COLORADO PARKS & WILDLIFE

Wildlife Research Reports

MAMMALS – JANUARY 2023

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WILDLIFE RESEARCH REPORTS

JULY 2021–DECEMBER 2022

MAMMALS RESEARCH PROGRAM

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

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EXECUTIVE SUMMARY

This Wildlife Research Report represents summaries (≤5 pages each with tables and figures) of wildlife research projects conducted by the Mammals Research Section of Colorado Parks and Wildlife (CPW) during 2021 and 2022. These research efforts represent long-term projects (4–11 years) in various stages of completion addressing applied questions to benefit the management and conservation of various mammal species in Colorado. In addition to the research summaries presented in this document, more technical and detailed versions of most projects (Annual Federal Aid Reports) and related scientific publications that have thus far been completed can be accessed on the CPW website at http://cpw.state.co.us/learn/Pages/ResearchMammalsPubs.aspx or from the project principal investigators listed at the beginning of each summary.

Current research projects address various aspects of wildlife management and ecology to enhance understanding and management of wildlife responses to habitat alterations, human-wildlife interactions, and investigating improved approaches for wildlife population monitoring and management. The Nongame Mammal Conservation Section addresses ongoing monitoring of lynx in the San Juan mountain range and preliminary results addressing influence of forest management practices on snowshoe hare density in Colorado. The Ungulate Management and Conservation Section includes a project addressing mule deer/energy development interactions to inform future development planning, a pilot evaluation of moose behavioral response to recent wolf-pack establishment in North Park, Colorado, an evaluation of factors influencing elk calf recruitment, and two studies addressing elk response to human recreation. The Predatory Mammals Management and Conservation Section describes a pilot research project developing longer-term research to address bobcat population demographics and improved monitoring approaches.

In addition to the ongoing project summaries described above, Appendix A includes final results presented to U.S. Bureau of Land Management addressing development of a spatial energy development planning tool to guide mule deer management on winter range. Appendix B includes publication abstracts (<1 page summaries) completed by CPW research staff since July 2021. These scientific publications provide results from recently completed CPW research projects and other collaborations with universities and wildlife management agencies. Topics addressed include nongame species ecology and conservation (application of joint species distribution models and a comparison of Canada lynx distribution pre and post spruce beetle outbreak), carnivore ecology and management (literature review related to common management questions associated with human-cougar interactions, an evaluation of human impact on movement and habitat use by male brown bears, and 3 publications addressing wolf-disease/parasite relationships), ungulate ecology and management (applying memory covariates to enhance assessment of mule deer habitat use patterns, addressing the influence of willow nutrition on moose calving rates, 2 publications addressing CWD status and data standardization for white-tailed deer management, factors influencing elk productivity and recruitment, and plant and mule deer responses to 3 mechanical treatment methods), university collaborations addressing wildlife genetics and disease research (characteristics of anelloviruses in domestic and wild cat species, and reconstructing viral phylogenies from commonly collected mountain lion tooth samples), and a *Journal of Wildlife Management* editorial evaluating the journal from established career scientists to provide suggestions for future improvement.

We have benefitted from numerous collaborations that support these projects and the opportunity to work with and train wildlife technicians and graduate students that will likely continue their careers in wildlife management and ecology in the future. Research collaborators include the CPW Wildlife Commission, statewide CPW personnel, Federal Aid in Wildlife Restoration, Colorado State University, Montana State University, University of Wyoming, Southern Illinois University, U.S. Bureau of Land Management, U.S. Forest Service, CPW big game auction-raffle grants, Species Conservation Trust Fund, Great Outdoors Colorado, CPW Habitat Partnership Program, Rocky Mountain Elk Foundation, Colorado Mule Deer Association, The Mule Deer Foundation, Muley Fanatic Foundation, EnCana Corp., ExxonMobil/XTO Energy, Marathon Oil, Shell Exploration and Production, WPX Energy, and numerous private land owners providing access to support field research projects.

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TABLE OF CONTENTS
MAMMALS WILDLIFE RESEARCH REPORTS

NONGAME MAMMAL CONSERVATION

UNGULATE MANAGEMENT AND CONSERVATION

PREDATORY MAMMAL MANAGEMENT AND CONSERVATION

APPENDIX B. MAMMALS RESEARCH PUBLICATION ABSTRACTS

NONGAME MAMMAL CONSERVATION

CANADA LYNX MONITORING IN COLORADO 2020-2021

CANADA LYNX MONITORING IN COLORADO 2021-2022

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

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Canada lynx monitoring in Colorado 2020 – 2021

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

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

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In an effort to restore a viable population of Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006. In 2010, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) determined that the reintroduction effort met all benchmarks of success and that the population of Canada lynx in the state was apparently viable and self-sustaining. In order to track the persistence of this new population and thus determine the long-term success of the reintroduction, a minimally-invasive, statewide monitoring program is required. From 2014−2021 CPW initiated a portion of the statewide monitoring scheme described in Ivan (2013) by completing surveys in a random sample of monitoring units ($n = 50$) from the San Juan Mountains in southwest Colorado ($n = 179$ total units; Figure 1).

During the 2020−2021 winter, personnel from CPW and USFS completed the seventh year of monitoring work on this same sample. Fourteen units were sampled via snow-tracking surveys conducted between December 1 and March 31. On each of 1–3 independent occasions, survey crews searched roadways (snow-covered paved roads and logging roads) and trails for lynx tracks. Crews searched the maximum linear distance of roads possible within each survey unit given safety and logistical constraints. Each survey covered a minimum of 10 linear kilometers (6.2 miles) distributed across at least 2 quadrants of the unit. The remaining 36 units could not be surveyed via snow tracking. Instead, survey crews deployed 4 passive infrared motion cameras in each of these units during fall 2020. Cameras were lured with visual attractants and scent lure to enhance detection of lynx in the area. Cameras were retrieved during summer or fall 2021 and all photos were archived and viewed by at least 2 observers to determine species present in each. Camera data were then binned such that each of 10 15-day periods from December 1 through April 30 was considered an 'occasion,' and any photo of a lynx obtained during a 15-day period was considered a 'detection' during that occasion.

Surveyors covered 744 km during snow tracking surveys and detected lynx at 7 units (Table 1). In 2020-21 surveyors collected more DNA samples than in previous years, likely because new environmental DNA (eDNA) sampling is more efficient to collect than the previous scat or hare sampling. As in 2019-20, significantly more photos were collected in 2020-21 than in the first 5 seasons of sampling. This can be mostly attributed to the use of new, more sensitive cameras along with new, high-capacity memory cards. However, for the fourth year in a row, we collected <50% of the number of lynx photos taken during the initial years of the monitoring effort (Table 2). In fact, the 36 lynx photos collected during the 2019-20 and 2020-21 seasons are the fewest recorded since the inception of the project. We initially considered at least 3 possible explanations for the lack of photos collected in recent years. First, we hypothesized that abnormal snow patterns (lack of snow in 2017–18, record snow in 2018–19) could have impacted detection probability. Second, lack of detections could have been due to the new lure (Caven's Violator 7; Minnesota Trapline Products, https://www.minntrapprod.com/Bobcat-and-Lynx/products/829/) we used in 2017–18, 2018–19, 2019-20, and 2020-21 after the lure we used previously (Pikauba; Luerres Forget's Lures, http://www.leurresforget.com/product.php?id_product=15) became unavailable. Finally, it could be that lynx have disappeared from a number of camera units. Unfortunately, the changes in snow and lure were confounded for a few years, thus making it difficult to determine which factor resulted in fewer detections. However, 2019-20 and 2020-21 were normal snow years, yet the number of lynx photos was still low. This suggests that abnormal snow was not the cause of the pattern we observed. Also, the number of snow tracking units with lynx has remained fairly steady throughout the project; we can think of no reason why snow track units would remain occupied while lynx blinked out of camera units, unless just by chance. Thus, we suggest that the new lure is less effective than the original. Fortunately the original formulation, Pikauba, is again available and will be deployed for the 2021-22 survey. We plan to utilize this lure for the remainder of the survey efforts, provided it remains available.

We obtained lynx detections for the first time in a unit near Mesa Mountain in the La Garitas. This detection represents the northernmost detection of lynx since surveys began. We also detected lynx for the first time in the unit that encompasses Fern Creek and lower Trout Creek west of Creede. This unit, however, is surrounded by other units where lynx have been detected several times previously. After a 1-year absence, lynx were again detected in the Barlow Creek Unit near Rico and the Pass Creek Unit near Wolf Creek Pass; lynx were not detected at the two units adjacent to Pass Creek, or at the southern Conejos Peak Unit after having been detected in all 3 last year (Figure 1).

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

As has been the case since the inception of our monitoring program, the proportion of the sample unit covered by spruce-fir forest was significantly and positively associated with the initial occupancy estimate in the time series. Even though local colonization and extinction were allowed to vary freely from year to year, annual estimates were near zero and varied little ($\varepsilon = 0.00–0.08$; $\gamma = 0.00–0.10$). Accordingly, derived occupancy was relatively stable across years ($\psi = 0.26–0.38$). The slope of the trend in occupancy through time was slightly positive but not significantly different from zero ($\beta = 0.017$, SE = 0.01; Figure 2). These results suggests that future analyses may benefit from fitting models that hypothesize occupancy is at or near equilibrium and extinction/colonization are either Markovian (as modeled here) or possibly zero. Similar to previous years, detection probability was relatively high for snow tracking surveys ($p = 0.69$, SE = 0.06), lower for camera surveys ($p = 0.23$, SE = 0.03) using Pikauba, and lowest for camera surveys utilizing Violator 7 ($p = 0.06$, SE = 0.02). We estimated that 38% of the sample units in the San Juan's were occupied by lynx (95% confidence interval: 20–55%) during 2020–21 (Figure 2). The spatial distribution of lynx in the San Juan mountains remained largely unchanged (Figure 1).

Table 1. Summary statistics from snow tracking effort.

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

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

Table 2. Summary statistics from camera effort.

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

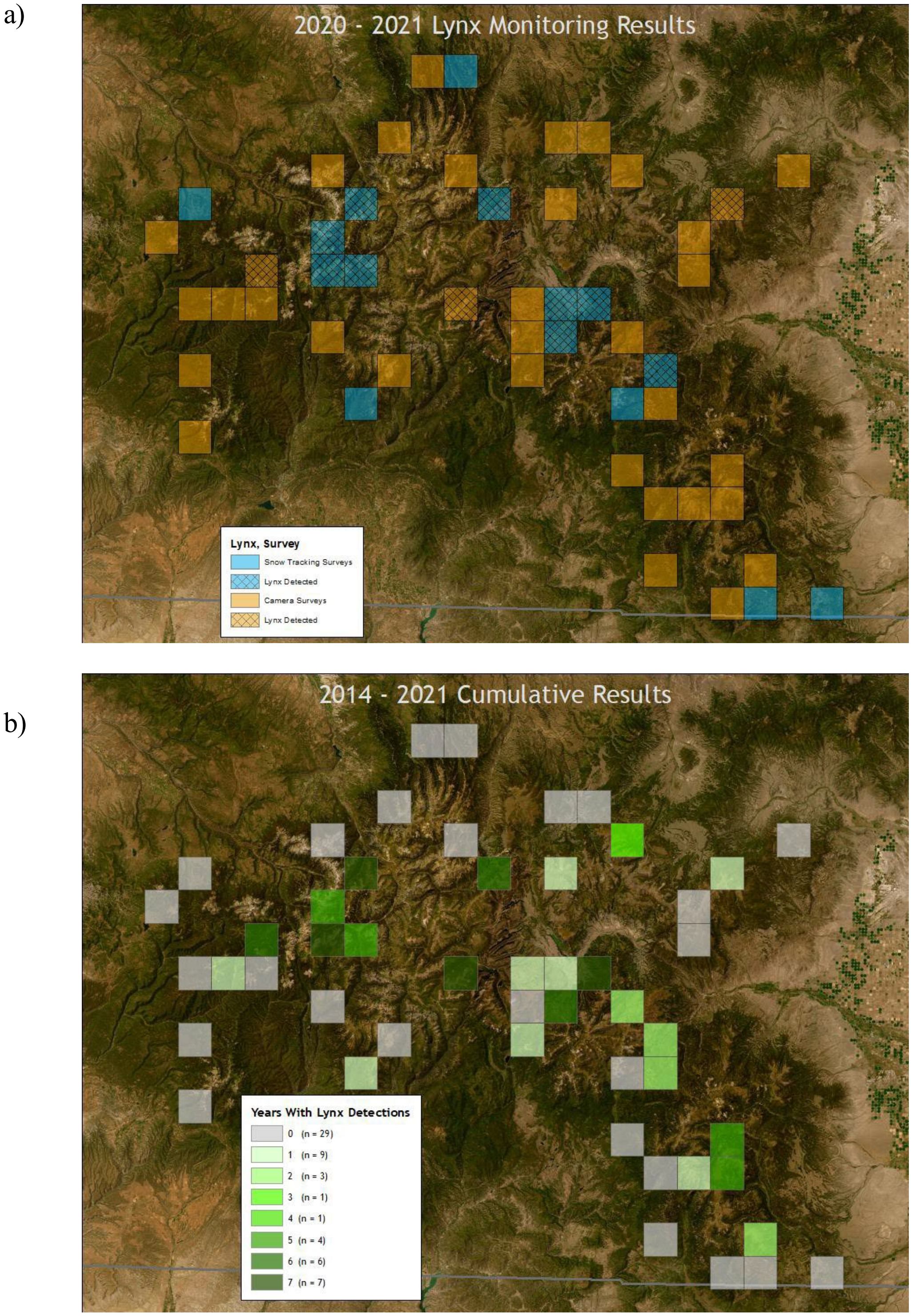

Figure 1. Lynx monitoring results for a) the current sampling season (2020–2021) and b) the cumulative monitoring effort (2014–2021), San Juan Mountains, southwest Colorado. Colored units (*n* = 50) depicted here are those selected at random from the population of units (*n* = 179) encompassing lynx habitat in the San Juan Mountains. Lynx were detected in 12 units in 2020−2021 and 24 units cumulatively since monitoring began in 2014−2015.

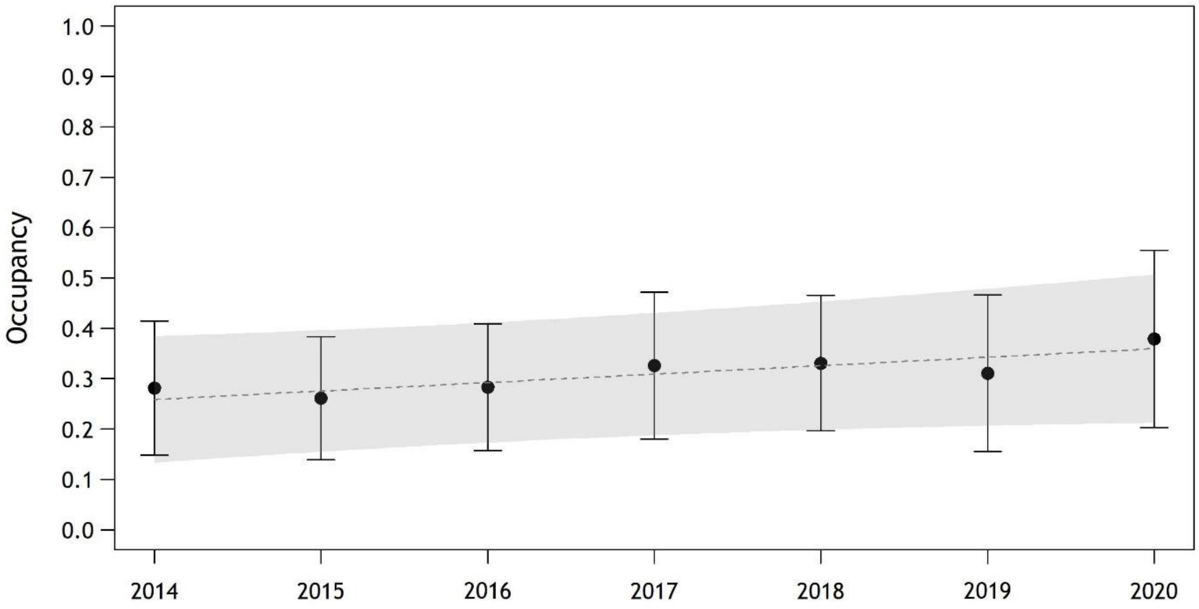

Figure 2. Occupancy estimates (Ψ) and trend (including 95%CI) for Canada lynx in the San Juan Mountains, southwest Colorado.

ERRATA: We note here that some data in Tables 1 and 2, and Figure 1 are incongruent with reports issued for the previous two seasons. This was due to inadvertent removal of filters in our database that were originally set to exclude pilot data from report tables, figures, and input files. These filters have been restored. The cumulative tables and figures presented here are accurate and supersede discrepancies with previous reports.

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Appendix 1. Model selection results for lynx monitoring data collected in the San Juan Mountains, Colorado, 2014–2021. Rankings are based on Akaike's Information Criterion adjusted for small sample size (AIC_c). We mostly sought to tease out best fitting models for detection, allowing constant detection (.), along with effects for survey type (ST), breeding season (B), substituting Violator 7 lure for Pikauba (V), and interactions to allow lure and breeding to act only on cameras. For these models we fixed the initial ψ to be a function of spruce-fir forest while local extinction (ε) and colonization (γ) were estimated annually to allow for non-equilibrium estimates in ψ that depended on previous year's occupancy state. Post-hoc, we added tested for equilibrium conditions (ε (.) γ (.)) or that occupancy from year to year was random ({ε = 1- γ}).

Model	AIC_c	ΔAIC_c	AIC_c Wts	No. Par.
ψ (Prop Spruce/Fir) ε (t) γ (t) *p* (ST+V+ST*V)	674.04	0.00	0.61	17
ψ (Prop Spruce/Fir) ε (t) γ (t) *p* (ST+B+V+ST*V)	675.88	1.85	0.24	18
ψ (Prop Spruce/Fir) ε (t) γ (t) *p* (ST+B+V+ST*B+ST*V)	676.77	2.74	0.15	19
ψ (Prop Spruce/Fir) ε (t) γ (t) *p* (ST)	697.55	23.52	0.00	15
ψ (Prop Spruce/Fir) ε (t) γ (t) *p* (ST+B)	699.41	25.38	0.00	16
ψ (Prop Spruce/Fir) ε (.) γ (.) *p* (.)	749.98	75.95	0.00	4
ψ (Prop Spruce/Fir) ε (t) γ (t) *p* (.)	768.42	94.38	0.00	14
ψ (Prop Spruce/Fir) {ε = 1- γ}*p* (1)	914.99	240.95	0.00	8

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Canada lynx monitoring in Colorado 2021 – 2022

Period Covered: July 1, 2021 – June 30, 2022

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

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During the 2021−2022 winter, personnel from CPW and USFS completed the eighth year of monitoring work on this same sample. Fourteen units were sampled via snow-tracking surveys conducted between December 1 and March 31. On each of 1–3 independent occasions, survey crews searched roadways (snow-covered paved roads and logging roads) and trails for lynx tracks. Crews searched the maximum linear distance of roads possible within each survey unit given safety and logistical constraints. Each survey covered a minimum of 10 linear kilometers (6.2 miles) distributed across at least 2 quadrants of the unit. The remaining 36 units could not be surveyed via snow tracking. Instead, survey crews deployed 4 passive infrared motion cameras in each of these units during fall 2021. Cameras were lured with visual attractants and scent lure to enhance detection of lynx in the area. Cameras were retrieved during summer or fall 2022 and all photos were archived and viewed by at least 2 observers to determine species present in each. Camera data were then binned such that each of 10 15-day periods from December 1 through April 30 was considered an 'occasion,' and any photo of a lynx obtained during a 15-day period was considered a 'detection' during that occasion.

Surveyors covered 692 km during snow tracking surveys and detected only 6 lynx tracks at 4 units, both all-time low for the program (Table 1). Significantly, more photos were collected in the past three seasons than in the first 5 seasons of sampling. This can be mostly attributed to the use of new, more sensitive cameras along with new, high-capacity memory cards. After four seasons (2017-2020) in which we collected the fewest lynx photos of any set of years on the project (<50% of the number of lynx photos taken during the initial years of the monitoring effort), the number of lynx photos collected this year rebounded substantially (Table 2). This substantiates our previous conclusions that the Violator7 lure (in use during those 4 season) was less effective than the Pikauba lure used this year and during the first 3 years of sampling. Pikauba will be utilized for the remainder of the survey efforts, provided it remains available.

We obtained lynx detections in the La Garita Mountains north of Creede for first time in 5 years. Lynx were detected in the two units near Conejos Peak after having not been detected last year. Snowtracking surveys did not provide lynx detections in either the Mineral Creek or Molas Pass units near Silverton, nor at the Lime Creek unit south of Creede. This lack of detections is notable because these 3 units are among the most reliable for detecting lynx in the entire study area; each has provided lynx detections for 6–7 of the 8 years these areas have been surveyed (Figure 1).

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

As has been the case since the inception of our monitoring program, the proportion of the sample unit covered by spruce-fir forest was significantly and positively associated with the initial occupancy estimate in the time series. Even though local colonization and extinction were allowed to vary freely from year to year, annual estimates were near zero and varied little ($\varepsilon = 0.00$–0.08; $\gamma = 0.00$–0.10) up until the most recent season when extinction probability was high ($\varepsilon = 0.40$, SE = 0.15). Accordingly, derived occupancy was relatively stable across years ($\psi = 0.26$–0.35), but dropped to the lowest level observed to date this past season ($\psi = 0.23$, SE = 0.07). The slope of the trend in occupancy through time was zero ($\beta = 0.001$, SE = 0.01; Figure 2), indicating stability. Similar to previous years, detection probability was relatively high for snow tracking surveys ($p = 0.65$, SE = 0.06), lower for camera surveys ($p = 0.22$, SE = 0.03) using Pikauba, and lowest for camera surveys utilizing Violator 7 ($p = 0.06$, SE = 0.02). We estimated that 24% of the sample units in the San Juan's were occupied by lynx (95% confidence interval: 11–37%) during 2021–22 (Figure 2). The broad spatial distribution of lynx in the San Juan's remained largely unchanged with the exception of no detection in 3 core snow tracking units where lynx are usually detected (Figure 1).

Table 1. Summary statistics from snow tracking effort.

Season	#Units Surveyed	#Units with Lynx	#Lynx Tracks	#Genetic Samples[a]	Lynx DNA[b]	Km Surveyed (Total)	Mean Km Surveyed per Visit	#CPW Personnel[c]	#USFS Personnel[c]
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2019-2020	14	7	11	3	2	640	19.4	15	3
2020-2021	15	9	14	12	7	790	18.8	17	3
2021-2022	13	4	6	5	4	692	18.7	11	3

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

Table 2. Summary statistics from camera effort.

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2017-2018	35	5	173,279	90	8	35	8
2018-2019	35	6	201,782	59	9	31	7
2019-2020	36	4	706,074	36	4	29	6
2020-2021	35	3	347,868	36	3	23	5
2021-2022	35	5	576,288	116	7	23	4

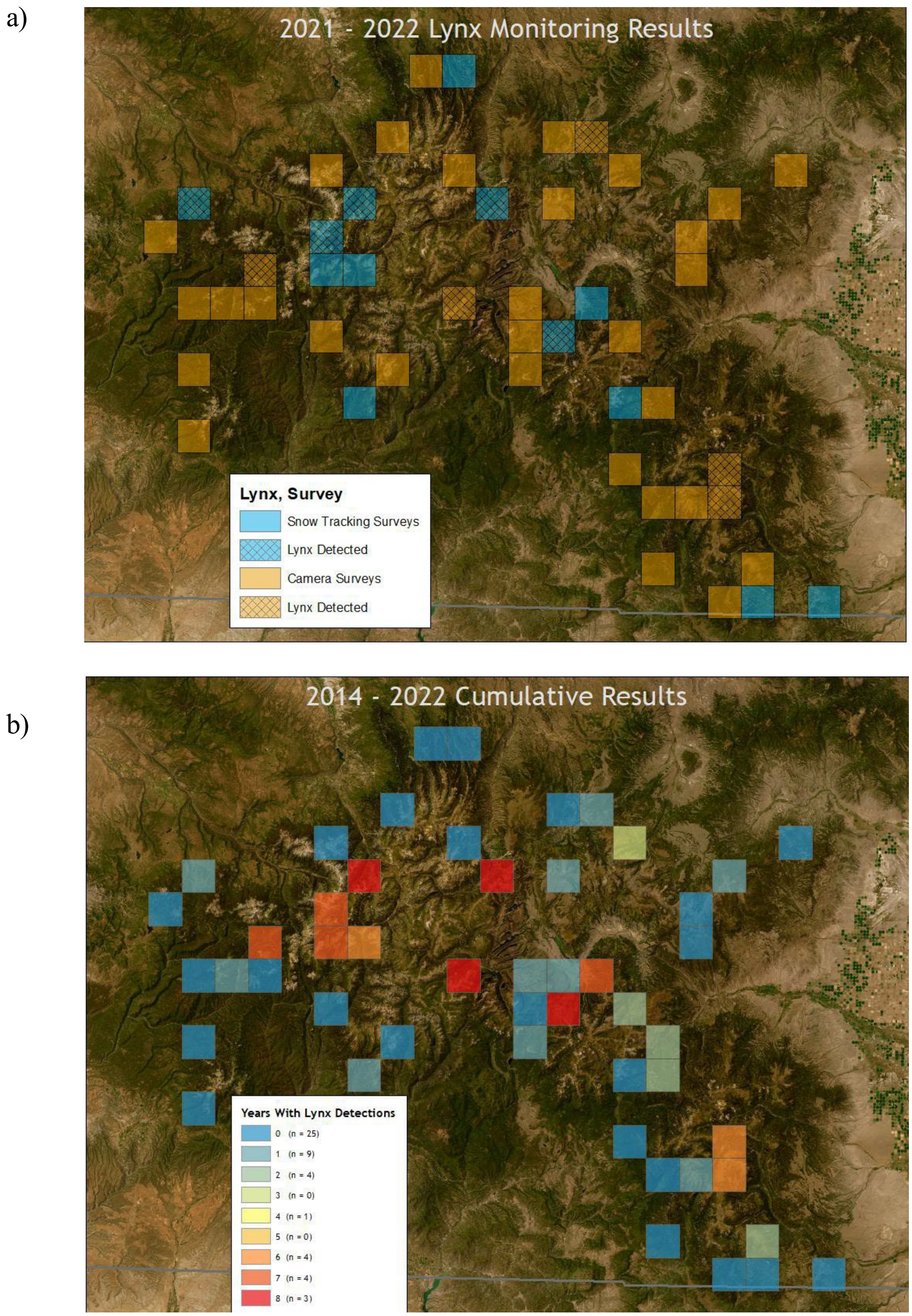

Figure 1. Lynx monitoring results for a) the current sampling season (2021–2022) and b) the cumulative monitoring effort (2014–2022), San Juan Mountains, southwest Colorado. Colored units (*n* = 50) depicted here are those selected at random from the population of units (*n* = 179) encompassing lynx habitat in the San Juan Mountains. Lynx were detected in 9 units in 2021−2022 and 25 units cumulatively since monitoring began in 2014−2015.

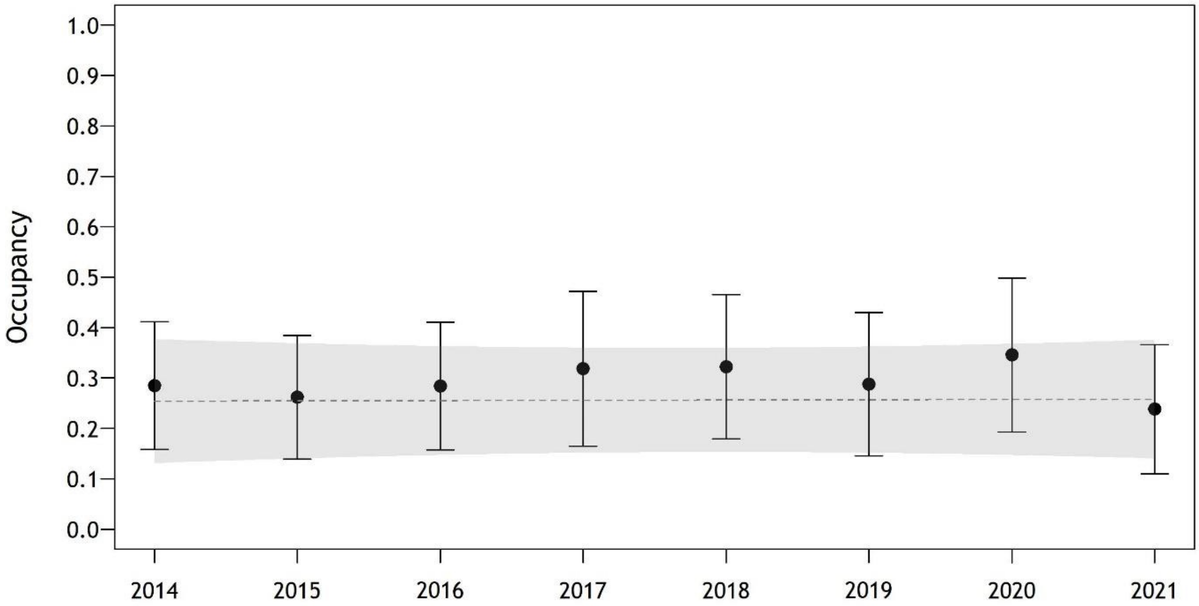

Figure 2. Occupancy estimates (Ψ) and trend (including 95%CI) for Canada lynx in the San Juan Mountains, southwest Colorado.

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Appendix 1. Model selection results for lynx monitoring data collected in the San Juan Mountains, Colorado, 2014–2022. Rankings are based on Akaike's Information Criterion adjusted for small sample size (AIC_c). We mostly sought to tease out best fitting models for detection, allowing constant detection (.), along with effects for survey type (ST), breeding season (B), substituting Violator 7 lure for Pikauba (V), and interactions to allow lure and breeding to act only on cameras. For these models we fixed the initial ψ to be a function of spruce-fir forest while local extinction (ε) and colonization (γ) were estimated annually to allow for non-equilibrium estimates in ψ that depended on previous year's occupancy state. Post-hoc, we added tested for equilibrium conditions (ε (.) γ (.)) or that occupancy from year to year was random ({$\varepsilon = 1- \gamma$}).

Model	AIC_c	ΔAIC_c	AIC_c Wts	No. Par.
ψ (Prop Spruce/Fir) ε (t) γ (t) p (ST+V+ST*V)	784.65	0.00	0.58	19
ψ (Prop Spruce/Fir) ε (t) γ (t) p (ST+B+V+ST*B+ST*V)	786.47	1.81	0.23	21
ψ (Prop Spruce/Fir) ε (t) γ (t) p (ST+B+V+ ST*V)	786.86	2.21	0.19	20
ψ (Prop Spruce/Fir) ε (t) γ (t) p (ST)	804.81	20.16	0.00	17
ψ (Prop Spruce/Fir) ε (t) γ (t) p (ST+B)	807.00	22.34	0.00	18
ψ (Prop Spruce/Fir) ε (.) γ (.) p (.)	859.30	74.64	0.00	4
ψ (Prop Spruce/Fir) ε (t) γ (t) p (.)	880.01	95.36	0.00	16
ψ (Prop Spruce/Fir) {$\varepsilon = 1- \gamma$}p (.)	1038.81	254.16	0.00	9

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, 2021 – June 30, 2022

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

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

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

During summer 2018, we established $n = 50$ 1-m^2 permanent circular plots within each of the stands selected for sampling. Plot locations within each stand were selected in a spatially balanced, random fashion. Technicians cleared and counted snowshoe hare pellets in each plot as they established them. These same plots were re-visited and re-counted during summers 2019 and 2020. In addition to sampling the previously cleared plots from 2018, technicians were able to install plots at 2 more replicate sites for each combination of forest type × management activity × time interval during 2019. Also, a handful of stands visited in 2019 and 2020 were re-classified or excluded because ground-truthing revealed they did not actually fit in the stratum for which they were selected. New stands were sampled in their place by pulling the next one from the spatially balanced list. Similarly, a handful more stands were replaced during the 2021 field season, and 12 new stands were selected to replace those that burned during the 2020 fire season. Currently, inference is based on $n = 130$ total stands. Finally, in 2021 and 2022, we sampled vegetation metrics in each stand that will hopefully account for the considerable noise we have observed (highly variable results for some strata) and allow us to better assess the effects of the treatments themselves.

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 2019‒22 data from previously cleared plots. For each forest type × management activity combination, we plotted mean pellet counts against "year since activity," then fit a curve (e.g., quadratic function) through the data (Figure 2).

Results from this preliminary analysis suggest that on average the highest snowshoe hare densities typically occur in unmanaged spruce-fir forests, and that unmanaged spruce-fir forests are estimated to have twice the relative hare density of unmanaged lodgepole pine forests (Figure 2). For both forest types, the fitted line suggests that even-aged management (e.g., clearcutting), immediately depresses relative hare density to near zero, but density rebounds and peaks 20-40 years after management before declining again 40-60 years after. Estimated peak hare densities after even-aged management in lodgepole systems tend to be higher than the control condition. However, in spruce-fir systems the estimated fitted line is flatter and peak densities fell short of the control condition. In both forest types, thinning (which often occurs 20-40 years after stands undergo even-aged management, especially in lodgepole) immediately depresses hare densities. In spruce-fir stands, densities were estimated to slowly recover through time in nearly linear fashion. However, they follow a peaked response in lodgepole pine, similar to the response to even-aged management. Uneven-aged management of spruce-fir forests results in immediate depression of relative hare density, which then recovers back to pre-treatment levels approximately 30 years after the treatment.

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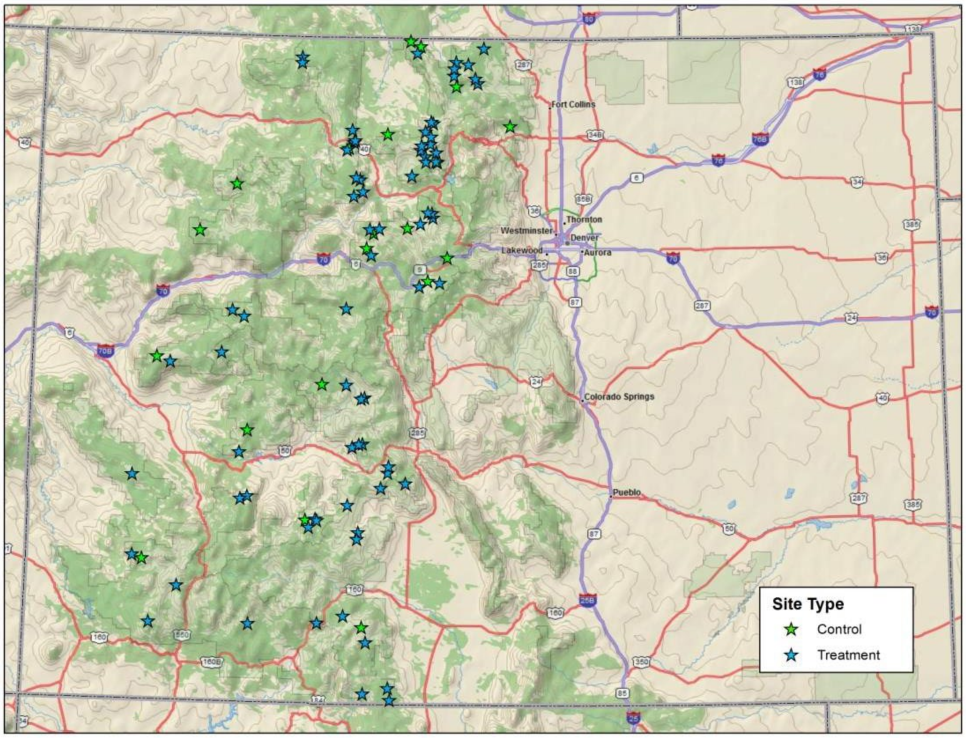

Figure 1. Location of all stands (*n* = 130) resampled for snowshoe hare pellets, June-September 2022.

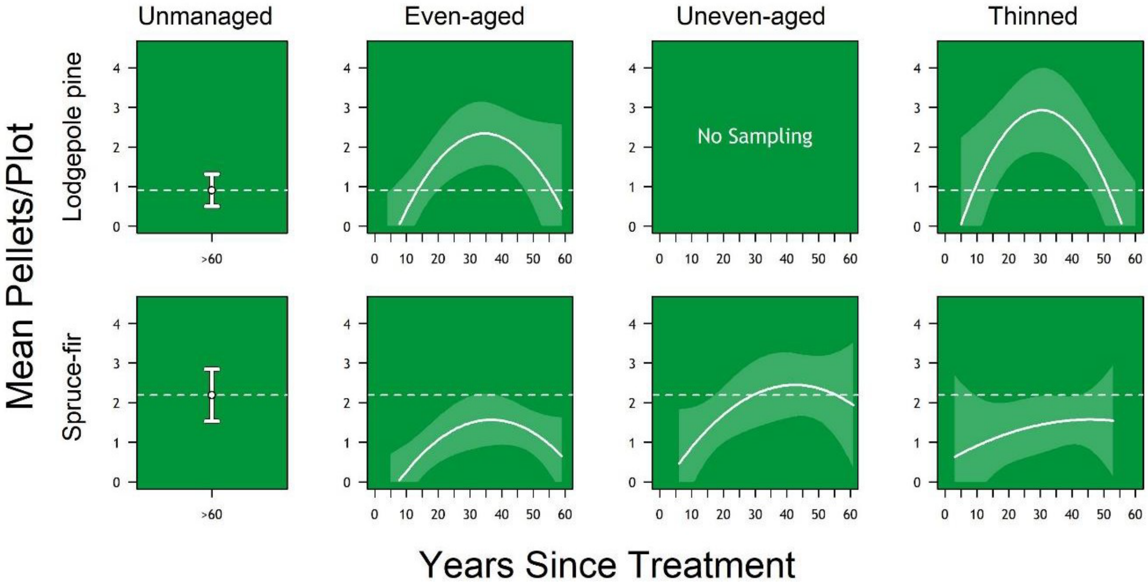

Figure 2. Fitted quadratic function (white line) and 95% CI (shaded polygon) relating pellet counts (i.e., relative snowshoe hare density) to time elapsed since treatment for each forest type × management activity combination. Dotted lines indicate the mean pellets/plot for the unmanaged controls for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

UNGULATE MANAGEMENT AND CONSERVATION

POPUATION PERFORMANCE OF PICEANCE BASIN MULE DEER IN RESPONSE TO NATURAL GAS RESOURCE EXTRACTION AND MITIGATION EFFORT TO ADDRESS HUMAN ACTIVITY AND HABITAT DEGREDATION

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

EVALUATING FACTORS INFLUENCING ELK RECRUITMENT IN COLORADO

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

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

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

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

Period Covered: July 1, 2021 – December 30, 2022

Principal Investigator: C. R. Anderson, Jr.

Personnel: D. Bilyeu-Johnston, CPW; M. Bonar, R. Marrotte J. Northrup, Trent University, Peterborough, Ontario, Canada; B. Gerber, University of Rhode Island; G. Wittemyer, Colorado State University. Project support received from Federal Aid in Wildlife Restoration, Bureau of Land Management, Colorado Mule Deer Association, Colorado Mule Deer Foundation, Muley Fanatic Foundation, Colorado State Severance Tax Fund, Caerus Oil and Gas LLC, EnCana Corp., ExxonMobil Production Co./XTO Energy, Marathon Oil Corp., Shell Petroleum, Williams and WPX Energy.

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

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

During this research segment, we developed an energy development planning tool to guide future energy development on mule deer winter range (Marrotte et al. 2022, Appendix A), and finalized 2 publications evaluating the influence of memory in mule deer habitat selection and site fidelity (Rheault et al. 2021, Appendix B) and addressing vegetation and mule deer responses to 3 mechanical treatment methods (Johnston and Anderson, *in press*, Appendix B). Results for this 11-year project (see Anderson 2021 for methods and previous publication abstracts) suggest: (1) annual adult female survival was consistent among areas averaging 79-87% annually, but overwinter fawn survival was variable, ranging from 31% to 95% within study areas, with annual and study area differences primarily due to early winter fawn condition, annual weather conditions, and factors associated with predation on winter range; (2) mule deer body condition early and late winter was generally consistent within areas, with higher variability among study areas early winter, primarily due to December lactation rates, and late winter condition related to seasonal moisture and winter severity; (3) late winter mule deer densities increased through 2016 in all study areas, ranging from 50% in North Ridge to 103% in North Magnolia, but have stabilized recently in 3 of the 4 study areas with recent decline evident in North Ridge (Figure 3); (4) migratory mule deer selected for areas with increased cover and increased their rate of travel through developed areas, and avoided negative influences through behavioral shifts in timing and rate of migration, but did not avoid development structures (Figure 4); (5) mule deer exhibited behavioral plasticity in relation to energy development, without evidence of demographic effects, where disturbance distance varied relative to diurnal extent and magnitude of development activity (Figure 5), which provide for useful mitigation options in future development planning; (6) energy development activity under existing conditions did not influence pregnancy rates, fetal rates or early fawn survival (0-6 months), but may have reduced fetal survival (March until birth) during 2012 when drought conditions persisted during the third trimester of doe parturition (Figure 6); and (7) mule deer use of treatment sites appears related to a combination of hiding cover, resulting from residual woody debris, and winter forage. Roller-chopped plots provide the best combination of hiding cover and winter forage, but mastication or chaining, applied leaving dispersed security cover, may be better options at large scales or when invasive species concerns exist.

Literature Cited:

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Johnston, D. B., and C. R. Anderson Jr. 2023. Plant and mule deer responses to pinyon-juniper removal by three mechanical treatment methods. Wildlife Society Bulletin, *In press*; DOI: 10.1002/wsb.1421

Marrotte, R. R., C. R. Anderson Jr. and J. M. Northrup. 2022. Developing a spatial planning tool for natural gas development on mule deer winter range. Final Report to Bureau of Land Management: Grant Agreement L18AC00068. 14pp.

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

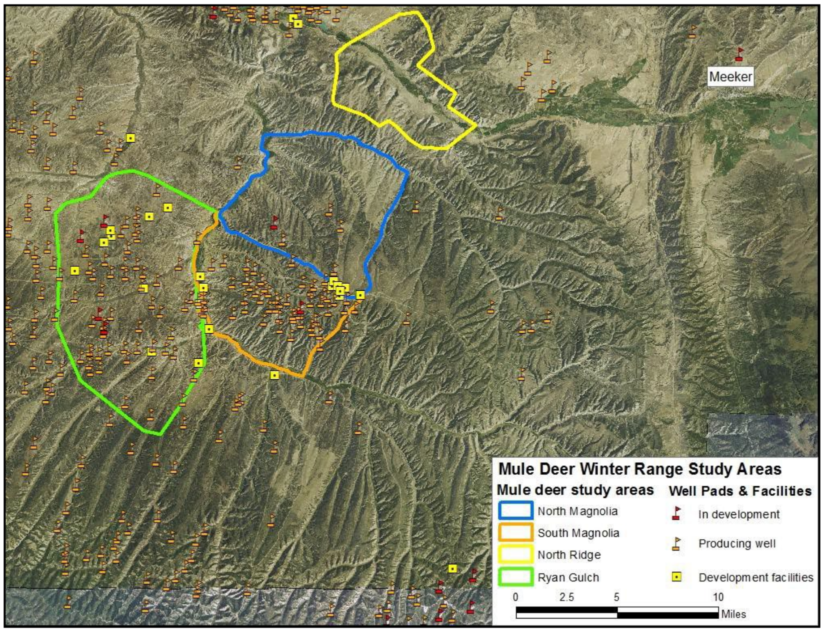

Figure 1. Mule deer winter range study areas relative to active natural gas well pads and energy development facilities in the Piceance Basin of northwest Colorado, winter 2013/14 (Accessed http://cogcc.state.co.us/ December 31, 2013; energy development activity has been minor since 2013).

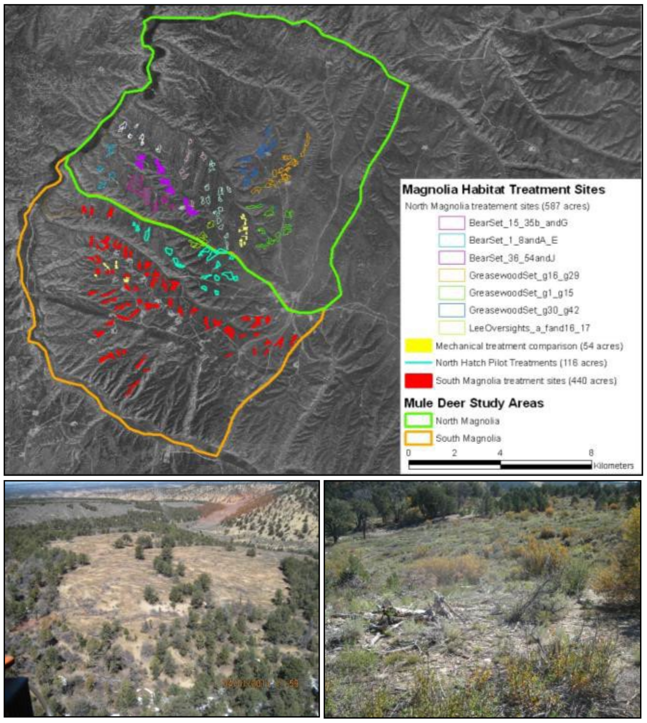

Figure 2. Habitat treatment site delineations in 2 mule deer study areas (604 acres each) of the Piceance Basin, northwest Colorado (Top; cyan polygons completed Jan 2011 using hydro-axe; yellow polygons completed Jan 2012 using hydro-axe, roller-chop, and chaining; and remaining polygons completed Apr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

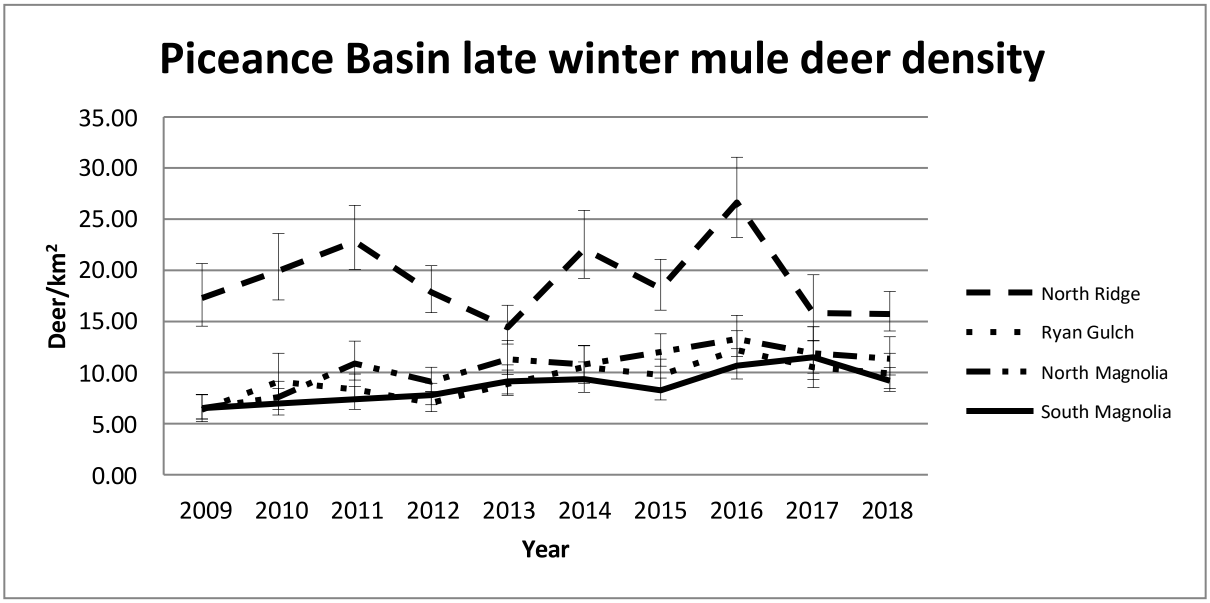

Figure 3. Mule deer density estimates and 95% CI (error bars) from 4 winter range herd segments in the Piceance Basin, northwest Colorado, late winter 2009–2018.

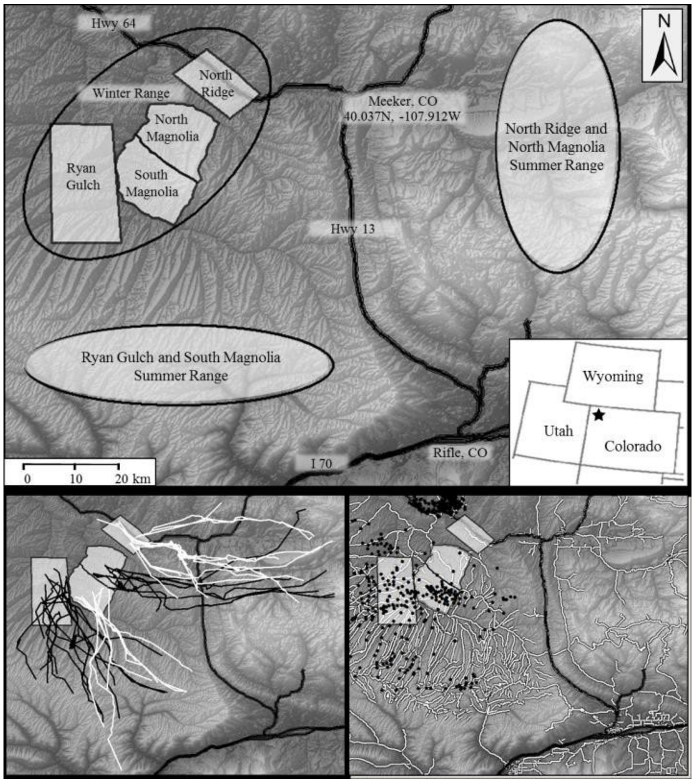

Figure 4. Mule deer study areas in the Piceance Basin of northwestern Colorado, USA (Top), spring 2009 migration routes of adult female mule deer (*n* = 52; Lower left), and active natural-gas well pads (black dots) and roads (state, county, and natural-gas; white lines) from May 2009 (Lower right; from 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).

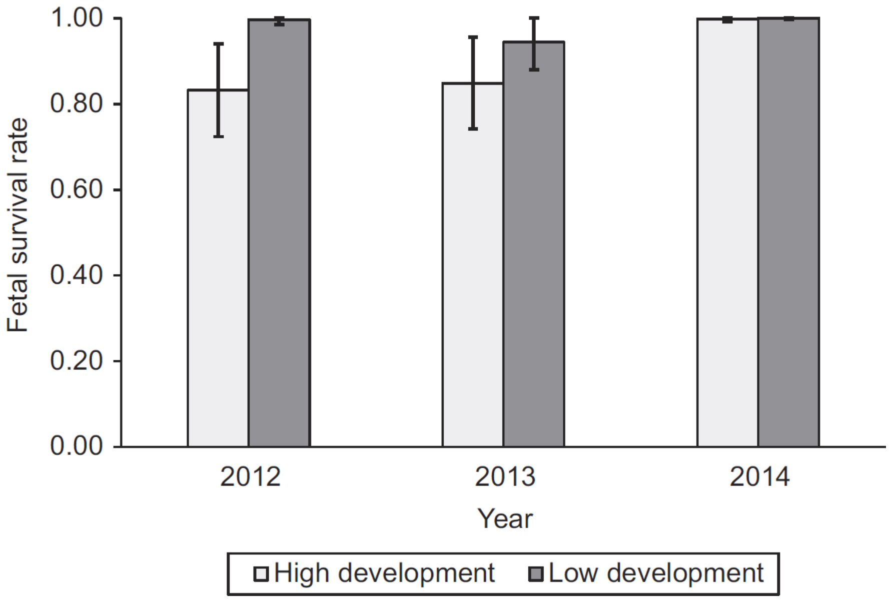

Figure 6. Model averaged estimates of mule deer fetal survival from early March until birth (late May–June) in high and low energy development study areas of the Piceance Basin, northwest Colorado, 2012–2014 (from Peterson et al. 2017; http://www.bioone.org/doi/pdf/10.2981/wlb.00341).

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

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

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

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

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

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

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

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

To implement this alternative approach to estimating calf survival, a total of 80 cow moose will be collared in North Park. Approximately 65 additional collars will be deployed during winter of 2022–2023. Collars will be deployed in a spatially balanced manner, with 40 collars on both the northern and southern halves of North Park. To expand this research to include additional prey species, 40 cow elk will be captured and collared during the winter of 2022–2023. Once available for observation, these elk will serve as sentinel animals that will allow researchers to quantify group size behavior, spatial distribution, and habitat use, relative to any known wolf activity.

Data collected from cow moose during 2022 did not deviate from data collected during 2013–2019. Between 2012–2022 survival of cow moose ranged from 91.2%–94.8%. During the same period, pregnancy rates of moose ranged from 54.8%–88.0.

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Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Evaluating factors influencing elk recruitment in Colorado

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

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

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

Since study initiation, we have collared 434 pregnant females in February-March, 702 neonates in May-August, and 196 6-month old calves in December (Table 1). Averaged across years, we estimated that the annual pregnancy rate of adult female elk was 93% in the Bear's Ears herd (excluding 2019 data where $n = 3$; range = 91-95%), 91% in the Trinchera herd (range = 78-96%), and 91% (range = 81-97%) in the Uncompahgre Plateau herd (Figure 3). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013). From 2017–2022, we estimated that the mean ingesta-free body fat (IFBF) of adult female elk was 6.90% in the Bear's Ears Herd, 7.30% in the Trinchera herd, and 7.39% in the Uncompahgre Plateau herd (Figure 4). When late-winter IFBF values are <8-9% for adult female elk that have lactated through the previous growing season, this suggests that there may be nutritional limitations, but it does not identify whether limitations are a result of summer-autumn or winter nutrition (R. Cook, personal communication). Averaged across years, we estimated that the mean date of calving was June 2 in the Bear's Ears and Trinchera herds, and June 3 in the Uncompahgre Plateau herd (Figure 5). We estimated that the mean weight of 6-month old elk calves was 221 lb (95% CI = 214.6-227.4 lb) from the Bear's Ears herd and 237.5 lb (95% CI = 231.1-243.9 lb) from the Uncompahgre Plateau elk herd.

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Table 1. The number of elk collared in each age class from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds from 2017-2022.

	Herd							
	E-2 Bear's Ears			E-20 Uncompahgre Plateau			E-33 Trinchera	
Year	Adult	Neonate	6-month	Adult	Neonate	6-month	Adult	Neonate
2017				23	40		22	57
2018				30	48		17	53
2019	2	49	25	30	49	25	30	46
2020	40	54	25	40	52	25	20	21
2021	40	53	25	40	52	25	20	21
2022	40	54	21	40	53	25		

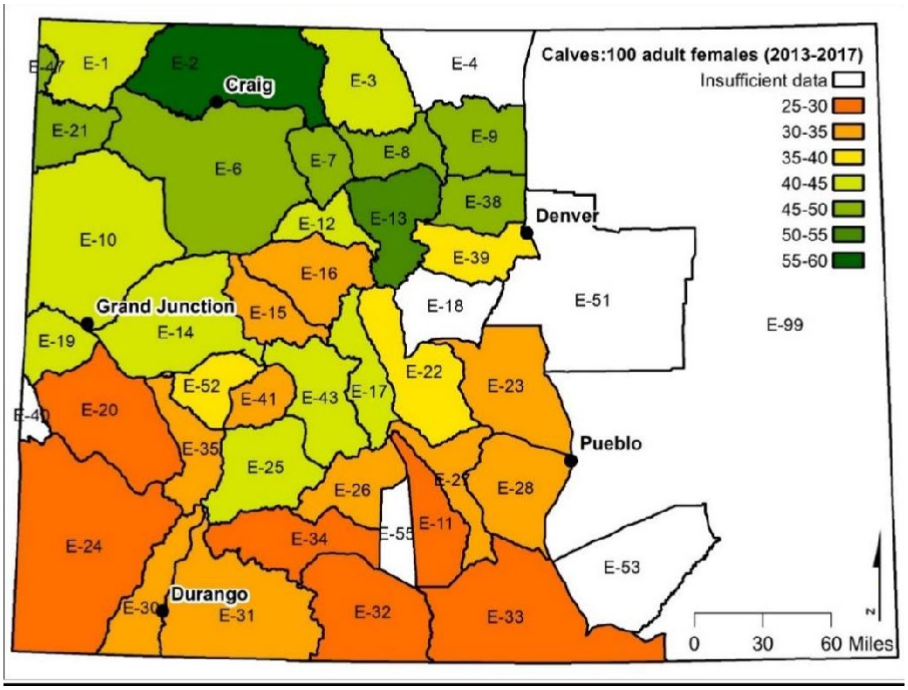

Figure 1. The number of elk calves per 100 adult females observed during December-February aerial surveys (5-year average from 2013-2017) within elk Data Analysis Units (DAUs; labeled with black text).

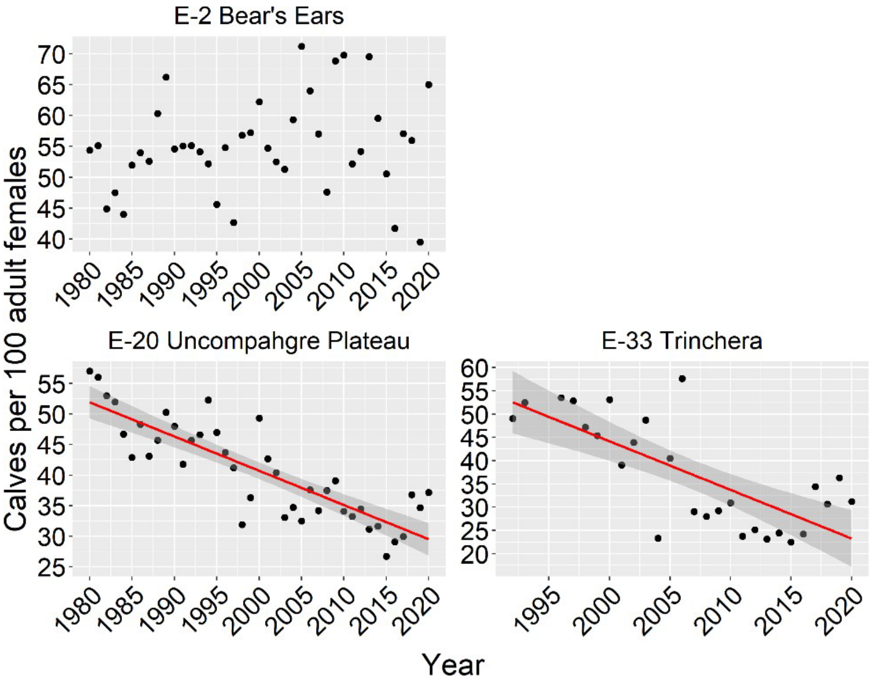

Figure 2. The estimated number of calves per 100 adult females observed annually during winter classification surveys in the Bear’s Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) elk herds from 1980-2020 (1992-2020 for the Trinchera herd). Red lines and shaded bands represent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

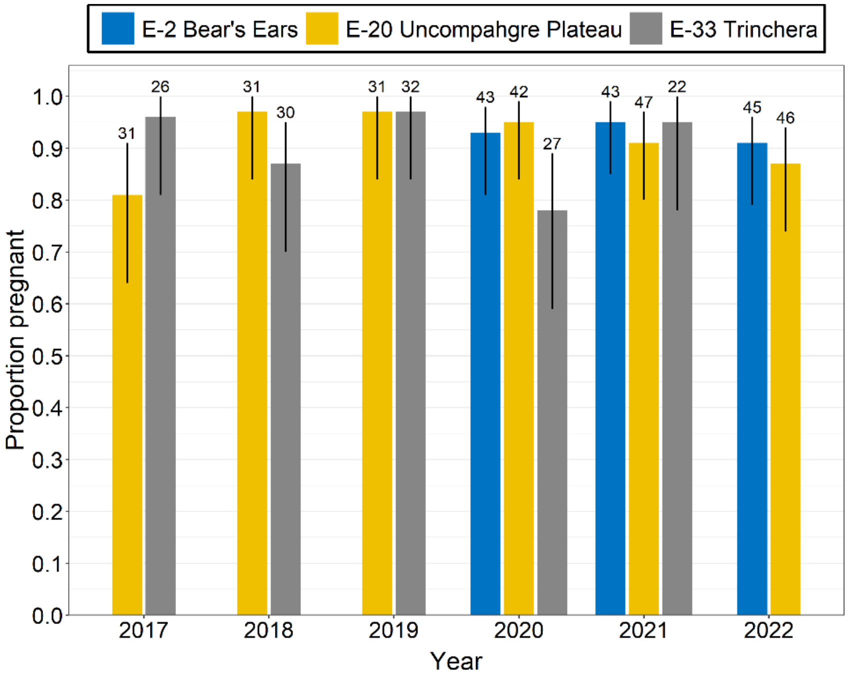

Figure 3. Estimated average pregnancy rates of adult female elk from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds sampled during late winter 2017-2022. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

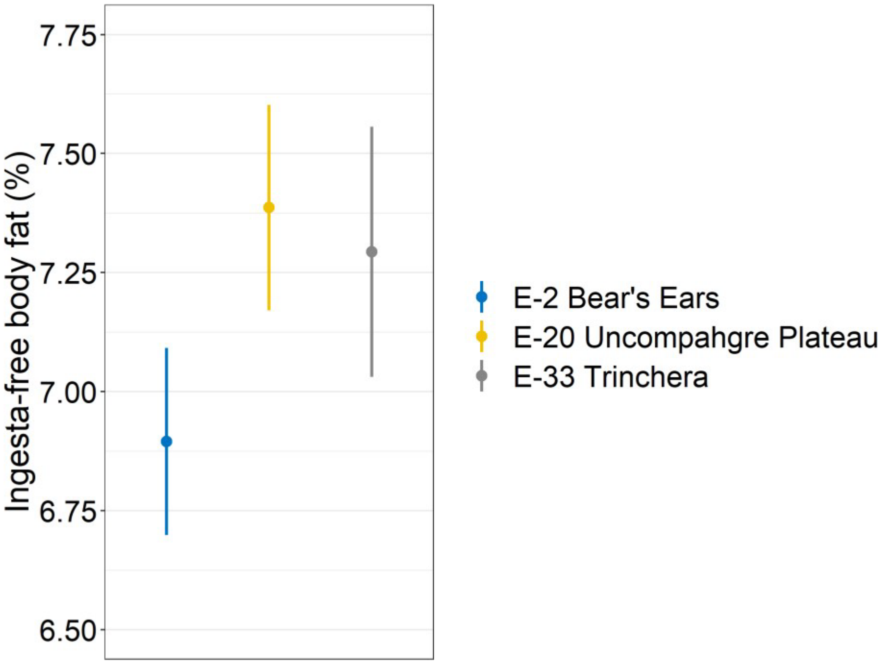

Figure 4. The estimated ingesta-free body fat (%) of adult female elk with 95% confidence intervals from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds sampled during late winter 2017-2022.

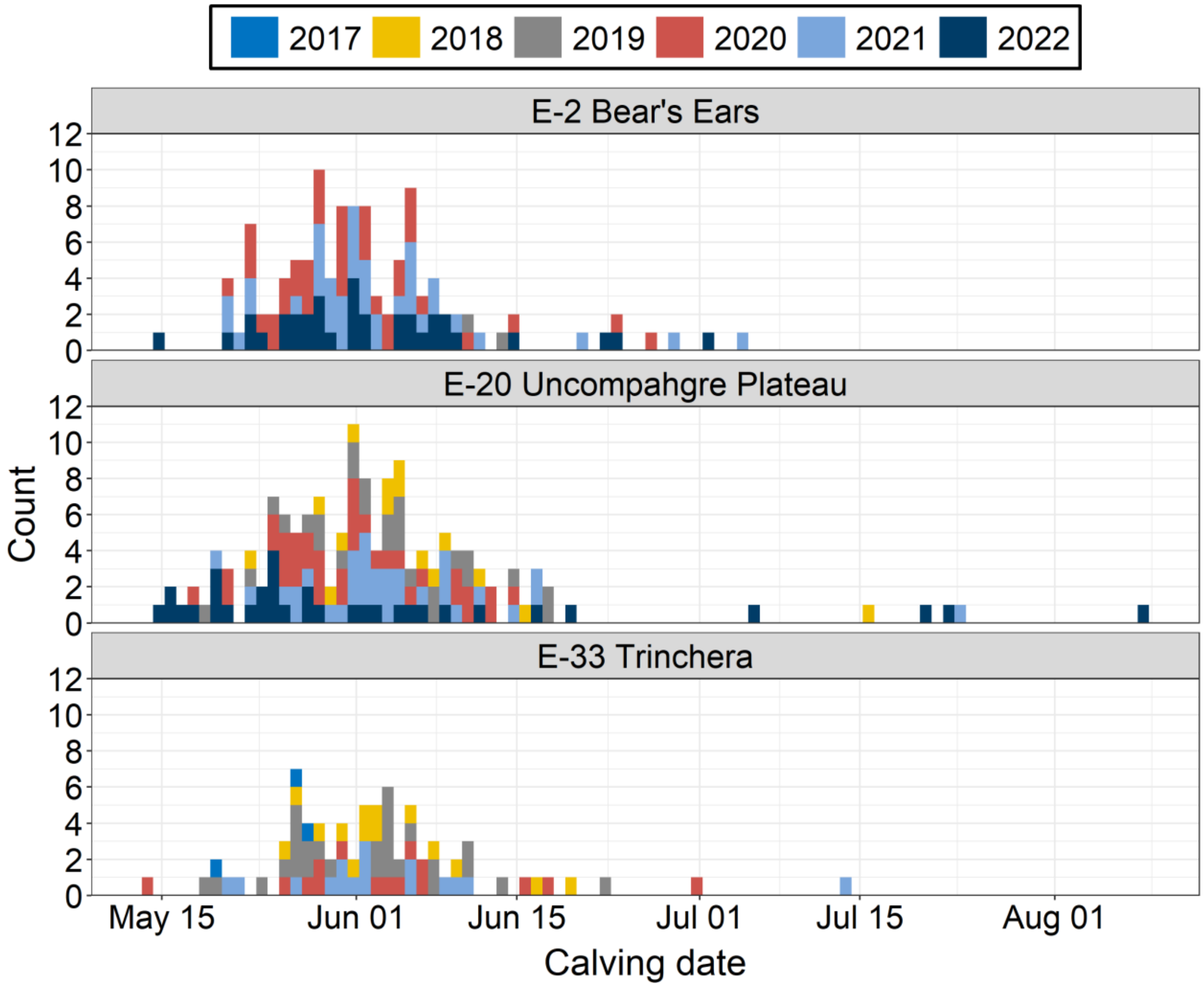

Figure 5. The estimated calving dates of collared female elk from the Bear's Ears (DAU E-2), Uncompahgre Plateau (DAU E-20), and Trinchera (DAU E-33) herds from 2017-2022.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

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

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

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

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This project has objectives on 2 scales. At the broad, elk herd-level scale, we are estimating pregnancy rates, calf survival rates, and cause-specific mortality rates to evaluate the importance of mortality sources for elk calf survival. More specifically, we are evaluating the influence of biotic (birth date, birth mass, gender, maternal body condition, habitat conditions), abiotic (previous and current weather conditions), and human-induced factors (i.e., relative exposure to recreational activities) on seasonal mortality risk of elk calves from birth to age 1 and on pregnancy rates of mature female elk. At the narrower geographic and temporal scale, we are using short-term (~3-4 weeks) changes in elk abundance within small study units (<65 km^2 [25 mi^2]) as a tool to evaluate the influence of human recreation on elk distribution. At this narrower scale, the primary objective is to evaluate the role that human recreation (e.g., hiking, mountain biking, horseback riding, trail running, hunting, etc.) has on the behavioral distribution of elk on spring calving, summer, and fall transition ranges. Coupled to the objective of detecting behaviorally influenced changes in abundance and density, we are evaluating the effectiveness of current recreational closures maintained by ski areas, counties, and federal land management agencies.

From 2019–2022, we have collared 144 pregnant females in March, 184 neonates in May-July, and 100 6-month old calves in December from the Avalanche Creek elk herd (Data Analysis Unit E-15; Table 1). Averaged across years, we estimated the annual pregnancy rate of adult female elk was 91% (95% CI = 85-95%; Fig. 1). Elk populations experiencing good to excellent summer-autumn nutrition typically have pregnancy rates ≥90% (Cook et al. 2013). We estimated that the mean ingesta-free body fat (IFBF) of adult female elk was 7.94 (95% CI = 7.59-8.31%). When late-winter IFBF values are <8-9% for adult female elk that have lactated through the previous growing season, this suggests that there may be nutritional limitations, but it does not identify whether limitations are a result of summer-autumn or winter nutrition (R. Cook, personal communication). Averaged across years, we estimated that the mean date of calving was June 3 (Fig. 2). We estimated that the mean weight of 6-month old elk calves was 247.9 lb (95% CI = 241.7-254.1).

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

Literature Cited:

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

Table 1. The number of elk collared in each age class from the Avalanche Creek elk herd (DAU E-15) from 2019–2022.

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

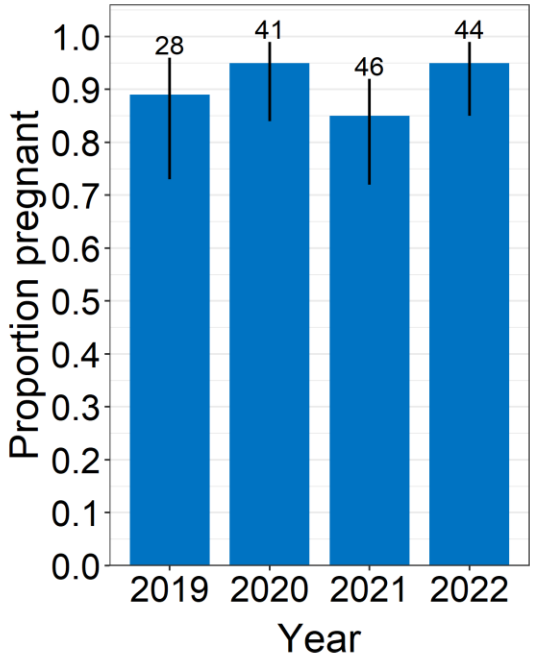

Figure 1. Estimated average pregnancy rates of adult female elk from the Avalanche Creek (DAU E-15) herds sampled during late winter 2019–2022. The sample size is given at the top of the 95% binomial confidence intervals (black lines).

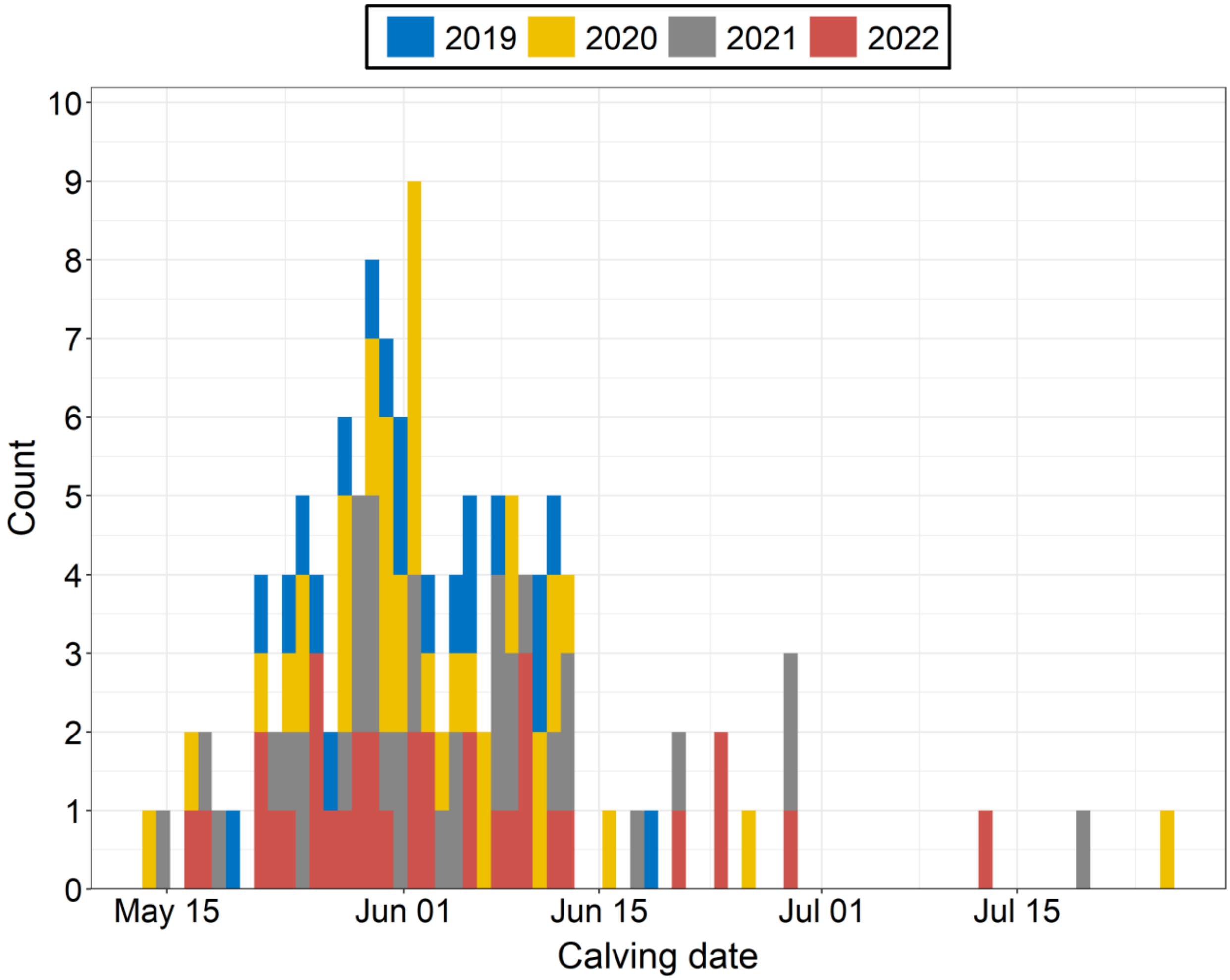

Figure 2. The estimated calving dates of collared female elk from the Avalanche Creek (DAU E-15) herd from 2019–2022.

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

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

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

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

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

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

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

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

During the 2020 and 2021 field season, we distributed handheld GPSs to recreationists (hikers, bikers, hunters) to record detailed tracks of human use within this trail system (Figure 3). In 2020, we collected over 100 GPS tracks. These tracks from recreationists and hunters will allow us to better quantify human recreation on the landscape and evaluate how elk respond to recreationists.

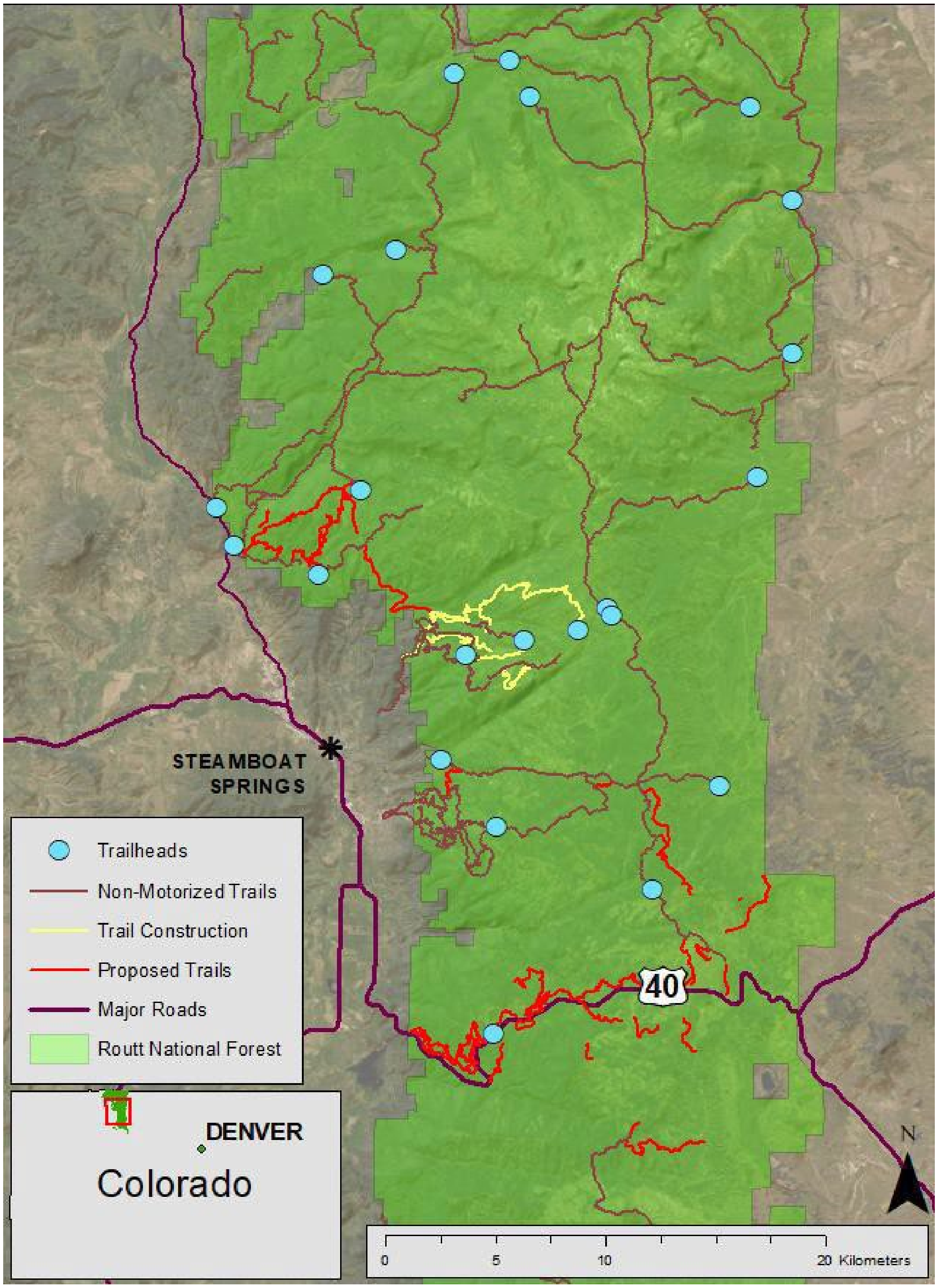

Figure 1. Routt National Forest study area located in northwest Colorado, USA.

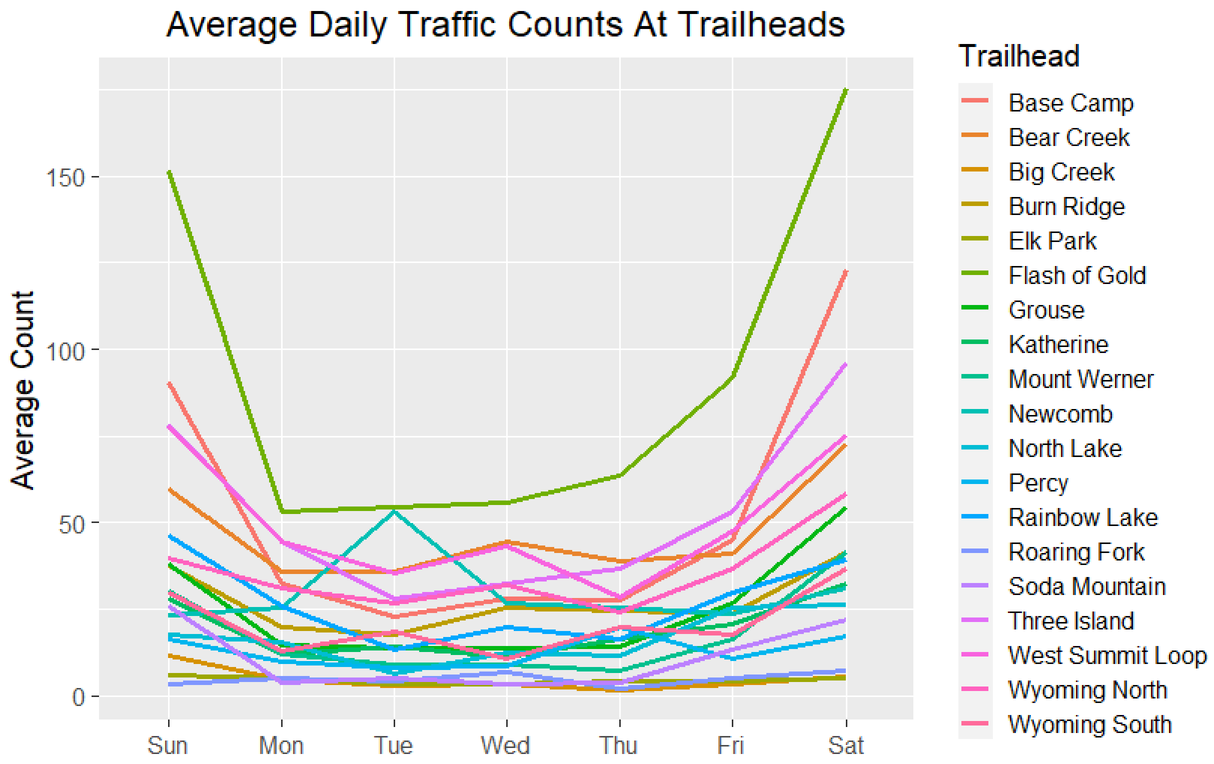

Figure 2. Daily trends in trailhead traffic documented with trail counters from June through October 2020, excluding Fish Creek Falls, Mad Creek, and Red Dirt trailheads, which received average daily counts >200.

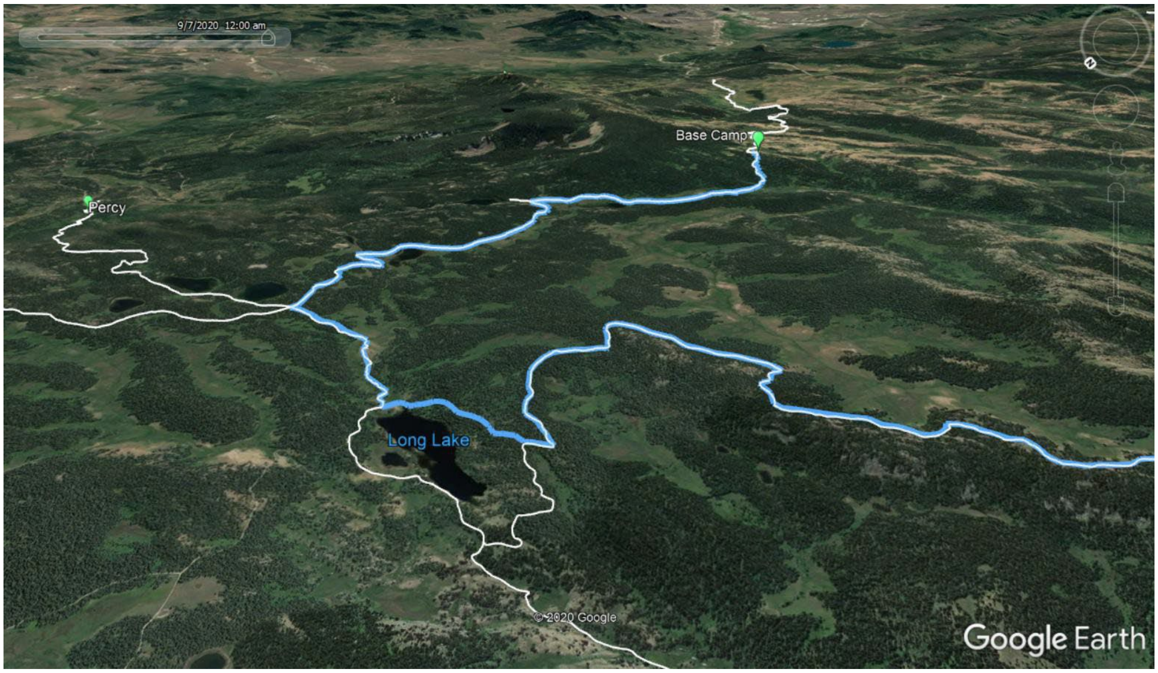

Figure 3. GPS track (blue) recorded from recreational mountain biker on trail system (white) in August 2020. Note the off-trail use near Long Lake.

PREDATORY MAMMALS MANAGEMENT AND CONSERVATION

BOBCAT POPULATION DENSITY ESTIMATION: A PILOT STUDY

Colorado Parks and Wildlife

WILDLIFE RESEARCH PROJECT SUMMARY

Bobcat Population Density Estimation: A Pilot Study

Period Covered: January 01, 2022 – December 31, 2022

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Personnel: Bill deVergie, Tom Knowles, Mike Swaro, Darby Finley, Garrett Smith, Brian Holmes, J.C. Rivale, Jenna Lopardo, Rhea Ebel-Childs, Tim Brtis, Doug Fitzpatrick, Rachel Baker, Charlee Manguso, Loredana McCurdy

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

We selected two study areas, 'Piceance' and 'Skull Creek,' in the northwest region within GMUs 10 and 22 (Figure 1). Each area was 20 x 20 km (400 km^2 area) in extent, with similar topography and habitat type composition. Piceance had higher historical bobcat harvest (>2.55 bobcats/100 km^2) than Skull Creek (nearly 0 bobcats/100 km^2). Habitat type composition was predominated by pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) and sagebrush (*Artemisia* spp.) communities in both study areas. CPW personnel started live-trapping bobcats on 11/18/2022 and captured five unmarked bobcats with three recaptures as of 12/31/2022. On average, an unmarked bobcat required approximately 100 trap nights for capture. CPW personnel also deployed 100 camera traps within the Piceance study area and 35 camera traps within the Skull Creek study area (Figure 1). Camera trap set-ups included visual and scent lure to draw marked and unmarked bobcats for picture taking or 'resights' in the case of marked bobcats. Live-trapping efforts in both study areas, remaining camera deployment in Skull Creek, and camera image collection will continue through spring of 2023, at which point photo identification and mark-resight analysis will commence. Information from this pilot study will be applied to develop a longer-term study plan addressing bobcat population dynamics and population estimation.

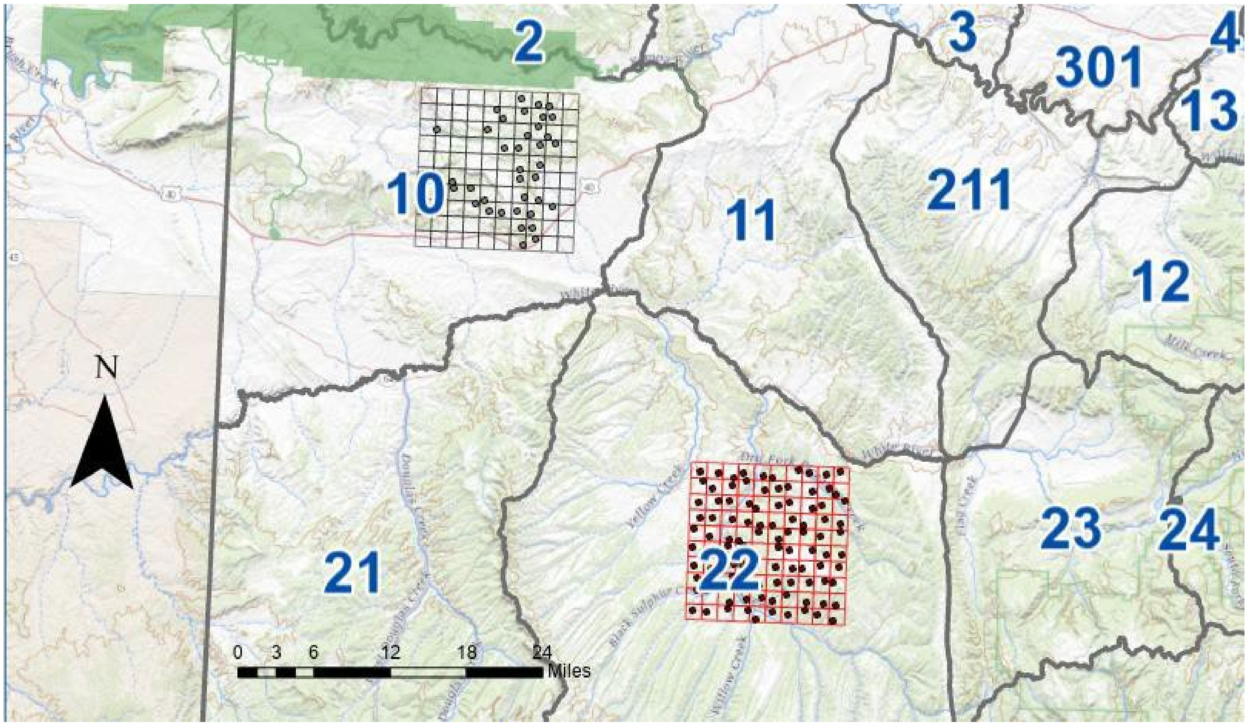


Figure 1. Bobcat study area boundaries (20 x 20 km) are subdivided into 100 2 x 2 km cells. The Piceance study area is shown in red (lower) in Game Management Unit (GMU) 22 with all 100 camera traps deployed (dark red dots). Thirty-five of the 100 camera traps have been deployed in the Skull Creek study area (upper) in GMU 10 as of 12/31/22, which is located south of Dinosaur National Monument (green shaded area) in northwest Colorado.

APPENDIX A. Final Report to BLM: Developing a spatial planning tool for natural gas development on mule deer winter range.

Developing a spatial planning tool for natural gas development on mule deer winter range

Robby M. Marrotte, Department of Biological Sciences, Trent University
Charles R. Anderson Jr., Mammals Research Section, Colorado Parks and Wildlife
Joseph M. Northrup, Environmental and Life Sciences Graduate Program, Trent University

Purpose

Developing a spatial planning tool for natural gas development on mule deer winter range.

Objectives

Using existing data collected on mule deer in the Piceance Basin, Colorado, we developed a tool that allows land managers to assess the potential impacts of future hydrocarbon development on mule deer behaviour and populations. This project had two phases:

1. Statistical modelling of movement data to optimize predictions of deer habitat selection.
2. Development of a user-friendly, web-based platform to assist in the development planning process by optimizing placement of infrastructure that minimizes disturbance to mule deer utilizing winter range.

Yearly Summaries

- ***2021***
    - Data and covariate gathering and development
        - We cleaned mule deer location data and filtered transition and summer range data (Table 1).
        - We defined the area of interest as the 4 study areas used by the mule deer in the Piceance Basin winter range addressed by Northrup et al. (2021): North Ridge, North Magnolia, South Magnolia, and Ryan Gulch (Figure 1).
        - We retrieved all necessary spatial and spatiotemporal data. Locations of roads, pipelines and facilities were digitized from National Agricultural Imagery Program (NAIP) imagery and ground truthed between 2010 and 2015.
            - Mule deer winter range study areas (Retrieved from Northrup et al. 2021).
            - Digital Elevation Model (DEM; Retrieved from https://earthexplorer.usgs.gov/).

            - Daily snow depth between 2009-2015 (Retrieved from Northrup et al. 2021).
            - Road network (Retrieved from Northrup et al. 2021).
            - Facility locations (Retrieved from Northrup et al. 2021).
            - Pipeline network (Retrieved from Northrup et al. 2021).
            - Landsat 8 (LS8) imagery between 2012-2019 (Retrieved from Google Earth Engine).
            - Modis imagery between 2009-2019 (Retrieved from Google Earth Engine).
            - Location and daily status of wells between 2009-2019 (Retrieved from cogcc.state.co.us). Wells were grouped onto pads and pad boundaries were digitized using NAIP imagery. Status of the pad was assigned as the status of the well with the most active development- e.g., if there were two wells on a pad and one was producing gas and the other was being drilled, the status of the pad was set as "drilling."
        - We built static and spatiotemporal layers (Table 2).
            - Static layers
                - Digital Elevation Model (DEM) derived: Elevation, Terrain Ruggedness Index (TRI), Slope, Solar-radiation Aspect Index.
                - Climate: Long-term average and standard deviation of snow depth.
                - Roads: Density of roads within 100-meter distance bands between 0.1-1 km.
                - Facilities: Density of facilities within 100-meter distance bands between 0.1-1 km.
                - Pipelines: Density of pipelines within 100-meter distance bands between 0.1-1 km.
                - LS8 derived: summer bands 1-7, summer NDVI, summer NDVI slope, winter bands 1-7, winter NDVI, winter NDVI slope.
            - Spatiotemporal layers
                - Modis derived: Biweekly NDVI, red, near-infrared, blue and middle-infrared.
                - Producing well pads derived: Daily density of producing well pads within 100-meter distance bands between 0.1-1 km.
                - Drilling well pads derived: Daily density of producing well pad within 100-meter distance bands between 0.1-1 km.
    - Model development
        - We created the background (available) and habitat use (i.e., deer GPS collar) locations. We set a ratio of 30 background locations for each

    habitat use location within each range. We based the probability of each background location on the frequency of use locations during each day between 2009-2019. Consequently, if 5% of use locations were on January 2nd, 2008, the same proportion of background locations were assigned to this day.
    - We trained machine learning resource selection functions using Extreme Gradient Boosting (XGBoost; Chen et al. 2015) using 80% of the entire dataset. We used 20% of the training data (i.e., 16% of the entire dataset) for model validation to help guide and tune the hyperparameters. We then used the remaining 20% of the data for testing the accuracy out-of-sample.

  - Dashboard
    - We developed a dashboard using the R Shiny package and Leaflet interactive maps that can be used to predict the impact of the placement of well pads (Figure 2).
- ***2022***
  - We deployed a prototype of the application on a University of Rhode Island server (shiny.celsrs.uri.edu/bgerber/). We fixed bugs relating to version differences between the server and the previous infrastructure on which we built the application.
  - We added the ability to predict the impact of roads in addition to well pads (Figure 3).
  - We fine-tuned the artificial intelligence model to increase the model's predictive accuracy on validation data.
  - We used the remaining data (testing data) to determine the weakness of the models across ranges and drilling periods (Table 3). We found that the model was generally capable of accurately predicting the drilling (2008-2012) and producing (2012-2019) periods. Comparatively, the model accuracy was lowest for North Magnolia during the producing period.
  - We invited resource managers to test-run the application and used their feedback to make it more user-friendly. We added the ability to visualize the percent change of habitat use during the drilling and producing period (Figure 4).
  - We finalized the model and application and uploaded a stable release of the application on the University of Rhode Island server.
  - We wrote the first draft of a manuscript detailing the steps to create the application. We plan on submitting this manuscript to the Journal of Wildlife Management in December 2022.

Background

Oil and natural gas development has seen significant increases across North America since the turn of the century (USEIA 2015), bringing substantial environmental impacts to developed areas. In western North America, much of this development has overlapped with the ranges of wildlife species (Northrup & Wittemyer 2013). One species for which this development has generated significant concern is the mule deer. Mule deer are an important recreational and economic resource across the intermountain west but have seen large-scale population fluctuations over the last several decades (Unsworth et al. 1999), along with recent declines (Bergman et al. 2015). Hydrocarbon development in mule deer winter range elicits behavioural responses from deer, including relative reductions in the use of large areas in their winter range (Sawyer et al. 2006, 2009; Northrup et al. 2015, 2016a, 2016b). During winter, deer have a negative energy balance, leading to declining conditions (Monteith et al. 2013) and occasional large-scale mortality events (White & Bartmann 1998). Thus, displacement from preferred areas or increased movements due to human activity could exacerbate these issues.

Hydrocarbon extraction is projected to continue to increase for the next two decades (USEIA 2022), modifying substantial areas of new land, much of which will be in the intermountain West (McDonald et al. 2009). Considering this ongoing and impending development in the mule deer winter range, managers need a more in-depth understanding of the impacts of hydrocarbon development. A major need for land and wildlife managers is spatial decision support tools that incorporate currently existing knowledge on how hydrocarbon development impacts mule deer to allow for science-based development and mitigation planning. Specifically, managers need tools that can be used to determine how much development to allow in an area, where and when to allow development to proceed (e.g., how to spatially configure development infrastructure on the landscape to reduce impacts to critical habitat), and the types of mitigation measures to implement to reduce the impacts of development on mule deer.

We leveraged existing large temporal and spatial scale datasets on mule deer habitat selection and demography from the Piceance Basin of Colorado to develop a spatial planning tool that can be used by managers in an adaptive management framework to plan development infrastructure and guide mitigation planning. We applied 10 years of combined movement, survival, and population abundance information. Much of these data have been previously analyzed and been used to quantify behavioral and demographic responses to energy development. We used this existing information in conjunction with new analyses that focused on optimizing our ability to predict the spatial responses of deer to energy development to produce a planning tool.

The spatial planning tool that we developed will allow land managers to assess how the spatial pattern of proposed development would impact mule deer behavior on pinyon juniper winter range. Further, it provides estimates of the uncertainty in expected impacts to deer and the opportunity to explore impacts under varying winter and moisture conditions. We envision a user-friendly platform that would ultimately allow managers and developers the ability to optimize the development footprint such that impacts to deer populations and habitat can be minimized.

Applicability of Planning Tool and Next Steps

The model underlying the shinyapp developed for this project was fit and tested using winter range data from the Piceance Basin. As such, the app is most valid for application to the winter ranges in the Piceance Basin from which the data originated. However, the model has potential utility outside of the Piceance Basin provided sufficient caution is taken in interpretation of the outputs. Several factors will influence how accurate the model is outside of the Piceance Basin: 1) the similarity of the habitat, including both vegetation and topography (e.g., topographically diverse dominated by pinion-juniper overstory), 2) the similarity of the development infrastructure, and 3) deer density, which is directly linked to their use of habitat. In the coming months, we will directly test the applicability of the developed models to mule deer habitat use outside of the specific winter ranges within the Piceance Basin and using data completely outside of the Piceance Basin. This will provide some guidance on the utility of the model for development planning elsewhere. Further, we plan to develop a companion tool that will allow users to apply the model elsewhere in Colorado. This tool will require user inputs for existing infrastructure of roads, well pads, pipelines, and facilities (e.g., compressor stations, gas plants). Prior to development of this companion tool, resource managers can contact Dr. Joseph Northrup at joe.northrup@gmail.com to discuss use outside of the Piceance Basin and coordinate application. Such application will again require user inputs for well pads, roads, pipelines and facilities. Further, caution in interpretation will be needed.

Tables

Table 1. The number of individuals and GPS fixes for adult female mule deer monitored on winter range in the Piceance Basin, Colorado USA between December 2008 to March 2019.

Winter	Number of Does					Number of Fixes				
	North Magnolia	North Ridge	Ryan Gulch	South Magnolia	Total	North Magnolia	North Ridge	Ryan Gulch	South Magnolia	Total
2007-2008	4	10	11	5	**30**	1,116	3,338	2,967	1,801	**9,222**
2008-2009	15	27	23	12	**77**	2,515	4,573	3,484	2,081	**12,653**
2009-2010	34	38	36	34	**142**	7,296	8,371	8,232	4,985	**28,884**
2010-2011	52	31	56	51	**190**	18,486	7,091	18,129	17,697	**61,403**
2011-2012	55	48	44	60	**207**	19,337	12,752	2,061	22,162	**56,312**
2012-2013	67	43	39	71	**220**	25,091	15,287	15,681	25,382	**81,441**
2013-2014	56	39	35	51	**181**	19,617	13,998	13,269	19,894	**66,778**
2014-2015	56	43	43	49	**191**	21,782	17,825	19,245	15,372	**74,224**
2015-2016	47	27	49	50	**173**	20,016	11,504	24,145	17,955	**73,620**
2016-2017	43	26	44	59	**172**	17,814	10,791	19,195	19,906	**67,706**
2017-2018	48	36	48	67	**199**	15,597	12,126	20,451	29,424	**77,598**
2018-2019	22	19	14	29	**84**	4,802	6,179	6,549	10,100	**27,630**
Total	**499**	**387**	**442**	**538**	**1,866**	**173,469**	**123,835**	**153,408**	**186,759**	**637,471**

Table 2. Habitat use prediction categories for mule deer does on their winter range in the Piceance Basin, Colorado, USA.

Derived predictors	Category	Variation	Description	Sources
Elevation (m) Terrain ruggedness index (TRI) Radiation Slope	Cover	Static	Topographic based predictors	Obtained from the United States Geological Survey https://earthexplorer.usgs.gov/
Mean Snow Depth Sd Snow Depth	Forage	Static	Daily modelled snow depth from 2008-2015	Obtained and derived by Liston and Elder (2006), Northrup et al. (2016b), Northrup et al. (2021)
L8 B1 Ultra Blue (0.435-0.451 µm) L8 B2 Blue (0.452-0.512 µm) L8 B3 Green (0.533-0.590 µm) L8 B4 Red (0.636-0.673 µm) L8 B5 NIR (0.851-0.879 µm) L8 B6 SIR 1 (1.566-1.651 µm) L8 B7 SIR 2 (2.107-2.294 µm) NDVI NDVI Slope	Cover and forage	Static	For each, median value for December-March 2013-2019 and June-September 2013-2019	USGS Landsat 8 Level 2, Collection 2, Tier 1 https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC08_C02_T1_L2
Modis Red (645nm) Modis NIR (858nm) Modis Blue (469nm) Modis MIR (2130nm/2105 - 2155nm) Modis NDVI	Cover and forage	Spatiotemporal	Nearest value in time between 2009 and 2019	Obtained from the Google Earth Engine MOD13Q1.006 Terra Vegetation Indices 16-Day Global 250m https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13Q1
Road density within 0-200, 200-400, 400-600, 600-800, and 800-1000 meters	Anthropogenic	Static	The density of roads for several distance bands	Obtained from the United States Geological Survey Digitized from aerial imagery obtained from the National Agricultural Imagery Program https://earthexplorer.usgs.gov/
Pipeline density within 0-200, 200-400, 400-600, 600-800, and 800-1000 meters	Anthropogenic	Static	The density of pipelines for several distance bands	Obtained from the White River Bureau of Land Management office and supplemented from aerial imagery obtained from the National Agricultural Imagery Program https://earthexplorer.usgs.gov/

Facility density within 0-200, 200-400, 400-600, 600-800, and 800-1000 meters	Anthropogenic	Static	The density of natural gas facilities for several distance bands	Digitized from aerial imagery obtained from the National Agricultural Imagery Program https://earthexplorer.usgs.gov/ and validated on the ground
Pad density within 0-200, 200-400, 400-600, 600-800, and 800-1000 meters	Anthropogenic	Spatiotemporal	Nearest value in time between 2009 and 2019 for density of drilling and producing well pads for several distance bands	Obtained from the Colorado Oil & Gas Conservation Commission cogcc.state.co.us
Pad density within 0-200, 200-400, 400-600, 600-800, and 800-1000 meters				

Table 3. Model accuracy (%) for adult female mule deer habitat use in 4 winter range study areas in the Piceance Basin, Colorado between 2008–2019. Sensitivity is the accuracy of the locations where mule deer were located from their GPS collars and specificity was the accuracy of the background availability data.

Range	**Development**	**Period**	**Sensitivity**			**Specificity**
			Training	**Validation**	**Testing**	
All Ranges	Low/High	**Drilling (2008-2012)**	94.44	74.78	74.76	72.25
North Magnolia	Low		93.04	73.91	73.96	69.52
North Ridge	None		95.24	73.82	74.46	75.43
Ryan Gulch	High		94.44	73.94	74.13	74.00
South Magnolia	High		95.21	76.90	76.22	71.25
All Ranges	Low/High	**Producing (2012-2019)**	93.35	73.89	73.62	72.11
North Magnolia	Low		91.00	72.11	71.13	69.40
North Ridge	None		94.96	73.59	74.91	74.74
Ryan Gulch	High		94.40	73.33	73.89	73.86
South Magnolia	High		93.75	76.29	74.96	71.63
All Ranges	Low/High	**Both (2008-2019)**	94.83	75.10	75.17	72.30
North Magnolia	Low		93.84	74.61	75.06	69.56
North Ridge	None		95.36	73.91	74.27	75.72
Ryan Gulch	High		94.45	74.12	74.20	74.03
South Magnolia	High		95.73	77.12	76.65	71.11

Figures

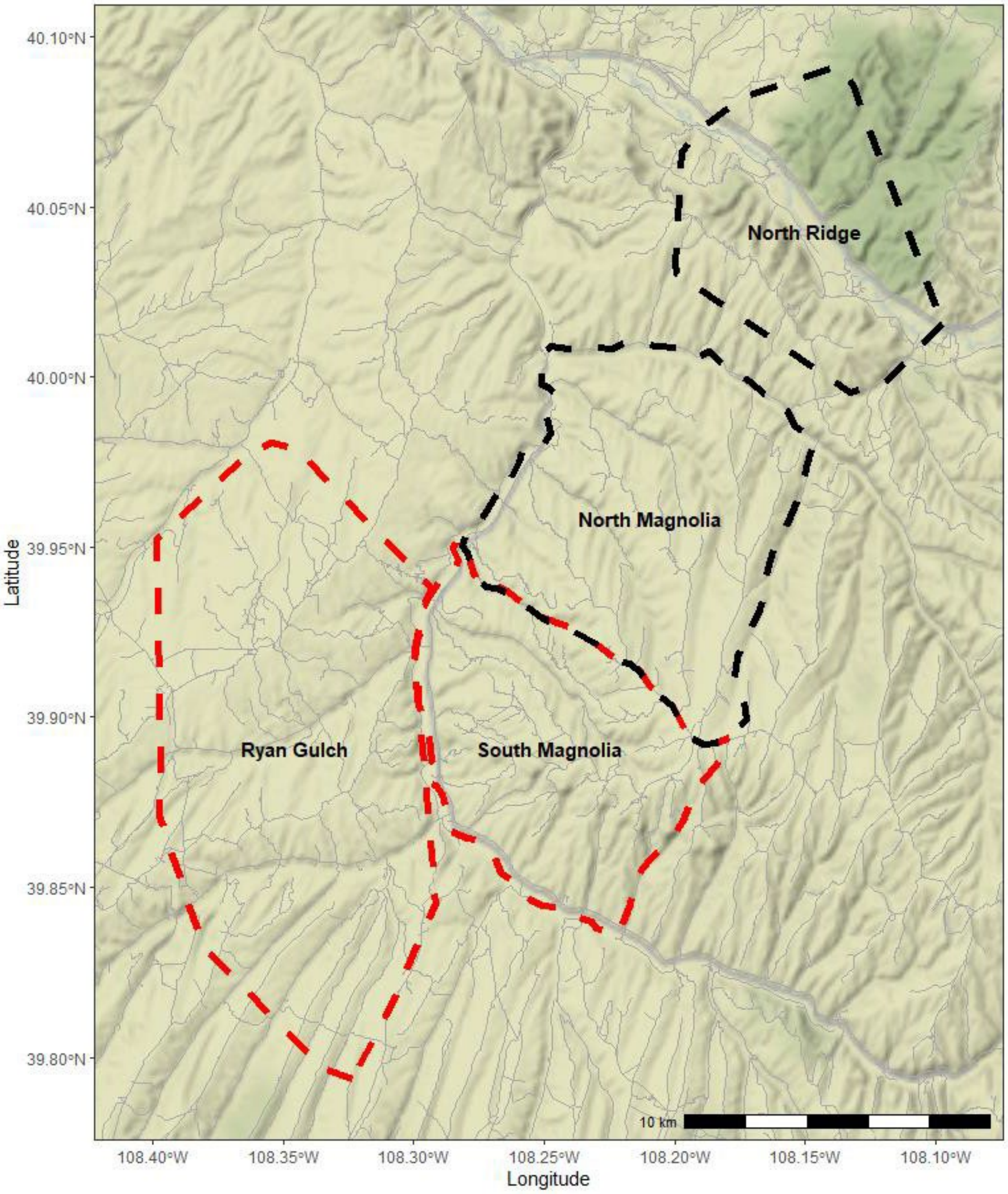


Figure 1. Mule deer winter range study areas in the Piceance Basin, Colorado, USA. The study areas are described in Northrup et al. (2021). Study areas contoured in red represent high development areas with numerous active natural gas wells and study areas contoured in black represent low development areas with few (North Magnolia) or no active natural gas wells (North Ridge).

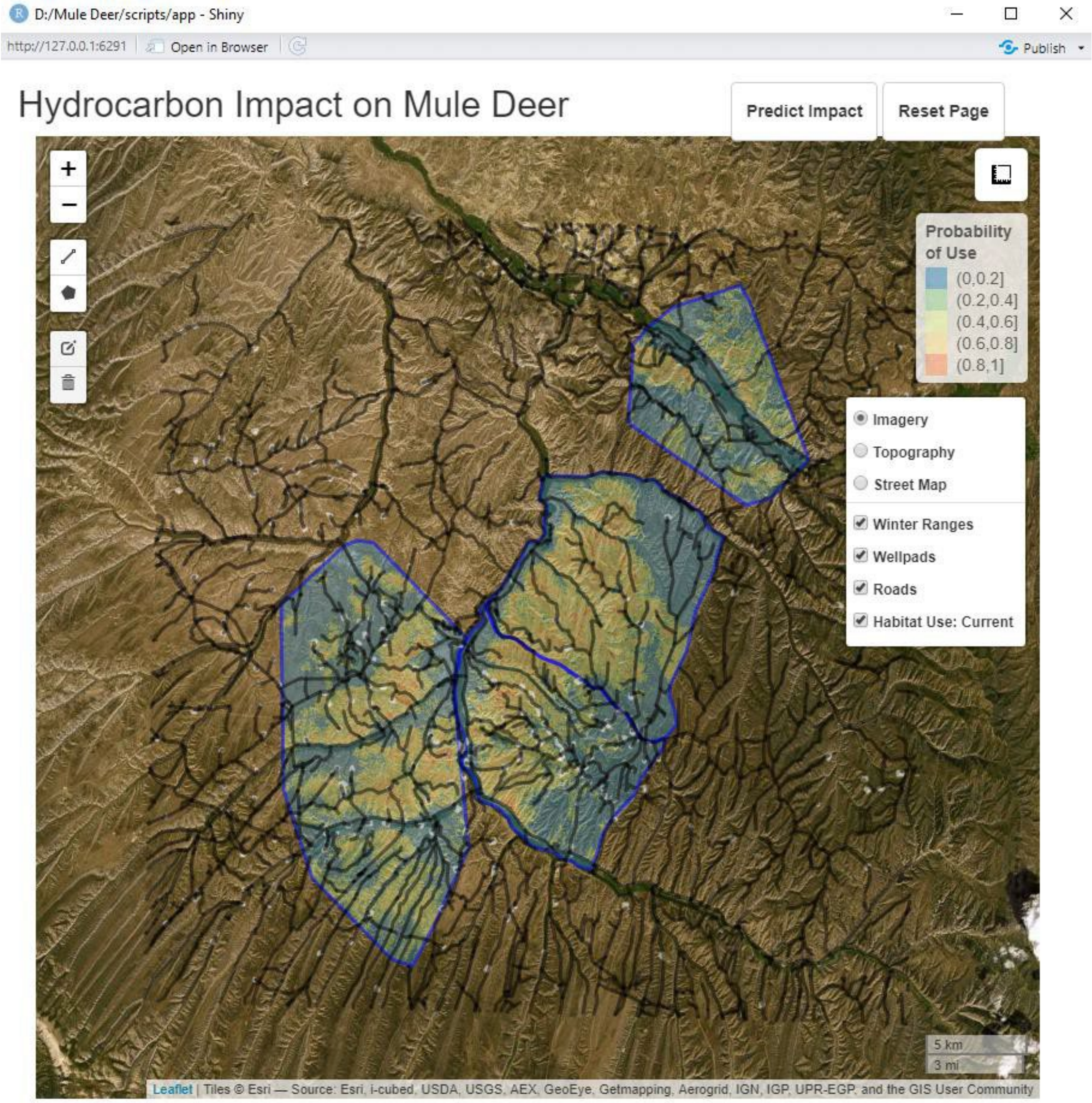
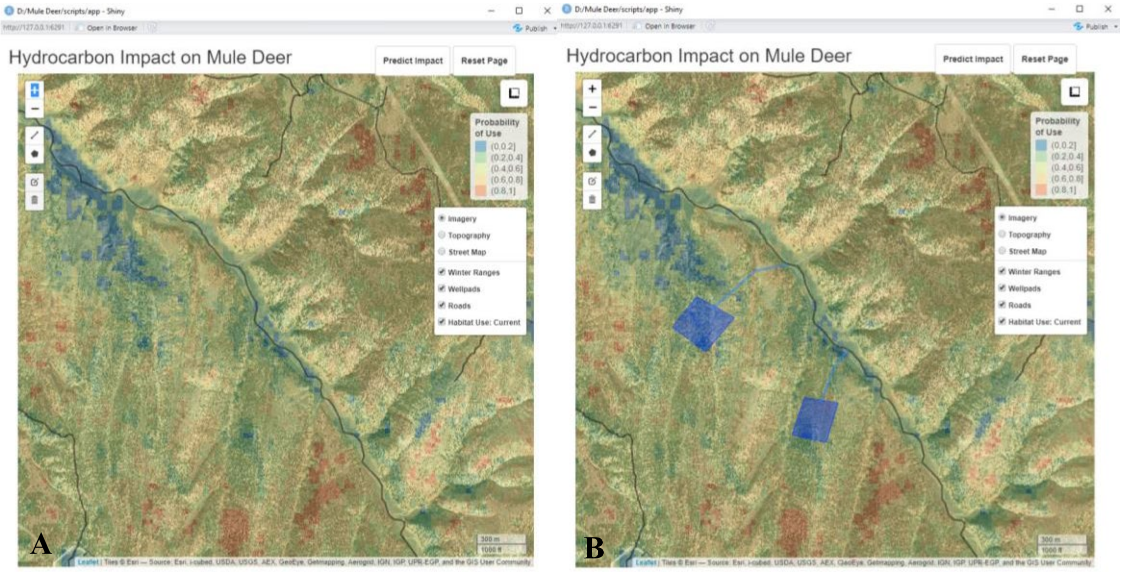


Figure 2. Mule deer hydrocarbon impact dashboard for predicting the impact of placing natural gas wells and roads within the Magnolia, Ryan Gulch, and North Ridge winter range study areas. The model was developed from mule deer GPS collar data acquired between 2009–2019.



● Imagery
○ Topography
○ Street Map
☑ Winter Ranges
☑ Wellpads
☑ Roads
☑ Habitat Use: Current

Figure 3. Example of placing natural gas well pads within the South Magnolia winter range study area. A) Area of interest for well pad development. B) Placement of new well pads and service roads.

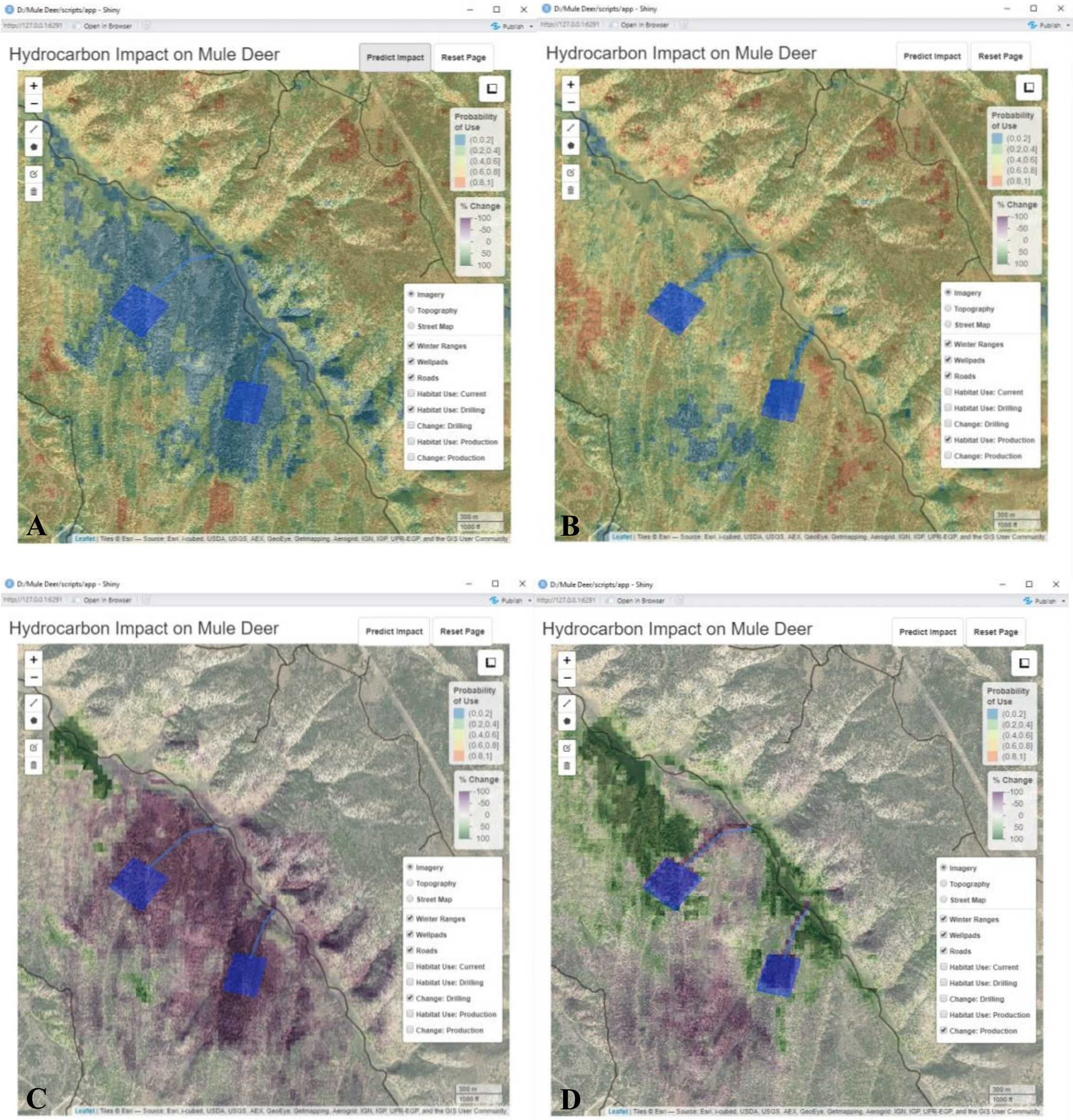


Figure 4. Predicted habitat use by mule deer during the winter months during the drilling phase (A) and during the producing phase (B). Percent change in habitat use during the drilling phase relative to predicted map with no well pads; green shading indicates an increase in predicted probability of use, while purple shading indicates a decrease in predicted probability of use and (C) producing phase relative to predicted map with no well pads; green shading indicates an increase in predicted probability of use, while purple shading indicates a decrease in predicted probability of use (D). Predicted habitat use and change in habitat use are relative to available habitat and scaled by category. Complete avoidance only occurred directly on well pads. The large apparent avoidance and change in habitat use apparent around well pads in the figures represent change in habitat use relative to baseline, but are not complete avoidance of the areas. Note that because the percent change is relative, apparently large percent changes can occur with small absolute change; e.g., a change from 0.01 to 0.02 is small in absolute terms but would be a 100% increase in probability of use.

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APPENDIX B. CPW mammal research abstracts published since July 2021.

Nongame Mammal Ecology and Conservation – page 54

- Community Confounding in Joint Species Distribution Models
- Keystone Structures Maintain Forest Function for Canada Lynx after Large-Scale Spruce Beetle Outbreak

Carnivore Ecology and Management – pages 55-57

- Human-Cougar Interactions: A Literature Review Related to Common Management Questions
- Disease Outbreaks Select for Mate Choice and Coat Color in Wolves
- Movement and Habitat Selection of a Large Carnivore in Response to Human Infrastructure Differs by Life Stage
- Parasitic Infection Increases Risk-Taking in a Social, Intermediate Host Carnivore
- Evaluating Noninvasive Methods for Estimating Cestode Prevalence in a Wild Carnivore Population

Ungulate Ecology and Management – pages 58-61

- Some Memories Never Fade: Inferring Multi-Scale Memory Effects on Habitat Selection of a Migratory Ungulate Using Step-Selection Functions
- Effects of Willow Nutrition and Morphology on Calving Success of Moose
- A Call to Action: Standardizing White-Tailed Deer Harvest Data in the Midwestern United States and Implications for Quantitative Analysis and Disease Management
- Cause of Death, Pathology, and Chronic Wasting Disease Status of White-Tailed Deer (*Odocoileus virginianus*) Mortalities in Wisconsin, USA
- Factors Influencing Productivity and Recruitment of Elk in Northern New Mexico
- Plant and mule deer responses to pinyon-juniper removal by three mechanical methods

Wildlife Genetics and Disease Research – pages 62-63

- Complex Evolutionary History of Felid Anelloviruses
- Viral Sequences Recovered From Puma Tooth DNA Reconstruct Statewide Viral Phylogenies

Journal of Wildlife Management Editorial – page 64

- EDITORS MESSAGE: A Perspective on the Journal of Wildlife Management

NONGAME MAMMAL ECOLOGY AND CONSERVATION

Community Confounding in Joint Species Distribution Models

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Citation: Van Ee, J. J., J. S. Ivan, and M. B. Hooten. 2022. Community confounding in joint species distribution models. Scientific Reports 12:12235; doi.org/10.1038/s41598-022-15694-6.

ABSTRACT Joint species distribution models have become ubiquitous for studying species-environment relationships and dependence among species. Accounting for community structure often improved predictive power, but can also affect inference on species-environment relationships. Specifically, some parameterizations of joint species distribution models allow interspecies dependence and environmental effects to explain the same sources of variability in species distributions, a phenomenon we call community confounding. We present a method for measuring community confounding and show how to orthogonalize the environmental and random species effects in suite of joint species distribution models. In a simulation study, we show that community confounding can lead to computational difficulties and that orthogonalizing the environmental and random species effects can alleviate these difficulties. We also discuss the inferential implications of community confounding and orthogonalizing the environmental and random species effects in a case study of mammalian responses to the Colorado bark beetle epidemic in the subalpine forest by comparing the outputs from occupancy models that treat species independently or account for interspecies dependence. We illustrate how joint species distribution models that restrict the random species effects to be orthogonal to the fixed effects can have computational benefits and still recover the inference provided by an unrestricted joint species distribution model. Published July 2022.

Keystone Structures Maintain Forest Function for Canada Lynx after Large-Scale Spruce Beetle Outbreak

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Citation: Squires, J. R., J. S. Ivan, K. E. Paolini, L. E. Olson, G. M. Jones, and J. D. Holbrook. 2022. Keystone structures maintain forest function for Canada lynx after large-scale spruce beetle outbreak. Environmental Research: Ecology 2:011001; https://iopscience.iop.org/article/10.1088/2752-664X/ac8eb7/meta

ABSTRACT Central to species conservation in an era of increased disturbance from climate change is understanding the primary mechanisms that facilitate how forest-dependent species respond to changes in forest structure and composition. Here, we leveraged a natural experiment to investigate how changed forest structure and function pre-spruce-beetle (*Dendroctonus rufipennis*) and post-beetle disturbance influenced the regional distribution of Canada lynx (*Lynx canadensis*) at their southern range periphery. We compared the distribution of Canada lynx that were reintroduced into Colorado, USA from 1999–2006 to the current (2015–2017) distribution following a spatial large-scale spruce beetle outbreak from 2007 to 2016. Canada lynx did not substantially alter their distribution following the wide-spread alteration of forest structure and composition following the insect outbreak. We used the Bhattacharyya's affinity metric to document that core (50% isopleth) and overall population ranges (95% isopleth) overlapped significantly at 50% and 77% respectively. In addition, areas of low and high relative use remained similar after the bark beetle outbreak and mapped onto one another in nearly a 1:1 fashion (Spearman rank correlation = 0.92, $p < 0.01$). The low impact of forest change on distribution was due to the keystone habitat elements (high horizontal forest cover, snowshoe hares) that remained functional. Thus, our results highlight that conservation scientists should increase their focus to understand the underlying mechanisms that impact wildlife distributions as climate-related disturbances becomes ever more amplified. Published December 2022.

CARNIVORE ECOLOGY AND MANAGEMENT

Human-Cougar Interactions: A Literature Review Related to Common Management Questions

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Citation: Human-Cougar Interactions Science Review Team. 2022. Human-Cougar Interactions: A Literature Review Related to Common Management Questions. Washington Department of Fish and Wildlife, Olympia, Washington, USA. 78 pp.

EXECUTIVE SUMMARY Interactions between humans and cougars (*Puma concolor*) present unique challenges for wildlife managers; reducing occurrences that lead to conflict is a priority for state and provincial wildlife agencies throughout western North America, including Washington. With an increase in management emphasis of human-wildlife conflict resolution, a growing body of scientific literature related to cougar wildland-urban ecology and the factors that contribute to interactions between cougars and people has developed. Based on discussions with the Fish and Wildlife Commission, our 10-member Human-Cougar Interaction Science Review Team assessed both the analytical and ecological merits of current literature, focusing on data and methods, to summarize the current state of knowledge on human-cougar interactions and factors affecting these interactions. We did not use our review findings to provide management recommendations or evaluate/suggest policy alternatives, but we did highlight important information gaps, research needs, and proposed strategies for conducting scientific investigations to benefit managers and policy makers in the future. We used bibliographic lists, keyword searches in research databases, and new literature encountered as citations within papers we reviewed to identify 96 potential studies for review. We evaluated 41 studies that aligned with eight commonly asked questions regarding how various factors contribute to cougar proximity to, and interactions with people. Our review concluded that the roles of cougar removals (Question 1), cougar population size or trajectory (Question 2), the abundance or diversity of prey (Question 3), human population size, distribution, or recreation levels (Question 6), human attitudes (Question 7), and competition with other large carnivores (Question 8) in cougar interactions with people remain uncertain. We found the studies evaluating the efficacy of nonlethal deterrents (Question 4) provided some evidence that these methods reduce conflict, most notably that flashing lights can reduce interactions in specific situations. Our review of papers investigating the role of landscape characteristics (Question 5) revealed spatial ecology to be the most reliably studied and best understood facet of cougar wildland-urban ecology; study designs in these investigations were also the most rigorous. Most cougar use, and subsequent interactions with people, occur at the wildland-urban interface or in exurban and rural residential settings immediately adjacent because these habitats provide both abundant native prey (deer) and stalking cover, or they retain enough native landcover, connectivity, and prey to support cougar use, but with a human presence at a level that does not substantially deter cougars. We identified only a limited number of informative studies in our review, primarily because many studies did not collect data to specifically address relevant management questions after developing testable hypotheses. Much of the literature we reviewed was derived from ad hoc mining of pre-existing data that had been collected for other routine reasons, data were often not assessed for accuracy, and confounding factors were inadequately addressed. Consequently, many factors theorized to contribute to cougar interactions with people require more rigorous investigation. Because wildland-urban systems are complex, and interactions encompass both human and cougar behavior, we recommend the use of long-term studies that incorporate both ecological and anthropogenic factors within a control-treatment design with replicate study sites to address questions with direct management relevance. Published January 2022

Disease Outbreaks Select for Mate Choice and Coat Color in Wolves

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Citation: Cubaynes, S., E. E. Brandell, D. R. Stahler, D. W. Smith, E. S. Almberg, S. Schindler, R. K. Wayne, A. P. Dobson, B. M. vonHoldt, D. R. MacNulty, P. D. Cross, P. J. Hudson, and T. Coulson. 2022. Disease outbreaks select for mate choice and coat color in wolves. Science 378:300–303; DOI: 10.1126/science.abi8745

ABSTRACT We know much about pathogen evolution and the emergence of new disease strains, but less about host resistance and how it is signaled to other individuals and subsequently maintained. The cline in frequency of black-coated wolves (*Canis lupus*) across North America is hypothesized to result from a relationship with canine distemper virus (CDV) outbreaks. We tested this hypothesis using crosssectional data from wolf populations across North America that vary in the prevalence of CDV and the allele that makes coats black, longitudinal data from Yellowstone National Park, and modeling. We found that the frequency of CDV outbreaks generates fluctuating selection that results in heterozygote advantage that in turn affects the frequency of the black allele, optimal mating behavior, and black wolf cline across the continent. Published October 2022.

Movement and Habitat Selection of a Large Carnivore in Response to Human Infrastructure Differs by Life Stage

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Citation: Thorsen, N. H., J. E. Hansen, O. G. Stoen, J. Kindberg, A. Zedrosser, and S. C. Frank. 2022. Movement and habitat selection of a large carnivore in response to human infrastructure differs by life stage. Movement Ecology, 10 (52); doi.org/10.1186/s40462-022-00349-y

ABSTRACT The movement extent of mammals is influenced by human-modified areas, which can affect population demographics. Understanding how human infrastructure influences movement at different life stages is important for wildlife management. This is true especially for large carnivores, due to their substantial space requirements and potential for conflict with humans. We investigated human impact on movement and habitat selection by GPS-collared male brown bears (*Ursus arctos*) in two life stages (residents and dispersers) in central Sweden. We identified dispersers visually based on their GPS locations and used hidden Markov models to delineate dispersal events. We used integrated step selection analysis (iSSA) to infer movement and habitat selection at a local scale (availability defined by hourly relocations), and resource selection functions (RSFs) to infer habitat selection at a landscape scale (availability defined by the study area extent). Movement of residents on a local scale was facilitated by small forestry roads as they moved faster and selected areas closer to forestry roads, and they avoided areas closer to larger public roads and buildings on both scales. Dispersers were more ambivalent in their response to human infrastructure. Dispersers increased their speed closer to small forestry roads and larger public roads, did not exhibit selection for or against any road class, and avoided areas closer to buildings only at local scale. Dispersers did not select for any features on the landscape, which is likely explained by the novelty of the landscape or their naivety towards it. Our results show that movement in male brown bears is life stage-dependent and indicate that connectivity maps derived from movement data of dispersing animals may provide more numerous and more realistic pathways than those derived from resident animal data alone. This suggests that data from dispersing animals provide more realistic models for reconnecting populations and maintaining connectivity than if data were derived from resident animals alone. Published November 2022.

Parasitic Infection Increases Risk-Taking in a Social, Intermediate Host Carnivore

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ABSTRACT *Toxoplasma gondii* is a protozoan parasite capable of infecting any warm-blooded species and can increase risk-taking in intermediate hosts. Despite extensive laboratory research on the effects of *T. gondii* infection on behaviour, little is understood about the effects of toxoplasmosis on wild intermediate host behavior. Yellowstone National Park, Wyoming, USA, has a diverse carnivore community including gray wolves (*Canis lupus*) and cougars (*Puma concolor*), intermediate and definitive hosts of *T. gondii*, respectively. Here, we used 26 years of wolf behavioural, spatial, and serological data to show that wolf territory overlap with areas of high cougar density was an important predictor of infection. In addition, seropositive wolves were more likely to make high-risk decisions such as dispersing and becoming a pack leader, both factors critical to individual fitness and wolf vital rates. Due to the social hierarchy within a wolf pack, we hypothesize that the behavioural effects of toxoplasmosis may create a feedback loop that increases spatial overlap and disease transmission between wolves and cougars. These findings demonstrate that parasites have important implications for intermediate hosts, beyond acute infections, through behavioural impacts. Particularly in a social species, these impacts can surge beyond individuals to affect groups, populations, and even ecosystem processes. Published November 2022.

Evaluating Noninvasive Methods for Estimating Cestode Prevalence in a Wild Carnivore Population

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ABSTRACT Helminth infections are cryptic and can be difficult to study in wildlife species. Helminth research in wildlife hosts has historically required invasive animal handling and necropsy, while results from noninvasive parasite research, like scat analysis, may not be possible at the helminth species or individual host levels. To increase the utility of noninvasive sampling, individual hosts can be identified by applying molecular methods. This allows for longitudinal sampling of known hosts and can be paired with individual-level covariates. Here we evaluate a combination of methods and existing long-term monitoring data to identify patterns of cestode infections in gray wolves in Yellowstone National Park. Our goals were: (1) Identify the species and apparent prevalence of cestodes infecting Yellowstone wolves; (2) Assess the relationships between wolf biological and social characteristics and cestode infections; (3) Examine how wolf samples were affected by environmental conditions with respect to the success of individual genotyping. We collected over 200 wolf scats from 2018–2020 and conducted laboratory analyses including individual wolf genotyping, sex identification, cestode identification, and fecal glucocorticoid measurements. Wolf genotyping success rate was 45%, which was higher in the winter but decreased with higher precipitation and as more time elapsed between scat deposit and collection. One cestode species was detected in 28% of all fecal samples, and 38% of known individuals. The most common infection was *Echinococcus granulosus sensu lato* (primarily E. canadensis). Adult wolves had 4x greater odds of having a cestode infection than pups, as well as wolves sampled in the winter. Our methods provide an alternative approach to estimate cestode prevalence and to linking parasites to known individuals in a wild host system, but may be most useful when employed in existing study systems and when field collections are designed to minimize the time between fecal deposition and collection. Published November 2022.

UNGULATE ECOLOGY AND MANAGEMENT

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

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

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

Effects of Willow Nutrition and Morphology on Calving Success of Moose

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Citation: Hayes, F. P., J. J. Millspaugh, E. J. Bergman, R. M. Callaway, and C. J. Bishop. 2022. Effects of willow nutrition and morphology on calving success of moose. Journal of Wildlife Management 86; https://doi.org/10.1002/jwmg.22175

ABSTRACT Across much of North America, populations of moose (*Alces alces*) are declining because of disease, predation, climate change, and anthropogenic-driven habitat loss. Contrary to this trend, populations of moose in Colorado, USA, have continued to grow. Studying successful (i.e., persistent or growing) populations of moose can facilitate continued conservation by identifying habitat features critical to persistence of moose. We hypothesized that moose using habitat with higher quality willow (*Salix* spp.) would have a higher probability of having a calf-at-heel (i.e., calving success). We evaluated moose calving success using repeated ground observations of collared individuals with calves in an occupancy model framework to account for detection probability. We then evaluated the impact of willow habitat quality and nutrition on moose calving success by studying 2 spatially segregated populations of moose in Colorado. Last, we evaluated correlations between willow characteristics (browse intensity, height, cover, leaf length, and species) and willow nutrition (dry matter digestibility [DMD]) to assess the utility of using those characteristics to assess willow nutrition. We found willow height and cover had a high probability of being positively associated with higher individual-level calving success. Willow DMD, browse intensity, and leaf length were not predictive of individual moose calving success; however, the site with higher mean DMD consistently had higher mean estimates of calving success for the same year. Our results suggest surveying DMD is likely not a useful metric for assessing differences in calving success of individual moose but may be of use at population levels. Further, the assessment of willow morphology and density may be used to identify areas that support higher levels of moose calving success. Published February 2022.

A Call to Action: Standardizing White-Tailed Deer Harvest Data in the Midwestern United States and Implications for Quantitative Analysis and Disease Management

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Citation: Brandell, E.E., D. J. Storm, T. R. Van Deelen, D. P. Walsh, and W. C. Turner. 2022. A call to action: standardizing white-tailed deer harvest data in the Midwestern United States and implications for quantitative analysis and disease management. Frontiers in Ecology and Evolution; https://doi.org/10.3389/fevo.2022.943411

ABSTRACT Recreational hunting has been the dominant game management and conservation mechanism in the United States for the past century. However, there are numerous modern-day issues that reduce the viability and efficacy of hunting-based management, such as fewer hunters, overabundant wildlife populations, limited access, and emerging infectious diseases in wildlife. Quantifying the drivers of recreational harvest by hunters could inform potential management actions to address these issues, but this is seldom comprehensively accomplished because data collection practices limit some analytical applications (e.g., differing spatial scales of harvest regulations and harvest data). Additionally, managing large-scale issues, such as infectious diseases, requires collaborations across management agencies, which is challenging or impossible if data are not standardized. Here we discuss modern issues with the prevailing wildlife management framework in the United States from an analytical point of view with a case study of white-tailed deer (Odocoileus virginianus) in the Midwest. We have four aims: (1) describe the interrelated processes that comprise hunting and suggest improvements to current data collections systems, (2) summarize data collection systems employed by state wildlife management agencies in the Midwestern United States and discuss potential for largescale data standardization, (3) assess how aims 1 and 2 influence managing infectious diseases in hunted wildlife, and (4) suggest actionable steps to help guide data collection standards and management practices. To achieve these goals, Wisconsin Department of Natural Resources disseminated a questionnaire to state wildlife agencies (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, Wisconsin), and we report and compare their harvest management structures, data collection practices, and responses to chronic wasting disease. We hope our “call to action” encourages reevaluation, coordination, and improvement of harvest and management data collection practices with the goal of improving the analytical potential of these data. A deeper understanding of the strengths and deficiencies of our current management systems in relation to harvest and management data collection methods could benefit the future development of comprehensive and collaborative management and research initiatives (e.g., adaptive management) for wildlife and their diseases. Published October 2022.

Cause of Death, Pathology, and Chronic Wasting Disease Status of White-Tailed Deer (*Odocoileus virginianus*) Mortalities in Wisconsin, USA

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ABSTRACT White-tailed deer (WTD; *Odocoileus virginianus*) are a critical species for ecosystem function and wildlife management. As such, studies of cause-specific mortality among WTD have long been used to understand population dynamics. However, detailed pathological information is rarely documented for free-ranging WTD, especially in regions with a high prevalence of chronic wasting disease (CWD). This leaves a significant gap in understanding how CWD is associated with disease processes or comorbidities that may subsequently alter broader population dynamics. We investigated unknown mortalities among collared WTD in southwestern Wisconsin, USA, an area of high CWD prevalence. We tested for associations between CWD and other disease processes and used a network approach to test for co-occurring disease processes. Predation and infectious disease were leading suspected causes of death, with high prevalence of CWD (42.4%; of 245 evaluated) and pneumonia (51.2%; of 168 evaluated) in our sample. CWD prevalence increased with age, before decreasing among older individuals, with more older females than males in our sample. Females were more likely to be CWD positive, and although this was not statistically significant when accounting for age, females were significantly more likely to die with end-stage CWD than males and may consequently be an underrecognized source of CWD transmission. Presence of CWD was associated with emaciation, atrophy of marrow fat and hematopoietic cells, and ectoparasitism (lice and ticks). Occurrences of severe infectious disease processes clustered together (e.g., pneumonia, CWD), as compared to noninfectious or low-severity processes (e.g., sarcocystosis), although pneumonia cases were not fully explained by CWD status. With the prevalence of CWD increasing across North America, our results highlight the critical importance of understanding the potential role of CWD in favoring or maintaining disease processes of importance for deer population health and dynamics. Published October 2022.

Factors Influencing Productivity and Recruitment of Elk in Northern New Mexico

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Citation: Watkins, B. E., E. J. Bergman, L. C. Dhaseleer, and L. J. Bernal. 2022. Factors influencing productivity and recruitment of elk in northern New Mexico. Journal of Wildlife Management: e22348; doi.org/10.1002/jwmg.22348

ABSTRACT Declining recruitment in elk (*Cervus canadensis*) populations is a common issue faced by managers in western North America. To better understand a decline in calf:female (≥1 yr) ratios in northern New Mexico, USA, we investigated the influence of bottom-up factors on the condition and productivity of 1,885 adult (≥2 yr), female Rocky Mountain elk (*C. c. nelsoni*) harvested on the Vermejo Park Ranch during December and January, 2009–2016. We used ingesta-free body fat (IFBF) estimated from kidney fat mass as a measure of condition. Based on maximum likelihood model selection, age, harvest date, hunt zone, pregnancy status, lactation status (as determined in Dec–Jan), June–August precipitation, and December–March mean temperature were important variables for predicting IFBF and field-dressed mass (FDM). Age, IFBF, FDM, harvest date, and June–August precipitation were important variables for predicting conception date, pregnancy rate, and lactation rate. Pregnancy status and lactation status were also important for predicting lactation rate and pregnancy rate, respectively. Older females (≥12 yr) had progressively lower IFBF and FDM and later conception dates than prime females (3–11 yr) and their pregnancy rates declined an average of approximately 9%/year after age 11. The probability of pregnancy in prime females generally exceeded 0.95 when IFBF was ≥12% and FDM was ≥155 kg in late December and early January. Lactating females had lower IFBF, FDM, pregnancy rates, and later conception dates than nonlactating females. The mean IFBF of females harvested on 1 December was generally 2.3–2.7 percentage points higher than values of females harvested on 31 January within age and lactation categories. There was strong evidence that greater IFBF and FDM, higher pregnancy rates, and earlier conception dates in nonlactating females and all adult females were related to increased June–August precipitation ($P < 0.01$) during the conception year, but, with the exception of conception date, there was little evidence in lactating females. Greater conception year June–August precipitation ($P = 0.04$) and greater mean annual IFBF of nonlactating females ($P < 0.01$), but not conception year IFBF of lactating females (P = 0.94), were related to higher subsequent September calf:female ratios. There was also strong evidence that earlier mean conception dates and higher pregnancy rates of adult females (P < 0.01) were related to higher calf:female ratios. The only birth year variables at least moderately related to higher calf:female ratios were lower mean IFBF (P = 0.03) and FDM (P = 0.02) of adult females that likely reflected negative lactation effects. Based on our bivariate models, September calves/100 females increased 10.7 calves per 0.1 increase in the annual adult pregnancy rate and 10.9 calves per 10-cm increase in June–August precipitation during the conception year. Our results indicated that bottom-up factors related to summer precipitation the previous year and age structure of the adult female population had meaningful effects on September calf:female ratios at Vermejo during our study. We found strong evidence of a nexus among summer precipitation, IFBF, conception dates, pregnancy rates, and following year calf:female ratios in nonlactating females but not in lactating females even though probability of pregnancy was primarily determined by IFBF irrespective of lactation status. Published December 2022.

Plant and Mule Deer Responses to Pinyon-juniper Removal by Three Mechanical Methods

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Citation: Johnston, D. B., and C. R. Anderson Jr. 2023. Plant and mule deer responses to pinyon-juniper removal by three mechanical treatment methods. Wildlife Society Bulletin, *In press*; DOI: 10.1002/wsb.1421

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

WILDLIFE GENETICS AND DISEASE RESEARCH

Complex Evolutionary History of Felid Anelloviruses

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

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

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

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

This technique should be considered as an opportunistic method to provide broad geographic sampling to define viral dynamics more accurately in wildlife. Published August 2021

JOURNAL OF WILDLIFE MANAGEMENT EDITORIAL

EDITORS MESSAGE: A Perspective on the Journal of Wildlife Management

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

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

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