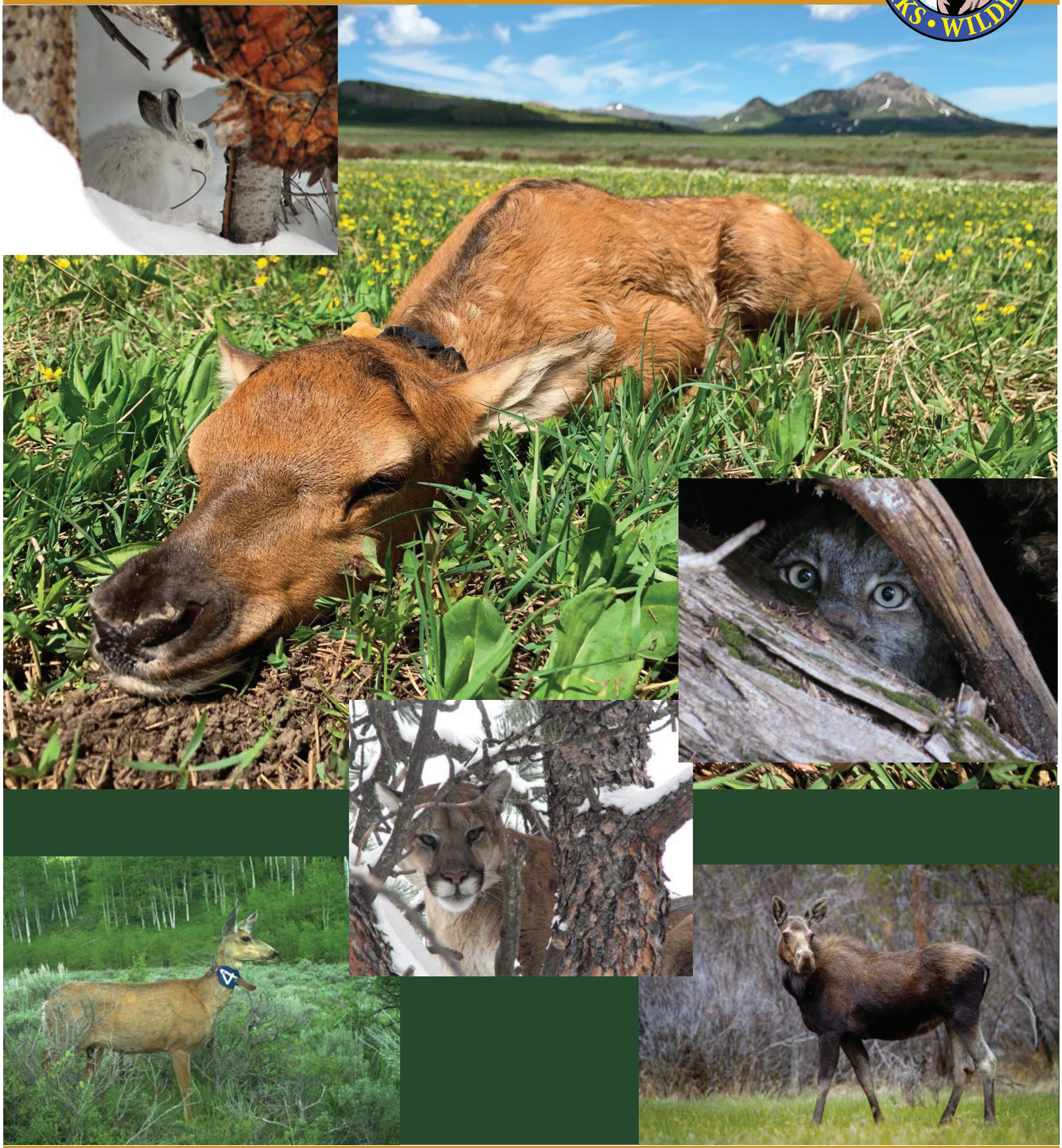
COLORADO PARKS & WILDLIFE

Wildlife Research Reports

MAMMALS – JULY 2020



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WILDLIFE RESEARCH REPORTS

JULY 2019–JUNE 2020

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) from July 2019 through June 2020. 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 influence of forest management practices on snowshoe hare density in Colorado. The Ungulate Conservation Section includes 4 projects addressing mule deer/energy development interactions to inform future development planning, evaluation of moose demographic parameters that will inform future moose management in Colorado, an evaluation of factors influencing elk calf recruitment, and a recent study initiated to address 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 15 publication abstracts (<2 page summaries) completed by CPW mammals research staff since July 2019. These scientific publications provide results from recently completed CPW research projects and other outside collaborations with universities and wildlife management agencies. Topics addressed include nongame species ecology and conservation (lynx associations with beetle killed forests, assessment of wolverine monitoring, distribution and habitat associations across 4 western states, snowshoe hare morphology, and lynx response to winter recreation), carnivore ecology and management (mountain lion population response to hunter harvest, factors limiting mountain lion populations, evaluation of Colorado's 2-strike black bear management directive, mountain lion/human interactions along Colorado's Front Range, and assessment of the social dynamics associated with black bear management along the urban-wildland interface), ungulate ecology and management (mule deer response to energy development activity, 2 publications addressing moose calf detection and estimating parturition dates, and application of acoustic technology to address mule deer foraging behavior), and wildlife genetics research (investigating mountain lion gene flow and genetic diversity).

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, City of Boulder and Jefferson County Open Space, City of Durango, 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, Wildlife Conservation Society, Summerlee Foundation, EnCana Corp., ExxonMobil/XTO Energy, Marathon Oil, Shell Exploration and Production, WPX Energy, and private land owners providing access to support field research projects.

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NONGAME MAMMAL CONSERVATION

CANADA LYNX MONITORING IN COLORADO

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

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Canada Lynx Monitoring in Colorado

Period Covered: July 1, 2018 – June 30, 2019

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

In an effort to restore a viable population of Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006. In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success, and that the population of Canada lynx in the state was apparently viable and self-sustaining. In order to track the persistence of this new population and thus determine the long-term success of the reintroduction, a minimally-invasive, statewide monitoring program is required. During 2014−2019 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 2018−2019 personnel from CPW and USFS completed the fifth 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 2018. 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 2019 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 510 km (317 mi) during snow tracking surveys and detected lynx at 6 units (Table 1). This represents a 5-year low in snow tracking effort and is due mostly to the record-setting snows experienced during the 2018–2019 winter. However, the mean distance surveyed per visit as well as the number of units with lynx remained similar to previous years. Surveyors collected more photos during 2018–2019 than in any other year. This was due in part to replacing snow tracking units with camera units in recent years, but mostly because many cameras were not retrieved until late summer or fall 2019 due to access issues related to the heavy snow pack. For the second year in a row we collected <50% of the number of lynx photos collected during the initial years of the monitoring effort, although the number of units with lynx returned to 'normal' after last year's low (Table 2). Perhaps the abnormal snow patterns during the past few years (lack of snow in 2017–18, record snow in 2018–19) impacted our detection probability. Alternatively, 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 2017–2018 and 2018–19 after the lure we used previously (Pikauba; Luerres Forget's Lures, http://www.leurresforget.com/product.php?id_product=15) became unavailable. Unfortunately, the changes in snow and lure are confounded, thus making it difficult to determine which factor resulted in fewer detections. We will use the same new lure in 2019–2020, which if accompanied by a normal snowfall, may allow us to retrospectively assess the lack of detections. Compared to previous years, we obtained new lynx detections at a camera unit near Table Mountain northwest of Creede and one north of Lemon Reservior. Also, we detected lynx again for only the second season at a unit west of Trujillo Meadows, near the New Mexico border. However, we failed to detect lynx in two units near Silverton that have had detections each winter since the inception of monitoring (Figure 1). Potential tracks were observed in each of these, but conditions were such that they could not be confirmed. An adult female with kittens was detected at cameras in a unit near Platoro Reservoir, thus documenting that at least some reproduction occurred in the study area.

We used the R (R Development Core Team 2018) package 'RMark' (Laake 2018) to fit standard occupancy models (MacKenzie *et al.* 2006) to our survey data using program MARK (White and Burnham 1999). Thus, we estimated the 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. 'Survey method' and 'year' were treated as group variables so that we could, based on previous work, 1) allow detection probability to vary by survey method, 2) allow for detection probability for 2017–18 and/or 2018–19 to differ from other years due to abnormal snow or new lure, and 3) include 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). We also considered a suite of covariates that could potentially explain variation in occupancy including proportion of the unit that was covered by spruce/fir forest, average years since bark beetle infestation, variability (standard deviation) in 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 as potential competitors). 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 ψ, allowing up to 2 of these covariates at a time, in addition to the covariates on detection. We included data from the pilot study (2010–11) as well as the first five years of monitoring (2014−2019) to maximize sharing of information across surveys.

Since the inception of our monitoring program, the best-fitting model characterized occupancy as a function of 2 covariates: the proportion of the sample unit covered by spruce-fir forest and the number of photos of hares recorded at camera stations (Appendix 1). However, for the 2018–19 sampling year, the best fitting model characterized occupancy as a function of proportion of the sample unit covered by spruce-fir and by the number of cougar photos recorded at camera sites. The association with spruce-fir was positive, indicating that the probability of lynx use increased with more spruce-fir; the association with cougars was negative, indicating that probability of lynx use decreased with more photos of cougars. The second best model included bobcat photos in addition to spruce-fir; again lynx use was negatively associated with increased bobcat photos. Other covariates appeared in top models with spruce-fir, but addition of these covariates did not improve AIC_c scores beyond the model with spruce-fir only (Appendix 1). This phenomenon indicates that these other variables were not informative. Detection probability was relatively high for snow tracking surveys (p = 0.59, SE=0.05), and relatively low for camera surveys (p = 0.22, SE = 0.03) during December–February and April, although detection at cameras increased to 0.39 (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 = 0.03, SE = 0.01 for December–February and April; p = 0.06, SE = 0.03 for breeding season), although it is unclear whether this drop in detection probability was due to abnormal snowpack or the alternate scent lure. We estimated that 31% of the sample units in the San Juan's were occupied by lynx (95% confidence interval: 12–60%)

during 2018–19. Confidence intervals were quite large for the second year in a row, owing to the extra parameter needed to model the "Violator 7 effect and to the low, poorly estimated detection probability that resulted (Figure 2). The spatial distribution of lynx in the San Juans remained largely unchanged (Figure 1).

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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

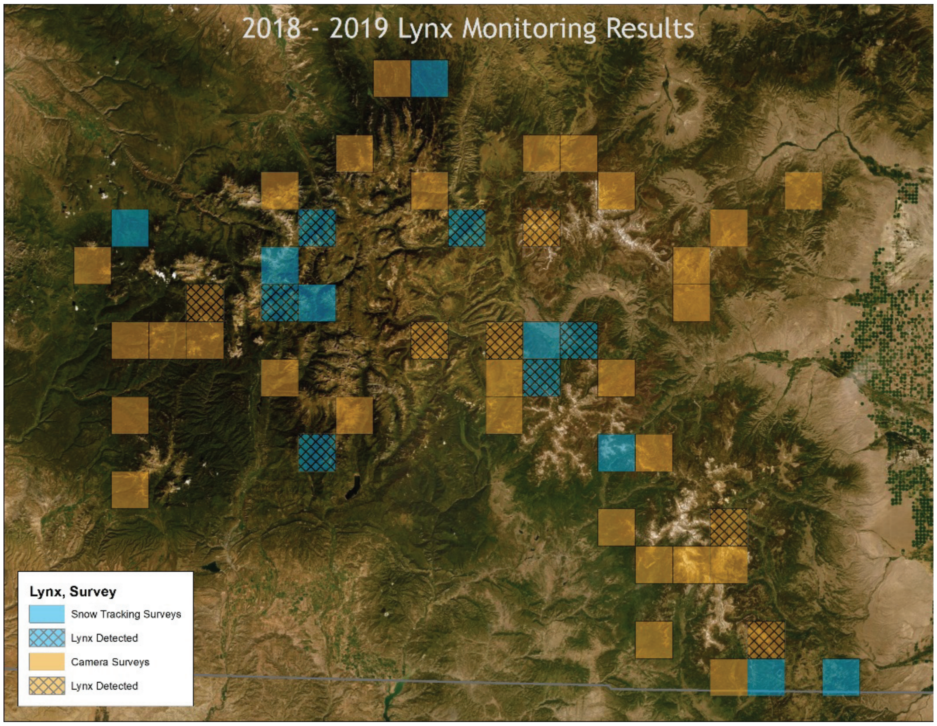
[a] Number of genetic samples (scat or hair) collected via backtracking putative lynx tracks
[b]DNA analysis confirms that all samples collected from putative lynx tracks were lynx
[c]DNA analysis confirms that 6 of 9 samples were lynx (1 coyote, 1 either mule deer or human, 1undetermined)
[d]DNA analyses confirmed that 5 of 7 samples were lynx (1 coyote, 1 snowshoe hare)
[e]DNA confirmation pending

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 (7)	134,694	301	14	46	12
2015–2016	31	7 (6)	101,534	455	10	33	9
2016–2017	33	6 (5)	168,705	251	10	29	9
2017–2018	35	5 (4)	173,279	90	8	35	8
2018–2019	36	7 (5)	204,243	60	10	31	7

[a] Number in parenthesis indicates units with lynx during the official survey period (Dec 1–Apr 30)

a)



b)

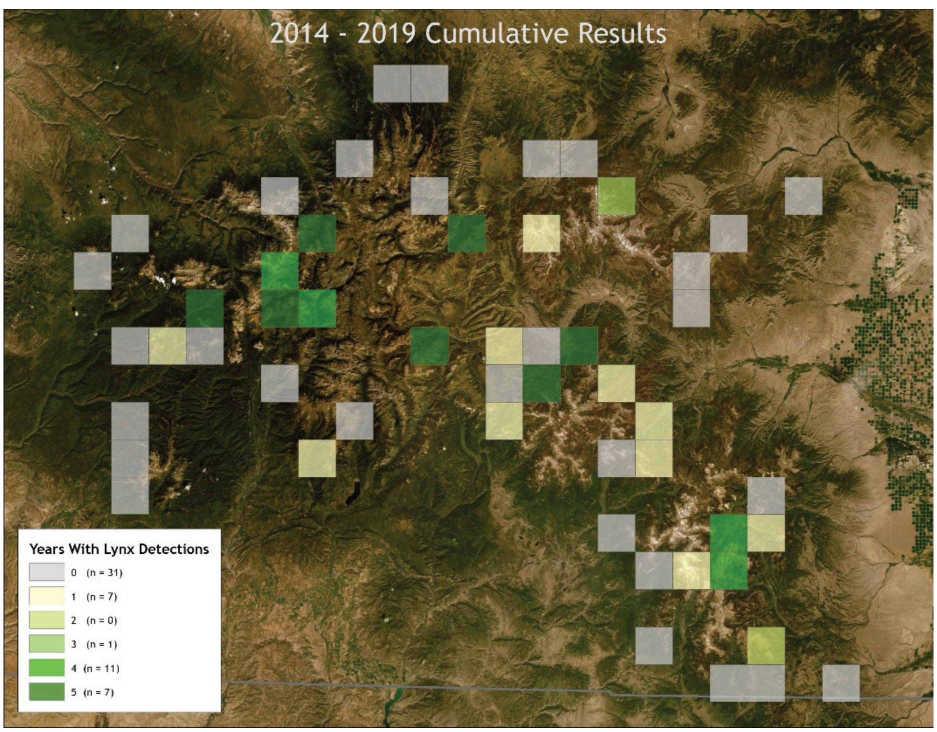


Figure 1. Lynx monitoring results for a) the current sampling season (2018–2019) and b) the cumulative monitoring effort (2014–2019), San Juan Mountains, southwest Colorado. Colored units (n = 50) indicate those selected at random from the population of units (n = 179) encompassing lynx habitat in the San Juan Mountains. Lynx were detected in 12 units in 2018−2019 and 23 units cumulatively since monitoring began in 2014−2015.

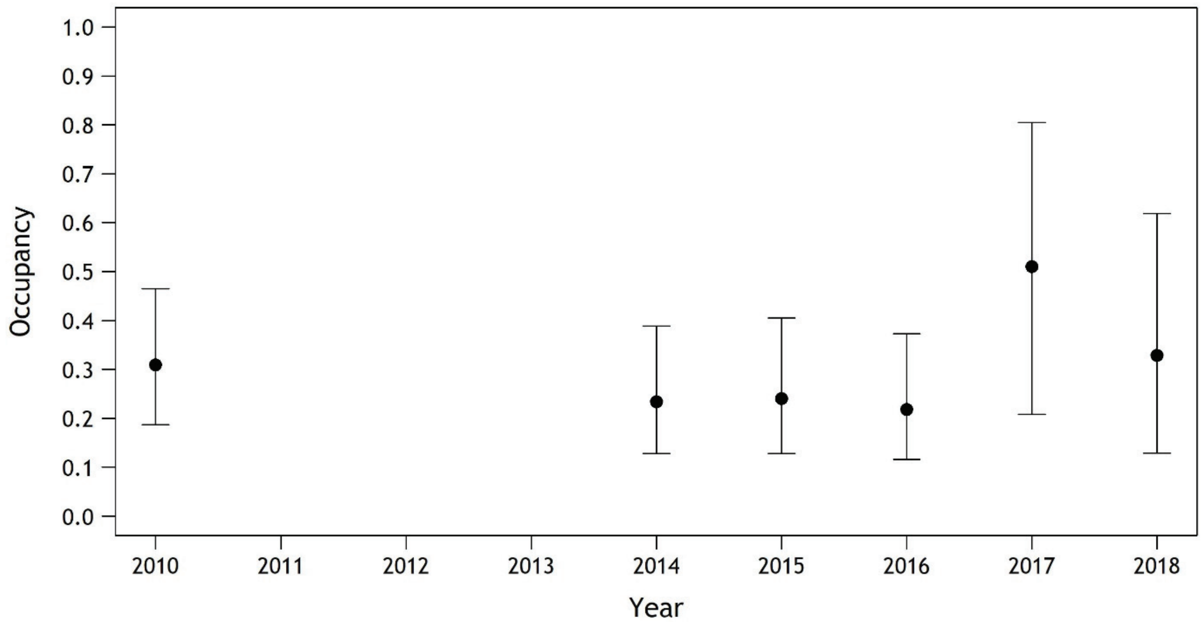


Figure 2. Model-averaged occupancy estimates and 95% confidence intervals for occupancy of Canada lynx in the San Juan Mountains, southwest Colorado. 'Year' indicates when the efforts were initiated (e.g., 2010−11, 2018−19).

Appendix 1. Model selection results for lynx monitoring data collected in the San Juan Mountains, Colorado, 2010–2019. Rankings are based on Akaike's Information Criterion adjusted for small sample size (AIC_c). Ten variables were considered as covariates to inform estimation of occupancy (ψ). The complete model set (n = 56) included all combinations of two, in addition to modeling detection (p) as a function of survey method, breeding season, and alternate lure used during the 2017–18 and 2018–19 seasons. Only the best 10 models are shown.

Model	AIC_c	ΔAIC_c	AIC_c Wts	No. Par.
p(Best[a]) ψ (Cougar + Prop Spruce/Fir)	817.89	0	0.64	12
p(Best) ψ (Bobcat + Prop Spruce/Fir)	820.87	2.98	0.15	12
p(Best) ψ (Prop Spruce/Fir)	822.92	5.03	0.05	11
p(Best) ψ (Prop Burned + Prop Spruce/Fir)	824.14	6.26	0.03	12
p(Best) ψ (Coyote + Prop Spruce/Fir)	824.26	6.38	0.03	12
p(Best) ψ (Years Since Beetles + Prop Spruce/Fir)	824.46	6.57	0.02	12
p(Best) ψ (Fox + Proportion Spruce/Fir)	824.61	6.72	0.02	12
p(Best) ψ (Hare + Proportion Spruce/Fir)	825.03	7.14	0.02	12
p(Best) ψ (Prop Beetle + Prop Spruce/Fir)	825.06	7.17	0.02	12
p(Best) ψ (Variability Beetles + Prop Spruce/Fir)	825.08	7.19	0.02	12

[a]Best-fitting structure for detection probability included effects for survey method, breeding season, and an effect for the 2017–18 and 2018–19 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

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 catetories: 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. Additionally, a handful of stands visited in 2019 and 2020 were re-classified or tossed based on field observations and new stands were sampled in their place by pulling the next one from the spatially balanced list. Currently, then inference is based on n = 130 total stands.

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 and 2020 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. 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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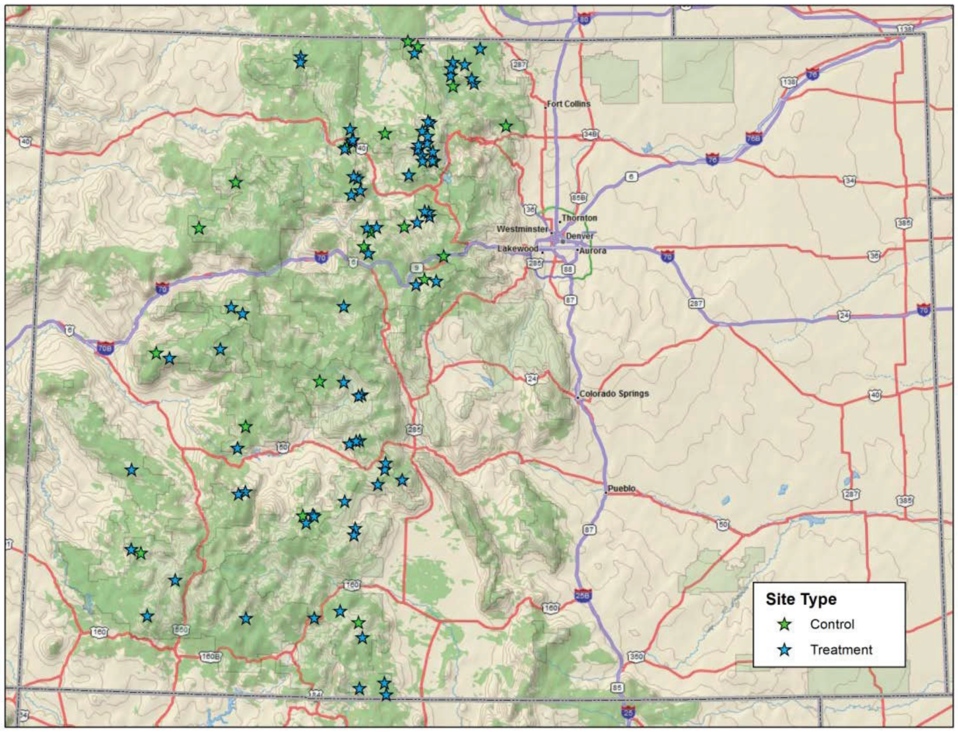

Figure 1. Location of all stands (n = 130) resampled for snowshoe hare pellets, June-September 2020.

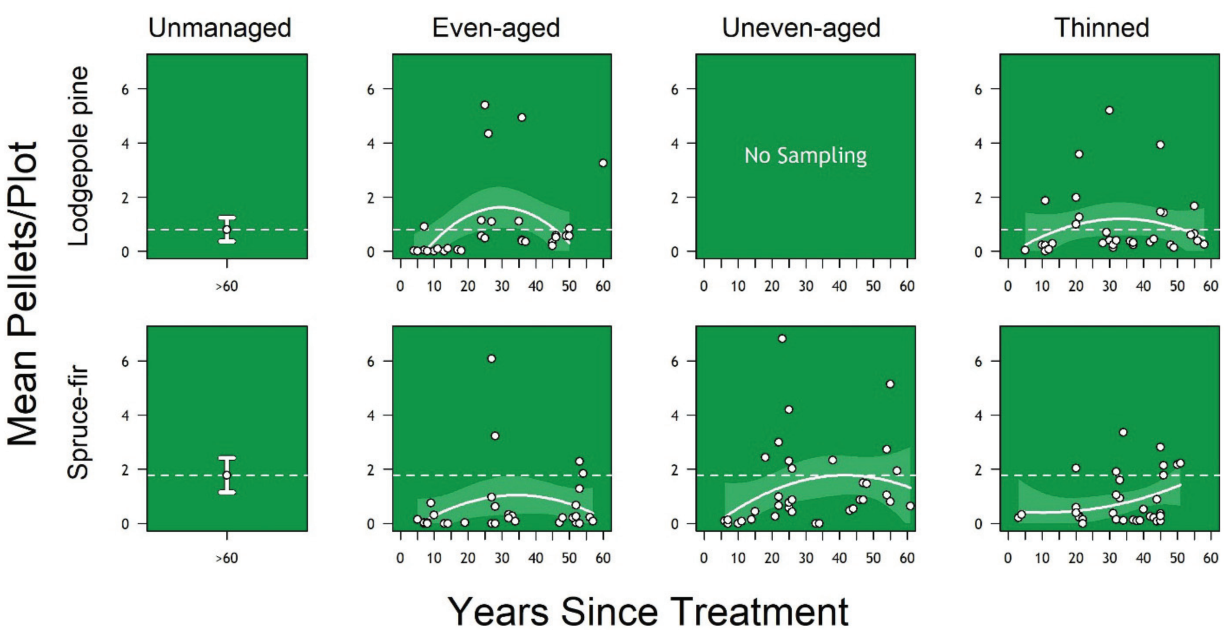

Figure 2. Fitted quadratic function (white line) and 95% CI (shaded polygon) relating pellet counts (i.e., relative snowshoe hare density) to time elapsed since treatment for each forest type × management activity combination. Dotted lines indicate the mean pellets/plot for the unmanaged controls for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

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

EVALUATING FACTORS INFLUENCING ELK RECRUITMENT IN COLORADO

SPATIOTEMPORAL EFFECTS OF HUMAN RECREATION ON ELK BEHAVIOR: AN ASSESSMENT WITHIN CRITICAL TIME STAGES

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, 2019 – June 30, 2020

Author: C. R. Anderson, Jr.

Personnel: D. Bilyeu-Johnston, D. Collins, B. deVergie, D. Finley, L. Gepfert, T. Knowles, B. Petch, J. Rivale, Z. Swennes, M. Way, CPW; L. Belmonte, BLM; 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.

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 (Fig. 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 (Fig. 2) with minor (North Magnolia) and extensive (South Magnolia) energy development, respectively.

During this research segment, we recovered the remaining store-on-board GPS collars from adult female mule deer during spring/summer 2019, completed the final year of measuring vegetation responses of habitat treatments completed spring 2013 and collected camera grid detections of summer/fall herbivore use of habitat treatment and control sites (preliminary results reported in Anderson 2020, Appendix B). Based on final (migration, mule deer behavioral responses, reproductive success and neonate survival; see Anderson 2020, Appendix A for publication abstracts) and preliminary data analyses (vegetation and herbivore response to habitat treatments, Anderson 2020, Appendix B) 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 (Fig. 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 (Fig. 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 (Fig 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 neonatal survival (March until birth) during 2012 when drought conditions persisted during the third trimester of doe parturition (Fig. 6).

Final results are pending to address vegetation and mule deer responses to assess habitat treatment mitigation options for energy development planning. 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 2020, Appencix 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 2020, Appendix A, and preliminary results describing vegetation and herbivore responses to habitat treatments are reported in Anderson 2020, Appendix B. 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.

Literature Cited:

Anderson, C. R., Jr. 2020. 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.

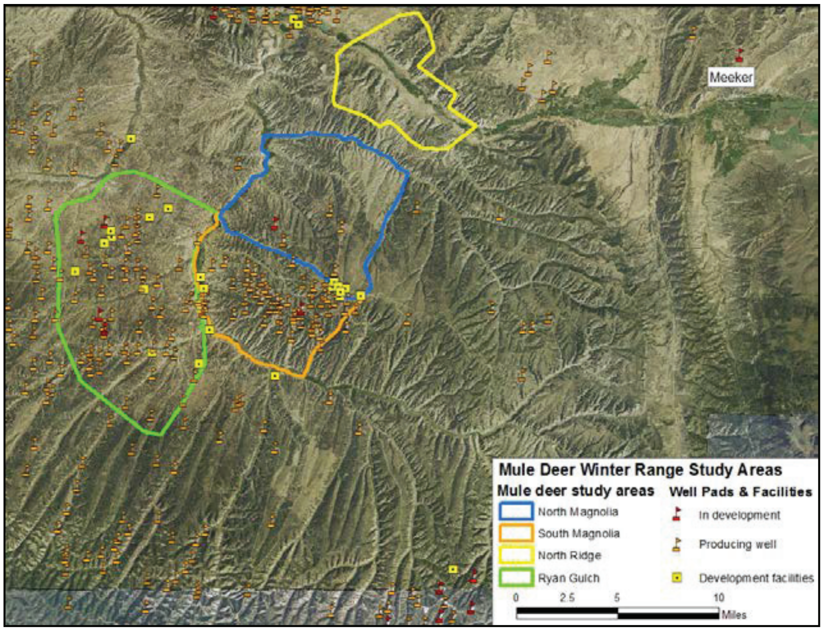

Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, winter 2013/14 (Accessed http://cogcc.state.co.us/ December 31, 2013; energy development activity has been minor since 2013).

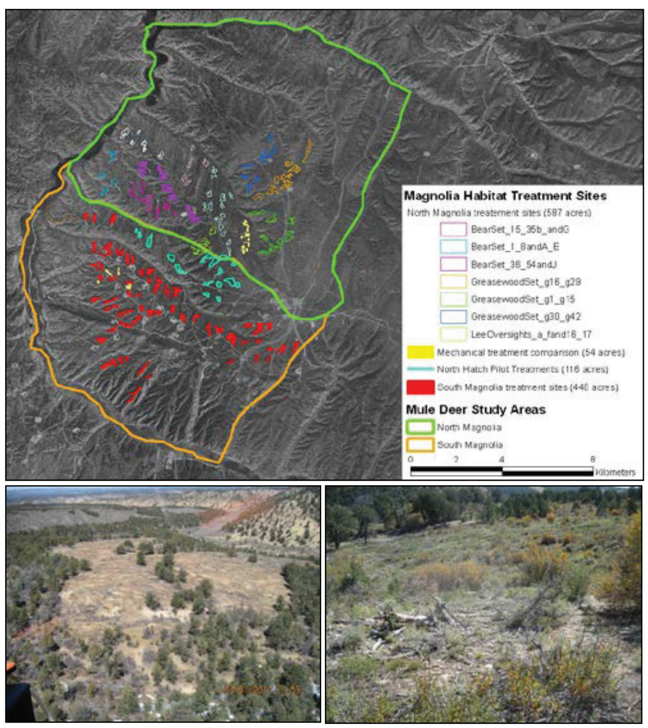

Figure 2. Habitat treatment site delineations in 2 mule deer study areas (604 acres each) of the Piceance Basin, northwest Colorado (Top; cyan polygons completed Jan 2011 using hydro-axe; yellow polygons completed Jan 2012 using hydro-axe, roller-chop, and chaining; and remaining polygons completed Apr 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).

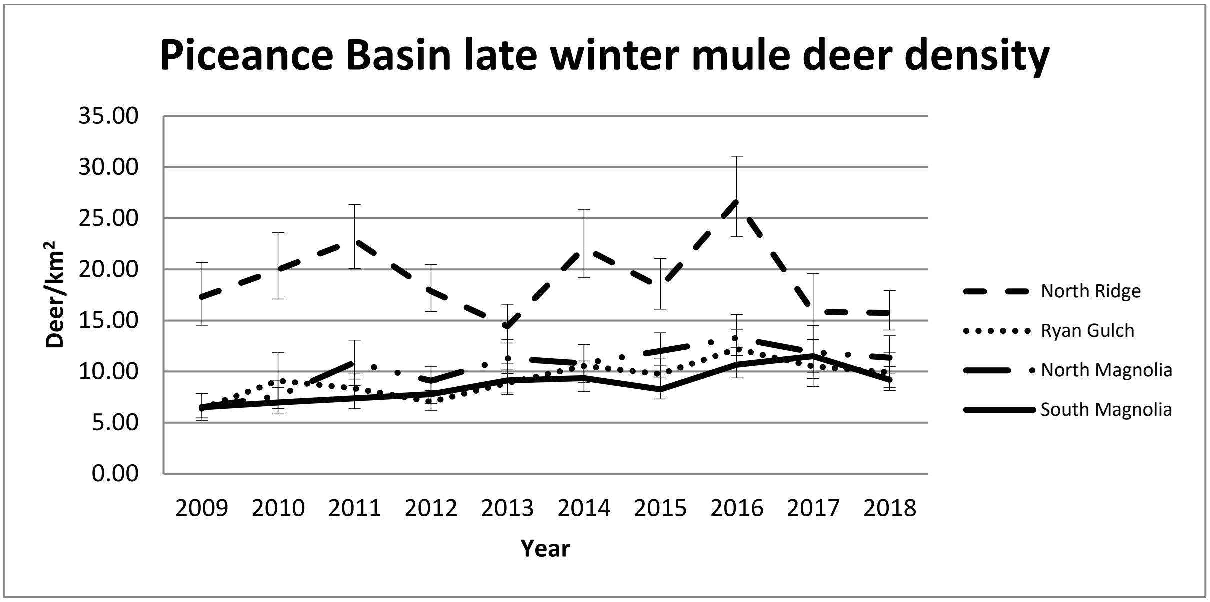

Figure 3. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009–2018.

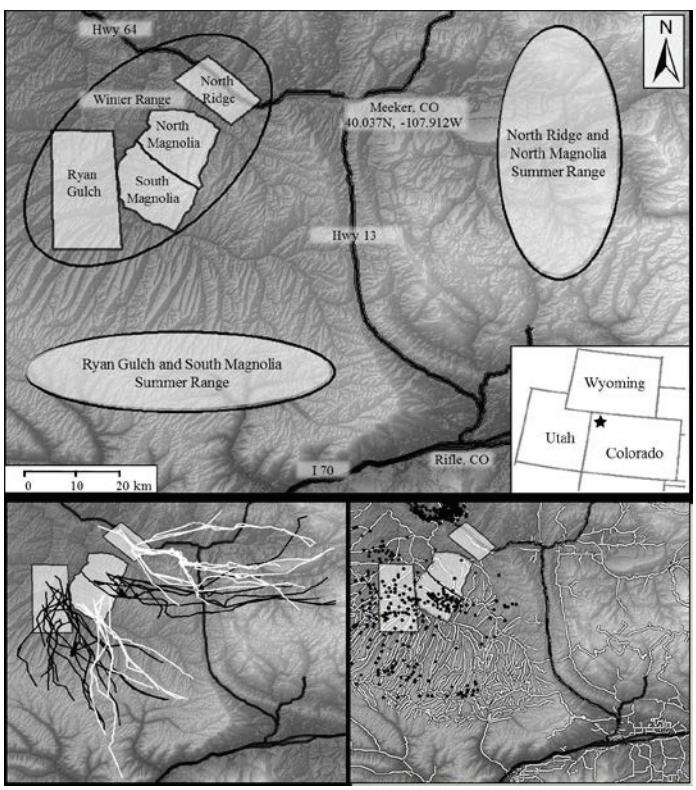

Figure 4. Mule deer study areas in the Piceance Basin of northwestern Colorado, USA (Top), spring 2009 migration routes of adult female mule deer (n = 52; Lower left), and active natural-gas well pads (black dots) and roads (state, county, and natural-gas; white lines) from May 2009 (Lower right; from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

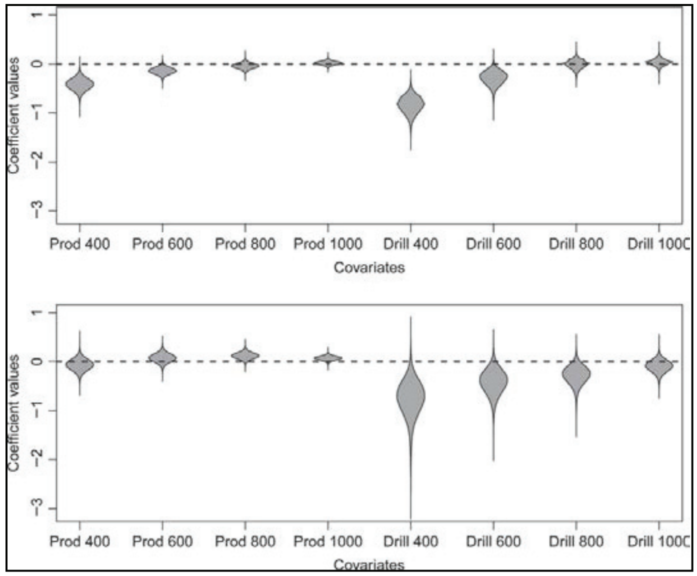

Figure 5. Posterior distributions of population-level coefficients related to natural gas development for RSF models during the day (top) and night (bottom) for 53 adult female mule deer in the Piceance Basin, northwest Colorado. Dashed line indicates 0 selection or avoidance (below the line) of the 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).

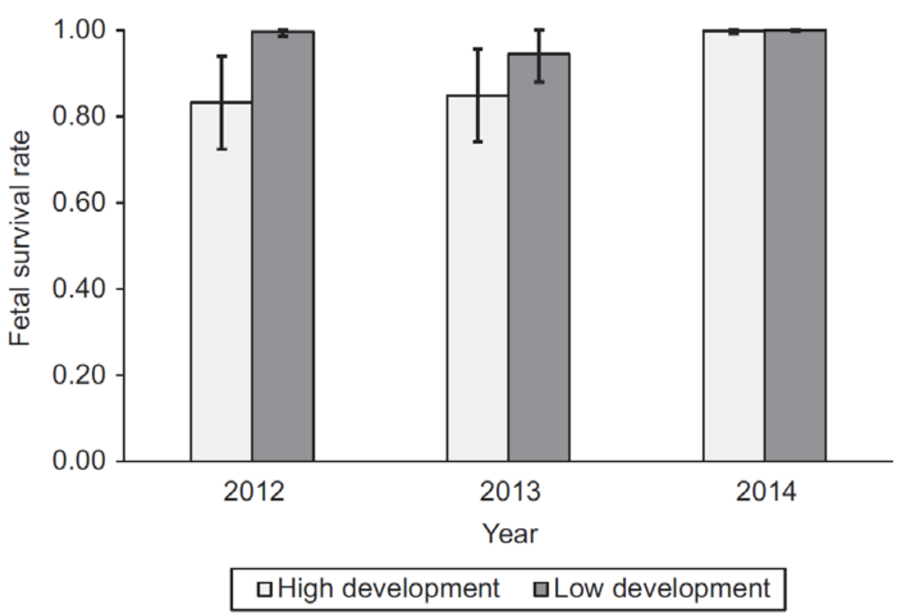

Figure 6. Model averaged estimates of mule deer fetal survival from early March until birth (late May–June) in high and low energy development study areas of the Piceance Basin, northwest Colorado, 2012–2014 (from Peterson et al. 2017; http://www.bioone.org/doi/pdf/10.2981/wlb.00341).

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

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

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

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

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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). 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. A primary objective during all years of this project was 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. Individual animals were recaptured to meet 2 objectives. First, most animals were fitted with GPS collars that have limited battery life. Recapture of individuals allowed replacement of older collars with newer collars that had longer battery life. The second objective was to establish a longitudinal data set that will allow us to determine long-term productivity of individual animals. In particular, repeated measurements of individuals will allow us to evaluate if different reproductive strategies occur within moose, and if those strategies can be linked to annual variation within individual condition. Over the course of this study, we observed that the probability of moose being pregnant was best predicted by considering maximum loin depth. Regional and annual effects in pregnancy rates are yet to be evaluated. Survival of radio collared animals was high in all study areas (85%–96%). Pregnancy rates were similar between areas (70% in NW Colorado, 60% in NE Colorado), but a high degree of annual variability was observed and strong inference was limited by samples size. Over the course of this study, calf-at-heel estimates at the time of capture have average 0.55.

Beginning during the summer of 2017 and continuing through the summer of 2019, vegetation sampling occurred in NW and NE Colorado. These efforts were directed at: 1) identifying willow community diversity at known moose locations, 2) determining if moose demonstrate preference among willow species while browsing, and 3) to determine the nutritional quality of willows throughout the summer period. Ultimately, these data showed a direct correlation between the probability that a cow moose was observed with a calf and the total amount of willow in the cow's home range. A similar correlation was not observed for any specific species of willow, nor was there a strong correlation with the dry-matter digestibility of willows.

Completed analyses of data from this project initially focused on quantification of detection probabilities. More specifically, ground observations used to estimate productivity and calf-at-heel rates are prone to observer bias and misclassification. When a cow moose was observed without a calf, there was some possibility that a calf was present but obscured from the observer's view. Relying on repeated observations of moose, this detection probability was estimated to be 0.80 (i.e., when a calf was present, it was actually observed 80% of the time). Estimation of this probability was necessary to facilitate an unbiased approximation of parturition timing, but also to minimize bias in future analyses that will focus on moose herd productivity from this study period.

Thus, data collected during this project met expectations. In particular, survival rates were consistently high in all study areas. However, a large degree variation within pregnancy rates was observed, which is intriguing. Despite variant and lower than expected pregnancy rates during the course of this study, observed winter calf-at-heel rates suggest that moose calf survival during the first 6 months of life is high. During FY 20-21, data collected during this study will be analyzed to reconstruct moose population dynamics and to formulate population and harvest management recommendations.

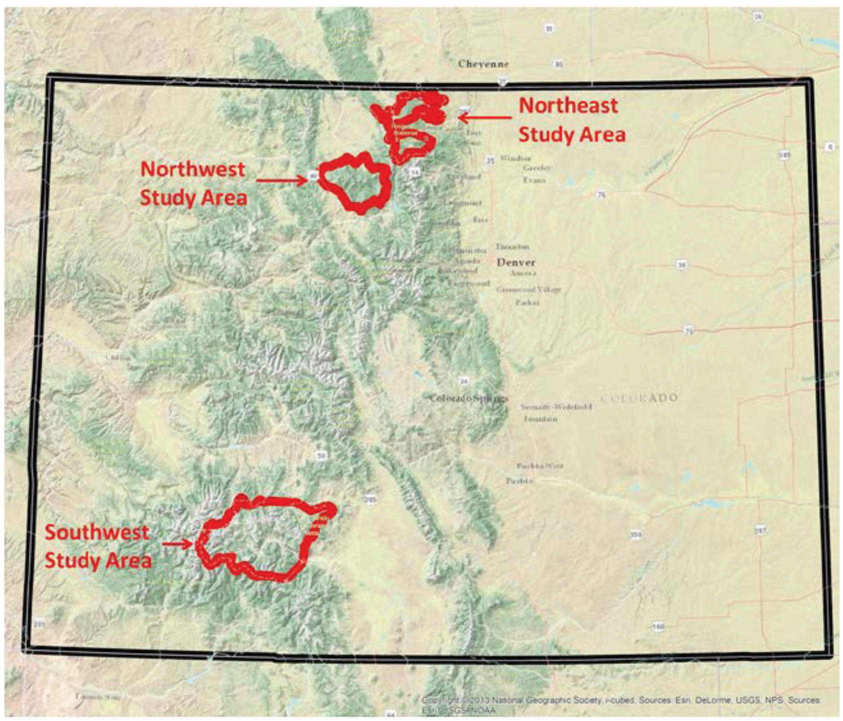

Figure 1. Moose research study areas, located in 3 regions in Colorado. A total of 255 moose were captured during winters between 2013–2014 and 2018–2019.

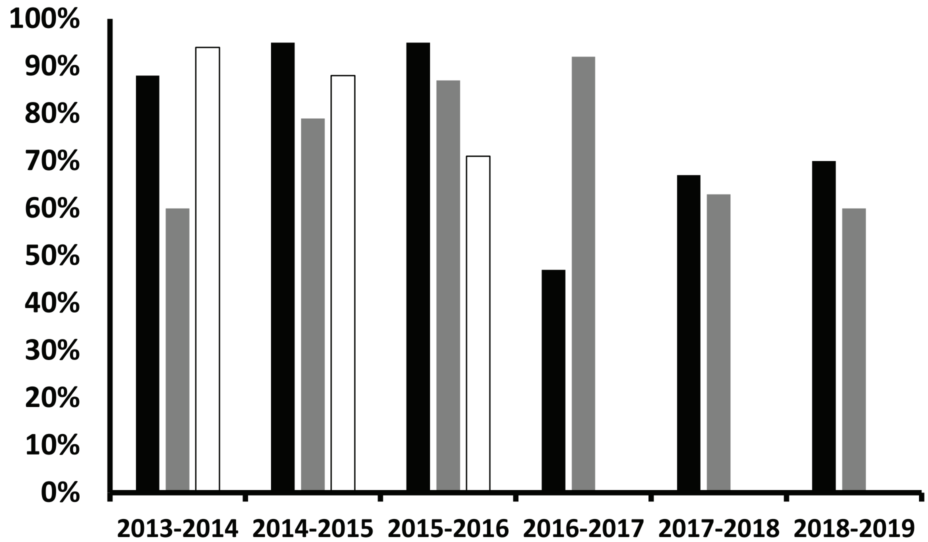

Figure 2. Pregnancy data were collected for all moose at the time of capture. Data from northwest Colorado are depicted by black bars, data from northeast Colorado are depicted by gray bars, and data from southwest Colorado are depicted by white bars. Data from southwest were sparse during 2015–2016 (n = 7 animals) and not collected between 2016–2019. The cause and consequences of the low pregnancy rate observed in northwest Colorado during 2016–2017 were never determined and that was considered to be an outlier event.

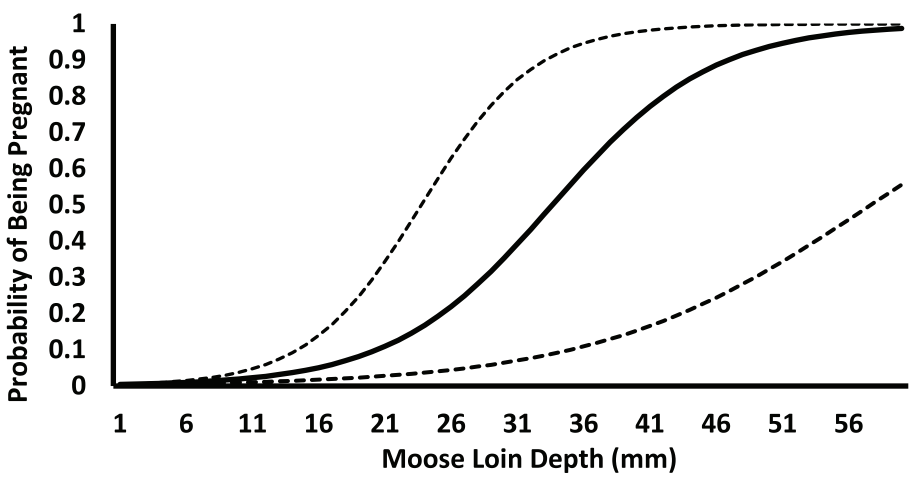

Figure 3. During the course of this study, probability of moose pregnancy has been best predicted by measured loin depth. The relationship between body condition and pregnancy status is reflected by the solid black line and from data collected during the all 5 years of the study (dotted lines represent 95% confidence intervals for moose pregnancy probability). 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.

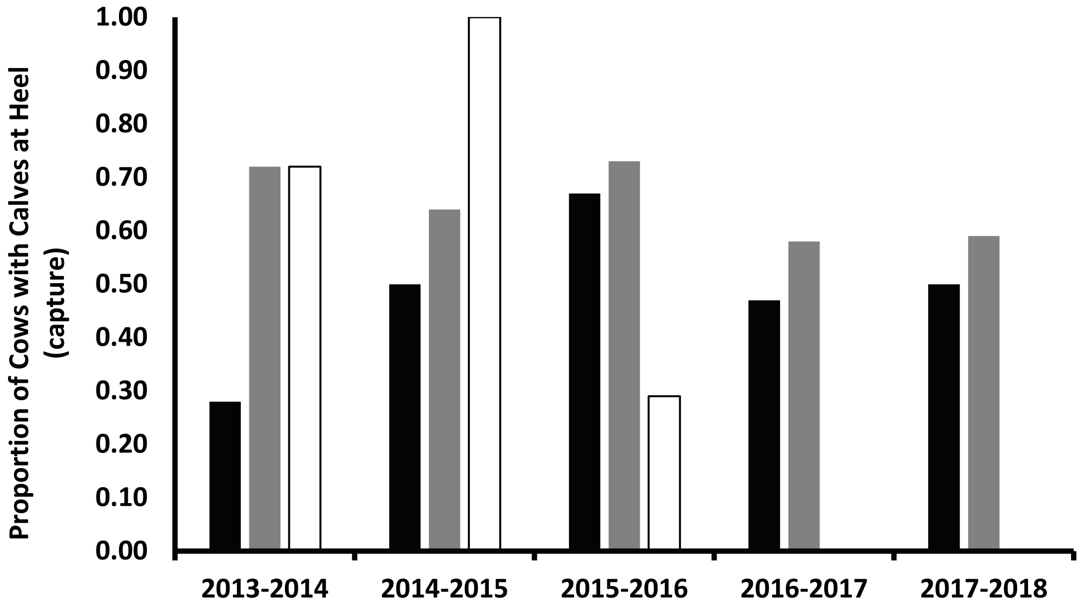

Figure 4. Moose calf-at-heel data were collected for all cow moose at the time of capture. Data from northwest Colorado are depicted by black bars, data from northeast Colorado are depicted by gray bars, and data from southwest Colorado are depicted by white bars. Data from southwest were sparse during 2015–2016 (n = 7 animals) and not collected during 2016–2017 or 2017–2018. Overall, recruitment of moose calves into the winter time period has consistently exceeded 50%. Anecdotal evidence suggests that overwinter survival of moose calves in Colorado is high, thereby lending evidence moose herds are likely stable or increasing despite documented highly variable pregnancy rates.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Evaluating factors influencing elk recruitment in Colorado

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

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, 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. 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, Colorado Parks and Wildlife (CPW) 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 (Fig. 1). In 2019, CPW 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.

During the past year we focused on capturing and collaring elk and working with stakeholders and collaborators on research logistics. Field efforts were centered on 2 objectives: 1) capturing adult female elk, and collaring and outfitting pregnant females with vaginal implant transmitters (VITs) to collect data on elk demography, body condition, reproduction, and behavior, and 2) capturing and collaring newborn and 6-month old elk to collect data on calf survival and cause-specific mortality.

In December 2019, we collared 50 6-month old elk calves, 25 each from the Bear's Ears (DAU E-2) and Uncompahgre Plateau (DAU E-20) elk herds. The mean weight of calves from the Bear's Ears herd was 101.8 kg (224.4 lb) (95% CI = 96.5-107.2 kg [212.7-236.3 lb]) 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.

During March 2020, we captured 113 adult female elk by helicopter net-gunning, 43 from the Bear's Ears herd, 27 from the Trinchera herd (DAU E-33), and 43 from the Uncompahgre Plateau herd. We radio-collared 98 pregnant elk and outfitted them with VITs, 40 each from the Bear's Ears and Uncompahgre Plateau herds, and 18 from the Trinchera herd. Additionally, we collared 1 non-pregnant elk from the Trinchera herd.

In 2020, we estimated that pregnancy rates of adult female elk were 93% in the Bear's Ears and Uncompahgre Plateau herds (both 95% CI = 81-98%; $n = 43$), and 78% in the Trinchera herd (95% CI = 59-89%; $n = 27$; Fig. 2). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90%.

We estimated the mean IFBF of adult female elk to be 6.51% from the Bear's Ears herd, 7.51% from the Trinchera herd, and 7.03% from the Uncompahgre Plateau herd (Fig. 3). 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).

During May-July 2020, we captured and collared 127 elk calves, 54 from the Bear's Ears herd, 21 from the Trinchera herd, and 52 from the Uncompahgre Plateau herd. From the Bear's Ears and Uncompahgre Plateau herds, we successfully captured and collared 90% (35/39) of the calves of adult female elk outfitted with VITs. From the Trinchera herd, we successfully captured and collared 100% (15/15) of the calves of adult female elk outfitted with VITs. 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 (Fig. 4).

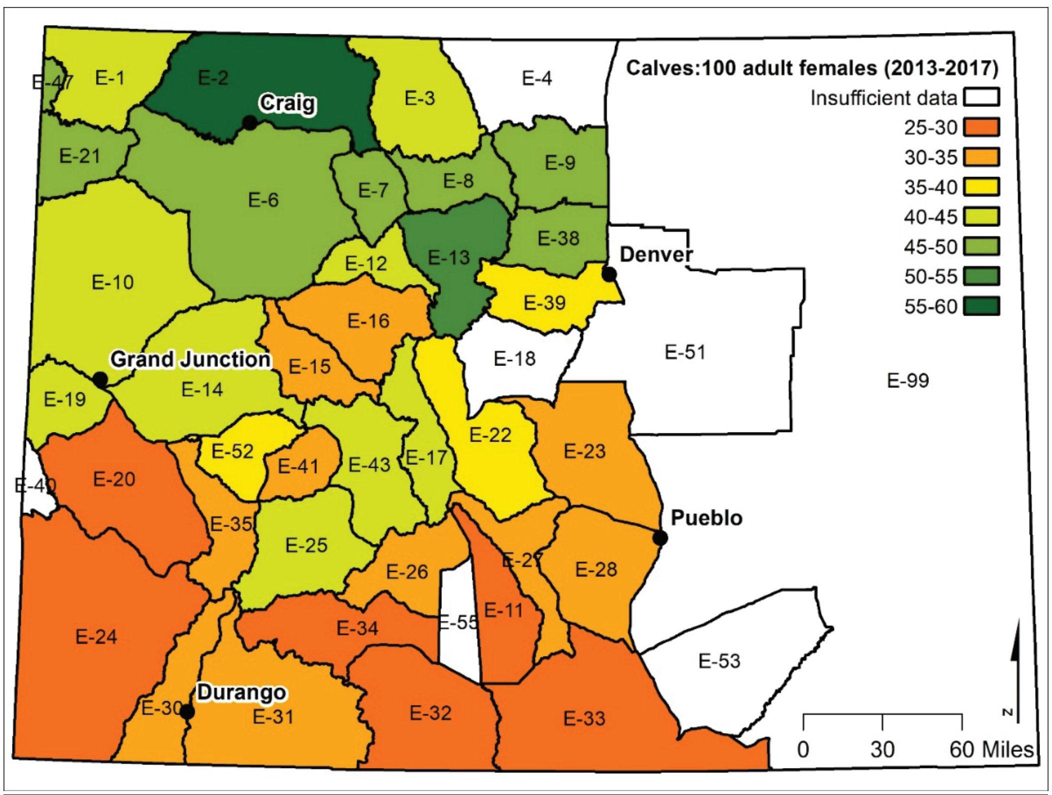

Figure 1. Number of elk calves per 100 adult females observed during December-February aerial surveys (5-year average from 2013-2017) within elk Data Analysis Units (DAUs; labeled with black text) in Colorado, USA.

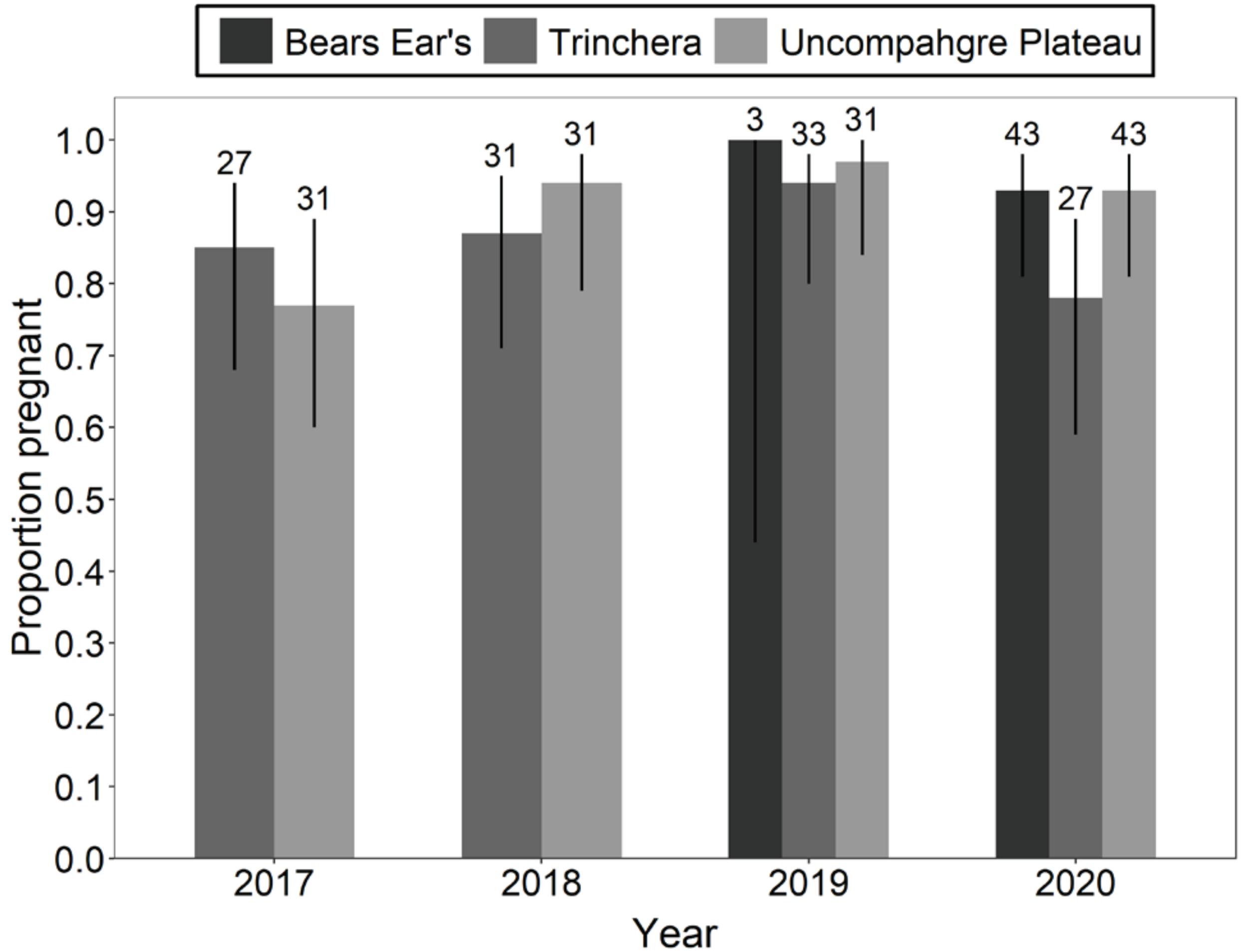

Figure 2. Estimated average pregnancy rates of adult female elk from the Bear's Ears, Trinchera, and Uncompahgre Plateau herds sampled during late winter 2017-2020 in Colorado, USA. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

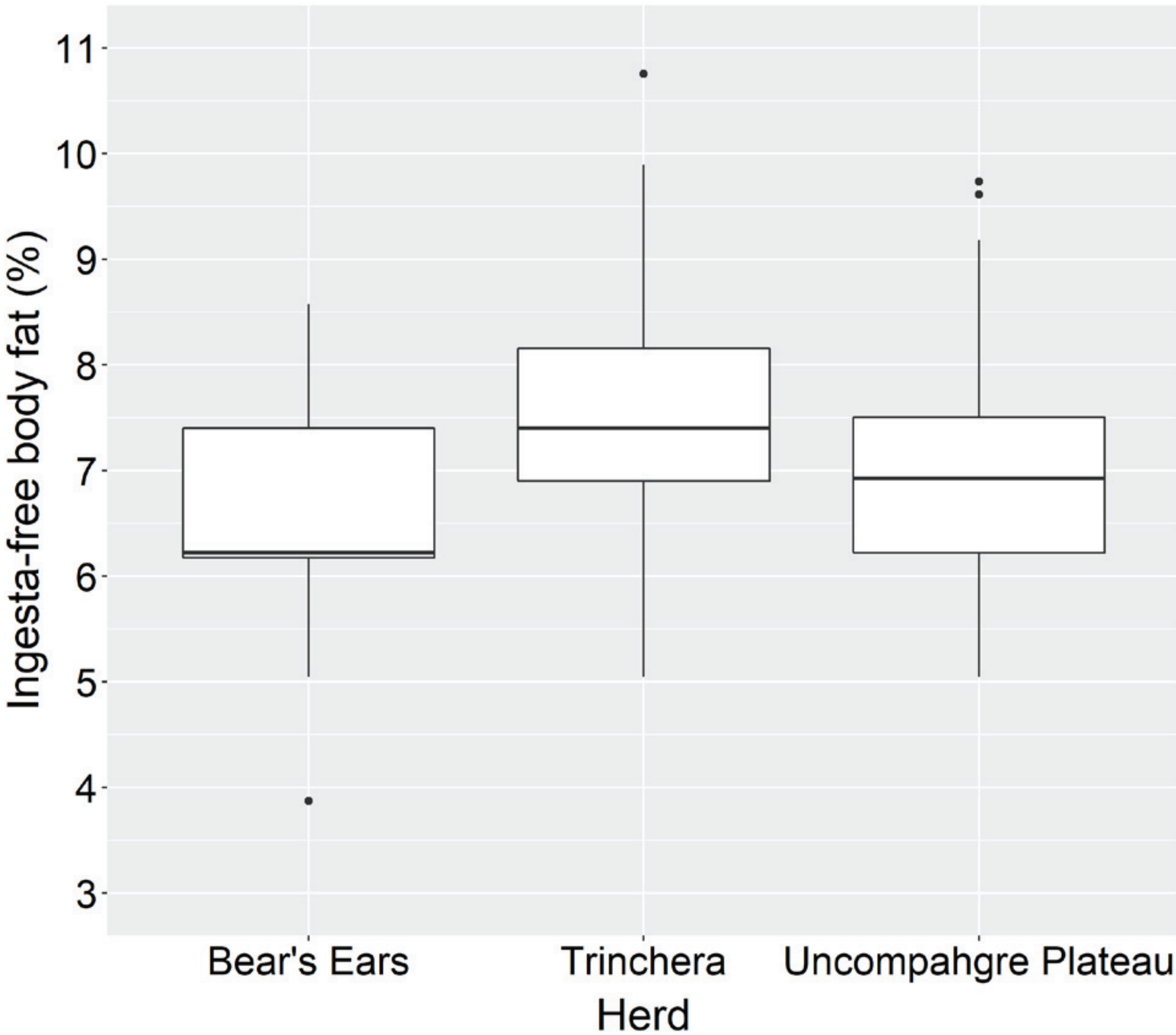

Figure 3. The estimated ingesta-free body fat (%) of adult female elk from the Bear's Ears (n = 43), Trinchera (n = 25), and Uncompahgre Plateau (n = 42) herds during late-winter 2020 in Colorado, USA.

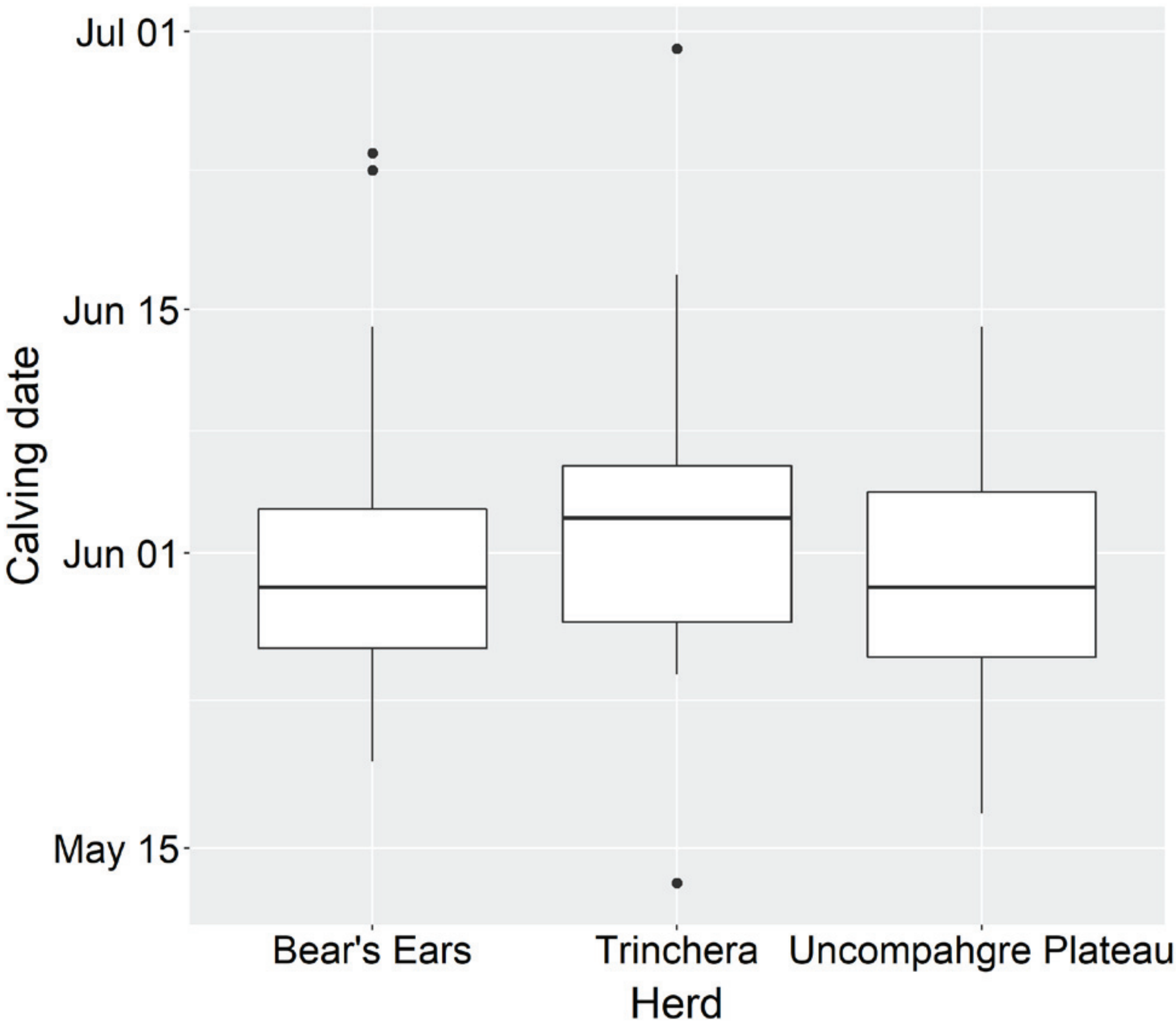

Figure 4. The distribution of calving dates of adult female elk estimated from vaginal implant transmitters (VITs) from the Bear's Ears (n = 39), Trinchera (n = 15), and Uncompahgre Plateau (n = 39) herds during 2020 in Colorado, USA.

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, 2019-June 30, 2020

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 (Fig. 1). 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 will form the basis of an M.S. thesis for a graduate student enrolled at the Haub School.

In January 2020, we collared 30 adult female elk from the resident portion of the Bear's Ears elk herd on U.S. Forest Service (USFS) land near Steamboat Springs. The estimated pregnancy rate was 93% (95% CI: 79-98%). This spring, summer, and fall we will be deploying trail counters and cameras at trailheads in the study area, and handing out GPS units to recreationists to quantify human recreation on the landscape and evaluate how elk respond to recreationists.

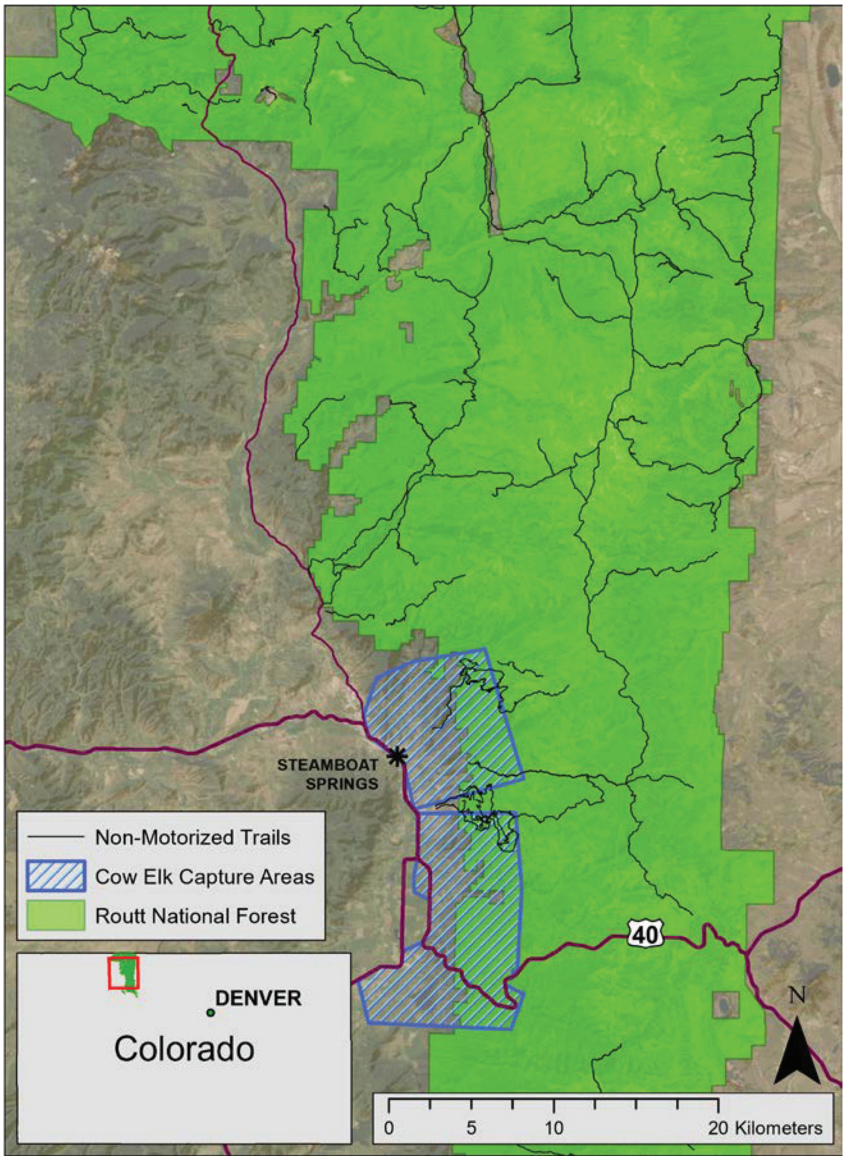

Figure 1. Routt National Forest study area located in northwest Colorado, USA.

SUPPORT SERVICES

RESEARCH LIBRARY ANNUAL REPORT

ANNUAL REPORT

COLORADO PARKS & WILDLIFE RESEARCH LIBRARY

JULY 1, 2019-JUNE 30, 2020

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

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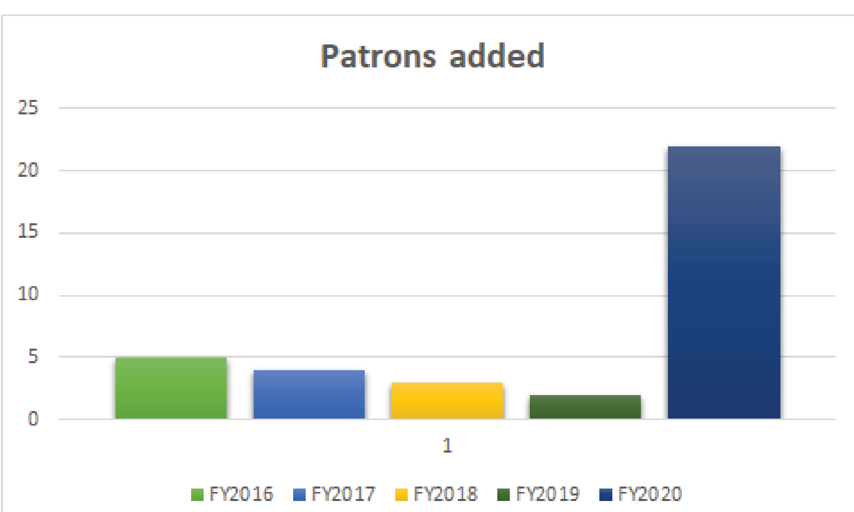
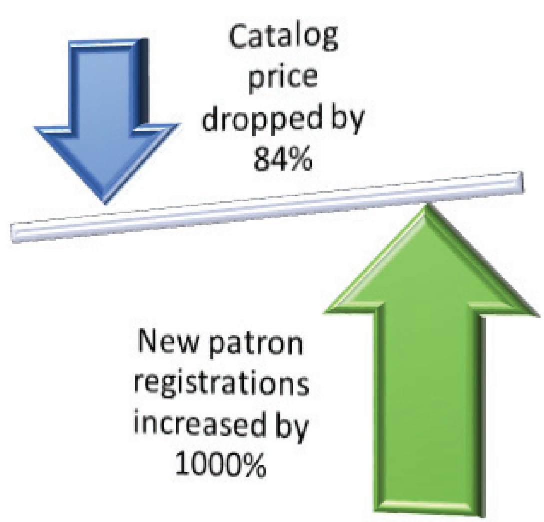
NEW LIBRARY CATALOG

In April, the Library switched to the new library catalog, AspenCat. AspenCat is a union catalog, meaning it is composed of a group of libraries that agree to share resources with each other. AspenCat is significantly cheaper than the old library catalog and offers more benefit to patrons, including the ability to check out e-books and e-audiobooks, from the participating public libraries.





HISTORY

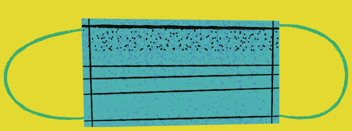
The Library was created in the late 1960s, at the Fort Collins office, to provide support primarily to the wildlife research sections. With the changing needs of CPW, the mission of the Library has expanded to serve all CPW staff regardless of location. The Library is now vital to the science-driven wildlife management work of the agency. The Librarian has become a valued partner in assisting with research and supplying full-text reference resources for the work done by biologists, researchers and wildlife managers across the state.

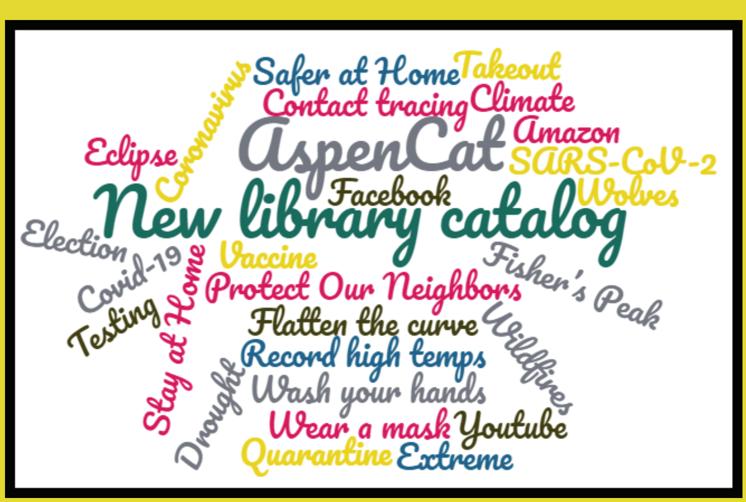
MISSION STATEMENT

The Research Library serves 2 purposes.

1. The library supports wildlife research and management by providing needed information including books and full-text articles.

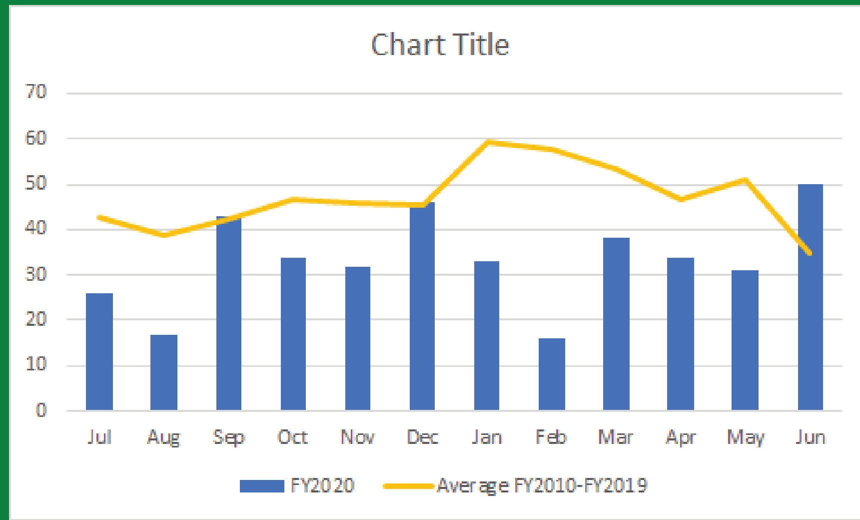
2. The library serves as an institutional repository for documents written by division staff and makes those freely available to the public.





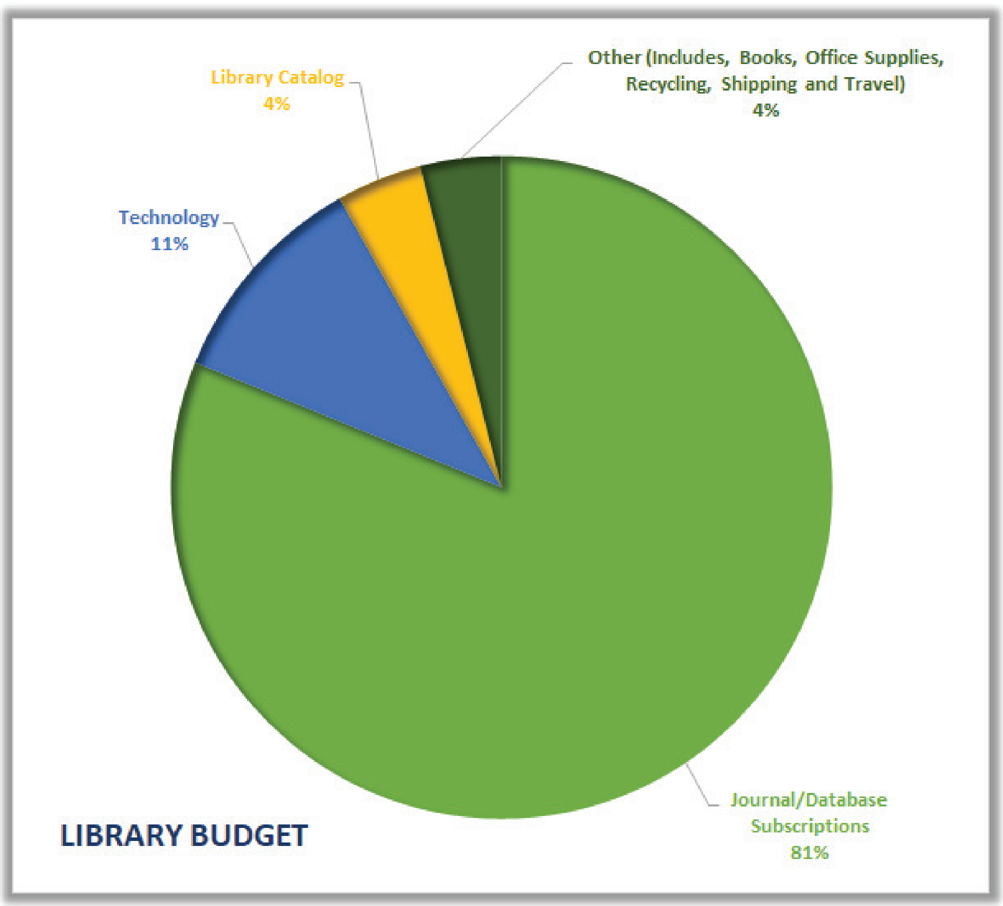
ARTICLES

Requests for articles have remained consistent with years past, despite many people working from home since March. There was a spike in June, but no obvious cause.



BUDGET

Journal and database subscriptions remain the bulk of the library budget. The library catalog fell from 20% of the budget in FY2019 to 4% in FY2020.

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APPENDIX A. CPW mammal research abstracts published July 2019 – November 2020.

NONGAME MAMMAL ECOLOGY AND CONSERVATION

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
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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

Wolverine Occupancy, Spatial Distribution, and Monitoring Design

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ABSTRACT In the western United States, wolverines (*Gulo gulo*) typically occupy high-elevation habitats. Because wolverine populations occur in vast, remote areas across multiple states, biologists have an imperfect understanding of this species' current distribution and population status. The historical extirpation of the wolverine, a subsequent period of recovery, and the lack of a coordinated monitoring program in the western United States to determine their current distribution further complicate understanding of their population status. We sought to define the limits to the current distribution, identify potential gaps in distribution, and provide a baseline dataset for future monitoring and analysis of factors contributing to changes in distribution of wolverines across 4 western states. We used remotely triggered camera stations and hair snares to detect wolverines across randomly selected 15-km × 15-km cells in Idaho, Montana, Washington, and Wyoming, USA, during winters 2016 and 2017. We used spatial occupancy models to examine patterns in wolverine distribution. We also examined the influence of proportion of the cell containing predicted wolverine habitat, human-modified land, and green vegetation, and area of the cluster of contiguous sampling cells. We sampled 183 (28.9%) of 633 cells that comprised a suspected wolverine range in these 4 states and we detected wolverines in 59 (32.2%) of these 183 sampled cells. We estimated that 268 cells (42.3%; 95% CI = 182–347) of the 633 cells were used by wolverines. Proportion of the cell containing modeled wolverine habitat was weakly positively correlated with wolverine occupancy, but no other covariates examined were correlated with wolverine occupancy. Occupancy rates (ψ) were highest in the Northern Continental Divide Ecosystem (ψ range = 0.8–1), intermediate in the Cascades and Central Mountains of Idaho (ψ range = 0.4–0.6), and lower in the Greater Yellowstone Ecosystem (ψ range = 0.1–0.3). We provide baseline data for future surveys of wolverine along with a design and protocol to conduct those surveys. Published March 2020

Latitudinal variation in snowshoe hare (*Lepus americanus*) body mass: a test of Bergmann's rule

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Abstract: The relationship between body size and latitude has been the focus of dozens of studies across many species. However, results of testing Bergmann's rule — that organisms in colder climates or at higher latitudes possess larger body sizes — have been inconsistent across studies. We investigated whether snowshoe hares (*Lepus americanus* Erxleben, 1777) follow Bergmann's rule by investigating differences in body mass using data from six published studies and from data of 755 individual hares captured from 10 populations across North America covering 26° of north latitude. We also explored alternative hypotheses related to variation in hare body mass, including winter severity, length of growing season, elevation, and snow depth. We found body mass of hares varied throughout their range, but the drivers of body mass differed based on geographic location. In northern populations, females followed Bergmann's rule, whereas males did not. In northern populations, male mass was related to mean snow depth. In contrast, in southern populations, body mass of both sexes was related to length of the growing season. These differences likely represent variation in the drivers of selection. Specifically, in the north, a large body size is beneficial to conserve heat because of low winter temperatures, whereas in the south, it is likely due to increased food supply associated with longer growing seasons. Published September 2019

Local climate determines vulnerability to camouflage mismatch in snowshoe hares

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ABSTRACT
Aim Phenological mismatches, when life-events become mistimed with optimal environmental conditions, have become increasingly common under climate change. Population-level susceptibility to mismatches depends on how phenology and phenotypic plasticity vary across a species' distributional range. Here, we quantify the environmental drivers of colour moult phenology, phenotypic plasticity, and the extent of phenological mismatch in seasonal camouflage to assess vulnerability to mismatch in a common North American mammal.
Location North America.
Time period 2010–2017.
Major taxa studied Snowshoe hare (*Lepus americanus*).
Results Spatial and temporal variation in moult phenology depended on local climate conditions more so than on latitude. First, hares in colder, snowier areas moulted earlier in the fall and later in the spring. Next, hares exhibited phenotypic plasticity in moult phenology in response to annual variation in temperature and snow duration, especially in the spring. Finally, the occurrence of camouflage mismatch varied in space and time; white hares on dark, snowless background occurred primarily during low-snow years in regions characterized by shallow, short-lasting snowpack.
Major conclusions Long-term climate and annual variation in snow and temperature determine coat colour moult phenology in snowshoe hares. In most areas, climate change leads to shorter snow seasons, but the occurrence of camouflage mismatch varies across the species' range. Our results underscore the population-specific susceptibility to climate change-induced stressors and the necessity to understand this variation to prioritize the populations most vulnerable under global environmental change. Published December 2019

Winter recreation and Canada lynx: reducing conflict through niche partitioning

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ABSTRACT Outdoor recreationists are important advocates for wildlife on public lands. However, balancing potential impacts associated with increased human disturbance with the conservation of sensitive species is a central issue facing ecologists and land managers alike, especially for dispersed winter recreation due to its disproportionate impact to wildlife. We studied how dispersed winter recreation (outside developed ski areas) impacted a reintroduced meso-carnivore, Canada lynx (*Lynx canadensis*), at the southern periphery of the species' range in the southern Rocky Mountains. On a voluntary basis, we distributed global positioning system (GPS) units to winter recreationists and documented 2143 spatial movement tracks of recreationists engaged in motorized and nonmotorized winter sports for a total cumulative distance of 56,000 km from 2010 to 2013. We also deployed GPS radio collars on adult Canada lynx that were resident in the mountainous topography that attracted high levels of dispersed winter recreation. We documented that resource-selection models (RSFs) for Canada lynx were significantly improved when selection patterns of winter recreationists were included in best-performing models. Canada lynx and winter recreationists partitioned environmental gradients in ways that reduced the potential for recreation-related disturbance. Although the inclusion of recreation improved the RSF model for Canada lynx, environmental covariates explained most variation in resource use. The environmental gradients that most separated areas selected by Canada lynx from those used by recreationists were forest canopy closure, road density, and slope.

Canada lynx also exhibited a functional response of increased avoidance of areas selected by motorized winter recreationists (snowmobiling off-trail, hybrid snowmobile) compared with either no functional response (hybrid ski) or selection for (backcountry skiing) areas suitable for nonmotorized winter recreation. We conclude with a discussion of implications associated with providing winter recreation balanced with the conservation of Canada lynx. Published October 2019

CARNIVORE ECOLOGY AND MANAGEMENT

Effects of Hunting on a Puma Population in Colorado

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EXECUTIVE SUMMARY We investigated effects of regulated hunting on a puma (*Puma concolor*) population on the UncompahgrePlateau (UPSA; 2,996 km2) in southwestern Colorado. We examined the hypothesis that an annual harvest rate averaging 15% of the estimated number of independent pumas 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 pumas. Our alternate hypothesis was that an annual harvest rate averaging 15% of the estimated number of independent pumas would result in a declining abundance of independent pumas. Under this hypothesis, we predicted that hunting mortality would be additive, with: 1) no reduction in other causes of mortality, thus overall survival would decline; and neither 2) enhanced reproduction, or 3) enhanced recruitment would fullyccompensate for hunting mortality.

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 puma hunting. We captured and marked pumas on the UPSA and monitored them year-round to examine puma demographics. We estimated abundance of independent pumas using the UPSA each winter during the Colorado puma hunting season from reference year 2 (RY2) to treatment year 5 (TY5) by using the Lincoln-Petersen method. In addition, we surveyed puma hunters to investigate how hunter behavior influenced harvest and the puma population.

We captured and marked 110 and 116 unique pumas in the reference and treatment periods, respectively, during 440 total capture events. Those pumas produced known-fate data for 75 adults, 75 subadults, and 118 cubs, which we used to estimate sex- and life stage-specific survival rates using program MARK. In the reference period, independent pumas using the UPSA more than doubled in abundance and exhibited high survival. Natural mortality was the major cause of death to independent pumas, 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 pumas on the UPSA. Abundance of independent pumas using the UPSA declined 35% after 4 years of hunting. Harvest rates of marked independent pumas with home ranges exclusively on the UPSA, overlapping the UPSA, and on adjacent management units representing the population-scale harvest averaged 22% annually in the same 4 years leading to the population decline. Adult females comprised 21% of the total harvest. Harvest rates from just the UPSA study area during the same period averaged 15%; but, as we note in the manuscript, the UPSA harvest estimate is biased and scale-dependent. The top-ranked adult survival model indicated a period effect interacting with sex best explained variation in survival. Annual adult male survival was higher in the reference period [$\hat{S}$ = 0.96, 95% Confidence Interval (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 survival model showed that female subadult survival was constant across the reference and treatment periods ($\hat{S}$ = 0.68, 95% CI = 0.43−0.84), while subadult male survival exhibited the same trend as adult male survival: 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 ($\hat{S}$mother alive = 0.51, 95% CI = 0.35−0.66; $\hat{S}$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, with a 59% decline in their abundance after 3 hunting seasons, and no males >6 years old detected after 2 hunting seasons. Successful puma hunters used dogs, selected primarily males, and harvested pumas in 1−2 median number of days.

Pumas born on the UPSA that survived to subadult stage exhibited traits of both philopatry and dispersal. Local recruitment and immigration contributed to positive population 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 mo., 95% CI = 15.5−21.1; treatment period = 19.4 mo., 95% CI = 16.2−22.6), while 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.

We found that a 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 puma abundance. At this scale total human-caused mortality rate averaged 27% annually. Mortality rates of independent pumas 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 largely added to other causes of mortality, and reproduction and recruitment did not compensate for hunting mortality. Puma hunters exhibited selection for male pumas, reduced male survival, and affected the sex and age structure of the population. We discuss our results in relation to a synthesis of published information on pumas in North America. We recommend how regulated hunting in a source-sink structure can be used to conserve puma populations, provide sustainable puma hunting opportunity, and address puma-human conflicts. Published June 2020

Puma population limitation and regulation: what matters in puma management?

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ABSTRACT Wildlife managers require reliable information on factors that influence animal populations to develop successful management programs, including the puma (*Puma concolor*), in western North America. As puma populations have recovered in recent decades because of restrictions on human-caused mortality, managers need a clear understanding of the factors that limit or regulate puma populations and how those factors might be manipulated to achieve management objectives, including sustaining puma and other wildlife populations, providing hunting opportunity, and reducing puma interactions with people. I synthesized technical literature on puma populations, behavior, and relationships with prey that have contributed to hypotheses on puma population limitation and regulation. Current hypotheses on puma population limitation include the social limitation hypothesis and the food limitation hypothesis. Associated with each of those are 2 hypotheses on puma population regulation: the social regulation hypothesis and the competition regulation hypothesis. I organize the biological and ecological attributes of pumas reported in the literature under these hypotheses. I discuss the validity of these hypotheses based on the limits of the research associated with the hypotheses and the evolutionary processes theoretically underlying them. I review the management predictions as framed by these hypotheses as they pertain to puma hunting, puma-prey relationships, and human-puma interactions. The food limitation and competition regulation hypotheses explain more phenomena associated with puma and likely would guide more successful management outcomes. Featured article November 2019 issue of Journal of Wildlife Management

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Summarizing Colorado's black bear two-strike directive 30 years after inception

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ABSTRACT Colorado Parks and Wildlife implemented a new statewide management policy in 1985 for nuisance black bears (*Ursus americanus*), known today as the 2-strike directive. It allowed wildlife managers to assess the repeatability of nuisance bear behavior after translocating them to quality bear habitat away from human food sources. We evaluated this directive using 30 years (1987–2016) of nuisance black bear capture records. Statewide, 53% of 1,093 bears caught, marked, and moved (1st strike) were never reported again, while 25% were killed for a 2nd strike, and hunters harvested 17%. Subadult males committed 2nd strikes more quickly than adult males and females. Although time between strikes was greatest for adult females (496 days), they had the largest probability of committing a 2nd strike among all cohorts. We found that the number of 1st strike captures, from late summer through fall was greatest during years of poor mast production. We suggest that the 2-strike policy has been an effective management tool for nuisance black bears in Colorado, USA, because of low rates of nuisance behavior following 1st-strike translocation. If a state or local management objective is to increase black bear populations, wildlife managers may increase tolerance of adult bears that have received their 1st strike in years when fall mast crops largely fail because they are less likely to commit a 2nd strike. Lower tolerance of subadult males may be warranted in bad food years, especially in areas where reductions in bear populations are desired, because they tend to repeat nuisance behaviors more quickly than other bears. Published Nov. 2019

Understanding and managing human tolerance for a large carnivore in a residential system

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ABSTRACT Human tolerance for interactions with large carnivores is an important determinant of their persistence on the landscape, yet the relative importance of factors affecting tolerance is not fully understood. Further, the impact of management efforts to alter tolerance has not been adequately assessed. We developed a model containing a comprehensive set of predictors drawn from prior studies and tested it through a longitudinal survey measuring tolerance for black bears (*Ursus americanus*) in the vicinity of Durango, Colorado, USA. Predictors included human-bear conflicts, outcomes of interactions with bears, perceptions of benefits and risks from bears, trust in managers, perceived similarity with the goals of managers, personal control over risks, value orientations toward wildlife, and demographic factors. In addition, we monitored changes in tolerance resulting from a bear-proofing experiment designed to reduce garbage-related conflicts in the community. Residents who perceived greater benefits associated with bears and more positive impacts from bear-related interactions had higher tolerance. Residents who perceived greater risks and more negative impacts and who had greater trust in managers, domination wildlife value orientations, and older age were less tolerant. Conflicts with bears were not an important predictor, supported by our finding that changes in conflicts resulting from our bear-proofing experiment did not affect tolerance. In contrast to conservation approaches that focus primarily on decreasing human-wildlife conflicts, our findings suggest that communication approaches aimed at increasing public tolerance for carnivores could be improved by emphasizing the benefits and positive impacts of living with these species. Published October 2019

Human–Cougar interactions in the wildland–urban interface of Colorado's Front Range

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ABSTRACT As human populations continue to expand across the world, the need to understand and manage wildlife populations within the wildland–urban interface is becoming commonplace. This is especially true for large carnivores as these species are not always tolerated by the public and can pose a risk to human safety. Unfortunately, information on wildlife species within the wildland–urban interface is sparse, and knowledge from wildland ecosystems does not always translate well to human-dominated systems. Across western North America, cougars (*Puma concolor*) are routinely utilizing wildland–urban habitats while human use of these areas for homes and recreation is increasing. From 2007 to 2015, we studied cougar resource selection, human–cougar interaction, and cougar conflict management within the wildland–urban landscape of the northern Front Range in Colorado, USA. Resource selection of cougars within this landscape was typical of cougars in more remote settings but cougar interactions with humans tended to occur in locations cougars typically selected against, especially those in proximity to human structures. Within higher housing density areas, 83% of cougar use occurred at night, suggesting cougars generally avoided human activity by partitioning time. Only 24% of monitored cougars were reported for some type of conflict behavior but 39% of cougars sampled during feeding site investigations of GPS collar data were found to consume domestic prey items. Aversive conditioning was difficult to implement and generally ineffective for altering cougar behaviors but was thought to potentially have long-term benefits of reinforcing fear of humans in cougars within human-dominated areas experiencing little cougar hunting pressure. Cougars are able to exploit wildland–urban landscapes effectively, and conflict is relatively uncommon compared with the proportion of cougar use. Individual characteristics and behaviors of cougars within these areas are highly varied; therefore, conflict management is unique to each situation and should target individual behaviors. The ability of individual cougars to learn to exploit these environments with minimal human–cougar interactions suggests that maintaining older age structures, especially females, and providing a matrix of habitats, including large connected open-space areas, would be beneficial to cougars and effectively reduce the potential for conflict. Published August 2019

UNGULATE ECOLOGY AND MANAGEMENT

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

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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 associatedhuman activity by examining habitat selection patterns of nearly 400 individual adult female mule deer. Concurrently, we assess ed 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.

Estimation of moose parturition dates in Colorado: incorporating imperfect detections

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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

Moose calf detection probabilities: quantification and evaluation of a ground-based survey technique

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

On-animal acoustic monitoring provides insight to ungulate foraging behavior

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ABSTRACT Foraging behavior underpins many ecological processes; however, robust assessments of this behavior for freeranging animals are rare due to limitations to direct observations. We leveraged acoustic monitoring and GPS tracking to assess the factors influencing foraging behavior of mule deer (*Odocoileus hemionus*). We deployed custom-built acoustic collars with GPS radiocollars on mule deer to measure location-specific foraging. We quantified individual bites and steps taken by deer, and quantified two metrics of foraging behavior: the number of bites taken per step and the number of bites taken per unit time, which relate to foraging intensity and efficiency. We fit statistical models to these metrics to examine the individual, environmental, and anthropogenic factors

influencing foraging. Deer in poorer body condition took more bites per step and per minute and foraged for longer irrespective of landscape properties. Other patterns varied seasonally with major changes in deer condition. In December, when deer were in better condition, they took fewer bites per step and more bites per minute. Deer also foraged more intensely and efficiently in areas of greater forage availability and greater movement costs. During March, when deer were in poorer condition, foraging was not influenced by landscape features. Anthropogenic factors weakly structured foraging behavior in December with no relationship in March. Most research on animal foraging is interpreted under the framework of optimal foraging theory. Departures from predictions developed under this framework provide insight to unrecognized factors influencing the evolution of foraging. Our results only conformed to our predictions when deer were in better condition and ecological conditions were declining, suggesting foraging strategies were state-dependent. These results advance our understanding of foraging patterns in wild animals and highlight novel observational approaches for studying animal behavior. Published August 2019

WILDLIFE GENETICS RESEARCH

Urbanization impacts apex predator gene flow but not genetic diversity across an urban-rural divide

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ABSTRACT Apex predators are important indicators of intact natural ecosystems. They are also sensitive to urbanization because they require broad home ranges and extensive contiguous habitat to support their prey base. Pumas (*Puma concolor*) can persist near human developed areas, but urbanization may be detrimental to their movement ecology, population structure, and genetic diversity. To investigate potential effects of urbanization in population connectivity of pumas, we performed a landscape genomics study of 130 pumas on the rural Western Slope and more urbanized Front Range of Colorado, USA. Over 12,000 single nucleotide polymorphisms (SNPs) were genotyped using double-digest, restriction site-associated DNA sequencing (ddRADseq). We investigated patterns of gene flow and genetic diversity, and tested for correlations between key landscape variables and genetic distance to assess the effects of urbanization and other landscape factors on gene flow. Levels of genetic diversity were similar for the Western Slope and Front Range, but effective population sizes were smaller, genetic distances were higher, and there was more admixture in the more urbanized Front Range. Forest cover was strongly positively associated with puma gene flow on the Western Slope, while impervious surfaces restricted gene flow and more open, natural habitats enhanced gene flow on the Front Range. Landscape genomic analyses revealed differences in puma movement and gene flow patterns in rural versus urban settings. Our results highlight the utility of dense, genome-scale markers to document subtle impacts of urbanization on a wide-ranging carnivore living near a large urban center. Published October 2019

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