/10.1002/ece3.7157

ABSTRACT The application of species distribution models (SDMs) to areas outside of where a model was created allows informed decisions across large spatial scales, yet transferability remains a challenge in ecological modeling. We examined how regional variation in animal-environment relationships influenced model transferability for Canada lynx (*Lynx canadensis*), with an additional conservation aim of modeling lynx habitat across the northwestern United States. Simultaneously, we explored the effect of sample size from GPS data on SDM model performance and transferability. We used data from three geographically distinct Canada lynx populations in Washington (n = 17 individuals), Montana (n = 66), and Wyoming (n = 10) from 1996 to 2015. We assessed

regional variation in lynx-environment relationships between these three populations using principal components analysis (PCA). We used ensemble modeling to develop SDMs for each population and all populations combined and assessed model prediction and transferability for each model scenario using withheld data and an extensive independent dataset (*n* = 650). Finally, we examined GPS data efficiency by testing models created with sample sizes of 5%–100% of the original datasets. PCA results indicated some differences in environmental characteristics between populations; models created from individual populations showed differential transferability based on the populations' similarity in PCA space. Despite population differences, a single model created from all populations performed as well, or better, than each individual population. Model performance was mostly insensitive to GPS sample size, with a plateau in predictive ability reached at ~30% of the total GPS dataset when initial sample size was large. Based on these results, we generated well-validated spatial predictions of Canada lynx distribution across a large portion of the species' southern range, with precipitation and temperature the primary environmental predictors in the model. We also demonstrated substantial redundancy in our large GPS dataset, with predictive performance insensitive to sample sizes above 30% of the original. Published January 2021

CARNIVORE ECOLOGY AND MANAGEMENT

Effects of Hunting on a Puma Population in Colorado

Kenneth A. Logan[a] and Jonathan P. Runge[b]

[a] Mammals Research Section, Colorado Parks and Wildlife, 2300 S. Townsend Avenue, Montrose, CO 81401, USA
[b] Terrestrial Programs, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

Citation: Logan, K. A. and J. P. Runge. 2020. Effects of hunting on a puma population in Colorado. Wildlife Monographs 209:1–35; DOI:10-1002/wmon.1061

ABSTRACT We investigated effects of regulated hunting on a puma (*Puma concolor*) population on the Uncompahgre Plateau (UPSA) in southwestern Colorado, USA. We examined the hypothesis that an annual harvest rate averaging 15% of the estimated number of independent individuals using the study area would result in a stable or increasing abundance of independent pumas. We predicted hunting mortality would be compensated by 1) a reduction in other causes of mortality, thus overall survival would stay the same or increase; 2) increased reproduction rates; or 3) increased recruitment of young animals. The study occurred over 10 years (2004–2014) and was designed with a reference period (years 1–5; i.e., RY1–RY5) without puma hunting and a treatment period (years 6–10; i.e., TY1–TY5) with hunting. We captured and marked pumas on the UPSA and monitored them year-round to examine their demographics, reproduction, and movements. We estimated abundance of independent animals using the UPSA each winter during the Colorado hunting season from reference year 2 (RY2) to treatment year 5 (TY5) using the Lincoln-Petersen method. In addition, we surveyed hunters to investigate how their behavior influenced harvest and the population. We captured and marked 110 and 116 unique pumas in the reference and treatment periods, respectively, during 440 total capture events. Those animals produced known-fate data for 75 adults, 75 subadults, and 118 cubs, which we used to estimate sex- and life stage-specific survival rates. In the reference period, independent pumas more than doubled in abundance and exhibited high survival. Natural mortality was the major cause of death to independent individuals, followed by other human causes (e.g., vehicle strikes, depredation control). In the treatment period, hunters killed 35 independent pumas and captured and released 30 others on the UPSA. Abundance of independent pumas using the UPSA declined 35% after 4 years of hunting with harvest rates averaging 15% annually. Harvest rates at the population scale, including marked independent pumas with home ranges exclusively on the UPSA, overlapping the UPSA, and on adjacent management units were higher, averaging 22% annually in the same 4 years leading to the population decline. Adult females comprised 21% of the total harvest. The top-ranked model explaining variation in adult survival ($\hat{S}$) indicated a period effect interacting with sex. Annual adult male survival was higher in the reference period ($\hat{S}$ = 0.96, 95% CI = 0.75–0.99) than in the treatment period ($\hat{S}$ = 0.40, 95% CI = 0.22–0.57). Annual adult female survival was 0.86 (95% CI = 0.72–0.94) in the reference period and 0.74 (95% CI = 0.63–0.82) in the treatment period. The top subadult model showed that female subadult survival was constant across the reference and treatment periods ($\hat{S}$ = 0.68, 95% CI = 0.43–0.84), whereas survival of subadult males exhibited the same trend as that of adult males: higher in the reference period ($\hat{S}$ = 0.92, 95% CI = 0.57–0.99) and lower in the treatment period ($\hat{S}$ = 0.43, 95% CI = 0.25–0.60). Cub survival was best explained by fates of mothers when cubs were dependent ($\hat{S}_{\text{mother alive}}$ = 0.51, 95% CI = 0.35–0.66; $\hat{S}_{\text{mother died}}$ = 0.14, 95% CI = 0.03–0.34). The age distribution for independent pumas skewed younger in the treatment period. Adult males were most affected by harvest; their abundance declined by 59% after 3 hunting seasons and we did not detect any males >6 years old after 2 hunting seasons. Pumas born on the UPSA that survived to subadult stage exhibited both philopatry and dispersal. Local recruitment and immigration contributed to positive growth in the reference period, but recruitment did not compensate for the losses of adult males and partially compensated for losses of adult females in the treatment period. Average birth intervals were similar in the reference and treatment periods (reference period = 18.3 months, 95% CI = 15.5–21.1; treatment period = 19.4 months, 95% CI = 16.2–22.6), but litter sizes (reference period = 2.8, 95% CI = 2.4–3.1; treatment period = 2.4, 95% CI = 2.0–2.8) and parturition rates (reference period = 0.63, 95% CI = 0.49–0.75; treatment period = 0.48, 95% CI = 0.37–0.59) declined slightly in the treatment period. Successful hunters used dogs, selected primarily males, and harvested pumas in 1–2 days (median). We found that an annual harvest rate at the population scale averaging 22% of the independent pumas over 4 years and with >20% adult females in the total harvest greatly reduced abundance. At this scale, annual mortality rates of independent animals from hunting averaged 6.3 times greater than from all other human causes and 4.6 times greater than from all natural causes during the population decline. Hunting deaths were largely additive and reproduction and recruitment did not compensate for this mortality source. Hunters generally selected male pumas, resulting in a decline in their survival and abundance, and the age structure of the population. We recommend that regulated hunting in a source-sink structure be used to conserve puma populations, provide

sustainable hunting opportunities, and address puma-human conflicts. Published March 2021

UNGULATE ECOLOGY AND MANAGEMENT

Estimation of Moose Parturition Dates in Colorado: Incorporating Imperfect Detections

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Citation: Bergman, E. J., F. P. Hayes, and K Aagaard. 2020. Estimation of moose parturition dates in Colorado: incorporating imperfect detections. Alces 56:127–135.

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. Published August 2020

Behavioral and Demographic Responses of Mule Deer to Energy Development on Winter Range

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Citation: Northrup, J. M., C. R, Anderson Jr., B. D. Gerber, and G. Wittemyer. 2021. Behavioral and demographic responses of mule deer to energy development on winter range. Wildlife Monographs 208:1–37; DOI:10-1002/wmon.1060

ABSTRACT Anthropogenic habitat modification is a major driver of global biodiversity loss. In North America, one of the primary sources of habitat modification over the last 2 decades has been exploration for and production of oil and natural gas (hydrocarbon development), which has led to demographic and behavioral impacts to numerous wildlife species. Developing effective measures to mitigate these impacts has become a critical task for wildlife managers and conservation practitioners. However, this task has been hindered by the difficulties involved in identifying and isolating factors driving population responses. Current research on responses of wildlife to development predominantly quantifies behavior, but it is not always clear how these responses scale to demography and population dynamics. Concomitant assessments of behavior and population-level processes are needed to gain the mechanistic understanding required to develop effective mitigation approaches. We simultaneously assessed the demographic and behavioral responses of a mule deer (*Odocoileus hemionus*) population to natural gas development on winter range in the Piceance Basin of Colorado, USA, from 2008 to 2015. Notably, this was the period when development declined from high levels of active drilling to only production phase activity (i.e., no drilling). We focused our data collection on 2 contiguous mule deer winter range study areas that experienced starkly different levels of hydrocarbon development within the Piceance Basin.

We assessed mule deer behavioral responses to a range of development features with varying levels of associated human activity by examining habitat selection patterns of nearly 400 individual adult female mule deer. Concurrently, we assessed the demographic and physiological effects of natural gas development by comparing annual adult female and overwinter fawn (6-month-old animals) survival, December fawn mass, adult female late and early winter body fat, age, pregnancy rates, fetal counts, and lactation rates in December between the 2 study areas. Strong differences in habitat selection between the 2 study areas were apparent. Deer in the less-developed study area avoided development during the day and night, and selected habitat presumed to be used for foraging. Deer in the heavily developed study area selected habitat presumed to be used for thermal and security cover to a greater degree. Deer faced with higher densities of development avoided areas with more well pads during the day and responded neutrally or selected for these areas at night. Deer in both study areas showed a strong reduction in use of areas around well pads that were being drilled, which is the phase of energy development associated with the greatest amount of human presence, vehicle traffic, noise, and artificial light. Despite divergent habitat selection patterns, we found no effects of development on individual condition or reproduction and found no differences in any of the physiological or vital rate parameters measured at the population level. However, deer density and annual increases in density were higher in the low-development area. Thus, the recorded behavioral alterations did not appear to be associated with demographic or physiological costs measured at the individual level, possibly because

populations are below winter range carrying capacity. Differences in population density between the 2 areas may be a result of a population decline prior to our study (when development was initiated) or area-specific differences in habitat quality, juvenile dispersal, or neonatal or juvenile survival; however, we lack the required data to contrast evidence for these mechanisms.

Given our results, it appears that deer can adjust to relatively high densities of well pads in the production phase (the period with markedly lower human activity on the landscape), provided there is sufficient vegetative and topographic cover afforded to them and populations are below carrying capacity. The strong reaction to wells in the drilling phase of development suggests mitigation efforts should focus on this activity and stage of development. Many of the wells in this area were directionally drilled from multiple-well pads, leading to a reduced footprint of disturbance, but were still related to strong behavioral responses. Our results also indicate the likely value of mitigation efforts focusing on reducing human activity (i.e., vehicle traffic, light, and noise). In combination, these findings indicate that attention should be paid to the spatial configuration of the final development footprint to ensure adequate cover. In our study system, minimizing the road network through landscape-level development planning would be valuable (i.e., exploring a maximum road density criteria). Lastly, our study highlights the importance of concomitant assessments of behavior and demography to provide a comprehensive understanding of how wildlife respond to habitat modification. Published January 2021

Elk Migration Influences the Risk of Disease Spillover in the Greater Yellowstone Ecosystem

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Citation: Rayl, N. D., J. A. Merkle, K. M. Profitt, E. S. Almberg, J. D. Jones, J. A. Gude, and P. C. Cross. 2021. Elk migration influences the risk of disease spillover in the Greater Yellowstone Ecosystem. Journal of Animal Ecology 90:1264-1275; doi.org/10.1111/1365-2656.13452.

Abstract

1. Wildlife migrations provide important ecosystem services, but they are declining. Within the Greater Yellowstone Ecosystem (GYE), some elk *Cervus canadensis* herds are losing migratory tendencies, which may increase spatiotemporal overlap between elk and livestock (domestic bison *Bison bison* and cattle *Bos taurus*), potentially exacerbating pathogen transmission risk.
2. We combined disease, movement, demographic and environmental data from eight elk herds in the GYE to examine the differential risk of brucellosis transmission (through aborted fetuses) from migrant and resident elk to livestock.
3. For both migrants and residents, we found that transmission risk from elk to livestock occurred almost exclusively on private ranchlands as opposed to state or federal grazing allotments. Weather variability affected the estimated distribution of spillover risk from migrant elk to livestock, with a 7%–12% increase in migrant abortions on private ranchlands during years with heavier snowfall. In contrast, weather variability did not affect spillover risk from resident elk.
4. Migrant elk were responsible for the majority (68%) of disease spillover risk to livestock because they occurred in greater numbers than resident elk. On a per-capita basis, however, our analyses suggested that resident elk disproportionately contributed to spillover risk. In five of seven herds, we estimated that the per-capita spillover risk was greater from residents than from migrants. Averaged across herds, an individual resident elk was 23% more likely than an individual migrant elk to abort on private ranchlands.
5. Our results demonstrate links between migration behaviour, spillover risk and environmental variability, and highlight the utility of integrating models of pathogen transmission and host movement to generate new insights about the role of migration in disease spillover risk. Furthermore, they add to the accumulating body of evidence across taxa that suggests that migrants and residents should be considered separately during investigations of wildlife disease ecology. Finally, our findings have applied implications for elk and brucellosis in the GYE. They suggest that managers should prioritize actions that maintain spatial separation of elk and livestock on private ranchlands during years when snowpack persists into the risk period. Published Feb. 2021

Some Memories Never Fade: Inferring Multi-Scale Memory Effects on Habitat Selection of a Migratory Ungulate Using Step-Selection Functions

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Citation: Rheault, H, C. R Anderson Jr, M. Bonar, R. R. Marrotte, T. R. Ross, G. Wittemyer, and J. M. Northrup. 2021. Some memories never fade: inferring multi-scale memory effects on habitat selection of a migratory ungulate using step-selection functions. Frontiers in Ecology and Evolution 9.702818; doi: 10.3389/fevo.2021.702818.

ABSTRACT Understanding how animals use information about their environment to make movement decisions underpins our ability to explain drivers of and predict animal movement. Memory is the cognitive process that allows species to store information about experienced landscapes, however, remains an understudied topic in movement ecology. By studying how species select for familiar locations, visited recently and in the past, we can gain insight to how they store and use local information in multiple memory types. In this study, we analyzed the movements of a migratory mule deer (*Odocoileus hemionus*) population in the Piceance Basin of Colorado, United States to investigate the influence of spatial experience over different time scales on seasonal range habitat selection. We inferred the influence of short and long-term memory from the contribution to habitat selection of previous space use within the same season and during the prior year, respectively. We fit step-selection functions to GPS collar data from 32 female deer and tested the predictive ability of covariates representing current environmental conditions and both metrics of previous space use on habitat selection, inferring the latter as the influence of memory within and between seasons (summer vs. winter). Across individuals, models incorporating covariates representing both recent and past experience and environmental covariates performed best. In the top model, locations that had been previously visited within the same season and locations from previous seasons were more strongly selected relative to environmental covariates, which we interpret as evidence for the strong influence of both short- and long-term memory in driving seasonal range habitat selection. Further, the influence of previous space uses was stronger in the summer relative to winter, which is when deer in this population demonstrated strongest philopatry to their range. Our results suggest that mule deer update their seasonal range cognitive map in real time and retain long-term information about seasonal ranges, which supports the existing theory that memory is a mechanism leading to emergent space-use patterns such as site fidelity. Lastly, these findings provide novel insight into how species store and use information over different time scales. Published July 2021.

Effects of Willow Nutrition and Morphology on Calving Success of Moose

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Citation: Hayes, F. P., J. J. Millspaugh, E. J. Bergman, R. M. Callaway, and C. J. Bishop. *In Press*. Effects of willow nutrition and morphology on calving success of moose. Journal of Wildlife Management 2022; https://doi.org/10.1002/jwmg.22175

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. Accepted for publication, In Press.

Host Relatedness and Landscape Connectivity Shape Pathogen Spread in the Puma, a Large Secretive Carnivore

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Citation: Fountain-Jones, N. M., S. Kraberger, R. B. Gagne, D. R. Trumbo, P. E. Salerno, W. C. Funk, K. Crooks, R. Biek, M. Alldredge, K. Logan, G. Baele, S. Dellicour, H. B. Ernest, S. VandeWoude, S. Carver, and M. E. Craft. 2021. Host relatedness and landscape connectivity shape pathogen spread in the puma, a large secretive carnivore. Communications Biology 4:12; doi: 10.1038/s42003-020-01548-2.

ABSTRACT Urban expansion can fundamentally alter wildlife movement and gene flow, but how urbanization alters pathogen spread is poorly understood. Here, we combine high resolution host and viral genomic data with landscape variables to examine the context of viral spread in puma (*Puma concolor*) from two contrasting regions: one bounded by the wildland urban interface (WUI) and one unbounded with minimal anthropogenic development (UB). We found landscape variables and host gene flow explained significant amounts of variation of feline immunodeficiency virus (FIV) spread in the WUI, but not in the unbounded region. The most important predictors of viral spread also differed; host spatial proximity, host relatedness, and mountain ranges played a role in FIV spread in the WUI, whereas roads might have facilitated viral spread in the unbounded region. Our research demonstrates how anthropogenic landscapes can alter pathogen spread, providing a more nuanced understanding of host-pathogen relationships to inform disease ecology in free-ranging species. Published January 2021

Viral Sequences Recovered From Puma Tooth DNA Reconstruct Statewide Viral Phylogenies

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Citation: Gagne, R. B., S., Kraberger, R. McMinn, D. R. Trumbo, C. R. Anderson Jr, K. A. Logan, M. W. Alldredge, K. Griffin, and S. VandeWoude. 2021. Viral sequences recovered from puma tooth DNA reconstruct statewide viral phylogenies. Frontiers in Ecology and Evolution 9:734462. doi: 10.3389/fevo.2021.734462

ABSTRACT Monitoring pathogens in wildlife populations is imperative for effective management, and for identifying locations for pathogen spillover among wildlife, domestic species and humans. Wildlife pathogen surveillance is challenging, however, as sampling often requires the capture of a significant proportion of the population to understand host pathogen dynamics. To address this challenge, we assessed the ability to use hunter collected teeth from puma across Colorado to recover genetic data of two feline retroviruses, feline foamy virus (FFV) and feline immunodeficiency virus (FIVpco) and show they can be utilized for this purpose. Comparative phylogenetic analyses of FIVpco and FFV from tooth and blood samples to previous analyses conducted with blood samples collected over a nine-year period from two distinct areas was undertaken highlighting the value of tooth derived samples. We found less FIVpco phylogeographic structuring than observed from sampling only two regions and that FFV data confirmed previous findings of endemic infection, minimal geographic structuring, and supported frequent cross-species transmission from domestic cats to pumas. Viral analysis conducted using intentionally collected blood samples required extensive financial, capture and sampling efforts. This analysis illustrates that viral genomic data can be cost effectively obtained using tooth samples incidentally-collected from hunter harvested pumas, taking advantage of samples collected for morphological age identification. This technique should be considered as an opportunistic method to provide broad geographic sampling to define viral dynamics more accurately in wildlife. Published August 2021

Complex Evolutionary History of Felid Anelloviruses

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Citation: Kraberger, S., L. E. Serieys, C. Richet, N. M. Fountain-Jones, G. Baele, J. M. Bishop, M. Nehring, J. S. Ivan, E. S. Newkirk, J. R. Squires, M. C. Lund, S. P. Riley, C. C. Wilmers, P. D. van Helden, K. Van Doorslaer, M. Culver, S. VandeWoude, D. P. Martin, and A. Varsani. 2021. Complex evolutionary history of felid anelloviruses. Virology 562:176–189; doi: 10.1016/j.virol.2021.07.013

ABSTRACT Anellovirus infections are highly prevalent in mammals, however, prior to this study only a handful of anellovirus genomes had been identified in members of the Felidae family. Here we characterise anelloviruses in pumas (*Puma concolor*), bobcats (*Lynx rufus*), Canada lynx (*Lynx canadensis*), caracals (*Caracal caracal*) and domestic cats (*Felis catus*). The complete anellovirus genomes (n = 220) recovered from 149 individuals were diverse. ORF1 protein sequence similarity network analysis coupled with phylogenetic analysis, revealed two distinct clusters that are populated by felid-derived anellovirus sequences, a pattern mirroring that observed for the porcine anelloviruses. Of the two-felid dominant anellovirus groups, one includes sequences from bobcats, pumas, domestic cats and an ocelot, and the other includes sequences from caracals, Canada lynx, domestic cats and pumas. Coinfections of diverse anelloviruses appear to be common among the felids. Evidence of recombination, both within and between felid-specific anellovirus groups, supports a long coevolution history between host and virus. Published July 2021

JOURNAL OF WILDLIFE MANAGEMENT EDITORIAL

EDITORS MESSAGE: A Perspective on the Journal of Wildlife Management

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Citation: Johnson, D. H., C. Anderson Jr., R. D. Applegate, L. Bailey, E. Cooch, J. Fieberg, A. B. Franklin, R. J. Gutierrez, K. V. Miller, J. D. Nichols, N. D. Niemuth, D. Otis, C. A. Ribic, M. M. Rowland, and T. L. Shaffer. 2021. Editorial Message: A perspective on the Journal of Wildlife Management. Journal of Wildlife Management 85:1305–1308; DOI: 10.1002/jwmg.22110

CONCLUSIONS A first principle of marketing a product, such as a journal, is identifying its target audience. Historically *JWM* was oriented toward on-the-ground and harvest managers. We suspect that over the years the journal has become more read by researchers and students and less used by actual managers. An argument could be made in favor of changing its title to the Journal of Wildlife Science, but much history would be lost causing a reset in the impact factor rating. We believe that both audiences can be served, but it will not be easy.

Collectively, our group offers a wide set of perspectives stemming from our personal experiences publishing in many journals including *JWM*, but we certainly do not reflect the entire spectrum of members of TWS. Therefore, we offer the following conclusions in support of our general comments above (refer to publication) with the expectation that others may either endorse our ideas or refute them. All of us have long held high regard for our society's primary journal. Yet we also believe that *JWM* could be improved. Some of our suggestions are easily implemented (e.g., focus more on facilitating author submissions than on the format of papers—layout and format of a journal are never as important as its content); others will be more challenging (e.g., deciding if the focus of *JWM* should be on game species because other journals provide more options to publish nongame research). In TWS, a possible way forward is for leadership to assess whether new directions in emphasis for *JWM* are warranted. But even if new directions are desired, given a more thorough evaluation than we have provided, we believe there is a perception among many potential authors that structural impediments discourage submission to *JWM*. Therefore, we hope our comments are taken in the context with which we wrote them: to improve the quality and stature of *JWM*.

All decisions, including any recommended changes to *JWM*, should be guided by objectives. For example, if our primary objective is to increase the impact factor of *JWM*, then we might take certain actions, whereas if we want to increase the value of *JWM* to managers we might do something very different. If we prefer a compromise that includes both objectives, perhaps unequally weighted, then our actions would again differ from those that focus only on one of them. We believe that any recommendations for changes to *JWM* must be preceded by a clear statement of what we would like these changes to accomplish. We authors differ in our opinions about the importance of journal impact factor, with some of us concerned that it is too low and others believing that it does not closely relate to the use of the journal. This variation suggests that the TWS membership should be involved in developing the objectives that are required to guide decisions about any changes to *JWM*. Published Sept. 2021