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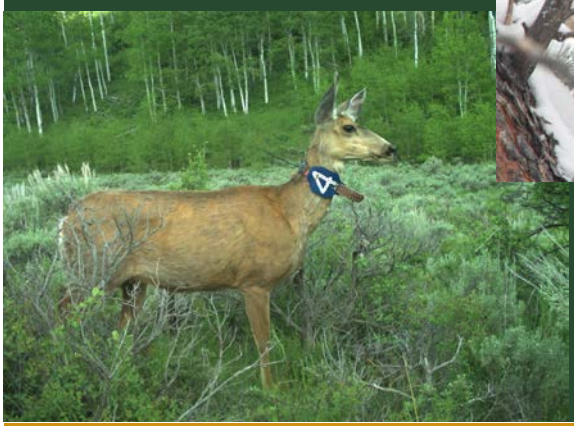
Wildlife Research Reports
MAMMALS – JULY 2019



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Wildlife Research Reports

July 2018 – June 2019

MAMMALS RESEARCH PROGRAM

Research Center, 317 West Prospect, Fort Collins, CO 80526

COLORADO PARKS AND WILDLIFE
RESEARCH POLICY AND PLANNING BRANCH

EXECUTIVE SUMMARY

This Wildlife Research Report represents summaries (≤6 pages each with tables and figures) of wildlife research projects conducted by the Mammals Research Section of Colorado Parks and Wildlife (CPW) from July 2018 through June 2019. 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 and habitat management. The Nongame Mammal Conservation Section addresses preliminary results of a recent project addressing influence of forest management practices on snowshoe hare density in Colorado. The Ungulate and Habitat Conservation Section includes 4 projects addressing mule deer/energy development interactions to inform future development planning, vegetation and animal responses to habitat treatments applied to mitigate energy development activity, evaluation of moose demographic parameters that will inform future moose management in Colorado, and a recent study to identify factors influencing elk calf recruitment. 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 18 publication abstracts (<1 page summaries) completed by CPW mammals research staff since July 2018. These scientific publications provide results from recently completed CPW research projects and other outside collaborations with universities and wildlife management agencies. Topics addressed include mammal responses to beetle-killed forests in Colorado, lynx response to winter recreation, carnivore ecology and management (factors limiting mountain lion populations, lion movements and human interactions along the urban-wildland interface; evaluation of Colorado's 2-strike black bear management directive; assessment of garbage storage and social dynamics associated with black bear management along the urban-wildland interface), ungulate ecology and management (evaluating elk-livestock brucellosis transmission risk, applying acoustic technology to address mule deer foraging behavior, using GPS data to identify mule deer birth sites), remote camera sampling (application to estimate a low density bobcat population, and development of machine learning technology to enhance photo processing time), and genetics and disease research (interpretation of black bear telomere length, virus detection from fecal DNA, and 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, Idaho State University, University of Wisconsin-Madison, Montana State University, 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, GOCO YIP internship program, 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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Eric Bergman, Wildlife Researcher
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TABLE OF CONTENTS
MAMMALS WILDLIFE RESEARCH REPORTS

NONGAME MAMMAL CONSERVATION

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

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, 2018 – June 30, 2019

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 and management response 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 and spruce-fir systems in Colorado.

To select forest stands for sampling, we first used U. S. Forest Service (USFS) spatial data to delineate all spruce-fir and lodgepole pine stands (stratum 1) on USFS land in Colorado, and identified all of the management activities that have occurred in each stand over time. With consultation from the USFS Region 2 Lynx-Silviculture Team, we then grouped relevant forest management activities (stratum 2) into 4 broad categories: even-aged management, uneven-aged management, thinning, and unmanaged controls. We wanted to assess both the immediate and long-term impacts of management on hare densities. Therefore, when selecting stands for sampling, we took the additional step of binning the date of the most recent management activity into 2-decade intervals (i.e., 0-20, 20-40, and 40-60 years before 2018). We then selected a spatially balanced random sample of 5 stands within each combination of forest type × management activity × time interval. This design ensured that we sampled the complete gradient of time since implementation for each management activity of interest in each forest type of interest. There is no notion of "completion date" for unmanaged controls, so we simply sampled 10 randomly selected stands from this combination. Also, uneven-aged lodgepole pine treatments are rare, so we did not sample that combination, leaving a total of $n = 105$ stands sampled (Figure 1).

During summer 2018, we established $n = 50$ 1-m^2 permanent circular plots within each of the $n = 105$ 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 were established. These same plots were re-visited and re-counted during summer 2019. 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, meaning that inference

from future years will be based on 7 stands within each combination, or n = 128 total stands (note that this total also reflects a handful of stands that were re-classified based field observations, along with new stands that were brought into the sample in 2019 to replace those that were reclassed).

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 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. 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, but in spruce-fir systems estimated peak densities approach, but never match, 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, but densities are estimated to slowly recover through time in nearly linear fashion, reaching their maximum 45-55 years after the treatment. As with the even-aged treatment, maximum hare density after thinning in lodgpole systems is estimated to be higher than the control condition, whereas in spruce-fir systems, the maximum hare density matches that of the control sites. Uneven-aged management of spruce-fir forests results in a similar snowshoe hare trajectory as that observed in thinned spruce-fir forests.

Note the two outliers on the right side of the even-aged lodgepole panel. These "high density" sites are represent even-aged lodgepole stands that happen to be surrounded by high quality spruce-fir forest on at least two sides. Thus, the high relative hare density observed at these sites may be due to the quality habitat in adjacent stands rather than by the quality of the sampled stands themselves. While we left them on the figure for transparency, we excluded them when fitting the curve as they appear to be true outliers. Also note that in some cases, 95% CIs are relatively large and overlap the control reference line in some panels. Thus, even though the fitted lines indicate the relationships discussed above, evidence for some of these patterns is moderate or weak. In future years, each panel will include cleared plot data from 6 additional sites, and each site will have data from multiple years (i.e., repeated measures). Both phenomena will greatly improve sample sizes, diminish the role of a few outlying data points, and tighten up our estimate, and corresponding inference, regarding the response of snowshoe hare density to forest management through time.

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Hodges, K. E., and L. S. Mills. 2008. Designing fecal pellet surveys for snowshoe hares. Forest Ecology and Management 256:1918-1926.

Ivan, J. S., and T. M. Shenk. 2016. Winter diet and hunting success of Canada lynx in Colorado. The Journal of Wildlife Management 80:1049-1058.

U.S. Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants: determination of threatened status for the contiguous U. S. distinct population segment of the Canada lynx and related rule, final rule. Federal Register 65:16052–16086.

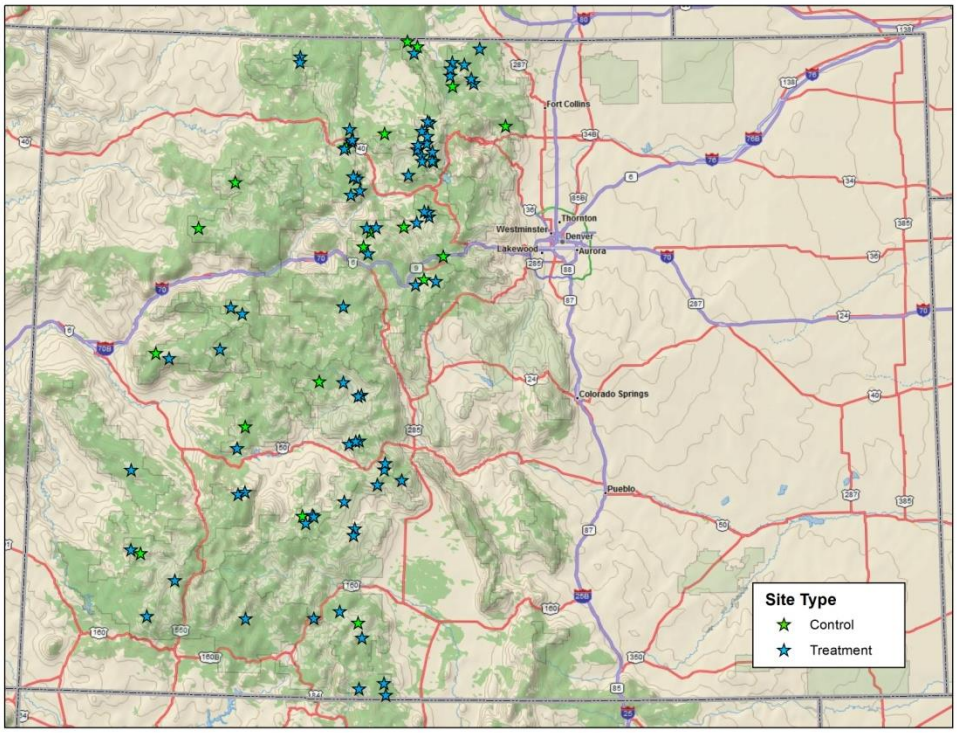

Figure 1. Location of all stands (n = 105) resampled for snowshoe hare pellets, June-September 2019.

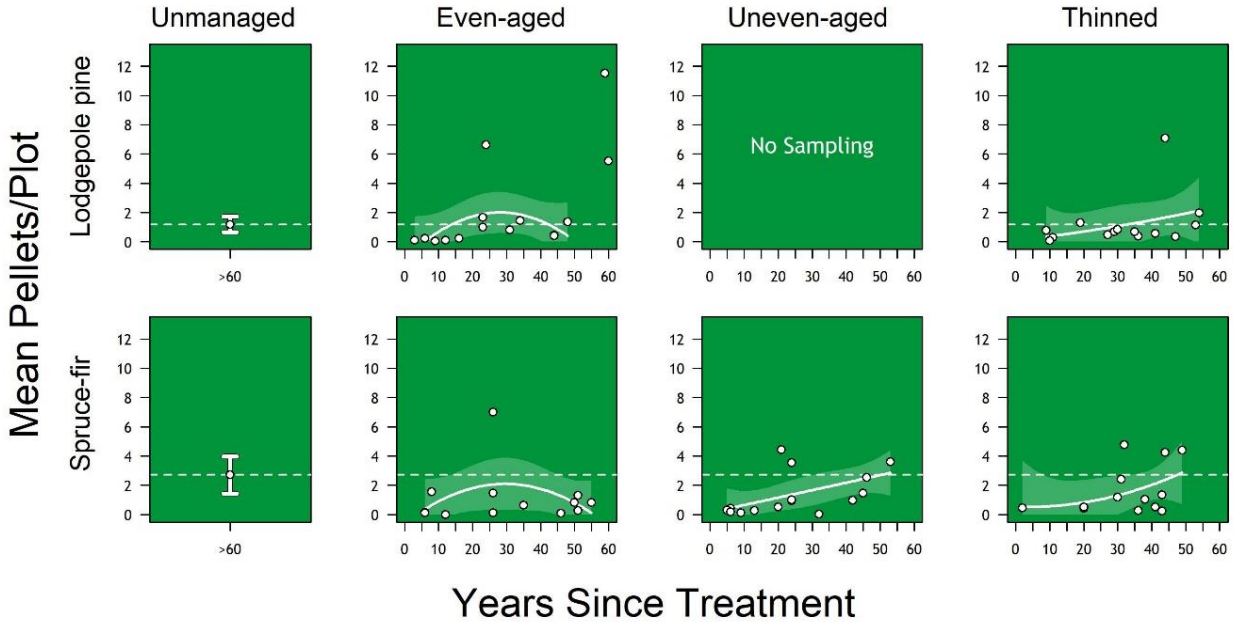

Figure 2. Fitted quadratic function (white line) and 95% CI (shaded polygon) relating pellet counts (i.e., relative snowshoe hare density) to time elapsed since treatment for each forest type × management activity combination. Dotted lines indicate the mean pellets/plot for the unmanaged controls for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

UNGULATE AND HABITAT 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

VEGETATION AND CAMERA DATA TO ACCOMPANY THE STUDY '*Population performance of Piceance Basin mule deer in response to natural gas resource selection and mitigation efforts to address human activity 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

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, 2018–June 30, 2019

Principal Investigator: Charles R. Anderson, Jr., Chuck.Anderson@state.co.us

Collaborators: Colorado Parks and Wildlife, BLM-White River Field Office, Idaho State University, Colorado State University, Federal Aid in Wildlife Restoration, EnCana Corp., ExxonMobil Prod. Co./XTO Energy, Marathon Oil Corp., Shell Petroleum, WPX Energy, Colorado Mule Deer Assn., Muley Fanatic Found., Colorado Mule Deer Found., Colorado State Severance Tax Fund, Boone & Crocket Club, and Safari Club Int.

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 and evaluation of energy development practices intended to improve mule deer fitness in areas exposed to extensive energy development.

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 habitat use and movement patterns, estimated annual neonatal, overwinter fawn and annual adult female survival, estimated annual early and late winter body condition of adult females, and estimated annual 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 removed store-on-board GPS collars from adult female mule deer, addressed mule deer winter concentration areas during a post-drilling production phase, measured vegetation response of habitat treatment sites and established camera grids to address summer/fall use of habitat treatments (see next research summary). Based on final (migration, mule deer behavioral responses, reproductive success and neonate survival) and preliminary data analyses 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, where disturbance distance varied relative to diurnal extent and magnitude of development activity, which may provide for several options in future development planning (Fig 5); 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) 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, and final results addressing the interaction of mule deer behavioral and demographic factors associated with energy development activity have recently been submitted for scientific peer-review and publication. Final data collection addressing GPS collar recovery and summer/fall use of habitat treatment sites will be completed by December 2019. Completion of this project, including data analyses and interpretation of results, is anticipated by fall/winter 2020-21.

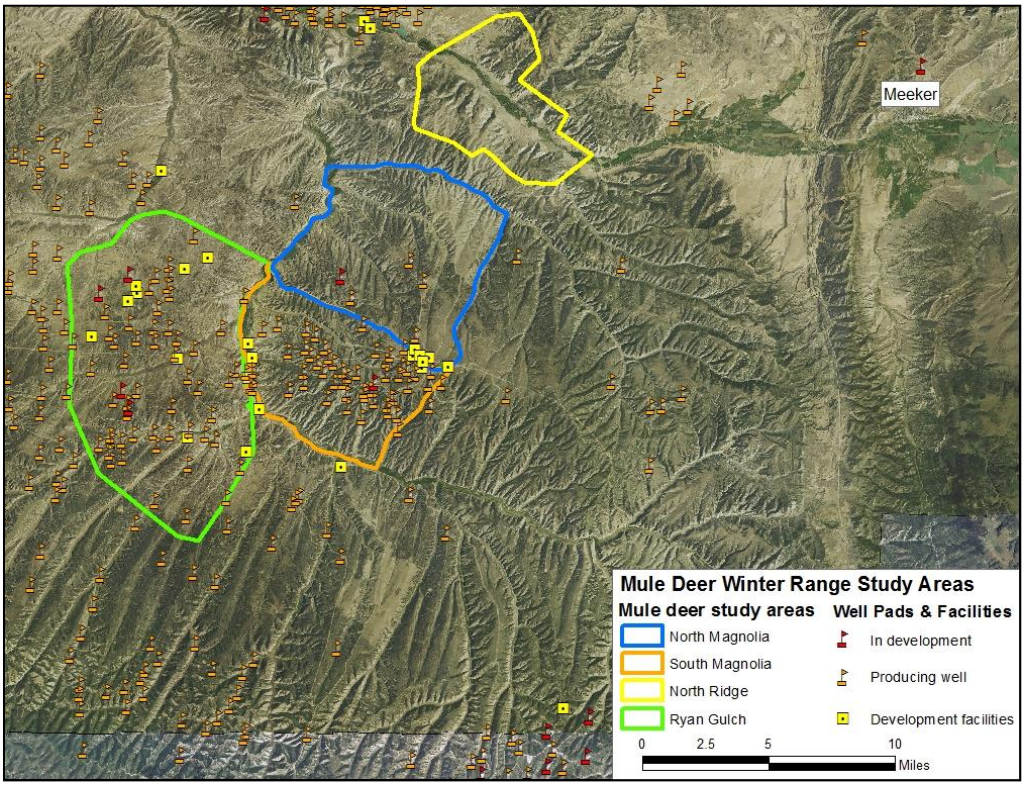

Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, winter 2013/14 (Accessed http://cogcc.state.co.us/ December 31, 2013; energy development activity has been minor since 2013).

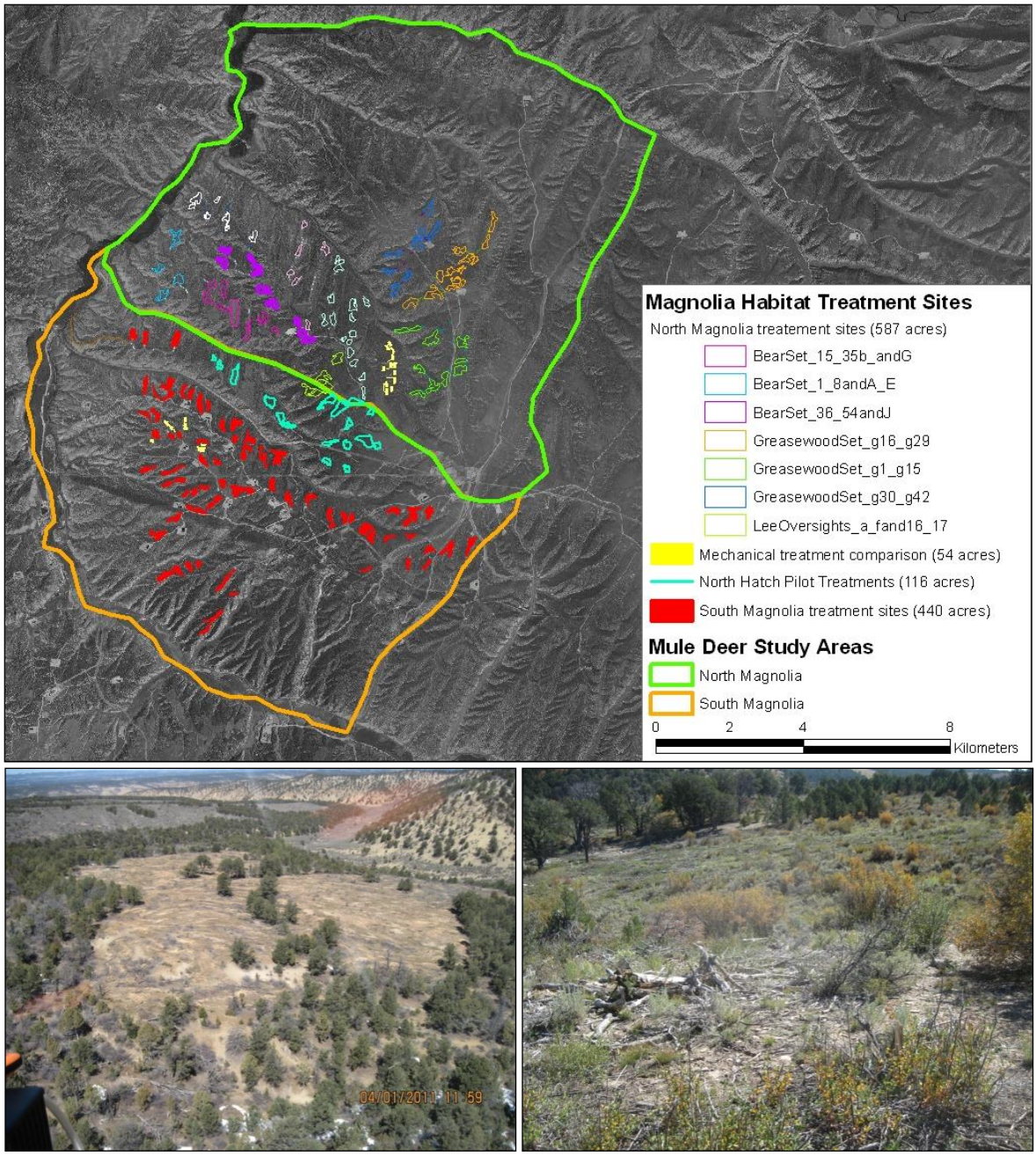

Figure 2. Habitat treatment site delineations in 2 mule deer study areas (604 acres each) of the Piceance Basin, northwest Colorado (Top; cyan polygons completed Jan 2011 using hydro-axe; yellow polygons completed Jan 2012 using hydro-axe, roller-chop, and chaining; and remaining polygons completed Apr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

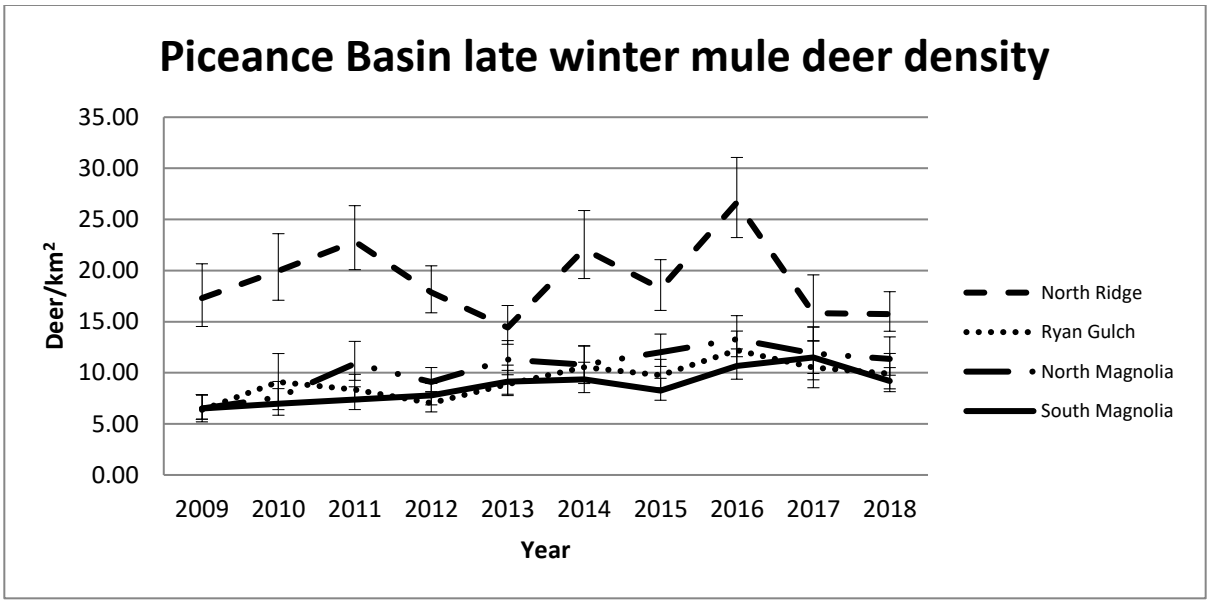

Figure 3. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009–2018.

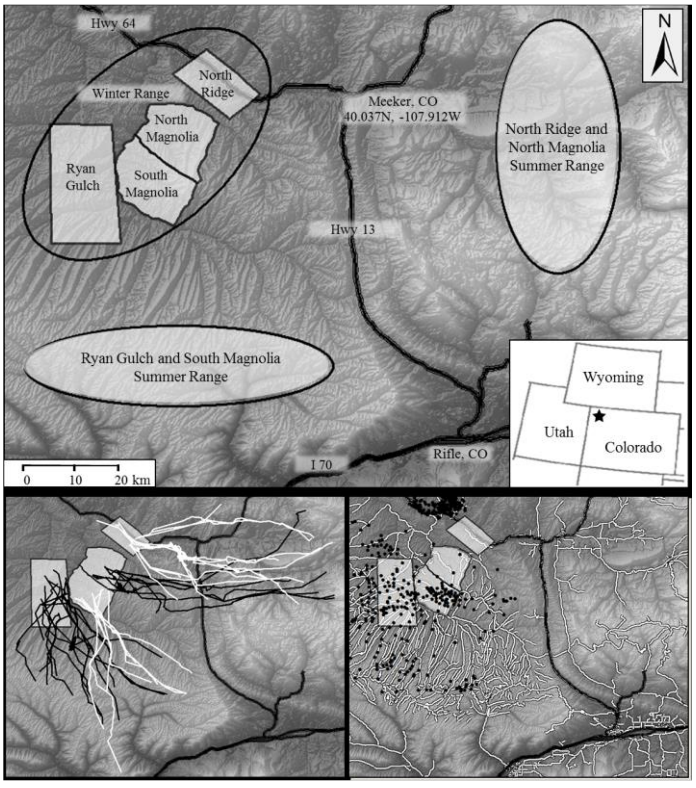

Figure 4. Mule deer study areas in the Piceance Basin of northwestern Colorado, USA (Top), spring 2009 migration routes of adult female mule deer (n = 52; Lower left), and active natural-gas well pads (black dots) and roads (state, county, and natural-gas; white lines) from May 2009 (Lower right; from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

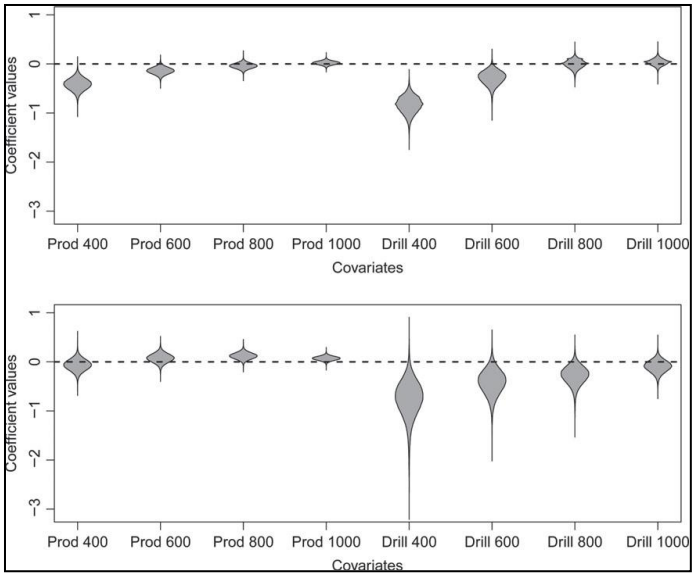

Figure 5. Posterior distributions of population-level coefficients related to natural gas development for RSF models during the day (top) and night (bottom) for 53 adult female mule deer in the Piceance Basin, northwest Colorado. Dashed line indicates 0 selection or avoidance (below the line) of the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

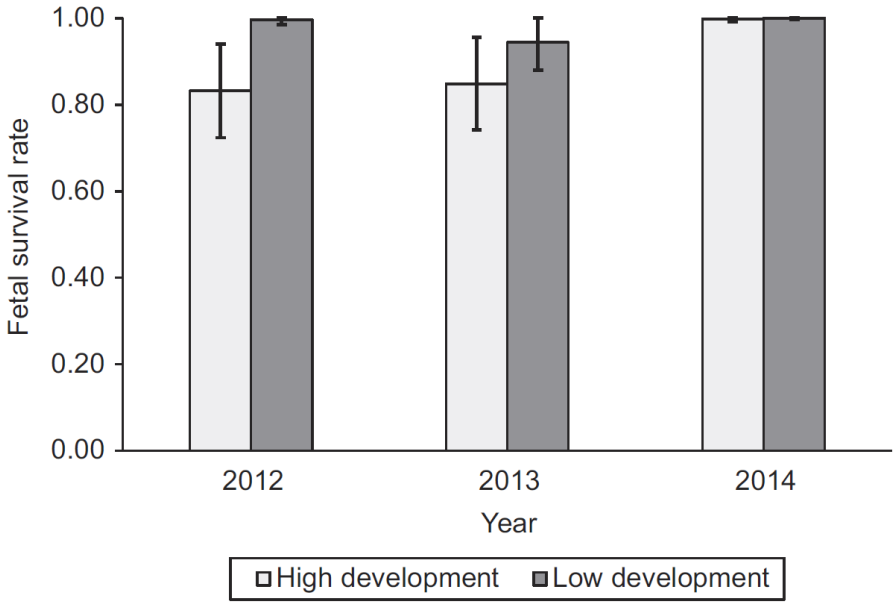

Figure 6. Model averaged estimates of mule deer fetal survival from early March until birth (late May–June) in high and low energy development study areas of the Piceance Basin, northwest Colorado, 2012–2014 (from Peterson et al. 2017; http://www.bioone.org/doi/pdf/10.2981/wlb.00341).

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Vegetation and camera data to accompany the study '*Population performance of Piceance Basin mule deer in response to natural gas resource selection and mitigation efforts to address human activity and habitat degradation'*

Period Covered: July 1, 2012–June 30, 2019

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

Collaborators: Colorado Parks and Wildlife, BLM-White River Field Office, Idaho State University, Colorado State University, Federal Aid in Wildlife Restoration, EnCana Corp., ExxonMobil Prod. Co./XTO Energy, Marathon Oil Corp., Shell Petroleum, WPX Energy, Colorado Mule Deer Assn., Muley Fanatic Found., Colorado Mule Deer Found., Colorado State Severance Tax Fund, Boone & Crocket Club, and Safari Club Int.

In 2011 and 2013, about 1,200 acres of pinyon and juniper (PJ) mastication treatments were completed in the Magnolia region of the Piceance Basin. Treated parcels averaged 7 acres in size, and were intended to increase winter range quality for deer. The treatments were part of a study to evaluate the effectiveness of PJ removal as mitigation for impacts of natural gas development on deer, with outcomes assessed in terms of deer population and demographic parameters. This summary addresses some side questions relevant to the main study, with outcomes assessed in terms of vegetation response and animal use of vegetation treatments.

We were interested in quantifying the understory forage produced by the mastication treatments. We used paired masticated/control point-intercept transects on a subset of parcels (Graham 2013) to quantify cover of plant groups relevant to deer nutrition. We used belt transects and trained ocular estimation, with benchmarks (Johnston 2018), to estimate summer utilization on individual shrubs, then scaled these to the plot level (Bilyeu, Cooper et al. 2007). We used belt transects of shrub canopy measurements, coupled with biomass equations developed for the study area (Johnston 2018) to quantify winter forage production of key browse species. Winter forage production was defined as current-year stems, not including leaves, not including biomass removed by summer browsing, and not including very small stems which would likely be shed prior to winter (Johnston 2018).

We were interested in how summer use of treatments, and use of treatments by non-target animals, impacted winter forage availability. Ten cattle exclosures, distributed broadly throughout the study area (Figure 1), were built within mastication treatments in 2011 and 2013. We assessed plant cover and summer shrub utilization within these using techniques described above. On paired masticated/control transects, we deployed Reconyx Hyperfire cameras July-November 2018-2019. These were programmed to facilitate creating an index of use: 5 pictures per motion trigger, 3 second interval between pictures, a 5 minute wait time between triggers, and a sensitivity setting of High (Rhodes, Larsen et al. 2018). An animal observed with their head down or other indication of foraging in one or more of

the photos in a 5 photo set was counted as one foraging event, and non-foraging occurrences were counted similarly. Sampling efforts by year are given in Table 1.

Because the plant cover data contained many zeros, we modeled presence/absence of each plant group separately from its cover where present (Fletcher, Mackenzie et al. 2005), using the lme4 package in R (Bates 2005). For both analyses, treatment, year, and their interaction were considered fixed effects, year was included as a categorical variable, and pair ID and plot ID were included as random effects. We used a similar approach for camera data for cattle and elk, which also contained many zeros.

In general, grasses responded positively to treatment (Figure 2a). Wheatgrass presence, wheatgrass cover, and needlegrass presence were higher in treated than untreated plots. Poa grass presence was higher in treated plots by 2018, although poa grass presence and cover initially had a negative response to treatment. Cheatgrass presence also responded positively to treatment (Figure 2a). Wheatgrasses, poa species, and cheatgrass all had significant year*treatment interactions for either presence or cover. Interannual variation in cover was greater in masticated plots than in control plots for these species groups (Figure 2a). Forbs responded positively to treatment. Annual forb and perennial forb presence were higher in treated than untreated plots (Figure 2b).

Some shrubs responded positively to treatment, while others did not. Snowberry cover was lower in treated plots in 2013, but in 2016 and 2018, cover was higher in treated plots (Figure 2c). Variation in snowberry cover was greater in masticated than in control plots (Figure 2c). Bitterbrush did not display any significant effects until 2018, when cover was higher in treated plots (Figure 2c). Serviceberry cover was lower in treated plots over all years (Figure 2d). Sagebrush cover was initially lower in treated plots, but by 2018 this difference was no longer significant (Figure 2d).

Summer utilization of serviceberry and mountain mahogany in 2018 was significantly higher in masticated than in control plots, but no differences were detected in bitterbrush or sagebrush. Winter forage production, which was summed over serviceberry, mountain mahogany, and bitterbrush, was significantly higher in masticated plots than in unmasticated plots in all years except 2016, when the pattern was reversed (Figure 3). There was no significant effect of exclosures on any plant cover group or on summer utilization in 2018.

Deer, horse, elk, and cattle all foraged more often in masticated plots than in controls in 2018 (Figure 4). Cattle were only observed foraging at 6 of 20 locations, horse were observed at 9, deer at 19, and elk at 6.

Mastication treatments had many positive effects on forage availability, including higher cover of desirable grass groups such as poa grasses and wheatgrasses, higher cover of perennial forbs, and usually higher productivity of winter-available shrub forage. There were some negative effects and some differences in effects among years, however. Cheatgrass was higher in masticated plots than in controls, and snowberry cover was higher in masticated plots in 2016 and 2018. 2016 was an unusual year compared to other years of this study, with very high productivity of grasses (including cheatgrass, especially in masticated plots), and unusually high productivity of winter-available forage of desirable shrubs in control but not masticated plots.

Summer shrub utilization in 2018 was higher in masticated plots than in controls. We lack any data on utilization from 2016, which might have helped explain if the lower production of winter-available forage in masticated plots was due to higher summer utilization in those plots that year. Another explanation for the 2016 results is that good conditions for grass, cheatgrass, and/or snowberry productivity in masticated plots led to increased competition which lessened productivity of desirable forage shrubs.

All four of the large herbivores of interest foraged more frequently in summer and fall in masticated plots than in control plots in 2018. The impact of cattle was concentrated in only a few plots, but they did forage frequently in plots where they occurred. Cattle use ended in September, prior to the period of heavy use by deer in October. The data from the cattle exclosures does not indicate that cattle are having any measurable negative effect on forage resources. In summary the impact of cattle on the

forage resources available to deer in mastication treatments seems minimal. However, the effect of the sum of cattle, horse, and elk foraging may have some impact.

In 2019, we collected vegetation data and camera data. 2019 is the last year of data collection for this study, and final analyses will be incorporated into publications in 2020-21.

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Johnston, D. B. (2018). Wildlife Research Report: Examining the effectiveness of mechanical treatments as a restoration technique for mule deer habitat. Fort Collins, CO, Colorado Parks and Wildlife.

Rhodes, A. C., R. T. Larsen and S. B. S. Clair (2018). "Differential effects of cattle, mule deer, and elk herbivory on aspen forest regeneration and recruitment." Forest Ecology and Management **422**: 273-280.

Table 1. Number of transects sampled for a given data type each year.

Variables quantified	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2018**	**2019**
Percent cover of plant functional groups	90*	90*	159	145		69	107†	40 (camera sites)
Winter-available forage of bitterbrush, serviceberry, mountain mahogany (*ShrubMassPerArea*)				70†	27†	63	75†	75†
Summer utilization of bitterbrush, serviceberry, mountain mahogany, and sagebrush							75†	75†
Index of deer, elk, horse, and cattle use in summer and fall, as determined by trail camera (*EventsPerDay*)							40 (2 cameras each)	40 (2 cameras each)

* Pretreatment data collected 2011-2012 will be added to a later report.

†Includes 24-30 locations taken at exclosure sites.

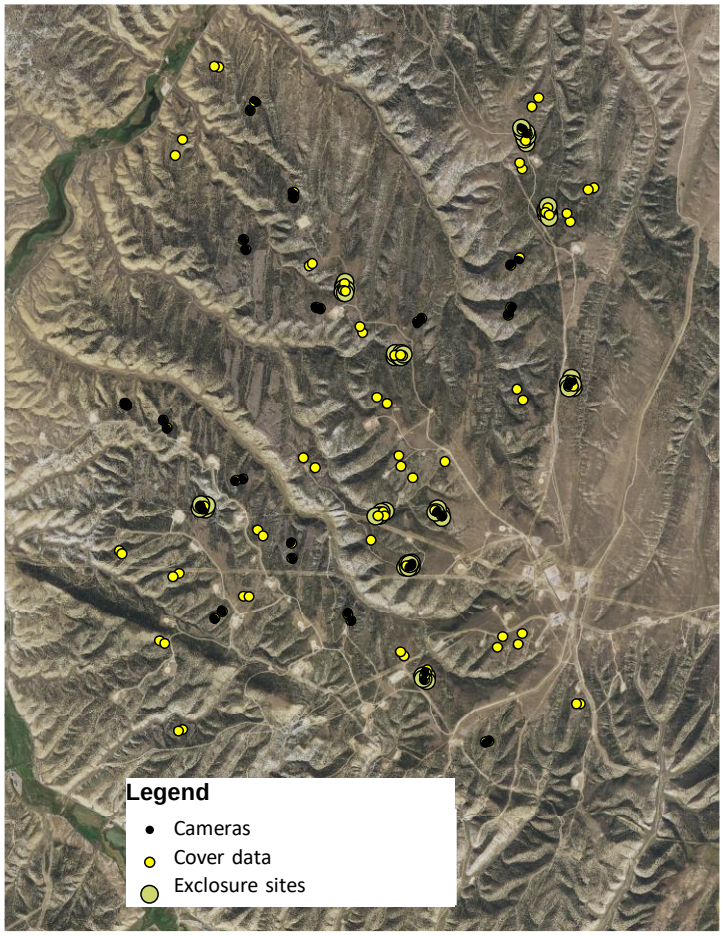


Figure 1. Sampling locations within the Magnolia region of the Piceance Basin.

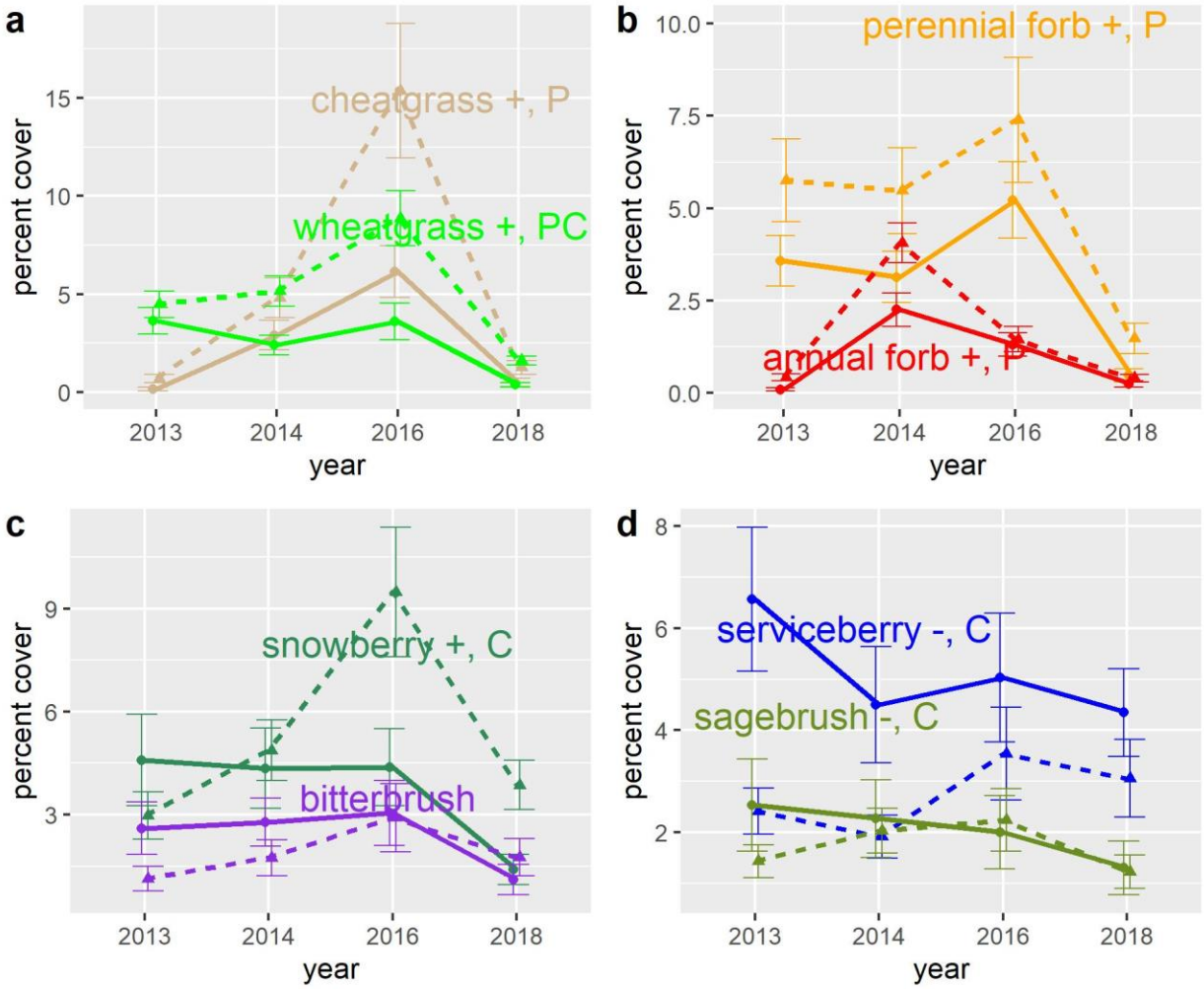


Figure 2. Cover of some plant functional groups and species important for evaluating habitat quality. Dashed lines indicate masticated plots and solid lines are controls. A "+" or "-" sign indicates significant positive or negative main effect of mastication across years ($\alpha = 0.05$). "P" indicates that the significant effect was observed in the presence/absence analysis, and "C" indicates a significant effect in the cover-where-present analysis.

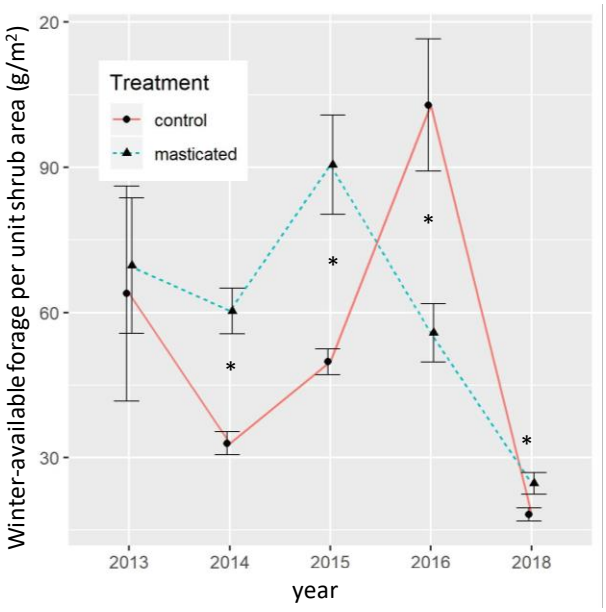


Figure 3. Mass of winter-available forage (current-year stem mass measured in September, not including leaves or mass removed by summer browsing) per unit shrub area. Data are summed over serviceberry, mountain mahogany, and bitterbrush. N=8 for 2013 and 2015 and 25-31 for other years. No transects inside fences were included. Error bars = SE. Stars indicate significant differences at alpha = 0.05

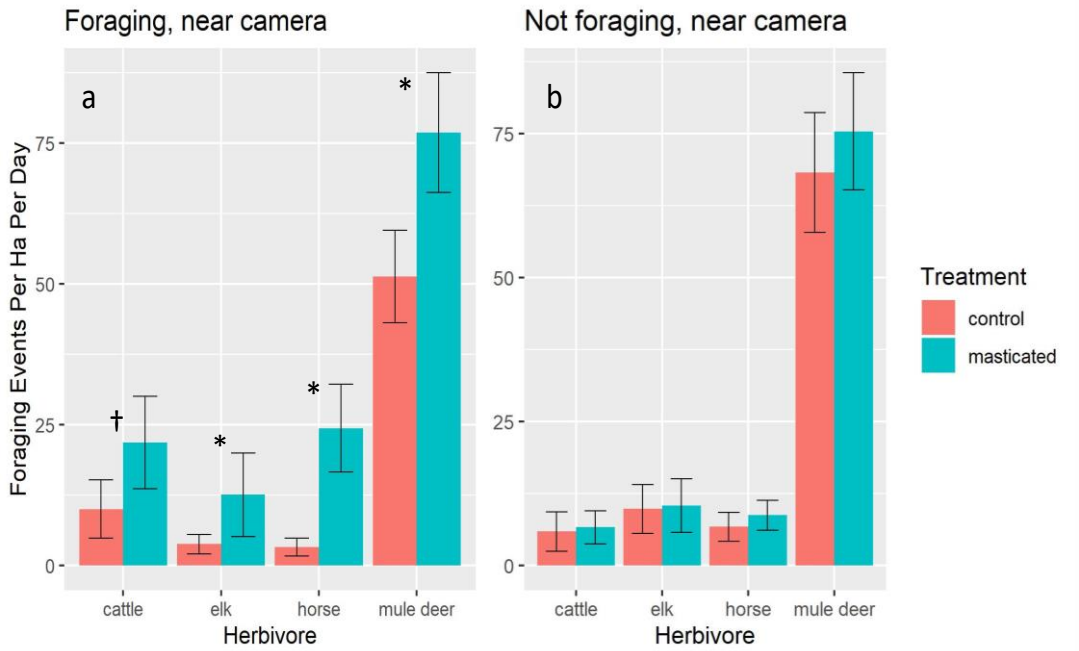


Figure 4. a) Average number of foraging events per hectare per day between mid-July and mid-November, 2018 in control versus masticated plots. Stars indicate significant differences at $\alpha = 0.05$. † indicates a significant difference in presence of foraging events. b) Average number of non-foraging observations per hectare per day.

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, 2018 – June 30, 2019

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

During November of 2013 we initiated a large scale moose research project in 3 of Colorado Parks and Wildlife's 4 geographical regions (NE, NW, and SW). 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. During winter of 2018–2019, 36 cow moose were captured. Of these 36 animals, 21 were captured in NW Colorado (8 recaptures and 13 new individuals) and 15 were captured in NE Colorado (7 recapture and 15 new individual). 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.

During the 2018–2019 winter, measured rump fat at the time of capture ranged between 0–11 mm among study areas. Measured loin depth at the time of capture ranged between 27–63 mm among study areas. Measured loin fat, at the time of capture, ranged between 0–5 mm. In comparison to the winter of 2017–2018, the values observed during 2018–2019 were consistently lower, but still within the range of expected values. Over the course of this study, we have observed that the probability of moose being pregnant was best predicted by considering maximum loin depth. Regional and annual effects in pregnancy rates were not evaluated. As has been the case during all years of the study, survival of radio collared animals was high in all study areas (85%–96%). During 2018–2019 pregnancy rates were similar between areas (70% in NW Colorado, 60% in NE Colorado), but strong inference was limited by samples size. However, in comparison to the preceding 5 winters of data collection, observed pregnancy rates between 60%–70% during 2018–2019 were consistent long-term rates. Over the course of this study, calf-at-heel estimates at the time of capture have average 0.55. During 2018–2019, the observed calf-at-heel rates in both NW Colorado (0.24) and NE Colorado (0.43) were lower than average.

Beginning summer 2017 and continuing through 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 will be used to develop a linkage between moose body condition, moose pregnancy, and moose habitat conditions.

Thus far, data collected during this project have met expectations. In particular, survival rates have been consistently high in all study areas. However, a large degree of variation within pregnancy rates have been 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 the remainder of FY 19-20 and during FY 20-21, data collected during this study will be analyzed to evaluate the relationship between moose pregnancy and browse availability and browse nutritional character will be discerned to help biologists project moose population trajectory and to refine moose herd management objectives. Similarly, various metrics (such as pregnancy rates and observed calf-at-heel ratios) will be evaluated in the context of their utility for long term management of moose in Colorado.

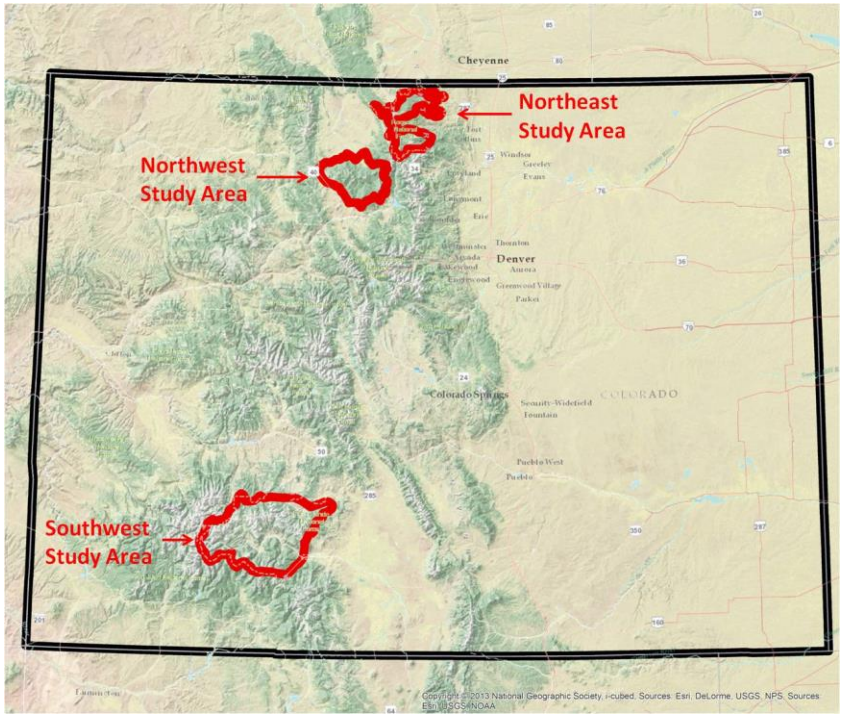


Figure 1. Moose research study areas, located in 3 regions in Colorado. A total of 255 moose were captured during winters between 2013–2014 and 2018–2019. During the winter of 2018–2019, a total of 36 moose were captured in the Northeast and Northwest study areas. Survival of moose was high in all study areas and during all years of the study.

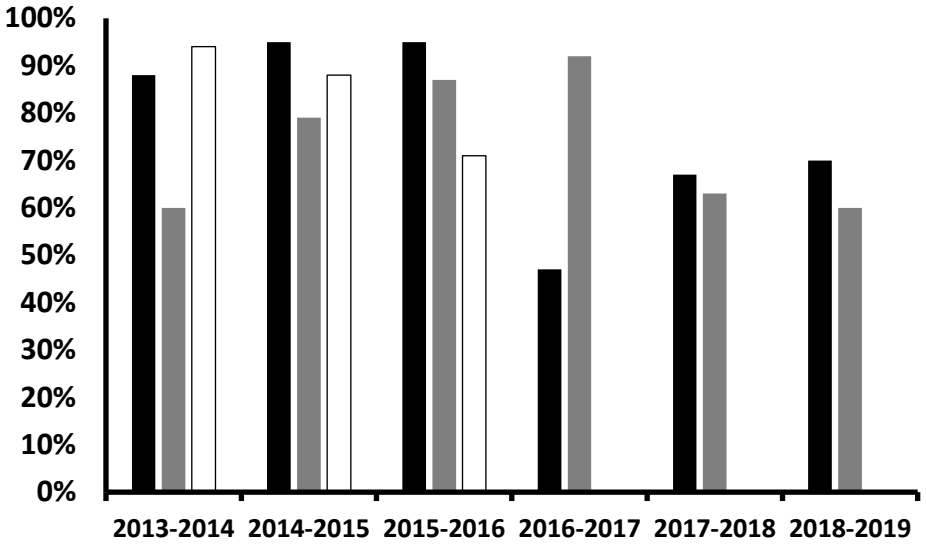


Figure 2. Pregnancy data were collected for all moose at the time of capture. Data from northwest Colorado are depicted by black bars, data from northeast Colorado are depicted by gray bars, and data from southwest Colorado are depicted by white bars. Data from southwest were sparse during 2015–2016 (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.

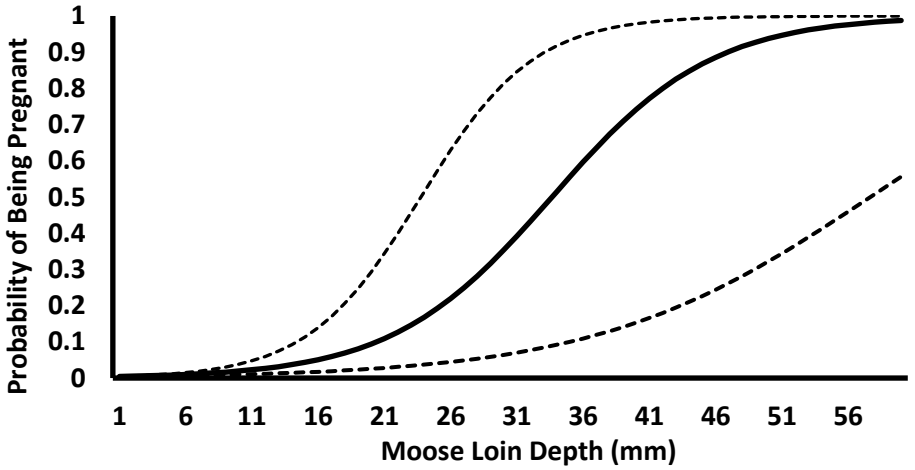


Figure 3. During the course of this study, probability of moose pregnancy has been best predicted by measured loin depth. The relationship between body condition and pregnancy status is reflected by the solid black line and from data collected during the all 5 years of the study (dotted lines represent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

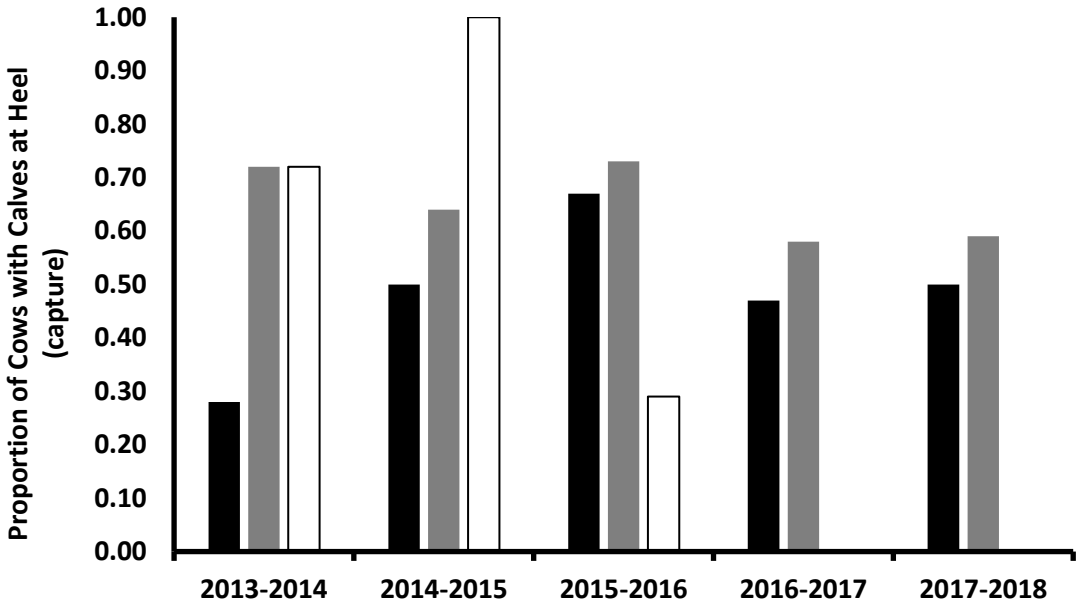


Figure 4. Moose calf-at-heel data were collected for all cow moose at the time of capture. Data from northwest Colorado are depicted by black bars, data from northeast Colorado are depicted by gray bars, and data from southwest Colorado are depicted by white bars. Data from southwest were sparse during 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, 2018-June 30, 2019

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

Over the last two decades, 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 in the state (Fig. 1). In FY2018-19, CPW expanded this pilot study work into a 3rd DAU (E-2), with high juvenile:adult female ratios, which will serve as a reference area. We plan to conduct this study for 6 additional years to better determine how various factors (habitat, weather condition, predation, human disturbance) may be impacting elk recruitment in Colorado.

During FY2018-19 we successfully worked with private landowners and personnel from CPW to coordinate field research logistics and initiate the first year of this study. We collected data on body condition and reproduction by capturing adult female elk, and we outfitted 62 pregnant females with GPS collars and vaginal implant transmitters (VITs; used to detect calf birth sites). We did not reach our target sample size of 30 collared pregnant females from the Bear's Ears herd because we halted capture operations due to acute mortalities that occurred during helicopter net-gunning. As a result, we had to adjust our sampling strategy for elk calves in this area to capture a greater number of opportunistically encountered calves due to the low number of calves available to capture from collared adult female elk. We successfully captured and collared >45 newborn elk from each study area, meeting our sample size objectives. Calf survival monitoring is ongoing with year one results pending the first year of data collection.

In 2019, we estimated that pregnancy rates of adult female elk were 100% in the Bear's Ears herd (95% CI = 44-100%; n = 3), 91% in the Trinchera herd (95% CI = 76-97%; n = 33), and 97% in the Uncompahgre Plateau herd (95% CI = 84-100%; n = 31; Fig. 2). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013).

We estimated the mean IFBF of adult female elk to be 5.8% from the Bear's Ears herd, 6.4% from the Trinchera herd, and 7.1% 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 and June 2019, we captured and collared 146 elk calves, 51 from the Bear's Ears herd, 46 from the Trinchera herd, and 49 from the Uncompahgre Plateau herd. From the Bear's Ears herd,

we successfully captured and collared 100% (2/2) of the calves of collared adult female elk outfitted with VITs. From the Trinchera herd, we successfully captured and collared 90% (27/30) of the calves of collared adult female elk outfitted with VITs. From the Uncompahgre Plateau herd, we successfully captured and collared 83% (25/30) of the calves of collared adult female elk outfitted with VITs. The estimated mean date of calving was June 11 in the Bear's Ears herd, June 1 in the Trinchera herd, and June 3 in the Uncompahgre Plateau herd (Fig. 4).

Data collection will continue through 2024 to address factors influencing elk calf recruitment in Colorado. CPW Animal Care and Use Committee protocols have been modified to insure sample size requirements will be achieved throughout the remainder of the study.

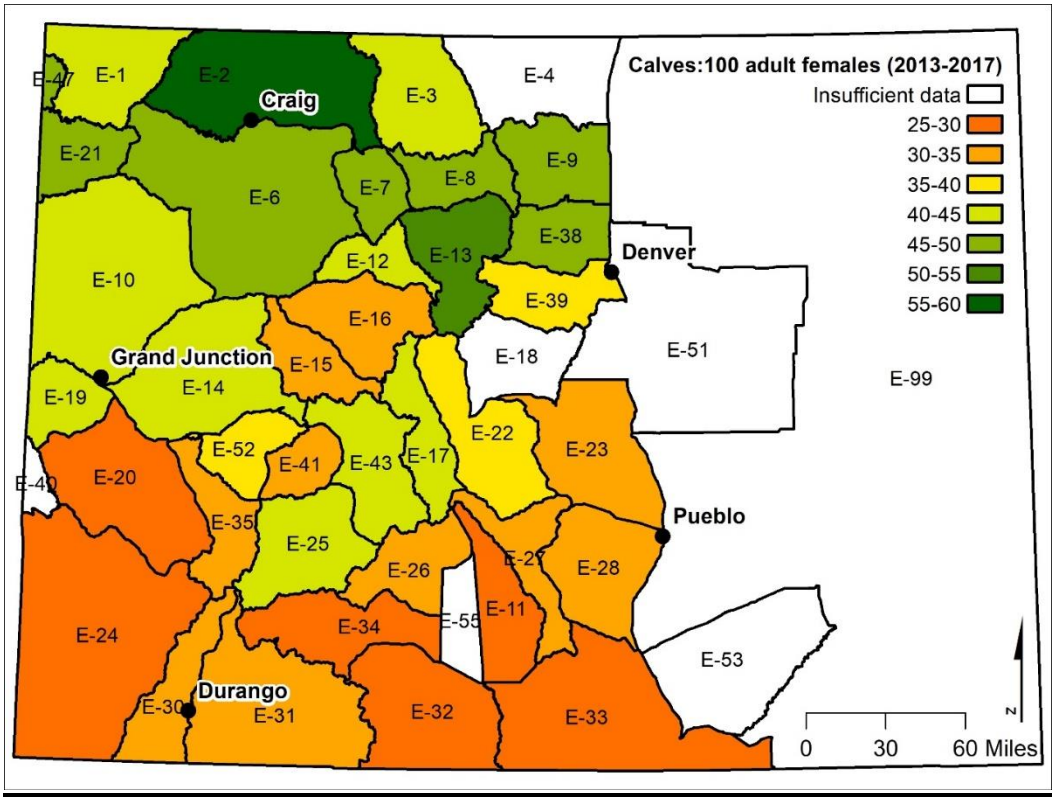


Figure 1. Number of elk calves per 100 adult females observed during December-February aerial surveys (5-year average from 2013-2017) within elk Data Analysis Units (DAUs; labeled with black text) in Colorado, USA.

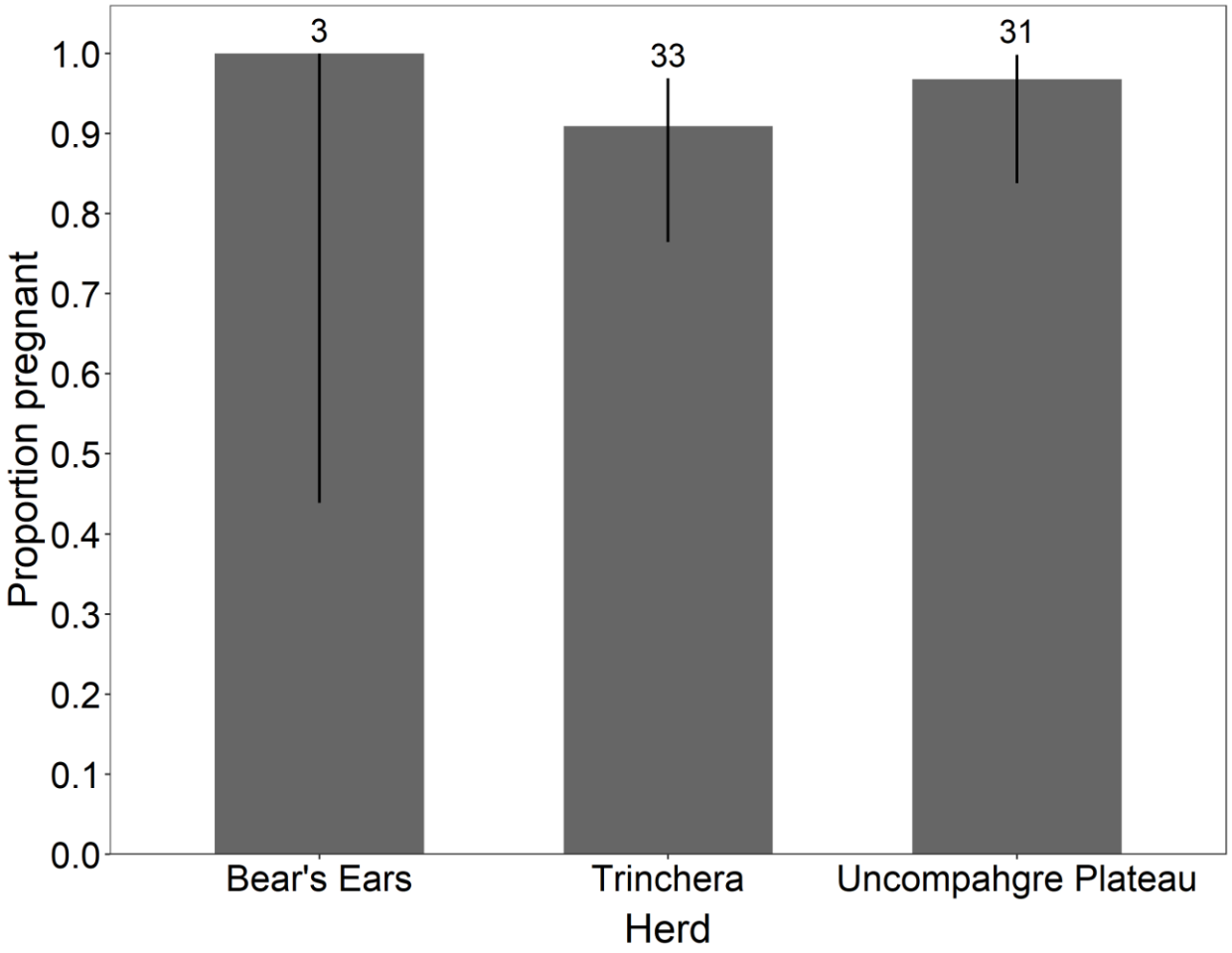


Figure 2. Estimated average pregnancy rates of adult female elk from the Bear's Ears, Trinchera, and Uncompahgre Plateau herds sampled during late winter 2019 in Colorado, USA. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

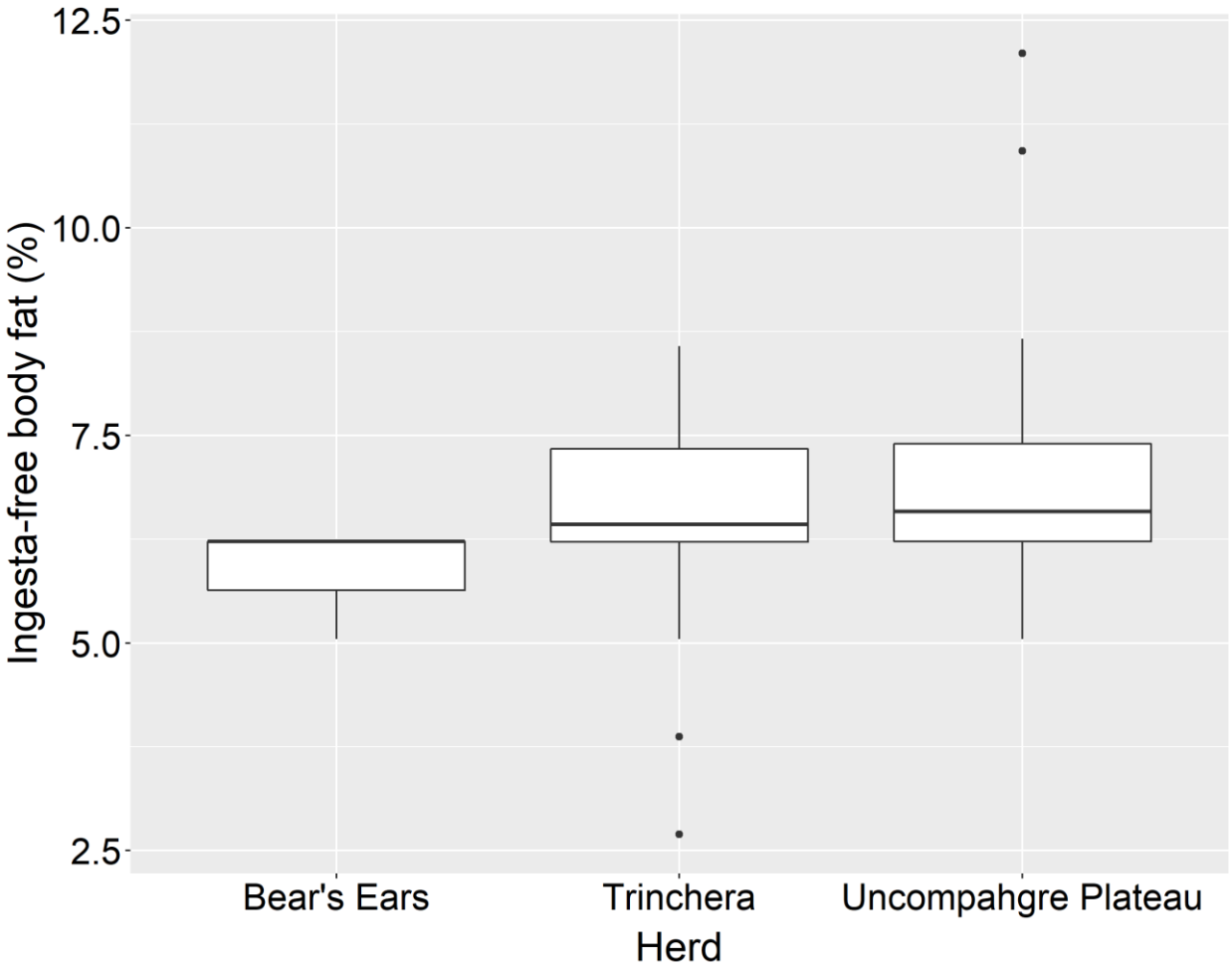


Figure 3. The estimated ingesta-free body fat (%) of adult female elk from the Bear's Ears (n = 3), Trinchera (n = 33), and Uncompahgre Plateau (n = 31) herds during late-winter 2019 in Colorado, USA.

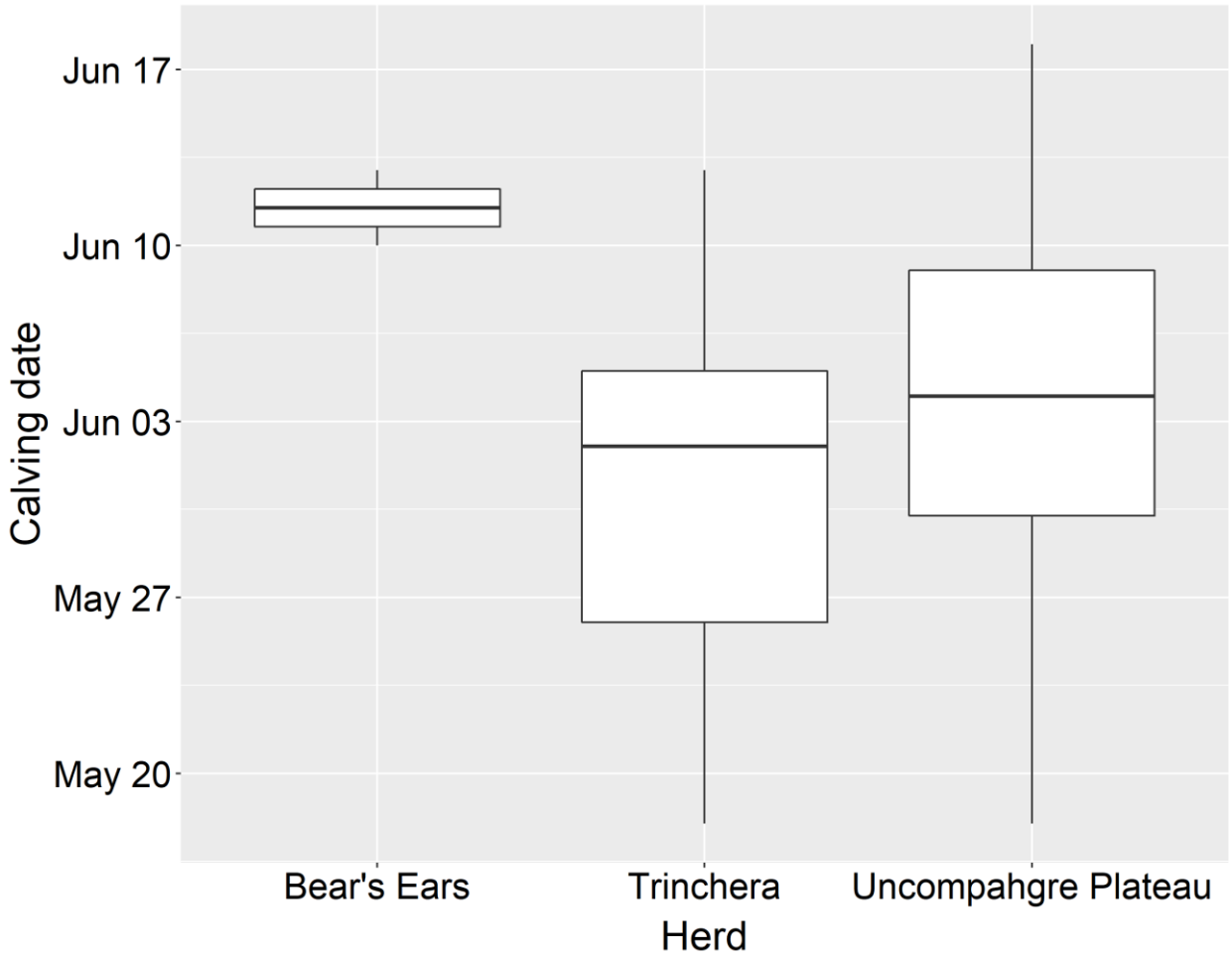


Figure 4. The distribution of calving dates of adult female elk estimated from vaginal implant transmitters (VITs) from the Bear's Ears (*n* = 2), Trinchera (*n* = 30), and Uncompahgre Plateau (*n* = 30) herds during 2019 in Colorado, USA.

SUPPORT SERVICES

RESEARCH LIBRARY ANNUAL REPORT

CPW Research Library Annual Report
July 1, 2018 – June 30, 2019

Author: Alexandria Austermann, alexandria.austermann@state.co.us
Library catalog: http://c10110.eos-intl.net/C10110/public/Index.aspx

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.

50+ Years

The Research Library has been in service

4 Librarians

Items in Collection

Titles: 16,728

Copies: 29,911

Notable Special Collections:

- **Federal Aid Reports:** 4,265
- **Division Reports:** 4,070
- **Articles by Division staff:** 1,292
- **Physical Journal Issues:** 8,194
- **Wildlife-related Books:** 7,593

Items in the collection include books, reports and physical journals. It does not include e-content.

Titles are unique items in the collection. A title may have multiple copies. The number of copies is the total number of items in the collection.

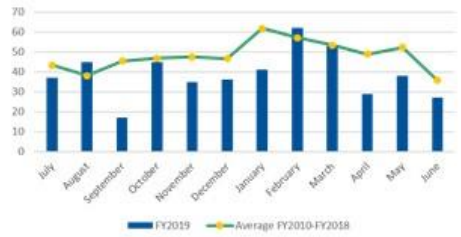
Special Collections are sub-sets of the overall collection.

All information in this report is preliminary and subject to further evaluation.

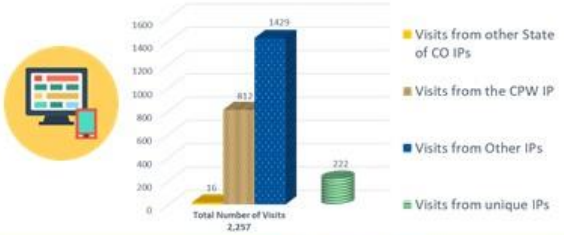
Information MAY NOT BE PUBLISHED OR QUOTED without permission of the author.

Manipulation of these data beyond that contained in this report is discouraged.

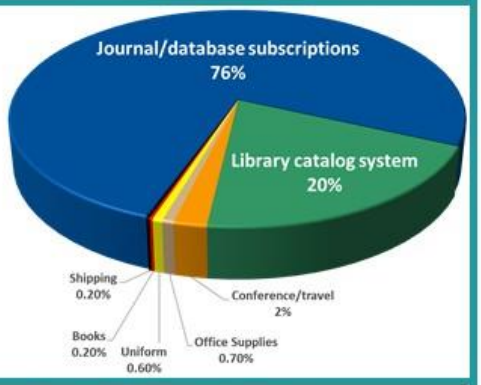
Articles Retrieved by Month



Visits to the Library Catalog by IP Address



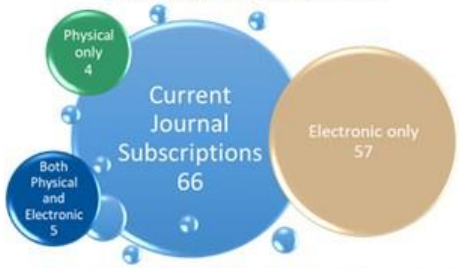
Library Budget



History of the Division

- 1897 Colorado Game, Fish and Forestry Department established
- 1899 Name changed to Colorado Department of Game and Fish
- 1963 Game & Fish Department and Department of Parks & Recreation merge to form Game, Fish & Parks Department
- 1971 Division of Game, Fish & Parks is separated into the Division of Wildlife and the Division of Parks & Outdoor Recreation
- 2011 Colorado State Parks merges with the Colorado Division of Wildlife to form Colorado Parks and Wildlife

Journal Subscriptions



The library also subscribes to several databases that provide access to thousands more journals.

APPENDIX A. CPW mammal research abstracts published July 2018 – November 2019.

MAMMAL RESPONSES TO BEETLE-KILLED FORESTS IN COLORADO

Mammalian responses to changed forest conditions resulting from bark beetle outbreaks in the southern Rocky Mountains

Jacob S. Ivan,[a] Amy E. Seglund,[b] Richard L. Truex,[c] and Eric S. Newkirk[a]
[a]Mammals Research Section, Colorado Parks and Wildlife, 317 West Prospect Road, Fort Collins, CO 80526 USA
[b]Species Conservation Section, Colorado Parks and Wildlife, 2300 South Townsend Avenue, Montrose, CO 81401 USA
[c]U.S. Department of Agriculture Forest Service, Rocky Mountain Region, 1617 Cole Boulevard, Building 17, Lakewood, CO 80401 USA

Citation: Ivan, J. S., A. E. Seglund, R. L. Truex, and E. S. Newkirk. 2018. Mammalian responses to changed forest conditions resulting from bark beetle outbreaks in the southern Rocky Mountains. Ecosphere 9(8); doi.org/10.1002/ecs2.2369

ABSTRACT Spruce beetle (*Dendroctonus rufipennis*) and mountain pine beetle (Dendroctonus ponderosae) outbreaks have impacted millions of acres of conifer forest from Alaska to northern Mexico. These species are native to North America, and periodic outbreaks have shaped the structure and composition of conifer forests for millennia. However, the extent and severity of current outbreaks, fueled by favorable climatic conditions and increased susceptibility of forests, are unmatched in recorded history. To characterize the response of a suite of mammalian species to beetle-induced changes in vegetation in the southern Rocky Mountains, we deployed cameras at 300 randomly selected sites during summer 2013–2014. Selected sites spanned gradients of years elapsed since bark beetle outbreaks (YSO) and severity. We fit single-season occupancy models to detection/non-detection data collected for each species to examine a variety of plausible relationships between use of a given stand and YSO, severity, or both. Ungulates exhibited a positive association with bark beetle activity, although the nature of these associations varied by species. Elk (*Cervus canadensis*) were positively associated with severity, but not YSO; mule deer (*Odocoileus hemionus*) exhibited the opposite relationship. Moose (*Alces alces*) responded in a quadratic fashion; use of forest stands adjacent to preferred willow habitat peaked 3–7 yr after an outbreak commenced, but only at high severity. Similarly, yellow-bellied marmot use of impacted stands adjacent to rock outcroppings followed a quadratic trend, but only at high severity. Red squirrel (*Tamiasciurus hudsonicus*) use declined in severely impacted stands, likely as a response to diminished cone crops. Golden-mantled ground squirrels (*Callospermophilus lateralis*) and chipmunks (*Neotamias* spp.) exhibited a shallow negative relationship with YSO, as did coyotes (*Canis latrans*). Contrary to our hypotheses, black bears (*Ursus americanus*), American marten (*Martes americana*), snowshoe hares (*Lepus americanus*), and porcupines (*Erethizon dorsatum*) did not appear to be substantially influenced by beetle activity. Red fox (*Vulpes vulpes*) use was positively associated with YSO, but overall use declined as severity increased. Note that changes in probability of use described here could reflect changes in abundance, home range size, habitat use, or some combination, and in several cases, there was considerable uncertainty across competing models. Published August 2018

LYNX RESPONSE TO WINTER RECREATION

Sharing the same slope: Behavioral responses of a threatened mesocarnivore to motorized and nonmotorized winter recreation

Lucretia E. Olson,[a] John R. Squires,[a] Elizabeth K. Roberts,[b] Jacob S. Ivan,[c] and Mark Hebblewhite[d]
[a]Rocky Mountain Research Station, U.S. Forest Service, 800 Beckwith Avenue, Missoula, MT 59801, USA
[b]White River National Forest, 900 Grand Avenue, Glenwood Springs, CO 80601, USA
[c]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA
[d]Wildlife Biology Program, Department of Ecosystem and Conservation Sciences, W.A. Franke College of Forestry and Conservation, University of Montana, 32 Campus Drive, Missoula, MT 59812, USA

Citation: Olson, L. E., J. R. Squires, E. K. Roberts, J. S. Ivan, and M. Hebblewhite. 2018. Sharing the same slope: Behavioral responses of a threatened mesocarnivore to motorized and nonmotorized winter recreation. Ecology and Evolution 8:8555–8572; doi.org/10.1002/ece3.4382

ABSTRACT Winter recreation is a widely popular activity and is expected to increase due to changes in recreation technology and human population growth. Wildlife are frequently negatively impacted by winter recreation, however, through displacement from habitat, alteration of activity patterns, or changes in movement behavior. We studied impacts of dispersed and developed winter recreation on Canada lynx (*Lynx canadensis*) at their southwestern range periphery in Colorado, USA. We used GPS collars to track movements of 18 adult lynx over 4 years, coupled with GPS devices that logged 2,839 unique recreation tracks to provide a detailed spatial estimate of recreation intensity. We assessed changes in lynx spatial and temporal patterns in response to motorized and nonmotorized recreation, as well as differences in movement rate and path tortuosity. We found that lynx decreased their movement rate in areas with high-intensity back-country skiing and snowmobiling, and adjusted their temporal patterns so that they were more active at night in areas with high-intensity recreation. We did not find consistent evidence of spatial avoidance of recreation: lynx exhibited some avoidance of areas with motorized recreation, but selected areas in close proximity to nonmotorized recreation trails. Lynx appeared to avoid high-intensity developed ski resorts, however, especially when recreation was most intense. We conclude that lynx in our study areas did not exhibit strong negative responses to dispersed recreation, but instead altered their behavior and temporal patterns in a nuanced response to recreation, perhaps to decrease direct interactions with recreationists. However, based on observed avoidance of developed recreation, there may be a threshold of human disturbance above which lynx cannot coexist with winter recreation. Published July 2018

Winter recreation and Canada lynx: reducing conflict through niche partitioning

John R. Squires,[a] Lucretia E. Olson,[a] Elizabeth K. Roberts,[b] Jacob S. Ivan,[c] and Mark Hebblewhite[d]
[a]Rocky Mountain Research Station, U.S. Forest Service, 800 Beckwith Avenue, Missoula, MT 59801, USA
[b]White River National Forest, 900 Grand Avenue, Glenwood Springs, CO 80601, USA
[c]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA
[d]Wildlife Biology Program, Department of Ecosystem and Conservation Sciences, W.A. Franke College of Forestry and Conservation, University of Montana, 32 Campus Drive, Missoula, MT 59812, USA

Citation: Squires, J. R., L. E. Olson, E. K. Roberts, J. S. Ivan, and M. Hebblewhite. 2019. Winter recreation and Canada lynx: reducing conflict through niche partitioning. Ecosphere 10(10); doi.org/10.1002/ecs2.2876

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

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

Kenneth A. Logan
Mammals Research Section, Colorado Parks and Wildlife, 2300 S. Townsend Avenue, Montrose, CO 81401, USA

Citation: Logan, K. A. 2019. Puma population limitation and regulation: what matters in puma management? Journal of Wildlife Management 83:1652–1666; doi.org/10.1002/jwmg.21753

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

Mathew W. Alldredge,[a] Frances E. Buderman,[b] and Kevin A. Blecha[c]
[a]Mammals Research Section, Colorado Parks and Wildlife, Fort Collins, CO, USA
[b]Colorado State University, Fort Collins, CO, USA
[c]Terrestrial Section, Colorado Parks and Wildlife, Gunnison, CO, USA

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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

Time-varying predatory behavior is primary predictor of fine-scale movement of wildland-urban cougars

Frances E. Buderman,[a] Mevin B. Hooten,[b] Mathew W. Alldredge,[c] Ephraim M. Hanks,[d] and Jacob S. Ivan[c]
[a]Colorado State University, Department of Fish, Wildlife, and Conservation Biology, 1484 Campus Delivery, Fort Collins, CO 80523, USA
[b]U.S. Geological Survey, Colorado Cooperative Fish and Wildlife Research Unit, Department of Fish, Wildlife, and Conservation Biology, 1484 Campus Delivery, Fort Collins, CO 80523, USA
[c]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA
[d]Pennsylvania State University, W-250 Millennium Science Complex, University Park, State College, PA 16802, USA

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Abstract
Background: While many species have suffered from the detrimental impacts of increasing human population growth, some species, such as cougars (*Puma concolor*), have been observed using human-modified landscapes. However, human-modified habitat can be a source of both increased risk and increased food availability, particularly for large carnivores. Assessing preferential use of the landscape is important for managing wildlife and can be particularly useful in transitional habitats, such as at the wildland-urban interface. Preferential use is often evaluated using resource selection functions (RSFs), which are focused on quantifying habitat preference using either a temporally static framework or researcher-defined temporal delineations. Many applications of RSFs do not incorporate time-varying landscape availability or temporally-varying behavior, which may mask conflict and avoidance behavior.
Methods: Contemporary approaches to incorporate landscape availability into the assessment of habitat selection include spatio-temporal point process models, step selection functions, and continuous-time Markov chain (CTMC) models; in contrast with the other methods, the CTMC model allows for explicit inference on animal movement in continuous-time. We used a hierarchical version of the CTMC framework to model speed and directionality of fine-scale movement by a population of cougars inhabiting the Front Range of Colorado, U.S.A., an area exhibiting rapid population growth and increased recreational use, as a function of individual variation and time-varying responses to landscape covariates.
Results: We found evidence for individual- and daily temporal-variability in cougar response to landscape characteristics. Distance to nearest kill site emerged as the most important driver of movement at a population-level. We also detected seasonal differences in average response to elevation, heat loading, and distance to roads. Motility was also a function of amount of development, with cougars moving faster in developed areas than in undeveloped areas.
Conclusions: The time-varying framework allowed us to detect temporal variability that would be masked in a generalized linear model, and improved the within-sample predictive ability of the model. The high degree of individual variation suggests that, if agencies want to minimize human-wildlife conflict management options should be varied and flexible. However, due to the effect of recursive behavior on cougar movement, likely related to the location and timing of potential kill-sites, kill-site identification tools may be useful for identifying areas of potential conflict. Published November 2018

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

Jonathan H. Lewis,[a] Mathew W. Alldredge,[a] Brian P. Dreher,[b] Janet L. George,[c] Scott Wait,[d] Brad Petch,[e] and Jon P. Runge[f]
[a]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA
[b]Terrestrial Section, Colorado Parks and Wildlife, 4255 Sinton Road, Colorado Springs, CO 80907, USA
[c]Terrestrial Section, Colorado Parks and Wildlife, 1313 Sherman Street, Denver, CO 80203, USA
[d]Terrestrial Section, Colorado Parks and Wildlife, 415 Turner Drive, Durango, CO 81303, USA
[e]Terrestrial Section, Colorado Parks and Wildlife, 711 Independent Avenue, Grand Junction, CO 81505, USA
[f]Terrestrial Programs, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

Citation: Lewis, J. H., M. W. Alldredge, B. P. Dreher, J. L. George, S. Wait, B. Petch, and J. P. Runge. 2019. Summarizing Colorado's black bear two–strike directive 30 years after inception. Wildlife Society Bulletin; doi.org/10.1002/wsb.1032

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

Assessing ecological and social outcomes of a bear-proofing experiment

Heather E. Johnson,[a] David L. Lewis,[a] Stacy A. Lischka,[b] and Stewart W. Breck[c]
[a]Mammals Research Section, Colorado Parks and Wildlife, 415 Turner Drive, Durango, CO 81303, USA
[b]Research, Policy, and Planning Branch, Colorado Parks and Wildlife, 317 W. Prospect Avenue, Fort Collins, CO 80526, USA
[c]U.S. Department of Agriculture National Wildlife Research Center, 4101 LaPorte Avenue, Fort Collins, CO 80521, USA

Citation: Johnson, H. E., D. L. Lewis, S. A. Lischka, and S. W. Breck. 2018. Assessing ecological and social outcomes of a bear–proofing experiment. Journal of Wildlife Management 82:1102–1114; DOI: 10.1002/jwmg.21427

ABSTRACT Human-black bear conflicts within urban environments have been increasing throughout North America, becoming a high priority management issue. The main factor influencing these conflicts is black bears foraging on anthropogenic foods within areas of human development, primarily on residential garbage. Wildlife professionals have advocated for increased bear-proofing measures to decrease the accessibility of garbage to bears, but little research has been conducted to empirically test the effectiveness of this approach for reducing conflicts. Between 2011 and 2016, we conducted a before-after-control-impact experiment in Durango, Colorado where we distributed 1,110 bear-resistant trash containers, enhanced education, and increased enforcement to residents in 2 treatment areas, and monitored 2 paired control areas. We examined the ecological and social outcomes of this experiment, assessing whether bear-resistant containers were effective at reducing conflicts; the level of public compliance (i.e., properly locking away garbage) needed to reduce conflicts; whether the effectiveness of bear-resistant containers increased over time; and if the distribution of bear-resistant containers changed residents' attitudes about bear management, support for ordinances that require bear-proofing, or perceptions of their future risk of garbage-related conflicts. After the bear-resistant containers were deployed, trash-related conflicts (i.e., observations of strewn trash) were 60% lower in treatment areas than control areas, resident compliance with local wildlife ordinances (properly locking away trash) was 39% higher in treatment areas than control areas, and the effectiveness of the new containers was immediate. Conflicts declined as resident compliance with wildlife ordinances increased to approximately 60% (by using a bear-resistant container or locking trash in a secure location), with minor additional declines in conflicts at higher levels of compliance. In addition to these ecological benefits, public mail surveys demonstrated that the deployment of bear-resistant containers was associated with increases in the perceived quality of bear management and support for ordinances that require bear-proofing, and declines in the perceived risk of future trash-related conflicts. Our results validate efforts by wildlife professionals and municipalities to reduce black bear access to human foods, and should encourage other entities of the merits of bear-proofing efforts for reducing human-bear conflicts and improving public attitudes about bears and their management. Featured article August 2018 issue of Journal of Wildlife Management

A conceptual model for the integration of social and ecological information to understand human-wildlife interactions

Stacy A. Lischka,[a,b] Tara L. Teel,[c] Heather E. Johnson,[d] Sarah E. Reed,[b,e] Stewart Breck,[f] Andrew Don Carlos,[c] Kevin R. Crooks[b]
[a]Research, Policy, and Planning Branch, Colorado Parks and Wildlife, 317 W. Prospect Ave., Fort Collins, CO 80526, USA
[b]Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, CO 80523, USA
[c]Department of Human Dimensions of Natural Resources, Colorado State University, Fort Collins, CO 80523, USA
[d]Research, Policy, and Planning Branch, Colorado Parks and Wildlife, 415 Turner Dr., Durango, CO 81301, USA
[e]Americas Program, Wildlife Conservation Society, 2300 Southern Blvd., Bronx, NY 10460, USA
[f]National Wildlife Research Center, USDA Wildlife Services, 4101 Laporte Ave., Fort Collins, CO 80521, USA

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ABSTRACT There is growing recognition that interdisciplinary approaches that account for both ecological and social processes are necessary to successfully address human-wildlife interactions. However, such approaches are hindered by challenges in aligning data types, communicating across disciplines, and applying social science information to conservation actions. To meet these challenges, we propose a conceptual model that adopts a social-ecological systems approach and integrates social and ecological theory to identify the multiple, nested levels of influence on both human and animal behavior. By accounting for a diverse array of influences and feedback mechanisms between social and ecological systems, this model fulfills a need for approaches that treat social and ecological processes with equal depth and facilitates a comprehensive understanding of the drivers of human and animal behaviors that perpetuate human-wildlife interactions. We apply this conceptual model to our work on human-black bear conflicts in Colorado, USA to demonstrate its utility. Using this example, we identify key lessons and offer guidance to researchers and conservation practitioners for applying integrated approaches to other human-wildlife systems. Published September 2018

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

Stacy A. Lischka,[a, b] Tara L. Teel,[c] H. E. Johnson,[d] and K. R. Crooks[b]
[a]Research, Policy, and Planning Branch, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA
[b]Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, CO 80523, USA
[c]Department of Human Dimentions of Natural Resources, Colorado State University, Fort Collins, CO 80523, USA
[d]Research, Policy, and Planning Branch, Colorado Parks and Wildlife, 415 Turner Drive, Durango, CO 81301, USA

Citation: Lischka, S. A., T. L. Teel, H. E. Johnson, and K. R. Crooks. 2019. Understanding and managing human toleralce for a large carnivore in a residential system. Biological Conservation 238:1081–1089; doi.org/10.1016/j.biocon.2019.07.034

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

UNGULATE ECOLOGY AND MANAGEMENT

Modeling elk-to-livestock transmission risk to predict hotspots of brucellosis spillover

Nathaniel D. Rayl,[a] Kelly M. Proffitt,[b] Emily S. Almberg,[b] Jennifer D. Jones,[b] Jerod A. Merkle,[c] Justin A. Gude,[d] and Paul C. Cross[e]
[a]Current Affiliation: Mammals Research Section, Colorado Parks and Wildlife, Grand Junction, CO 81505, USA
[b]Montana Fish, Wildlife and Parks, Bozeman, MT 59718, USA
[c]Wyoming Cooperative Fish and Wildlife Research Unit, Dept. of Zoology and Physiology, University of Wyoming, Laramie, WY 82071, USA
[d]Montana Fish, Wildlife and Parks, Helena, MT 59718, USA
[e]U.S. Geological Survey, Northern Rocky Mountain Science Center, Bozeman, MT 59715, USA

Citation: Rayl, N. D., K. M. Proffit, E. S. Almberg, J. D. Jones, J. A. Merkle, J. A. Gude, and P. C. Cross. 2019. Modeling elk-to-livestock transmission risk to predict hotspots of brucellosis spillover. Journal of Wildlife Management 83:817–829; doi.org/10.1002/jwmg.21645

ABSTRACT Wildlife reservoirs of infectious disease are a major source of human-wildlife conflict because of the risk of potential spillover associated with commingling of wildlife and livestock. In the Greater Yellowstone Ecosystem, the presence of brucellosis (*Brucella abortus*) in free-ranging elk (*Cervus canadensis*) populations is of significant management concern because of the risk of disease transmission from elk to livestock. We identified how spillover risk changes through space and time by developing resource selection functions using telemetry data from 223 female elk to predict the relative probability of female elk occurrence daily during the transmission risk period. We combined these spatiotemporal predictions with elk seroprevalence, demography, and transmission timing data to identify when and where abortions (the primary transmission route of brucellosis) were most likely to occur. Additionally, we integrated our predictions of transmission risk with spatiotemporal data on areas of potential livestock use to estimate the daily risk to livestock. We predicted that approximately half of the transmission risk occurred on areas where livestock may be present (i.e., private property or grazing allotments). Of the transmission risk that occurred in livestock areas, 98% of it was on private ranchlands as opposed to state or federal grazing allotments. Disease prevalence, transmission timing, host abundance, and host distribution were all important factors in determining the potential for spillover risk. Our fine-resolution (250-m spatial, 1-day temporal), large-scale (17,732 km^2) predictions of potential elk-to-livestock transmission risk provide wildlife and livestock managers with a useful tool to identify higher risk areas in space and time and proactively focus actions in these areas to separate elk and livestock to reduce spillover risk. Published March 2019

On-animal acoustic monitoring provides insight to ungulate foraging behavior

Joseph M. Northrup,[a] Alexandra Arvin,[a] Charles R. Anderson Jr.,[b] Emma Brown,[c] and George Whittemyer[a]
[a]Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO 80523, USA
[b]Mammals Research Section, Colorado Parks and Wildlife, Fort Collins, CO 80526, USA
[c]National Parks Service Natural Sounds and Skies Division, Fort Collins, CO 80525, USA

Citation: Northrup, J. M., A. Arvin, C. R. Anderson Jr., E. Brown, and G. Whittemyer. 2019. On-animal acustic monitoring provides insight to ungulate foraging behavior. Journal of Mammology 100:1479–1489; doi.org/10.1093/jmammal/gyz124

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

Using maternal mule deer movements to estimate timing of parturition and assist fawn captures

Mark E. Peterson,[a] Charles R. Anderson Jr.,[b] M. W. Alldredge,[b] and P. F. Doherty Jr.[a]
[a]Department of Fish, Wildlife, and Conservation Biology, Colorado State University, 1474 Campus Delivery, Fort Collins, CO 80523, USA
[b]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

Citation: Peterson, M. E., C. R. Anderson Jr., M. W. Alldredge, and P. F. Doherty Jr. 2018. Using maternal mule deer movements to estimate timing of parturition and assist fawn captures. Wildlife Society Bulletin 42:616–621; doi.org/10.1002/wsb.935

ABSTRACT Movement patterns of maternal ungulates have been used to determine parturition dates and aid in locating fawns, which may be important for understanding reproductive rates (e.g., pregnancy and fetal), but such methods have not been validated for mule deer (*Odocoileus hemionus*). We first determined timing of parturition using vaginal implant transmitters (VITs) and then predicted timing of parturition using VITs in conjunction with Global Positioning System collar data in the Piceance Basin of northwestern Colorado, USA, during 2012–2014. We examined daily movement rate to determine differences in movement rate among days (7 days pre- and postpartum) and for movement patterns indicative of parturition. Mean daily movement rate (m/day) of 102 maternal deer decreased by 46% from 1 day preparturition (mean = 1,253, SD = 1,091) to parturition date (mean = 682, SD = 574), and remained at this low rate 1–7 days postpartum. We applied an independent data set to validate predicted parturition dates based on daily movement rate. We estimated day of parturition correctly (i.e., day 0), within 1–3 days postparturition, and ≥4 days postparturition of field-reported dates for 10 (29%), 21 (60%), and 4 (11%) maternal females, respectively. For novel data sets, we predict that a mule deer female whose daily movement rate decreases by ≥46% and remains low ≥3 days postparturition particularly when preceded by a sudden increase in movement—has given birth. However, we caution that disturbance of deer by field crews should be minimized, and if birth sites are not found, neonatal mortality will be underestimated. Our results can help determine timing and general location of parturition as an aid in capturing fawns when the use of VITs is not feasible, with the ultimate objective of estimating pregnancy, fetal, and fawn survival rates if birth sites are found. Published December 2018

REMOTE CAMERA SAMPLING

Estimating density and detection of bobcats in fragmented Midwestern landscapes using spatial capture–recapture data from camera traps

Christopher N. Jaques,[a] Robert W. Klaver,[b] Tim C. Swearingen,[a] Edward D. Davis,[a] Charles R. Anderson,[c] Jonathan A. Jenks,[d] Christopher S. Deperno,[e] and Robert D. Bluett[f]
[a]Department of Biological Sciences, Western Illinois University, Macomb, IL 61455, USA
[b]Department of Natural Resource Ecology and Management, U.S. Geological Survey, Iowa Cooperative Fish and Wildlife Research Unit, Iowa State University, Ames, IA 50011, USA
[c]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA
[d]Department of Natural Resource Management, South Dakota State University, Brookings, SD 57007, USA
[e]Department of Forestry and Environmental Resources, Fisheries, Wildlife, and Conservation Biology Program, North Carolina State Univeristy, Raleigh, NC 27695, USA
[f]Illinois Department of Natural Resources, 1 Natural Resources Way, Springfield, IL 62702, USA

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ABSTRACT Camera-trapping data analyzed with spatially explicit capture–recapture (SCR) models can provide a rigorous method for estimating density of small populations of elusive carnivore species. We sought to develop and evaluate the efficacy of SCR models for estimating density of a presumed low-density bobcat (Lynx rufus) population in fragmented landscapes of west-central Illinois, USA. We analyzed camera-trapping data from 49 camera stations in a 1,458-km2 area deployed over a 77-day period from 1 February to 18 April 2017. Mean operational time of cameras was 52 days (range = 32–67 days). We captured 23 uniquely identifiable bobcats 113 times and recaptured these same individuals 90 times; 15 of 23 (65.2%) individuals were recaptured at ≥2 camera traps. Total number of bobcat capture events was 139, of which 26 (18.7%) were discarded from analyses because of poor image quality or capture of only a part of an animal in photographs. Of 113 capture events used in analyses, 106 (93.8%) and 7 (6.2%) were classified as positive and tentative identifications, respectively; agreement on tentative identifications of bobcats was high (71.4%) among 3 observers. We photographed bobcats at 36 of 49 (73.5%) camera stations, of which 34 stations were used in analyses. We estimated bobcat density at 1.40 individuals (range = 1.00–2.02/100 km^2). Our modeled bobcat density estimates are considerably below previously reported densities (30.5 individuals/100 km^2) within the state, and among the lowest yet recorded for the species. Nevertheless, use of remote cameras and SCR models was a viable technique for reliably estimating bobcat density across west-central Illinois. Our research establishes ecological benchmarks for understanding potential effects of colonization, habitat fragmentation, and exploitation on future assessments of bobcat density using standardized methodologies that can be compared directly over time. Further application of SCR models that quantify specific costs of animal movements (i.e., least-cost path models) while accounting for landscape connectivity has great utility and relevance for conservation and management of bobcat populations across fragmented Midwestern landscapes. Published June 2019

Machine learning to classify animal species in camera trap images: Applications in ecology

Michael A. Tabak, Mohammad S. Norouzzadeh, David W. Wolfson, Steven J. Sweeney, Kurt C. Vercauteren, Nathan P. Snow, Joseph M. Halseth, Paul A. Di Salvo, Jesse S. Lewis, Michael D. White, Ben Teton, James C. Beasley, Peter E. Schlichting, Raoul K. Boughton, Bethany Wight, Eric S. Newkirk, Jacob S. Ivan, Eric A. Odell, Ryan K. Brook, Paul M. Lukacs, Anna K. Moeller, Elizabeth G. Mandeville, Jeff Clune, Ryan S. Miller (reference publication for author affiliations)

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Abstract

1. Motion-activated cameras (“camera traps”) are increasingly used in ecological and management studies for remotely observing wildlife and are amongst the most powerful tools for wildlife research. However, studies involving camera traps result in millions of images that need to be analysed, typically by visually observing each image, in order to extract data that can be used in ecological analyses.

2. We trained machine learning models using convolutional neural networks with the ResNet-18 architecture and 3,367,383 images to automatically classify wildlife species from camera trap images obtained from five states across the United States. We tested our model on an independent subset of images not seen during training from the United States and on an out-of-sample (or "out-of-distribution" in the machine learning literature) dataset of ungulate images from Canada. We also tested the ability of our model to distinguish empty images from those with animals in another out-of-sample dataset from Tanzania, containing a faunal community that was novel to the model.
3. The trained model classified approximately 2,000 images per minute on a laptop computer with 16 gigabytes of RAM. The trained model achieved 98% accuracy at identifying species in the United States, the highest accuracy of such a model to date. Out-of-sample validation from Canada achieved 82% accuracy and correctly identified 94% of images containing an animal in the dataset from Tanzania. We provide an R package (Machine Learning for Wildlife Image Classification) that allows the users to (a) use the trained model presented here and (b) train their own model using classified images of wildlife from their studies.
4. The use of machine learning to rapidly and accurately classify wildlife in camera trap images can facilitate non-invasive sampling designs in ecological studies by reducing the burden of manually analysing images. Our R package makes these methods accessible to ecologists. Published Nov. 2018

GENETICS AND DISEASE RESEARCH

The cascading effects of human food on hibernation and cellular aging in free-ranging black bears

Rebecca Kirby,[a] Heather E. Johnson,[b] Mathew W. Alldredge,[b] and Johathan N. Pauli[a]
[a]Department of Forestry and Wildlife Ecology, University of Wisconsin–Madison, USA
[b]Mammals Research Section, Colorado Parks and Wildlife, Durango and Fort Collins, USA

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ABSTRACT Human foods have become a pervasive subsidy in many landscapes, and can dramatically alter wildlife behavior, physiology, and demography. While such subsidies can enhance wildlife condition, they can also result in unintended negative consequences on individuals and populations. Seasonal hibernators possess a remarkable suite of adaptations that increase survival and longevity in the face of resource and energetic limitations. Recent work has suggested hibernation may also slow the process of senescence, or cellular aging. We investigated how use of human foods influences hibernation, and subsequently cellular aging, in a large-bodied hibernator, black bears (*Ursus americanus*). We quantified relative telomere length, a molecular marker for cellular age, and compared lengths in adult female bears longitudinally sampled over multiple seasons. We found that bears that foraged more on human foods hibernated for shorter periods of time. Furthermore, bears that hibernated for shorter periods of time experienced accelerated telomere attrition. Together these results suggest that although hibernation may ameliorate cellular aging, foraging on human food subsidies could counteract this process by shortening hibernation. Our findings highlight how human food subsidies can indirectly influence changes in aging at the molecular level. Published February 2019

Identification of circular single-stranded DNA viruses in faecal samples of Canada lynx (*Lynx canadensis*), moose (*Alces alces*) and snowshoe hare (*Lepus americanus*) inhabiting the Colorado San Juan Mountains

Simona Kraberger,[a] Kara Waits,[b] Jake Ivan,[c] Eric Newkirk,[c] Sue VandeWoude,[a] and Arvind Varsani[b]
[a]Department of Microbiology, Immunology & Pathology, Colorado State University, Fort Colling, CO 80523, USA
[b]The Biodesign Center for Fundamental and Applied Microbiomics, Center for Evolution and Medicine, School of Life Sciences, Arizona State University, Tempe, AZ 85287, USA
[c]Mammals Research Section, Colorado Parks and Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, USA

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ABSTRACT The San Juan Mountains of southern Colorado provide subalpine habitat for a suite of mammalian species including Canada lynx (*Lynx canadensis*), moose (*Alces alces*) and snowshoe hare (*Lepus americanus*). In the winter field season of 2016 five faecal samples from lynx, and one each from moose and snowshoe hare were collected to identify small single-stranded DNA viruses associated with these three prominent species. Thirty-two novel viruses were identified and classified as members of two well established ssDNA families *Genomoviridae* ($n = 22$) and *Microviridae* ($n = 10$) and one recently proposed new family, *Smacoviridae* ($n = 1$). In addition one highly novel circular ssDNA virus was identified which at present does not group with any known family. A high level of genomovirus diversity was identified from faeces collected between and across the three mammal species, with full genome-wide pairwise comparisons showing 57%–97% identity. Twenty genomoviruses can be assigned to the genus *Gemycircularvirus* and represent 11 species, and two into a distinct species in the genus *Gemykolovirus*. The single smacovirus identified from moose also represents a distinct smacovirus species. Ten microviruses, seven from moose, one from snowshoe hare and two from lynx, all are part of the *Gokushovirinae* subfamily. The two from lynx are highly similar to a microvirus previously detected in domestic cat (sharing 88%–90% genome-wide identity), indicating this may be a common felid gut microbiome associated virus. Our findings highlight the broad range of diverse ssDNA viruses present in three mammals inhabiting the San Juan Mountains. Published Oct. 2018

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

Daryl R. Trumbo,[a] Patricia E. Salerno,[a] Kenneth A. Logan,[b] Mathew W. Alldredge,[b] Roderick B. Gagne,[c] Christopher P. Kozakiewicz,[d] Simona, Kraberger,[c] Nicholas, M. Fountain-Jones,[e] Meggan E. Craft,[e] Scott Carver,[d] Holly B. Ernest,[f] Kevin R. Crooks,[g] Sue VandeWoude,[c] and W. Chris Funk[a]
aDepartment of Biology, Colorado State University, Fort Collins, CO, USA

bMammals Research Section, Colorado Parks and Wildlife, Montrose and Fort Collins, CO, USA
cDepartment of Microbiology, Immunology, and Pathology, Colorado State University, Fort Collins, CO, USA
dDepartment of Biological Sciences, University of Rasmania, Hobart, TAS., Australia
eDepartment of Veterinary Population Medicine, University of Minnesota, Saint Paul, MN, USA
fDepartment of Veterinary Sciences, University of Wyoming, Laramie, WY, USA
gDepartment of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, CO, USA

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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