



HAUB SCHOOL OF ENVIRONMENT AND NATURAL RESOURCES

Monteith Shop Annual Program Update 2017

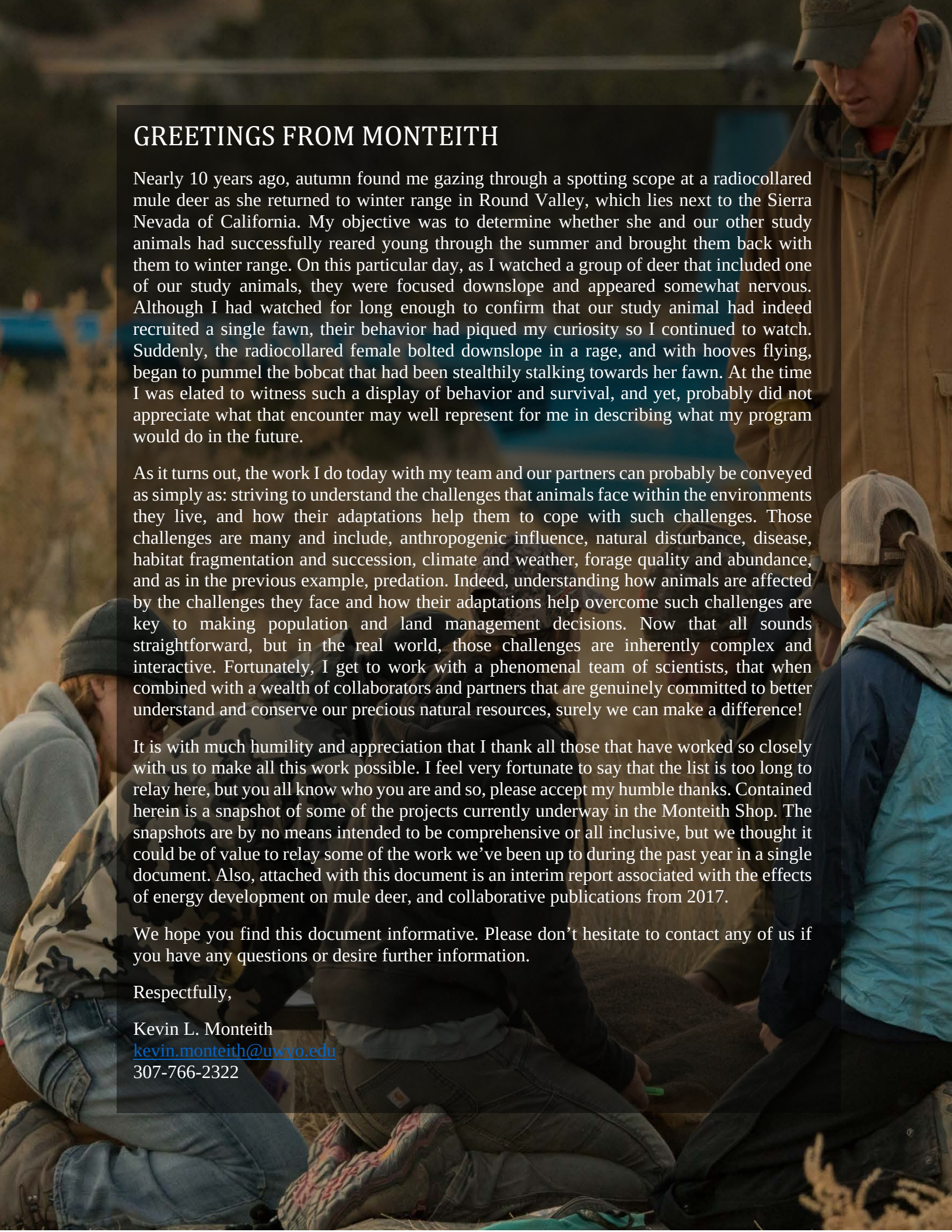


UNIVERSITY OF WYOMING

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Cover Photo Credit: Samantha Dwinnell

A background photograph showing several people in outdoor gear, including hats and jackets, in a field setting. One person is visible in the upper right, looking down. Another person is in the lower right, wearing a blue jacket and a white cap. The scene appears to be a field research or conservation site.

GREETINGS FROM MONTEITH

Nearly 10 years ago, autumn found me gazing through a spotting scope at a radiocollared mule deer as she returned to winter range in Round Valley, which lies next to the Sierra Nevada of California. My objective was to determine whether she and our other study animals had successfully reared young through the summer and brought them back with them to winter range. On this particular day, as I watched a group of deer that included one of our study animals, they were focused downslope and appeared somewhat nervous. Although I had watched for long enough to confirm that our study animal had indeed recruited a single fawn, their behavior had piqued my curiosity so I continued to watch. Suddenly, the radiocollared female bolted downslope in a rage, and with hooves flying, began to pummel the bobcat that had been stealthily stalking towards her fawn. At the time I was elated to witness such a display of behavior and survival, and yet, probably did not appreciate what that encounter may well represent for me in describing what my program would do in the future.

As it turns out, the work I do today with my team and our partners can probably be conveyed as simply as: striving to understand the challenges that animals face within the environments they live, and how their adaptations help them to cope with such challenges. Those challenges are many and include, anthropogenic influence, natural disturbance, disease, habitat fragmentation and succession, climate and weather, forage quality and abundance, and as in the previous example, predation. Indeed, understanding how animals are affected by the challenges they face and how their adaptations help overcome such challenges are key to making population and land management decisions. Now that all sounds straightforward, but in the real world, those challenges are inherently complex and interactive. Fortunately, I get to work with a phenomenal team of scientists, that when combined with a wealth of collaborators and partners that are genuinely committed to better understand and conserve our precious natural resources, surely we can make a difference!

It is with much humility and appreciation that I thank all those that have worked so closely with us to make all this work possible. I feel very fortunate to say that the list is too long to relay here, but you all know who you are and so, please accept my humble thanks. Contained herein is a snapshot of some of the projects currently underway in the Monteith Shop. The snapshots are by no means intended to be comprehensive or all inclusive, but we thought it could be of value to relay some of the work we've been up to during the past year in a single document. Also, attached with this document is an interim report associated with the effects of energy development on mule deer, and collaborative publications from 2017.

We hope you find this document informative. Please don't hesitate to contact any of us if you have any questions or desire further information.

Respectfully,

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NEW TEAM MEMBERS

Kristin Denryter

Kristin Denryter is a postdoctoral researcher who joined the Monteith Shop in June 2017. She completed her PhD at the University of Northern British Columbia, where she studied foraging and nutritional ecology woodland caribou. For this work, Kristin, with her collaborators, spent three summers taking hand-reared caribou out to remote areas on the landscape across the mountains and boreal forests of northern British Columbia. While at study sites, Kristin and her collaborators collected detailed observations of the foraging behavior of these caribou — recording every bite caribou consumed, by species (e.g., plants, mushrooms, lichens). From these data, Kristin and her collaborators were able to determine diet composition and diet quality (e.g., energy content, protein content), as well as the overall nutritional value of different plant communities for caribou during summer.



Before completing her PhD, Kristin completed a Master's and a Bachelor's degree in biology at Northern Michigan University and Madonna University, respectively. During this time, Kristin also worked on a variety of wildlife and conservation projects, including projects on snowshoe hare in Michigan, separate projects on dung beetles and banded mongoose in Africa, coyotes and small mammals in Nevada, and restoration of coastal marshes in Mississippi, among others.

Currently, Kristin is working on a project aimed at determining the nutritional carrying capacity of ranges for Sierra Nevada bighorn sheep in the Sierra Nevada of California. This project is a partnership between the Monteith Shop (Kristin and Kevin) and the California Department of Fish and Wildlife (Tom Stephenson). For this project, Kristin is leading intensive vegetation sampling efforts that will be used to quantify the value of food supplies on Sierra bighorn ranges and developing an energetics model to determine the energy needs of Sierra bighorn. Other planned work to complete this project includes assessing habitat selection by Sierra bighorn using new habitat maps (completed by Matt Hayes) and, using measurements of body fat, assessing proximity of sheep herds to animal-indicated nutritional carrying capacity.



Photo credits: A. Brar (left), R. Cook (right).

Rhiannon Jakopak

Rhiannon joins the Monteith Shop as a master's student working to identify how migration can influence species distribution and population dynamics. She is broadly interested in mammal ecology, but is especially interested in better understanding that processes that determine how species occupy landscapes. She hopes that her research can help to inform better management, conservation, and policy.



She completed her undergraduate degree as a double major in Wildlife and Fisheries Biology and Management and Religious Studies at the University of Wyoming in 2016. Beginning in her undergraduate and continuing into her graduate work, she has worked on projects that address myriad aspects of mammalian ecology, from the benefits of caching behavior to the population consequences of various life history strategies. Before starting her graduate work on mule deer, she was lucky enough to work with multiple species of small mammals, including her favorite animal: Mearns' pouched mouse. Her most impressive professional achievements to date include watching a northern flying squirrel glide across the canopy during field work and preparing a museum specimen of a maned rat.

When Rhiannon isn't being a graduate student, she likes to spend time hiking, turning roadkill into keepsakes, trying to identify birds, reading anything (short stories lately), and playing with her ferrets, Laverne and Shirley.



Tana Verzuh



Tana Verzuh joined the Monteith Shop in fall 2017 as a MSc student in the Cooperative Fish and Wildlife Research Unit. Tana grew up in the mountains of Colorado. She got her bachelor's in zoology from Colorado State where she got her first taste of fieldwork with Dr. Mike Baker studying song types of black-capped chickadees. While at CSU, she also spent 3 years working in a wheat genetics lab, honing her lab skills. After that, it was onward with her education at Montana State University where she received her MSc in science education. Her capstone project looked at a new wildlife-vehicle collision mitigation system implemented in southwest Colorado.

Post-graduation, Tana spent 6 years working as a Career Services Specialist at Fort Lewis College in Durango, CO. Although she thoroughly enjoyed working with and mentoring undergraduate students, she ultimately knew she had to get back to the wildlife field. She was lucky enough to get a job

with Dr. Heather Johnson at Colorado Parks and Wildlife on a project studying how urban development affects black bear behavior and population dynamics. She spent four years on the project, one summer doing hair snares, and 3 winter field seasons crawling in dens. During this time, she also branched out to work with ungulates. She spent 2 summers working on a neonatal mule deer project looking at factors affecting survival and one summer on an elk calf study also looking at neonatal survival. In her down-time with the agency, she assisted with baiting and trapping mountain lions for a study in the Arkansas Valley.

In the fall of 2017, she started at the University of Wyoming and will be continuing the Snowy Range moose project, looking at cause-specific mortality of adult female moose. Her ultimate goal is a PhD, not only to conduct relevant science, but also to be able to communicate that science effectively to diverse groups of people. When not in the field for work, Tana enjoys rafting, mountain biking, split-boarding, surfing, fly fishing, gardening, cooking, and international travel.



WYOMING RANGE MULE DEER PROJECT

Project Background

In recent decades, mule deer abundance throughout the West has struggled to reach historic numbers, and Wyoming is no exception to the nearly ubiquitous trend of population declines. In response to concerns of mule deer populations in Wyoming, in 2007, the Wyoming Game and Fish Commission adopted the *Wyoming Mule Deer Initiative* (MDI) with the intent to develop individual management plans for key populations. Of particular concern was the Wyoming Range mule deer population in western Wyoming—one of the largest mule deer herds in the state and a premier destination for mule deer hunting in the country. The Wyoming Range mule deer population has undergone dynamic changes in recent decades from a population high of >50,000 in the late 1980s, to a sustained population of ~30,000 during much of the last decade (Fig. 1). Consequently, the Wyoming Range mule deer population was identified as a top priority for the development of a management plan according to the MDI. The first of the population-specific management plans, the *Wyoming Range Mule Deer Initiative* (WRMDI), was finalized in 2011 following a collaborative public input process. To direct development of an effective management plan, it was recognized by the Mule Deer Working Group (2007) that the “*Success and implementation of these plans will depend upon our ability to identify limiting factors to mule deer populations and their habitats*”. Accordingly, the Wyoming Range Mule Deer Project was initiated 2013 to address the need for research in identifying the factors that regulate the Wyoming Range mule deer population.

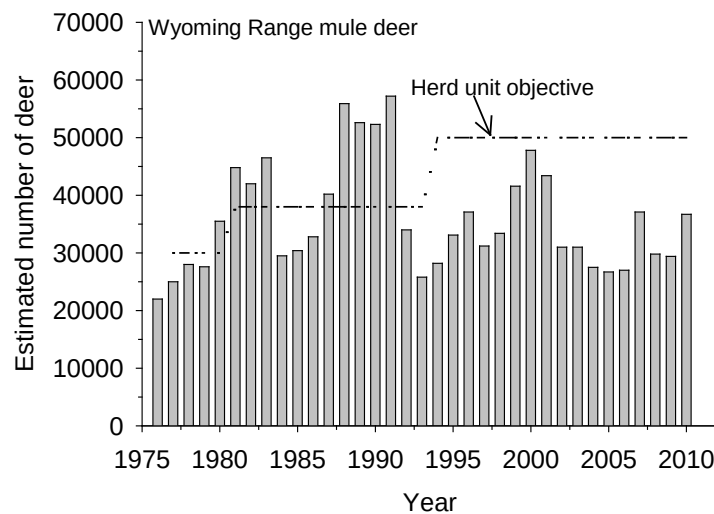


Figure 1. Estimated population size of the Wyoming Range mule deer herd relative to herd unit objective, 1976-2010.

The overarching goal of the Wyoming Range Mule Deer Project is to investigate the nutritional relationships among habitat conditions, climate, and behavior to understand how these factors interact to regulate population performance. We initiated the project in March 2013 with the capture of 70 adult, female mule deer on two discrete winter ranges for migratory, Wyoming Range mule deer (Fig. 2). In summer 2015, we initiated Phase II of the Wyoming Range Mule Deer

Project that focuses on survival and cause-specific mortality of neonate mule deer. Since the initiation of the project, we have tracked and monitored the survival, behaviors, reproduction, and habitat conditions of 164 adult female and 195 juvenile mule deer of the Wyoming Range. This update highlights some of our many discoveries on mule deer ecology since the initiation of the project.

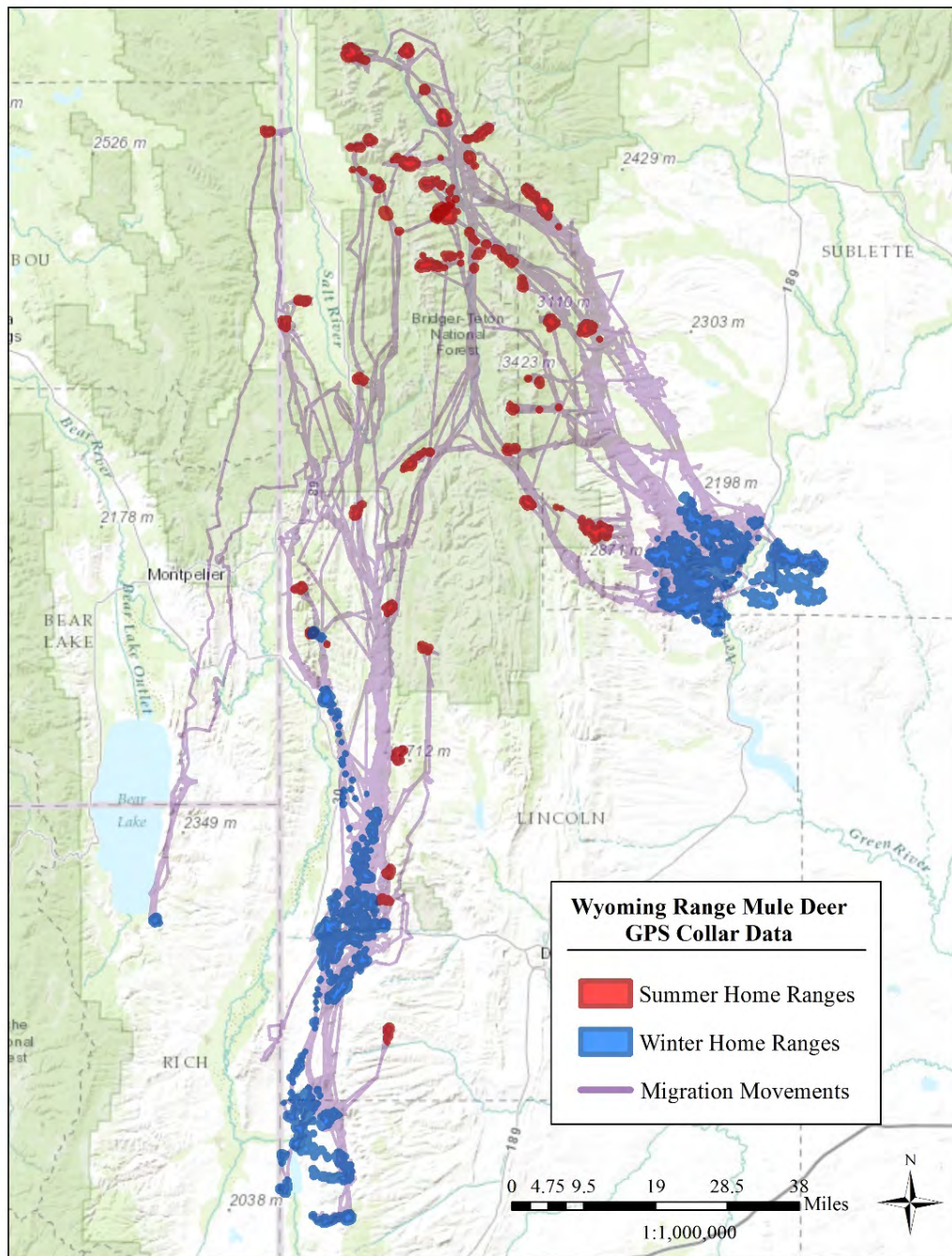


Figure 2. Winter and summer home ranges (based on 95% Kernel Utilization Distribution of GPS collar data) as well as migration movements of Wyoming Range mule deer.

A Nutritional Ecology Framework: Linking the Individual to the Population

Using a nutritional ecology framework, we aim to evaluate how conditions of all seasonal ranges mule deer encounter throughout the year—ranges used during summer, winter, and migration—affect individual animals. Using this unique approach, we can develop a comprehensive understanding of how the connections individual mule deer have with their environments influences population dynamics.

Mule Deer Capture

Since March 2013, we have captured and recaptured 164 adult, female mule deer. Upon each capture, in addition to fitting each animal with a GPS collar, we collect a suite of data on individual animals including age, nutritional condition, morphometry, and pregnancy. Animals are recaptured each spring (in March) and autumn (in December) to monitor longitudinal changes in nutritional condition and reproduction. In doing this, we can link various life-history characteristics with behaviors and habitat conditions of individual animals.

Nutritional Condition

At each capture event, we use ultrasonography to measure fat reserves (i.e., % body fat). By recapturing collared mule deer and measuring body fat each autumn and spring, we are able to track changes in nutritional condition between summer and winter seasons.

Although most animals lost fat in the winter and gained fat in the summer, the rate at which fat reserves increased or decreased varied widely among individual animals (Fig. 3). A suite of factors can influence fat dynamics between winter and summer seasons, but availability of food on seasonal ranges and number of fawns a female raises have the greatest effect on fat dynamics.

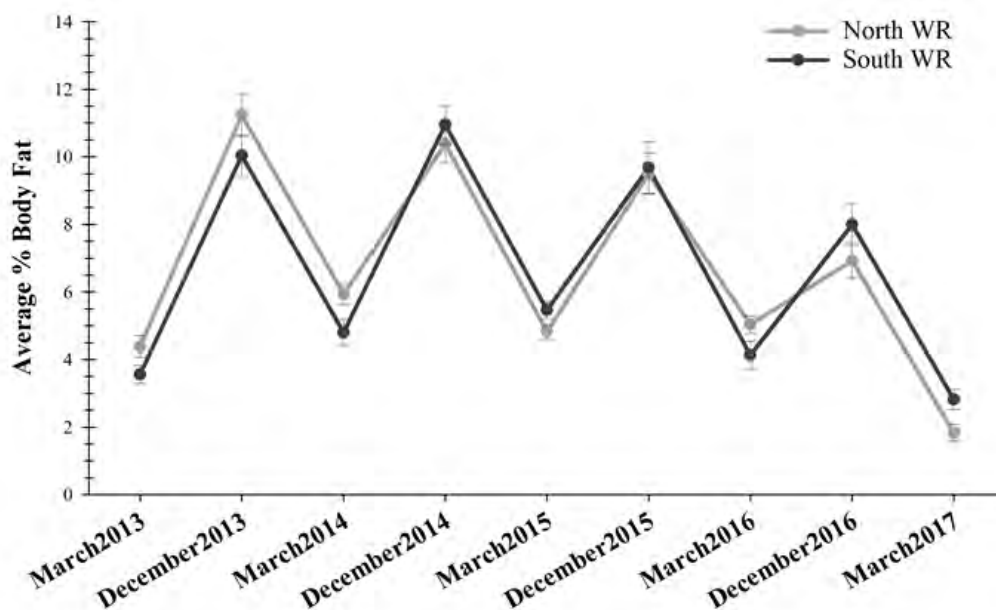


Figure 3. Average % body fat of adult, female mule deer on North (near Big Piney, WY) and South (near Cokeville and Evanston, WY) winter ranges for Wyoming Range mule deer.

Reproduction

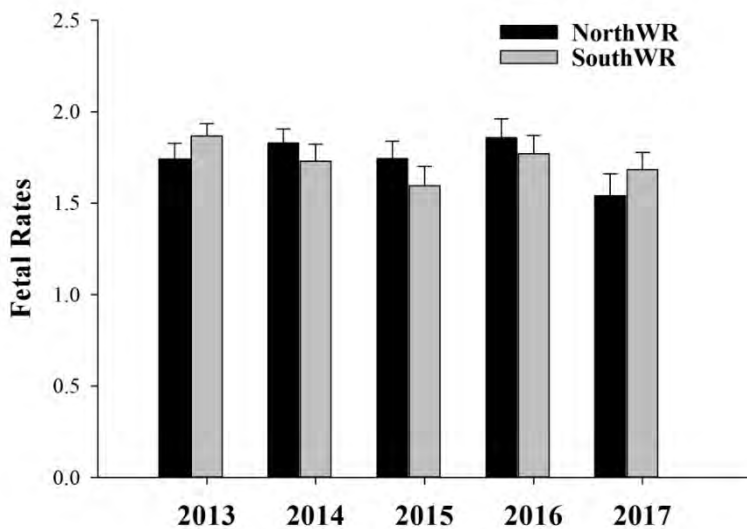


Figure 4. Fetal rates (average number of fetuses per pregnant animal) on North (near Big Piney, WY) and South (near Cokeville and Evanston, WY) winter ranges for Wyoming Range mule deer in 2013-2017.

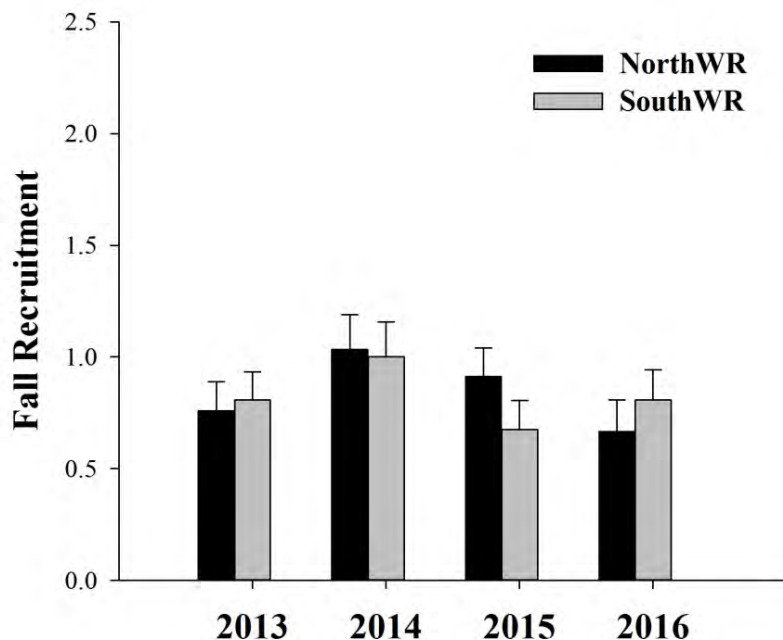


Figure 5. Fall recruitment rates (average number of fawns at heel of female, adult mule deer) of collared mule deer on North (near Big Piney, WY) and South (near Cokeville and Evanston, WY) winter ranges for Wyoming Range mule deer in 2013-2016.

Reproductive success of individual animals greatly influences population dynamics; therefore, we closely monitor pregnancy and recruitment of young for each of our study animals. We use ultrasonography to monitor pregnancy rates of our study animals during spring capture events. Each autumn, as animals arrive to winter range, we evaluate fall recruitment using on-the-ground observations of the number of fawns at heel of our collared adults.

Pregnancy rates among mule deer of the Wyoming Range were typically high and ranged between 90-99%. Furthermore, most animals were pregnant with twins each year resulting in relatively high fetal rates (average number of fetuses per pregnant animal was 1.74 ± 0.03 across years; Fig. 4). Although fetal rates tended to be high, recruitment of young tended to be low. Since 2013, approximately half of the potential fawns born in early summer survived to autumn, and fall recruitment averaged 0.83 ± 0.05 fawns per collared female for Wyoming Range mule deer (Fig. 5).

Disentangling the Relative Role of Predation, Habitat, Climate, and Disease on Fawn Survival

Fawn Capture

In March 2015, we initiated Phase II of the Wyoming Range Mule Deer Project by recapturing collared deer and deploying a vaginal implant transmitter (VIT) in pregnant females. VITs were used to indicate where and when birth occurred. Once birth events were identified, we captured and collared fawns born to our collared females as well as fawns that were found opportunistically throughout the Wyoming Range. Since 2015, we have successfully collared 195 fawns and have been continually monitoring their survival.



	2015	2016	2017
Number of Fawns Tracked	58	70	67
Median Birthdate	June 10	June 13	June 17
Summer Mortality	45%	56%	52%
Winter Mortality	10%	44%	NA
Total Mortality	55%	100%	NA

Cause-Specific Mortality of Fawns

To evaluate cause-specific mortality of fawns, we tracked daily survival of all fawns captured 2015 – 2017. When a mortality was detected, we immediately investigated the event to ensure an accurate assessment of the cause of mortality. There was a breadth of various causes for fawn mortality including predation, disease, malnutrition, drowning, hypothermia, vehicle-collision, and just being caught in vegetation. The proportion of fawns that died because of the aforementioned causes varied from year to year (Fig. 8).

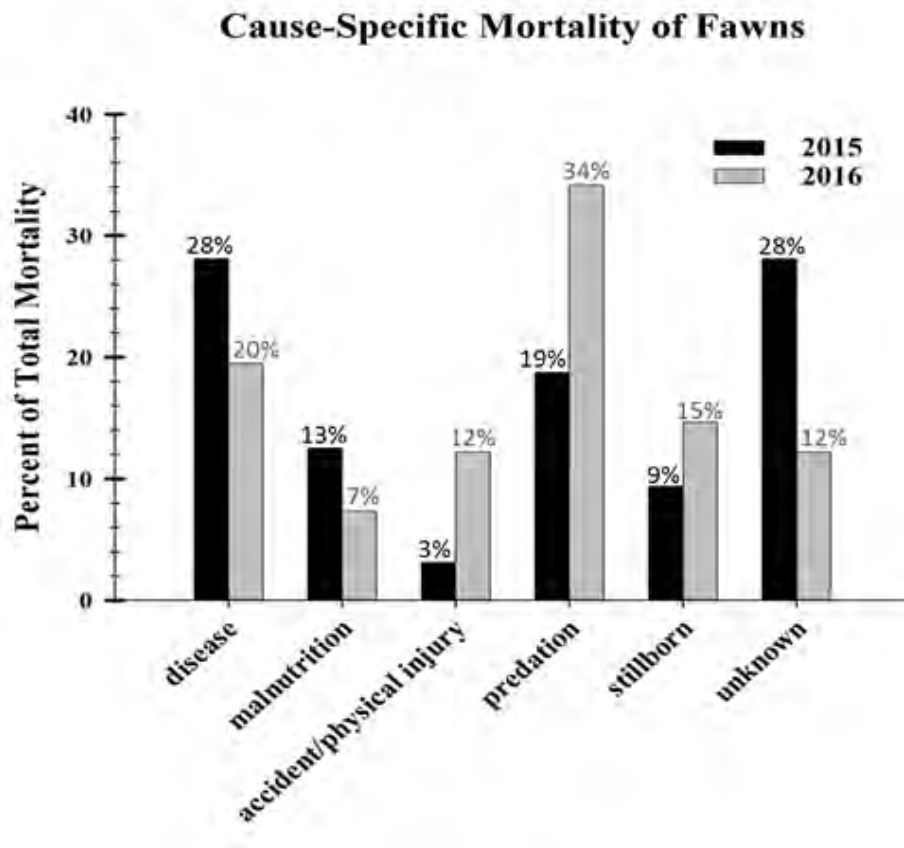


Figure 8. The relative occurrences of various causes of mortality for mule deer fawns of the Wyoming Range in 2015 and 2016.

In 2015, disease was the leading cause of death and accounted for 28% of all mortalities. The most prevalent disease adenovirus hemorrhagic disease (AHD). AHD is a viral disease that can cause internal hemorrhaging and pulmonary edema. Although AHD was detected in mule deer populations before, it was not previously known to be a major mortality factor in Wyoming. Nevertheless, the discovery of AHD in the Wyoming Range mule deer population has been motivation for further research into the epidemiology of AHD.

We are still awaiting necropsy results from the Wyoming State Vet Lab from samples collected from fawn mortalities in 2017; therefore, the relative influence of various causes of mortality—specifically, disease and malnutrition—on fawn mortality is still pending. Regardless, nearly 30% of mortalities in 2017 were because fawns were stillborn. Currently, this is the leading cause of death for fawns in 2017.



Habitat and Maternal Conditions

The condition of a female and the habitat conditions she experiences in the summer may be very important in predicting and understanding fawn survival—especially in understanding the influence of malnutrition and disease on fawn survival. Therefore, we are coupling data on summer

habitat conditions with information on maternal condition (i.e., nutritional condition) to evaluate how it influences fawn survival.

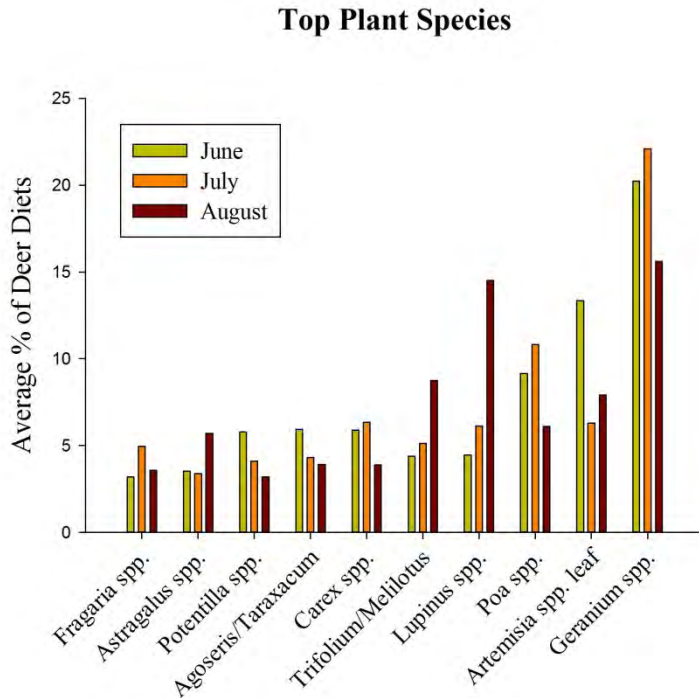
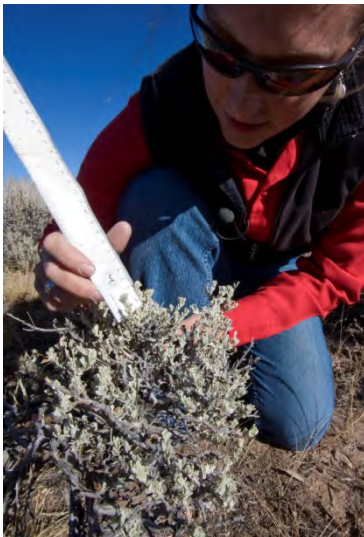


Figure 7. The top ten plant genera within diets (according to the average % of diets comprised of each plant genera) of Wyoming Range mule deer. Diet composition was evaluated in June, July, and August of 2013 and 2014.

Since 2013, we have evaluated the quality and availability of plants within the diets of Wyoming Range mule deer during summer. To assess mule deer diets, we collected fecal samples from summer home ranges of collared deer and used microhistology to identify plant species within their diets (Fig. 7) in summer 2013 and 2014. Based on frequency of plants within mule deer diets, we then collected plant clippings that we analyzed for quality (e.g., crude protein and digestibility). We are now coupling data on diet quality with forage availability by quantifying the abundance of key forage species at known locations of collared mule deer throughout the summer.



Effects of Winter Severity on Survival and Reproduction

Adult Winter Survival

Winter of 2016/2017 proved to be a tough on mule deer. Conditions on winter ranges for Wyoming Range mule deer were severe with snowpack levels exceeding 200% and numerous days of sub-zero weather. These harsh winter conditions strongly affected winter survival and only 63% of our collared adults survived from November until summer 2017 (compared with >90% in years past). Older animals and animals that entered winter in poor condition were more susceptible to succumbing to winter exposure (Fig. 9).

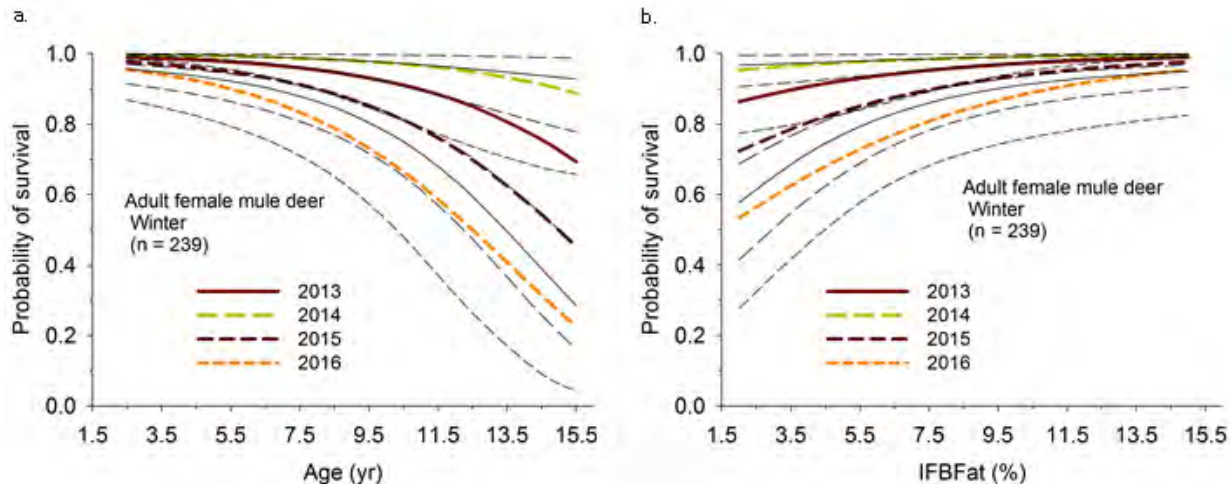


Figure 9. The effects of age (a) and December body fat (IFBFat %; b) on the probability of survival overwinter. Probability of survival decreased as animals aged and as the % body fat (IFBFat %) in December decreased.

Fawn Winter Survival

Winter conditions tend to have the greatest effect on survival of fawns, and this winter was no exception. We observed 100% mortality of the fawns we collared in summer 2016 (44% died overwinter). Mortality rates of that caliber can have substantial repercussions on population dynamics because the majority of an entire cohort of deer is gone. Although these numbers are staggering, winter die-offs, like the one observed this winter, do occasionally occur and populations do eventually rebound. We have now found ourselves with a unique opportunity to evaluate how mule deer populations rebound from harsh winters.

Nutritional Condition

Nutritional condition in March 2017, measured as % body fat, was the lowest we have observed in our research (2.3% in 2017 compared with 4.0–5.3% in 2013–2016; Fig. 3). Although it is rare to see animals in this poor of condition, it was surely a product of deep snow restricting access to forage and heightened energy expenditures associated with locomotion in deep snow and thermoregulation in plummeting temperatures.

Pregnancy

Despite extremely poor nutritional condition of animals in March 2017, fetal rates among winter ranges were comparable to the preceding 4 years (Fig. 4) and pregnancy rates remained high.

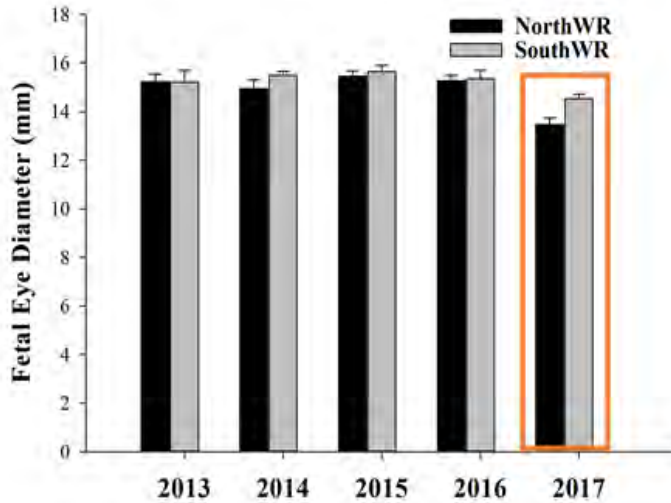


Figure 10. Average fetal eye diameter measured in March of each year. Fetal eye diameter was significantly smaller in March 2017 compared with any other year.

Interestingly, average eye diameter of fetuses was lower in March 2017 (14.0 ± 0.18) than in previous years (15.3 ± 0.11 ; Fig. 10). Fetal eye diameter is a measure of fetal development and is often used to estimate the timing of birth.

Carryover Effects

Newborn fawns caught in 2017 were significantly lighter than newborn fawns caught in previous years (Fig. 11). This was of little surprise because of the overall poor nutritional condition of pregnant females and the smaller eye diameter of fetuses measured in March 2017. With this information, we are now in a position to better evaluate the influence of birth weight and maternal condition on summer survival of fawns.

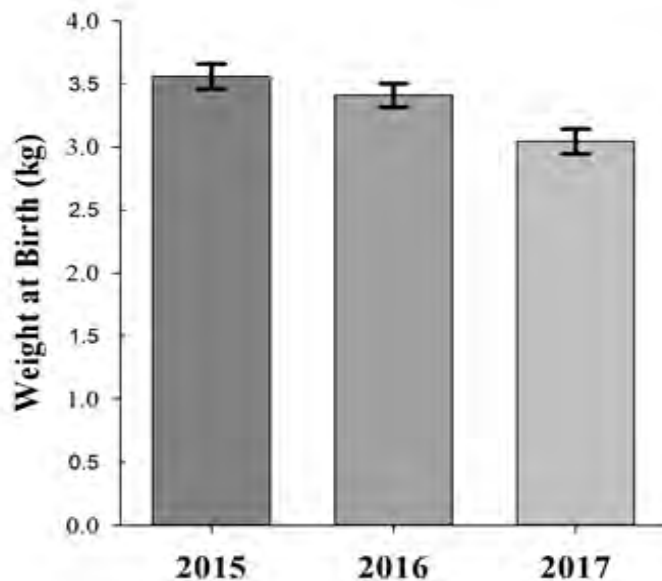


Figure 11. Average weight of fawns captured <48 hours from birth. Fawns were significantly lighter in 2017 compared with the previous two years.



Spring Migration

At the largest spatial scale, migration is recognized as a strategy that allows migrants to exploit high-quality resources available on one seasonal range, while avoiding resource deficiencies on the other. Much less is known, however, about the fine scale movement behaviors that animals make during migration. This portion of the Wyoming Range Mule Deer Project aims to understand the importance of food resources available during migration, and how the habitat quality of migratory routes influences survival and reproduction of migratory mule deer in the Wyoming Range.

Spring migration is a critical time for migrants, in which they must recover from harsh winter conditions and prepare for upcoming reproductive costs. It is hypothesized that movement from low elevation winter ranges to high elevation summer ranges, allows migrants to extend the amount of time they are exposed to young, highly palatable forage. Following a wave of newly emergent, high-quality forage along elevational gradients, is known as “surfing the green wave”. This project will investigate the role of the migration route as critical habitat, with the aim to better understand the importance of migration as well as to inform management strategies to protect migration in the Wyoming Range and beyond.

Project Objectives

1. Test the green wave hypothesis in migratory mule deer and explore the source of individual variability in green-wave surfing (Completed, see below).
2. Investigate the influence of drought on green-wave surfing (In progress).
3. Understand the relative importance of green-wave surfing to fitness (In progress).



Testing the Green Wave Hypothesis

Deer should select plants that are at intermediate growth stages (i.e. not too old or not too young) because plants which are greening up are both easy to digest and available in large enough quantities to maximize energetic gains. If deer surf a wave of plant green-up, then the timing of their movements during spring migration should be perfectly matched with the timing of peak green-up in plants. When we tested this prediction, this is indeed what we found (Figure 1). We noticed, however, that there was a lot of variability in the green-wave surfing ability of individuals. To further investigate the source of this difference in green-wave surfing we considered how the progression of the green-wave across individual routes may differ. We found that some routes had long, easy to follow gradients in plant green-up, while other routes had short, rapid and difficult to follow gradients in plant green-up. Together this difference in the amount of time when green-up was available along a migration route (i.e. the green-up duration) and the gradient of green-up from winter range to summer range (i.e. the order of green-up), which we refer to as the “greenscape”, largely explained the differences in green-wave surfing across individual deer using different migration routes.

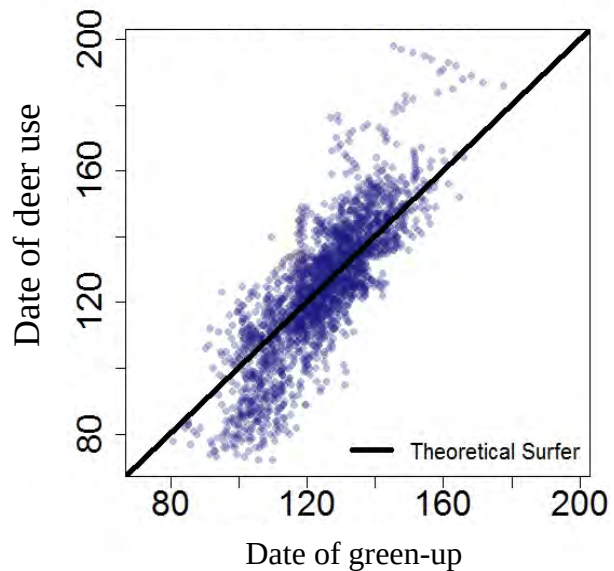


Figure 1. Evidence for green-wave surfing by mule deer in the Wyoming Range. The black line represents the theoretical prediction of a perfect match between the date of green-up and the date of deer use. Data points fall close to this line, suggesting that in general deer are surfing the green wave.

What have we learned?

- Green wave surfing is key to the foraging benefit of migration.
- The migration route provides critical habitat.
- Timing is key, thus activities that may alter the ability of deer to exploit the green wave should be avoided or minimized during the spring migration period.
- The greenscape (i.e. the duration and order of green-up along a migration route) determines the quality of a route.

This research is published! For more information, see:

Aikens, E.O., M. J. Kauffman, J. A. Merkle, S. P. H. Dwinell, G. L. Fralick, and K. L. Monteith. 2017. The greenscape shapes surfing of resource waves in a large migratory herbivore. *Ecology Letters* 20:741-750.



Partners

The Wyoming Range Deer Project is a collaborative partnership in inception, development, operations, and funding. Without all the active partners, this work would not be possible. Funds have been provided by the Wyoming Game and Fish Department, Wyoming Game and Fish Commission, Wyoming Wildlife and Natural Resource Trust, Muley Fanatic Foundation, Bureau of Land Management, Knobloch Family Foundation, U.S. Geological Survey, National Science Foundation, Wyoming Governor's Big Game License Coalition, Boone and Crockett Club, Animal Damage Management Board, Ridgeline Energy Atlantic Power, Bowhunters of Wyoming, and the Wyoming Outfitters and Guides Association. Special thanks to the Wyoming Game and Fish Department, Bureau of Land Management, and Wyoming State Veterinary Lab for assistance with logistics, lab analyses, and fieldwork. Also, thanks to the Cokeville Meadows National Wildlife Refuge and U.S. Forest Service for providing field housing.



For More Information, Contact Us:



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SNOWY RANGE MOOSE PROJECT

Shiras moose have seen declines in recent decades across much of their statewide range because of a likely multitude of factors. The Snowy Range herd, which colonized the area following an introduction into North Park Colorado in the 1970s, is thought to be robust to these changes. Relatively new, lacking wolves or grizzly bears, and with a moderate rate of human harvest, the Snowy Range herd may be free of density-dependent pressures and existing as a small but highly productive population. Despite the impressions of stable population performance, the landscape of the Snowy Range has been altered dramatically by the mountain pine beetle, and the moose herd has not been studied since 2006. Moreover, effects of pine beetle outbreak on large mammals are almost entirely unknown. A collaborative study initiated in fall 2014 presents an excellent opportunity to examine the relationship between moose habitat use and seral changes brought about by bark beetles. Losses in forest canopy may have complex implications for moose, which are sensitive to warm temperatures. Increased light penetration may spur a release of food resources on the forest floor while potentially reducing the value of forests as a refuge from high temperatures. In winter, less snow may be suspended above the forest floor, decreasing the importance of dense conifers as an easier path to move through in deep snows.

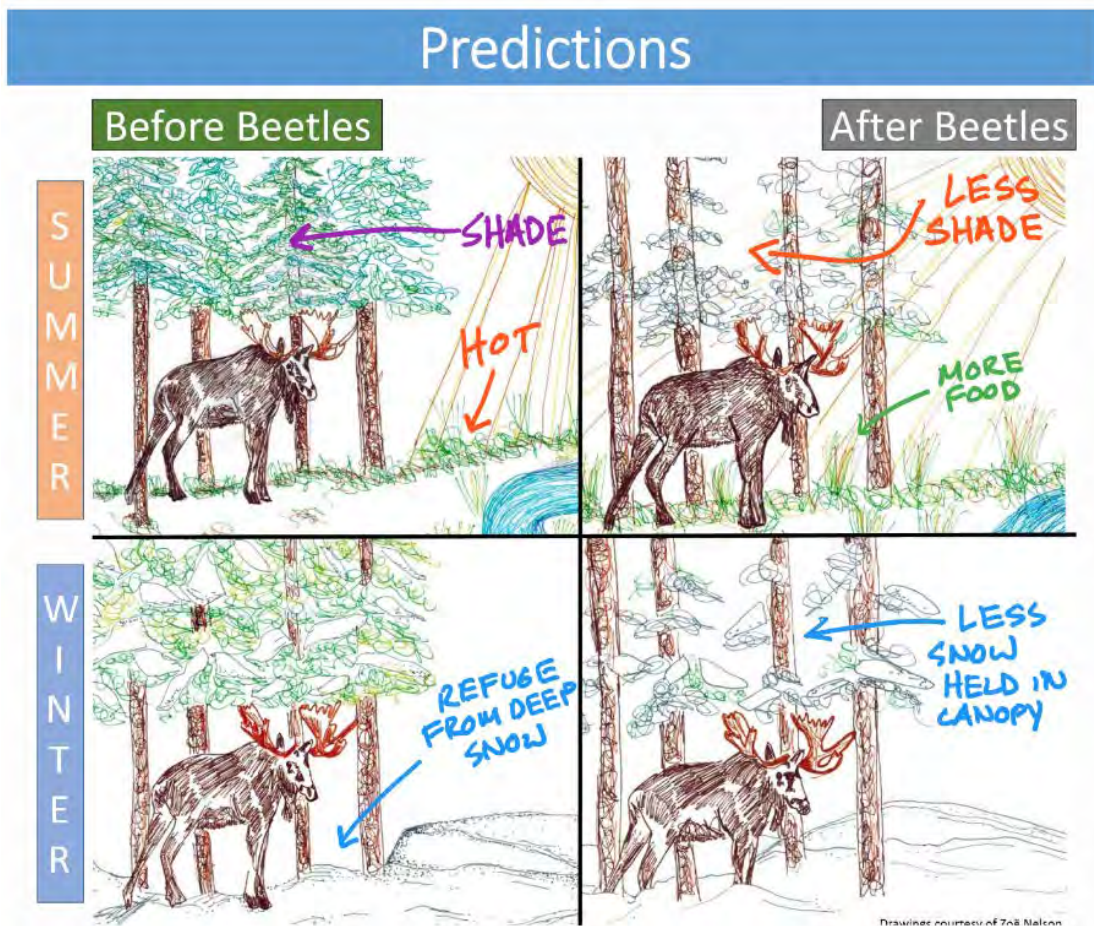


Figure 1: How beetle-killed forest may affect moose.

Project approach

The project began its field component in March 2015 — we captured 30 female moose (29 adults and one yearling) by helicopter darting on lands within and surrounding the Medicine Bow National Forest. We fit captured moose with GPS collars set to collect a location every 90 minutes, mirroring the same GPS schedule as the previous moose study in the area. Moose were last collared in the Snowy Range in 2005 and 2006 for a winter habitat use study, which was before the peak die-off of trees from bark beetles. We are comparing patterns of habitat selection between moose in the different time periods (2006, the previous study, and a decade later, the current study) to examine how the landscape-scale changes of the bark beetles may have changed how moose choose their habitat in the Snowy Range.

In addition to the GPS data, we gathered measurements of nutritional condition on collared moose by recapturing them twice per year (in March and December) and measuring their fat reserves with an ultrasound. At each recapture, we also measured pregnancy, whether they had a calf with them, and collected biological samples. Obtaining a time-series data set of reproductive status and body condition in addition to fine-scale movement data will allow us to answer complex questions about how habitat use is related to individual fitness. We also will use the demographic data to estimate where the Snowy Range moose herd sits relative to the nutritional carrying capacity (i.e., how many moose the habitat can support) of the mountain range.

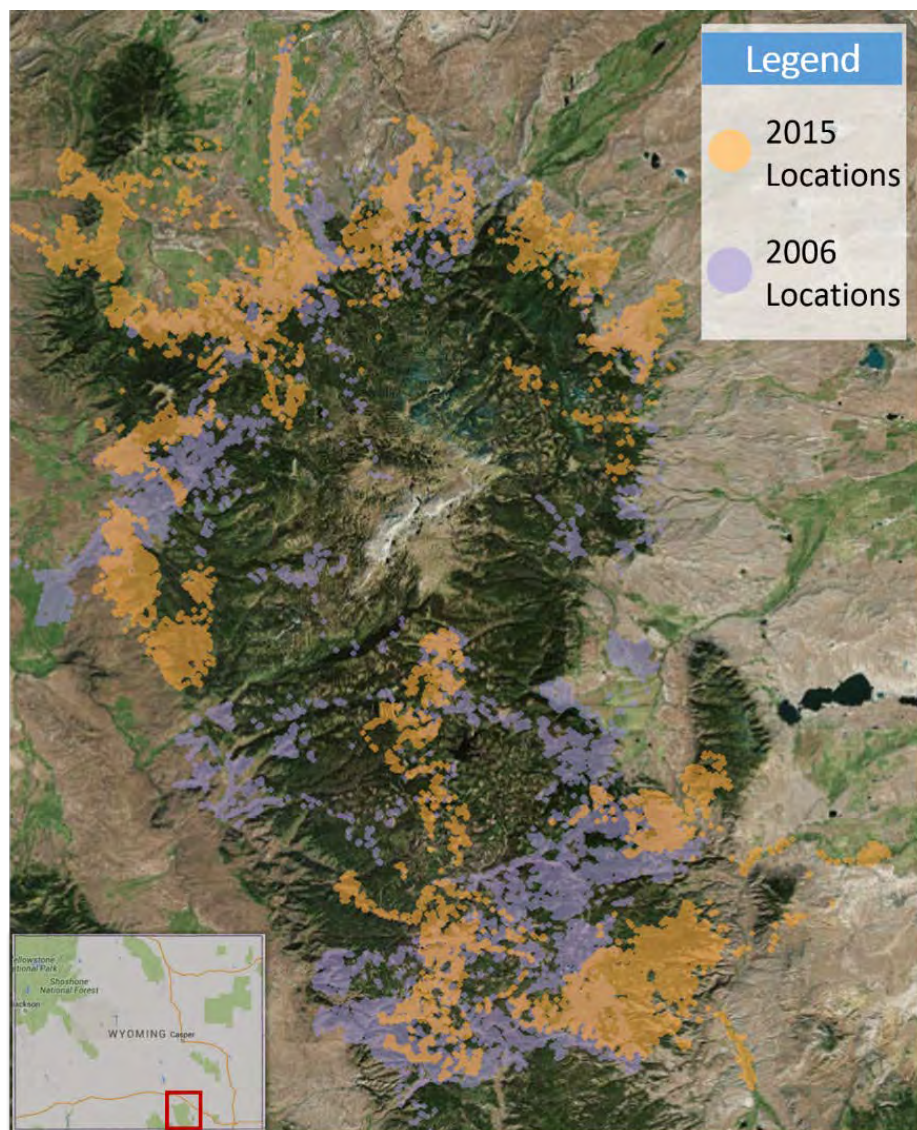


Figure 2: One year of moose GPS locations from each dataset.

Summer fieldwork and supplemental data

We completed two field seasons in 2015 and 2016 in addition to the five helicopter captures.

Calf production and survival

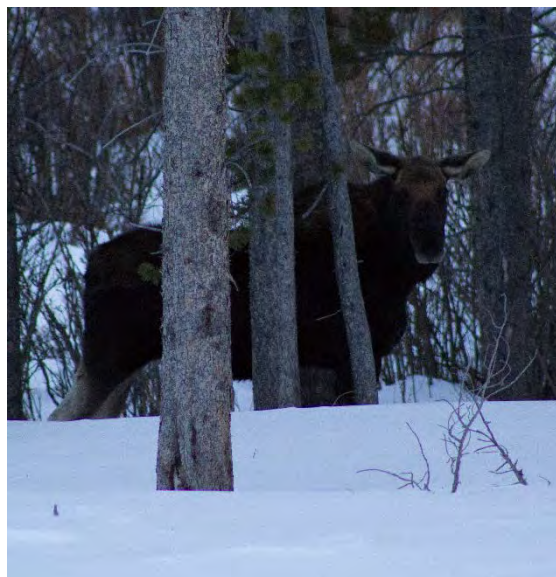
Each moose that we confirmed to be pregnant at March capture was the subject of continued monitoring through the summer. We located collared moose on foot at the beginning of July and the end of August to observe whether she successfully produced a calf and if so whether she had twins. An abundance of twins is indicative of a growing moose population, and calf survival can be influential in population dynamics in some scenarios. Calves were located again by helicopter at the following December and March recaptures.

Willow communities

Willows are among the most important food sources for moose in the Rocky Mountains but are susceptible to over-use by foraging ungulates. Philip Baigas, a master's student working on the previous Snowy Range moose study, conducted willow condition estimates in the area in 2008 to determine whether willows were escaping browsing pressure. The same protocol was implemented again by Brett Jesmer, a Ph.D. student studying moose state-wide, in the same areas five years later. We re-surveyed plots that had been sampled in 2008 and 2013 to track whether browsing pressure on willows has changed appreciably. This work helps us understand how the quality of a primary habitat type used by moose may have fluctuated in conjunction with the changes brought by bark beetles.

Understory composition in pine forest

The increased light penetration and decreased water interception from dead trees may increase the value of conifer forests as food sources for moose. We sampled the species composition of understory plants in conifer forests in mature and regenerated lodgepole pine stands to see whether more beetle kill means more understory growth. We are making use of fecal data collected by Brett Jesmer to see whether understory plants sampled in our field work are plants that moose eat. At each pine forest site, we measured horizontal cover and canopy closure to estimate how much shade conifer forests provide. These measurements will help us understand what beetle kill might mean for moose in the summer months.



Hunter-harvested kidney samples

Capturing moose is a costly and time-intensive process; management is best-served by supplying low-cost tools that can be used for continued monitoring. Moose store some of their body fat reserves around their kidneys, which are often discarded by hunters along with other organ tissue. We provided moose hunters in the Snowy Range with sampling kits during the 2015 and 2016

hunting seasons which they could use to return the kidneys, a blood sample, and a tooth for aging to the Wyoming Game and Fish Department. We processed kidneys from hunter-killed moose to estimate their fat reserves and compared these measurements to the body fat levels of collared moose.

PRELIMINARY FINDINGS

All findings listed in this report are still preliminary and are subject to change in final analyses.

Demographic rates

We were able to follow eighteen of the original thirty moose through the entire project period. The collar of one moose failed after the first year, and she was never successfully relocated. We examined the carcass of any project moose that died during the study and we re-deployed their collar on a new moose during the next recapture. In total, we tracked 44 moose at some point over the course of the study.

Pregnancy

Moose are bred in the fall and give birth in early summer. We measured pregnancy at each capture event, as moose can lose or re-absorb their fetus during gestation if their nutritional condition changes. We determined pregnancy using an ultrasound each March, although fetuses were usually too large for us to tell whether a moose was carrying twins or a single fetus. We used a blood test to determine pregnancy during December captures because most fetuses were too small to detect with an ultrasound — we cannot determine if a moose is carrying twins or a single fetus with a blood test and are currently awaiting the lab results. The March pregnancy rate (calculated as the number of pregnant females divided by all sampled females) ranged from 78.6–85.7%, which was higher than the pregnancy rates measured in the Sublette moose study (Table 1). The pregnancy rates were relatively close to a historical estimate of the national average. Our rates were much lower than what has previously been reported in the Snowy Range, although we are unable to compare them to our December rates at this time.

Table 1: Pregnancy rates of project moose compared with other moose studies.

State	Region	Year	Pregnancy Rate	Sample Size	Time
WY	Snowy Range	2005	100	n=6	December
WY	Snowy Range	2004	90.9	n=11	December
WY	Snowy Range	2016	85.7	n=28	March
Nation	All	1950s-1980s	84.2	Average of 64	Unknown
WY	Snowy Range	2017	78.6	n=28	March
WY	Snowy Range	2015	78.6	n=28	March
WY	Sublette	2013	73.8	n=65	February
WY	Sublette	2014	67.5	n=40	February
WY	Sublette	2012	64.5	n=48	February
WY	Sublette	2011	47.8	n=23	February

Adult survival

We recorded one year of low and another of very high rate of adult survival over the course of the study. The low survival rate in the first year of the study (79.8%, Table 2) triggered a continuation of the project, discussed at the end of the report. It is not uncommon to see changes in adult survival rate between years, reflected in similar studies listed in Table 2.

Table 2: Annual survival rate of project moose compared with other moose studies.

State	Region	Year	Survival Rate	Sample Size	Estimation Method
WY	Snowy Range	2017	95.8		Kaplan
WY	Sublette	2012	87.1	n=48	Kaplan
WY	Sublette	2014	86.4	n=44	Kaplan
WY	Sublette	2011	82.6	n=23	Kaplan
WY	Snowy Range	2016	79.8	n=29	Kaplan
WY	Sublette	2013	77.7	n=66	Kaplan

Although formal survival analyses are still pending, the age of the moose and its body condition were correlated with its survival probability each year. In general, the older moose with lower body fat levels were those that did not survive (Figure 3). A simple multiple logistic regression of the effect of body fat and age on survival suggests that each additional percent of body fat increased the survival odds of a moose by 106%, whereas each additional year of age decreased their survival odds by 32% (Figure 4). This calculation models whether the moose lived or died during the two years of the project, excluding capture mortalities.



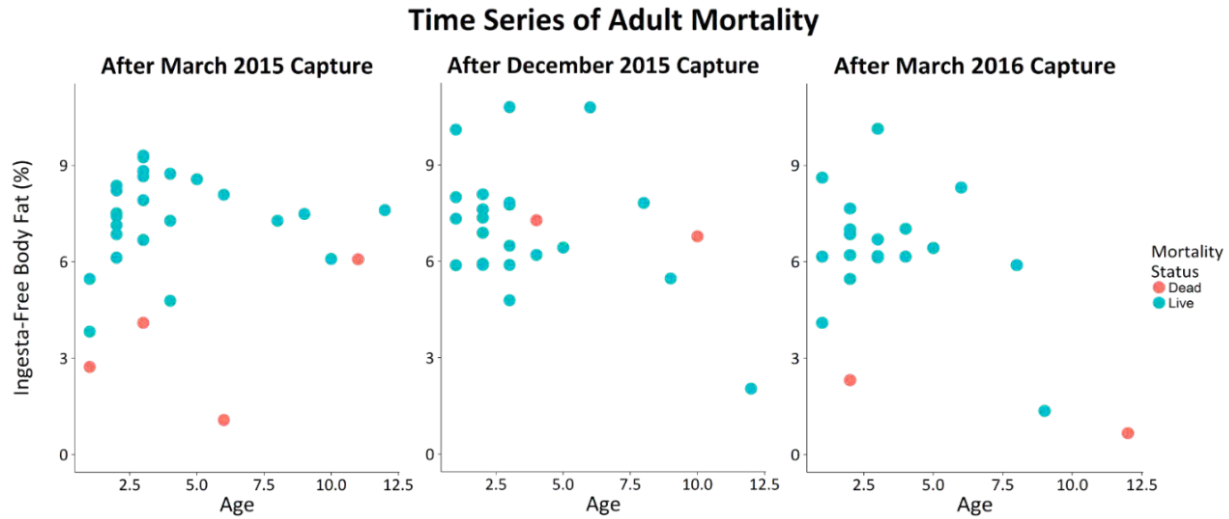


Figure 3: Age and body condition of moose that survived and died in the first year of the study. The plot is intended to be read left-to-right — each red colored point is a moose that died following that capture but before the next capture. Moose with lower body condition (towards the bottom of the plots) and higher age (towards the right of each plot) were more likely to die.

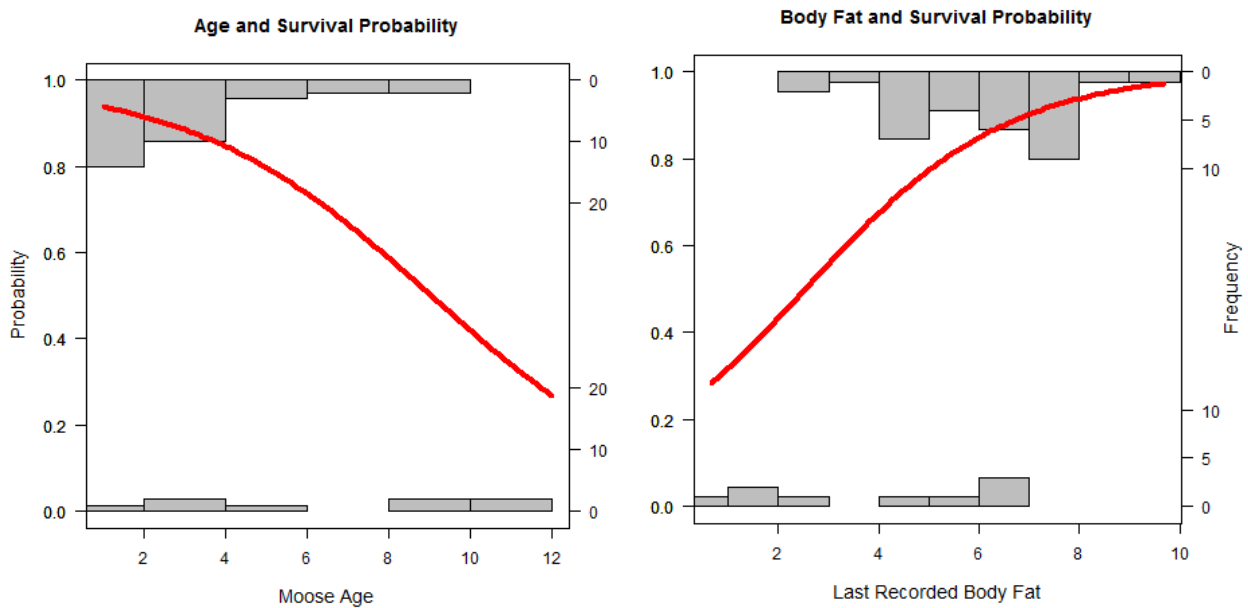


Figure 4: Logistic regressions of moose age and moose body condition vs. survival probability. Histograms on the top and bottom represent the distribution of observations for each outcome (survival, 1, or death, 0). The red line approximates the probability of the survival based on the predictor variable.

Calf production and survival

Moose that we tracked for this project did not twin successfully in either year. We observed one set of twins in the summer of 2015, but the moose only had one calf in subsequent winter observations. We did receive reports of other, non-radio-collared, moose with twins throughout the project, but the lack of apparent twinning in our sample suggests that it is not widespread in the population. Our calf survival and recruitment analyses are still pending, as we have to account statistically for imperfect detection probability from helicopter observations. Therefore, the patterns in Table 3 may change when we transition from a simple proportion estimation method.

Table 3: Calf survival rate of project moose compared with other moose studies.

State	Region	Year	Interval	Calf Survival	Sample Size	Method
WY	Snowy Range	2015	10-month	47.4	n=19	Proportion
WY	Snowy Range	2016	10-month	33.3	n=15	Proportion
WY	Sublette	2014	9-month	75	n=24	Kaplan
WY	Sublette	2012	9-month	66.6	n=27	Kaplan
WY	Sublette	2013	9-month	64.5	n=31	Kaplan
WY	Snowy Range	2015	7-month	76.2	n=21	Proportion
WY	Snowy Range	2016	7-month	61.1	n=18	Proportion



Nutritional condition

Body fat is the currency by which moose finance their survival and reproduction. The seasons of Wyoming bring abundant forage in the summer and fall months and strip it away during long winters. Males rapidly accumulate body fat during the summer which they then spend during the rut so they can devote more time to finding and mating with females than eating — body fat allows them to incur an energy deficit without perishing. Similarly, a female moose can use stored body fat to buoy her through a late-winter period of resource scarcity. Producing milk for a calf or two is energetically costly, and a moose may devote excess energy to milk production without being able to store it as body fat. Measuring body fat allows us to examine how moose movements and population performance are related. We expected December fat measurements to be higher than March fat measurements because moose would still retain most of the body reserves accumulated over the summer. Instead, the average December fat was lower than the average March fat in 2015, although the expected relationship held in 2016. Average March body fat declined throughout the study (Figure 5). Though final analyses are still pending, we are noticing a surprisingly high energetic cost associated with raising a calf, and many calf-rearing moose lost body fat through the summer instead of gaining it.

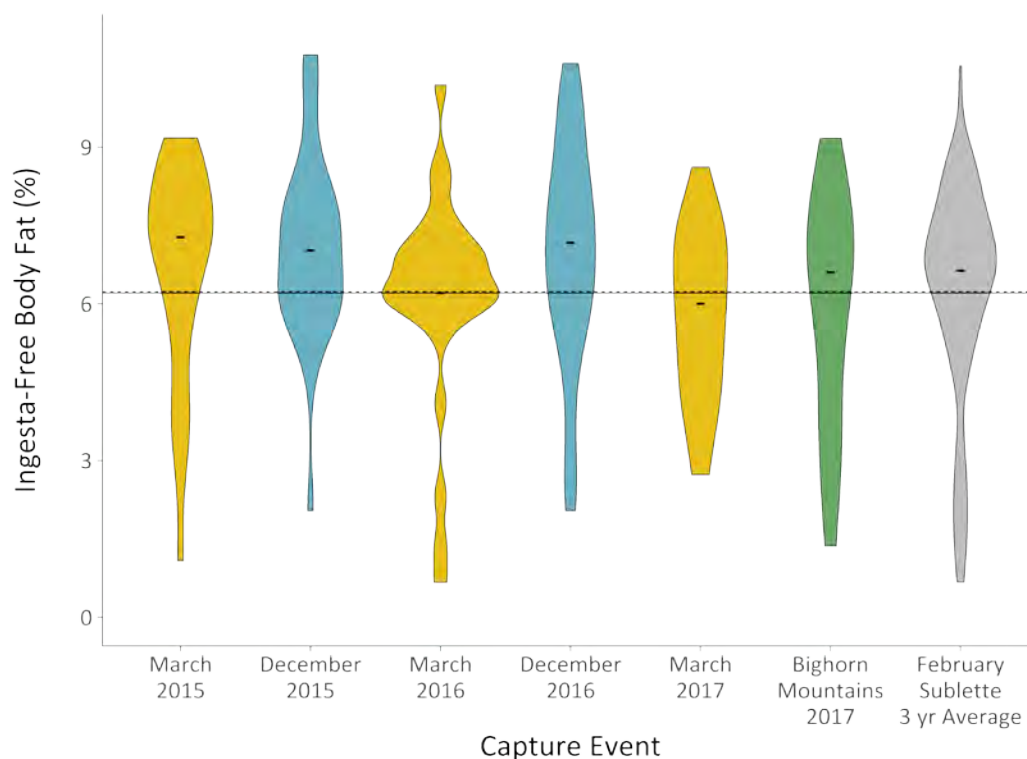


Figure 5: Distribution of measurements of moose body fat across captures. The measurements for the Bighorn and Sublette moose studies are included for reference. Each shape represents the distribution of body fat measurements in each capture. Wider areas have more measurements near that number than narrower areas. Horizontal tick marks represent the median value for each capture event. The horizontal line represents the average body fat measurement for March captures in the Snowy Range study (solid) and Sublette moose study (dashed). They differ by 0.02%.

Nutritional condition and demography

Moose with higher body fat had a higher likelihood of being pregnant in March, and the relationship between high body fat and good parenting extended somewhat to the probability that a moose had a calf with her at March recapture. We are excited to dive deeper into these data over the coming months.

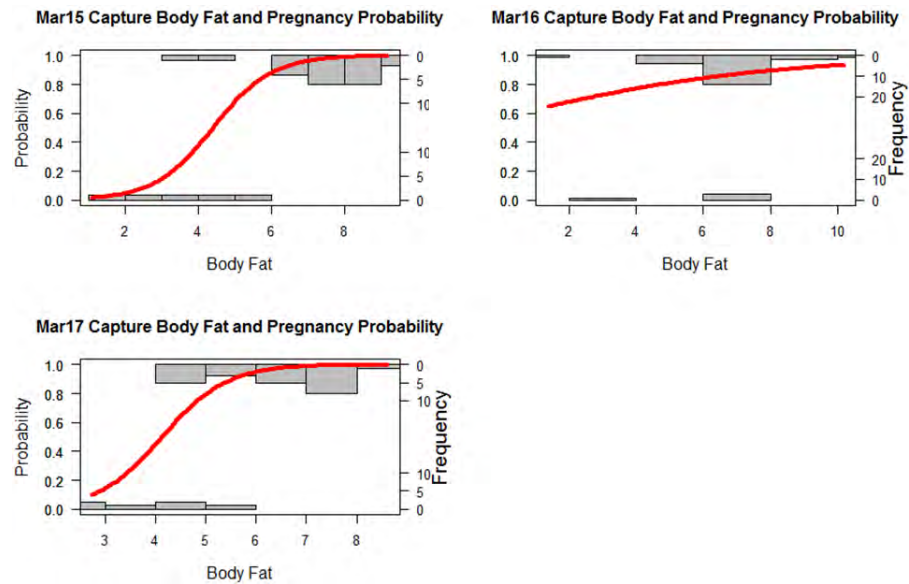


Figure 6: Logistic regressions of moose body fat in March and the probability of that moose being pregnant. The relationship was not as strong in March 2016.



Figure 7: Logistic regressions of moose body fat in March and the probability of that moose having a calf-at-heel during capture.

Kidney samples

Many hunters participated in the kidney sampling program, although participation was stronger in 2015 than 2016. A key assumption of kidney-fat-index studies is that the fat surrounding the kidneys has been included in-total with the sample and has not been disturbed. It can be difficult for a person to find a fat-enclosed kidney and we received several samples that were trimmed of all fat. As a result, many submitted kidneys could not be analyzed and had to be discarded, yielding a weak sample size. A requirement of hunting female moose in the Snowy Range is that the moose must not have a calf-at-heel. Collared moose without a calf-at-heel had higher body fat in December 2015 than 2016, on average, a trend that was mirrored in the kidney fat index. These data should be taken with a grain or two of salt — kidney sample sizes are nine and four, respectively (Figure 8).

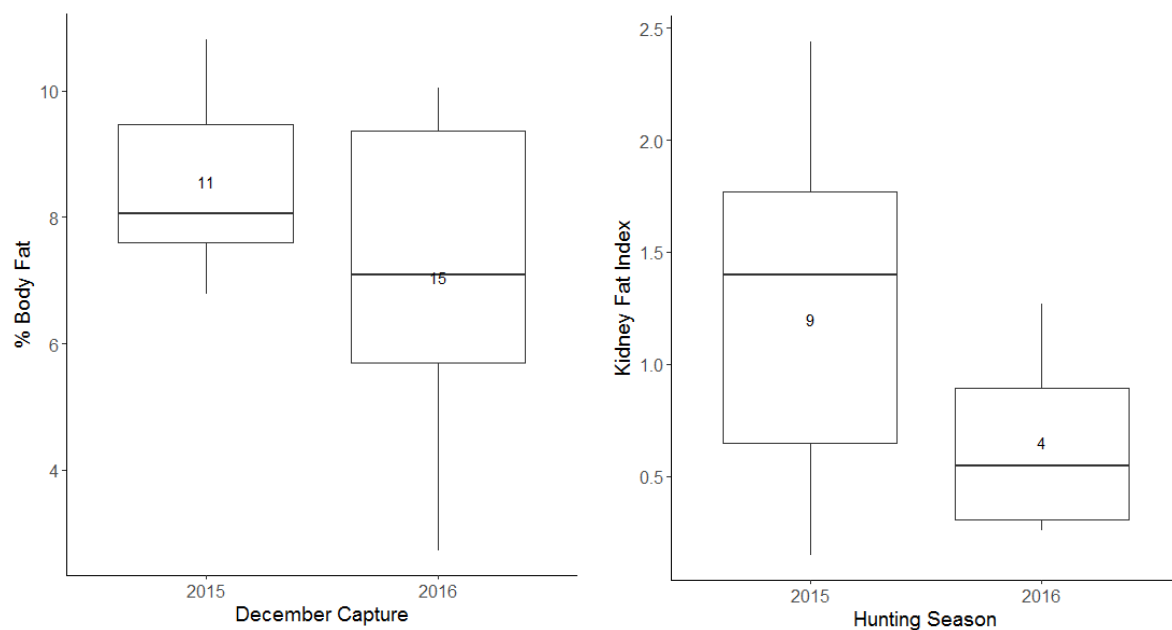


Figure 8: Distribution of December body fat measurements of collared moose without a calf-at-heel (Panel 1), and kidney fat indices of harvested female moose (Panel 2). Bolded horizontal lines represent medians and numbers indicate sample size.



Willow condition

We implemented the Keigley Live-Dead Index method of estimating browsing pressure so we could compare our measurements with those collected at the same plots during previous studies. We surveyed 20 willow plots in 2015 and 42 plots in 2016. The focal species for the majority of plots were Planeleaf willow, although we also sampled Drummond, Booth, and Whiplash willow plots. Our findings suggest that Planeleaf willow communities, a preferred forage species for moose, have improved substantially in the last eight years. Moose and elk harvest also have increased during that period.

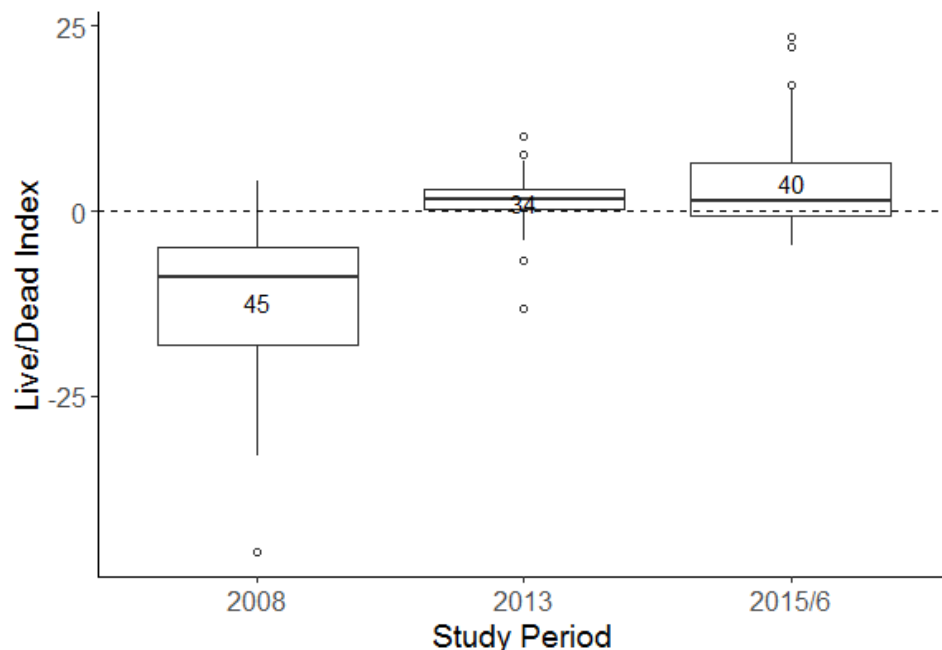


Figure 9: Distribution of indices of browsing pressure for Planeleaf willow communities across three time periods. Bolded horizontal lines represent median values and numbers indicate the sample size. Hollow circles are plots that had extremely high or low values. Values below zero (dotted line) indicate high browsing pressure that is suppressing annual growth. Values above zero suggest that the willows can grow despite browsing.



Habitat selection

We are still refining our habitat classification model, which is a necessary step (and computational bottleneck) in completing analyses. When finished, we will use the habitat model in resource selection analyses to compare how habitat use patterns may have changed between now and a decade ago. We also will aim to determine how the habitat composition of each moose's home range is related to their body condition. Project moose showed a variety of movement behaviors and used conifer forests to varying degrees. Many moose wintered in higher-elevation conifer forest and summered in lower-elevation river corridors. Some moose were migratory within the Snowy Range, although they were the exception rather than the rule.

Custom land-cover classification

Existing habitat maps for the Snowy Range are insufficient for answering project questions. As such, we are creating a high-resolution map of the major vegetation types in the area to use in our movement and habitat-selection analyses. The new map will allow us to delineate small riparian areas and aspen stands that might otherwise be lumped-in with the surrounding pine trees in other habitat maps. Furthermore, we can map individual live and dead trees (Figure 10), which allows us to estimate the extent and intensity of beetle-kill throughout moose range. Creating the map is a time-consuming, but essential, process in completing project objectives.



Figure 10: Example area from an early-stage land-cover model. We are building the classification layer at half-meter resolution, meaning that each pixel in the image represents a 0.5m x 0.5m area on the ground. The tree-level distinction between live and dead pines is apparent in the upper-left corner.

Understory in a pine forest

We completed 54 surveys in mature lodgepole pine forest and 30 surveys in regenerated forest. Analyses of these data are on hold until we finish the land-cover classification and photographic analysis of horizontal cover. We are also double-checking the data to ensure that we correctly identified some plant species. We will then determine whether plant communities differ depending on how much of the canopy is dead, whether mature and regenerated stands differ, and how shade structure differs between coniferous and riparian areas. We will also use diet data collected by Brett Jesmer to evaluate whether conifer forests hold important food plants for moose and if so, what might drive the variation in their presence.



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Historical Snowy Range Data

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Snowy Range Moose Diet Data and Willow Data

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Sublette Moose Project Data

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UPCOMING WORK

Final analyses and reporting

We are in the process of completing the analyses for the project. We anticipate finalizing the results by December 2017 or January 2018, at which point we will publish a final report summarizing the project findings. We will be preparing manuscripts for publication in peer-reviewed scientific journals during this time. Project reports and publications will be provided to the Wyoming Game and Fish Department and made publicly available on the project website:

<http://wyocoopunit.org/projects/demographics-and-nutritional-response-of-moose-to-beetle-kill-in-the-snowy-range>

Project continuation

The Wyoming Game and Fish Department approved a proposal to continue the moose research in the Snowy Range to answer new questions about the specific causes of adult mortality, as well as address other aspects of moose ecology. The field component of the current phase of the project concluded in March 2017 with the final recapture and removal of GPS store-on-board collars. Moose that we recaptured at this time were fit with new satellite-uplink collars with a 60-minute location schedule, which began the field component for the second phase of moose research in this area. It is our hope and intention that the data collected during the first phase of the project can be put to use in phase two, answering different questions and continuing to contribute to effective moose management. Tana Verzuh began work as a MSc student in the fall of 2017 looking specifically at cause-specific mortality of adult female moose.



ACKNOWLEDGMENTS

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DEER-ELK ECOLOGY RESEARCH PROJECT

Background

Mule deer have had a complex history throughout the western United States. In the days of the early settlers and pioneers, mule deer were relatively rare; many trappers and explorers reported only occasional sightings of mule deer whereas other big game species were regularly observed. At the beginning of the 20th century, mule deer populations had been drastically reduced in number due largely to overharvest, market hunting, and overgrazing. Protections were put in place in the early to mid-1900s, eventually leading to ideas such as the North American Model of Wildlife Conservation, which was followed by a dramatic increase in mule deer populations. Mule deer populations peaked between the 1940s to the early 1960s throughout the western US.



Fast forward a few decades to the present day. With a lens to examine population fluctuations over the past 40+ years, a clear pattern has emerged. Populations, at least in Wyoming, appear to go through cyclical periods of increase followed by sharp declines. In reviewing literature and historical documents, concerns about mule deer tend to follow huge decreases in populations and when they subsequently rise, research and management become less important. Another point that seems clear in Wyoming is that although we have this see-saw in population numbers, there is a general declining trend since at least the 1970s. On average, Wyoming has seen roughly a 20% reduction in mule deer populations.

The population swings, and the general decline of mule deer since the 1970s have been difficult to understand. A variety of factors have been proposed to explain these declines, including:



overharvest, harsh winters, habitat, drought, predation, and disease. A conundrum has been the observation of viable and growing elk populations while mule deer in the same systems continue to struggle. Questions arise regarding potential competition between mule deer and elk, or the conditions that have fostered growth of elk while being detrimental for deer. The complexity of these questions and the difficulty in answering them has meant that gaining a more complete understanding of reasons for fluctuations or stagnant growth in population numbers has been elusive.

Without a solid understanding of the why and how associated with population fluctuations, it is incredibly difficult for targeted management to achieve desired outcomes. The aforementioned questions and concerns have helped to initiate the Deer-Elk Ecology Research Project, wherein we aim to elucidate and quantify the relative roles of habitat, climate, predation, and competition on the performance of deer and elk, with our study system being the Greater Little Mountain Areas south of Rock Springs. This high desert system, with historic abundance of deer and near lack of elk historically compared with a currently thriving elk population and struggling deer population make an ideal model system to address these questions.

Components of the Deer-Elk Ecology Research Project

Adult Captures

To better understand nutritional dynamics of adult female mule deer and elk, we initially began capturing and collaring females in November of 2015, where we captured a sample of 55 female mule deer and 35 female elk. Each November we recapture our radio-collared female mule deer to assess nutritional condition and overall health of each animal. Every April, we again recapture all our female mule deer and additionally our radio-collared female elk to assess nutritional condition, pregnancy, and fit pregnant females with Vaginal Implant Transmitters (VITs) to aid in neonate captures during the summer. These ‘double captures’ in November and April allow us to track nutritional condition of individuals across seasons.



Neonate Captures



To understand the magnitude to which neonate survival drives mule deer and elk populations south of Rock Springs, we began capturing and monitoring newborn mule deer that belong to our collared females in the summers of 2016 and 2017, and will continue to capture and monitor into the summer of 2018. We began capturing and collaring elk calves that belong to our collared females in 2017, and will continue to capture and monitor in 2018. With each fawn or calf we capture, we fit them with an expandable radio-collar that allows us to monitor their survival. In the event that a mortality occurs, we investigate as quickly as possible to determine the cause of death.

Diet Analysis

Fecal samples will be analyzed to examine dietary overlap between elk and deer. In addition, we are collecting any incidental fecal samples, including: pronghorn, feral horse and livestock. The goal is to collect three rounds of fecal samples per year to detail dietary overlap throughout the summer months. Presumably, diets will shift as moisture decreases, plants senesce, and their relative quality and abundance changes. Once we analyze fecal samples to identify diet composition, subsequent summers we also will be collecting plant samples from key forage species to measure nutritional quality of those plants. With a single round of fecal samples collected, we have obtained nearly 900 individual fecal samples across the GLMA. Knowledge of diet composition will be key to evaluating potential dietary overlap among ungulate species, but also to help understand what key forage items help to grow mule deer and elk in this arid landscape.

Male Mule Deer

The GLMA is a popular destination for mule deer hunters. Despite its popularity, evidence from Wyoming Game and Fish composition surveys suggest that buck:doe ratios have decreased in the past decade. Additionally, anecdotal evidence from locals suggest that mule deer bucks are harder to find during hunting season than previous years. One possible explanation for these observed patterns is that bucks may be moving south into Utah and Colorado before hunting season rolls around. While we don't know if this is happening, the possibility exists and may have significant implications for mule deer population dynamics, hunting, and management of this population. We will distribute GPS collars on mule deer bucks throughout the study area to better understand their habitat use and movements during different times of the year. We'll continue by collaring an additional 25 new animals each year of the project.

Coyotes

With the recent support of key funders including the Animal Damage Management Board, and the Southwest Chapter of the Muley Fanatic Foundation, we began integrating focused work on



coyotes to the DEER Project in April of 2017. We aim to quantify the effects of coyote demography, behavior, and space use on survival of young mule deer and elk. We will evaluate patterns of habitat selection of coyotes and determine how that coincides with habitat use of mule deer and elk, with a specific eye towards parturition and areas occupied during rearing of newborns, the period of most vulnerability for neonates. We began capturing adult coyotes in April of 2017.

Project update

Reproduction and nutritional condition

During our spring 2017 capturing effort, we captured or recaptured 30 female elk, 46 female mule deer, 19 yearling males and 3 yearling females that were captured as neonates in summer of 2016. We aim to maintain a sample size of 35 adult female elk and 50 adult female mule deer; keeping our sample size is not always possible because weather conditions, collar malfunctions, mortalities, and accessibility of animals to capture. Of the 30 elk that we captured, 28 were pregnant and of the 46 mule deer, 44 were pregnant. All pregnant female elk had a single fetus whereas fetal rate for our mule deer was 1.5 as compared with 1.7 for the spring of 2016. All pregnant females were fit with VITs to aid in determining birth site locations and to help in neonate capture and monitoring efforts.

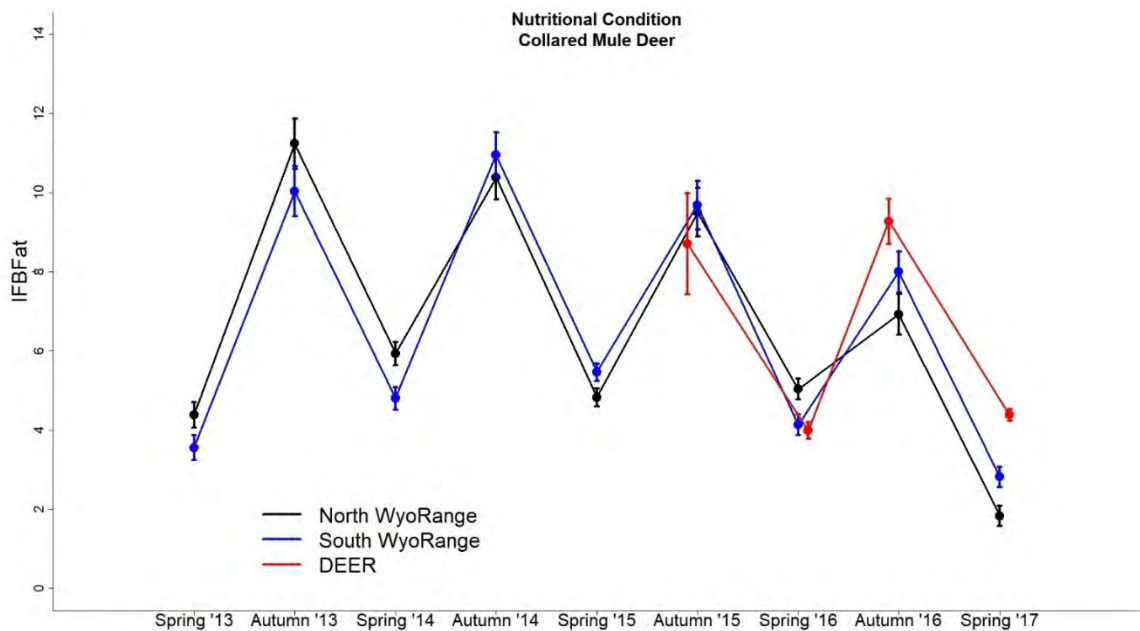


Figure 1. Comparison of nutritional condition of adult female mule deer in both the North and South Wyoming Range, and the DEER Project.

Nutritional condition of deer for the DEER project has provided a valuable comparison to our long-term data in the Wyoming Range (Fig. 1). Although we might expect deer south of Rock Springs to be fatter in autumn because we capture them a month earlier, that was only true in autumn 2016 when deer in the Wyoming Range were at the lowest nutritional condition post-summer that we had measured since the beginning of that project. In contrast, deer were markedly fatter in spring in the Little Mountain area than following winter in the Wyoming Range. Despite the general notion of severe winter conditions across much of western WY, it would appear as though the winter south of Rock Springs at least ameliorated early and the extra moisture may well have been very beneficial to deer that reside there.

Neonate survival

Mule Deer Fawns

Mule deer neonate captures began much earlier in 2017 than 2016 with the first live fawn being born 24 May, compared with 31 May during the summer of 2016 (Fig. 2). Mule deer parturition overall shifted earlier this year compared with 2016; peak date of parturition was 31 May in the summer of 2017 compared with 10 June in the summer of 2016. Fawns in 2017 were generally smaller in size, which may be correlated to shorter gestation periods and early parturition dates as compared with typical years. Data from next summer will help add resolution to this question.

Average fawn weight and length in 2017 was 3.1 kg (~6.8 pounds) and 60.1 cm respectively while average fawn weight and length in 2016 was 3.8 kg (~8.4 pounds) and 60.5 cm respectively. Through the summer of 2017, we have witnessed roughly 35% mortality of our collared fawns versus nearly 75% during the summer of 2016.

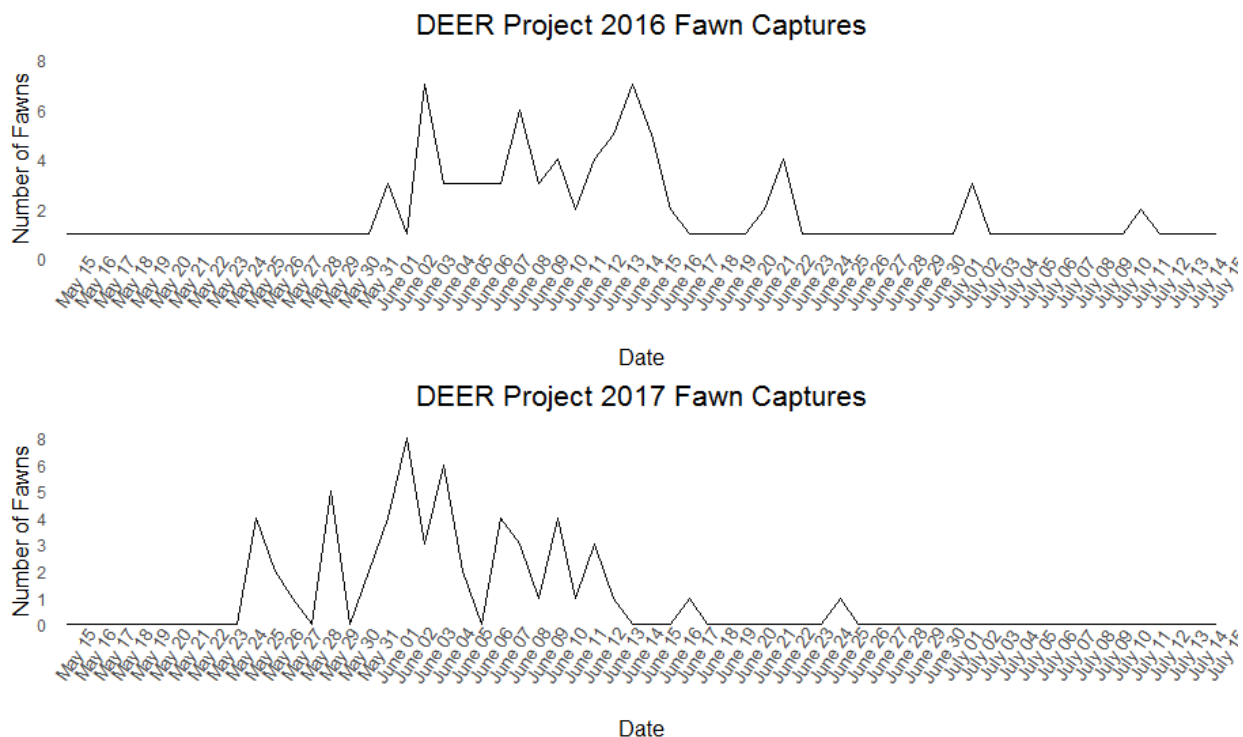


Figure 2. Timing of fawn captures in 2016 and 2017 for the DEER Project.

Elk Calves

The summer of 2017 saw the initiation of capturing and monitoring of elk calves. This work aims to understand the patterns and processes regulating a high desert elk population, while leveraging the wealth of information being recorded during the ongoing DEER Project. Our aim was to capture and collar calves from pregnant female elk that we fit with VITs in April of 2017.

Interestingly, our captured elk calves were mostly male by a large margin—over 75 percent of the calves were male. Of the 16 elk calves we captured, 5 were lost during the summer with 4 succumbing to predation events and one dying from unknown causes shortly after birth occurred. Somewhat surprising was the timing of elk parturition as compared with mule deer parturition. Although we had expected elk to birth before the deer, mule deer parturition this year peaked at the end of May whereas elk parturition peaked in mid-June. The large discrepancy in dates could be a function of the abnormally early mule deer parturition in 2017 or could point to other unknown reasons not before observed or identified in high desert mule deer and elk populations.

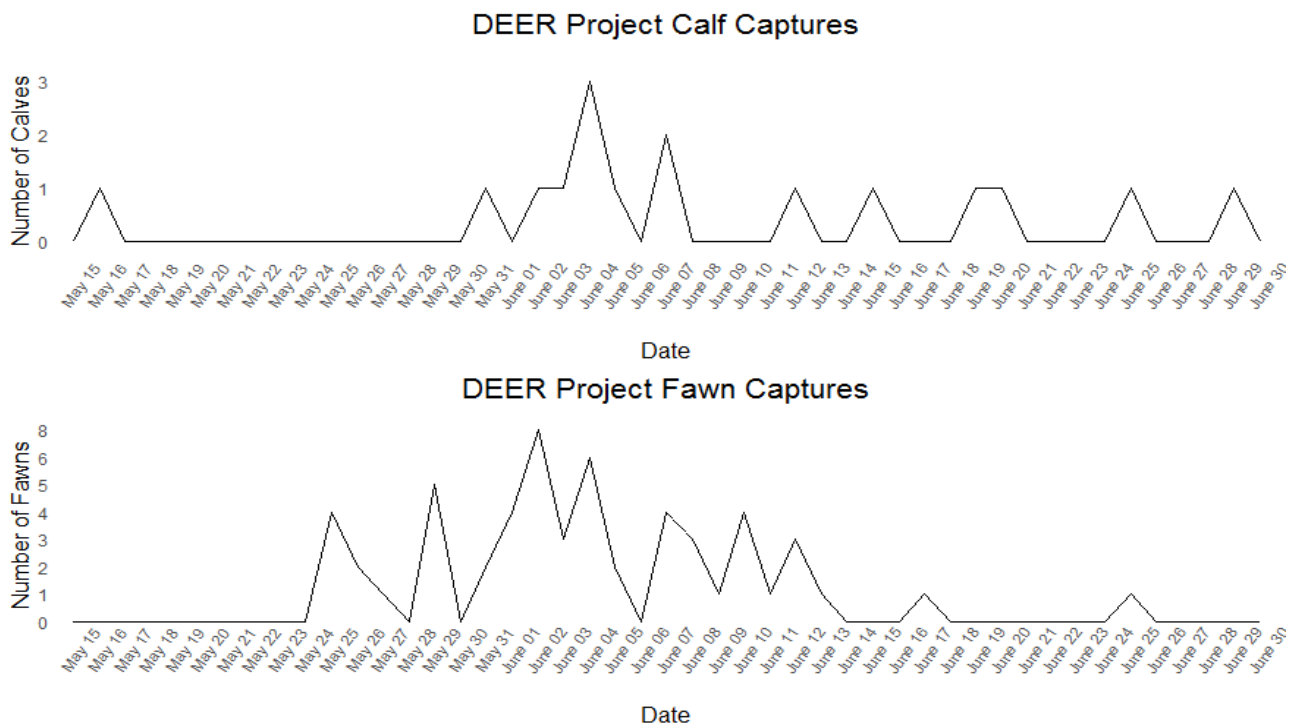


Figure 3. Timing of captures of elk calves and mule deer fawns in 2017. Fawn and calf captures peaked at about the same time.

Fecal Samples and Diet Analysis

During the 2016 summer field season, we began collecting fecal samples from our collared animals at three times throughout the summer. To accomplish this, we use real-time GPS data from individuals and create a “homerange”; the area an animal spends the majority of its time in. We then visit these areas to obtain fecal samples that are representative of our collared animals, whose age, nutritional condition, and recruitment status are known. This way, we can tie diet items and preference back to individual and population-level performance.



During the 2016 and 2017 summer field seasons, we collected over 2,000 fecal samples from mule deer, elk and other incidental species (cattle, horses) throughout the study area in June, July and August. We dried and homogenized those samples and sent them off to be analyzed via DNA metabarcoding. DNA metabarcoding is a relatively new analytical technique which extracts DNA from the vegetation material present in a fecal sample to determine the plants that an animal consumed. We are still analyzing these data but we are already seeing a high degree of overlap between mule deer and elk diets.

The summer of 2016 was a typical year with a moderate winter and a moderate amount of precipitation throughout the winter months, whereas the winter of 2017 presented much of Wyoming with heavy snowpack and sub-zero temperatures for months at a time. By sampling throughout the life of the project, we'll be able to build a more complete picture of key diet items and how these diet items tie into sustaining populations of deer and elk.



Male deer

Currently we have nearly 50 yearling and adult male mule deer collared throughout the study area. So far, we have not seen any directional movement out of the study area before the hunting season sets in, however, a male fawn that was captured as a newborn during summer 2016, and that we were able to recapture and put a GPS collar on in the spring of 2017, departed what appeared to be his summer range just north of Pine Mountain in the southeastern portion of the study area. In just 2 short days, this 1-year old male moved north, crossed I80 between Rock Springs and Green River, to a new destination north of Pilot Butte, west of Rock Springs. The timing and decision to “migrate” in the middle of summer is a bit abnormal, and the location of his movement likely is more reflective of a dispersal event where he is establishing a new summer range. It begs the question if he will return, or perhaps establish a new winter range this autumn. Time will tell if this young male retains some of what he learned during his upbringing, or if he simply has adopted an entirely new movement strategy.



Figure 4. Movement of a yearling male mule deer during the summer of 2017.



Coyotes

Currently we have 9 coyotes collared throughout the study area. Of those 9 coyotes, 7 are females and 2 are males. We are continuing our trapping efforts throughout November and December to hopefully reach a sample size of 20-30 coyotes. A preliminary look at the GPS data from collars shows that these coyotes have very large (~40 sq. miles) territories. One of the larger males clearly has about a 30 square mile territory that he patrols on a regular basis. Another of the collared females that we captured in April of 2017 who was pregnant, clearly stayed around her den with her pups until November when her pups dispersed.

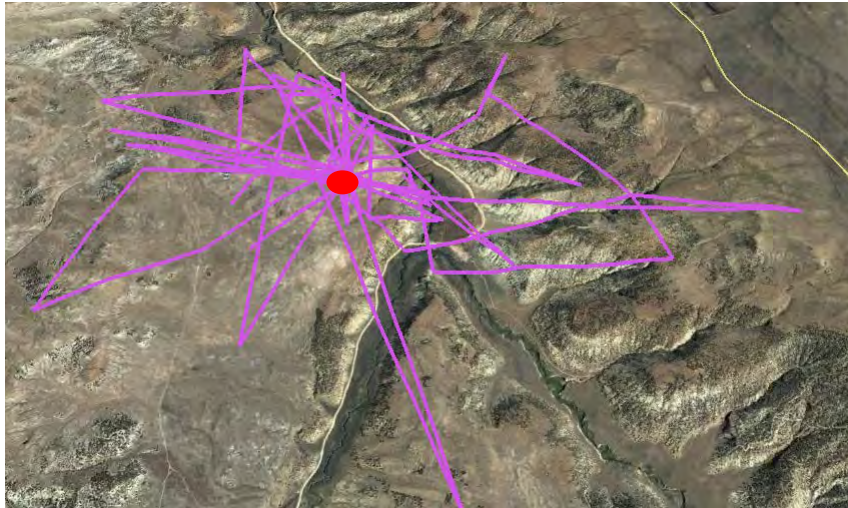


Figure 5. Movement of a pregnant female coyote from 24 April to 15 May, 2017.

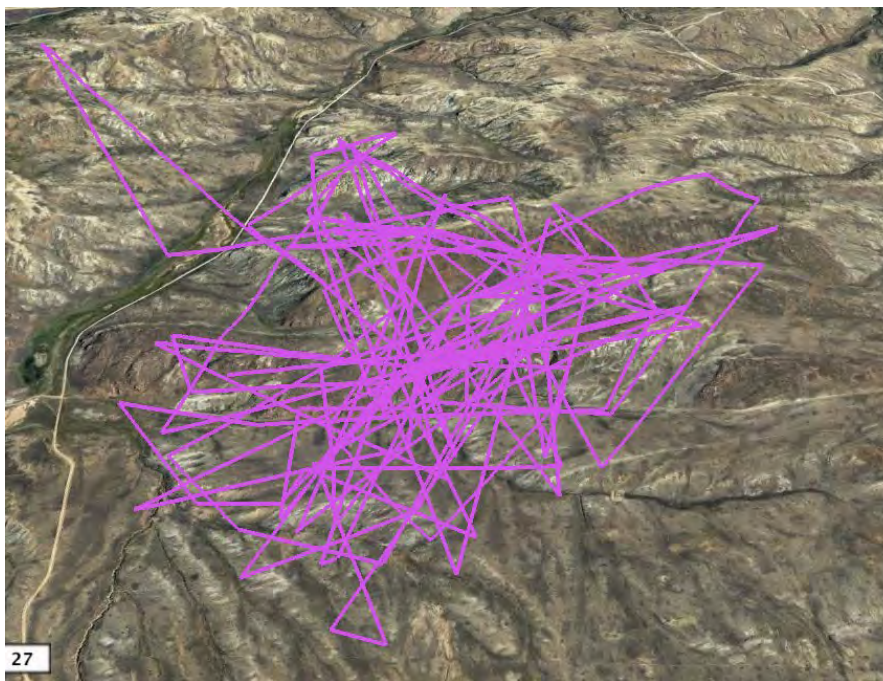


Figure 6. Movement of a mature male coyote from April 24-May 15, 2017. The territory of this male is about 30 square miles.

Going Forward

The Deer-Elk Ecology Research Project is beginning year 3 and it seems as though we just collared our first animals yesterday. We are beginning to see patterns emerge in the data of overlapping diets between mule deer and elk and some type of alteration of distributions of each species relative to the others. We have observed higher signals of predation on neonate deer in the Greater Little Mountain Area than in the Wyoming Range and we are also witnessing a difference in patterns of nutritional condition of deer south of Rock Springs than in the Wyoming Range. It is an exciting time on the DEER Project as we lay the foundation to be able to unravel some complex questions and better understand what factors are structuring landscapes of large ungulates. Now while the final assessments and conclusions from this study will take time, patience, and perseverance, we are poised to markedly advance our understanding of the dynamics of our highly prized deer and elk populations. We thank everyone for their support and look forward to sharing information with you as we progress.



Partners

The Deer-Elk Ecology Research Project would not be possible without generous contributions and continued support from the Wyoming Game and Fish Department, Muley Fanatic Foundation Headquarters, the Southwest, Kemmerer, Flaming Gorge, Upper Green, and Casper Chapters of the Muley Fanatic Foundation, Wyoming Governor's Big Game License Coalition, Bureau of Land Management, Bowhunters of Wyoming, National Science Foundation, Wyoming Wildlife and Natural Resource Trust, and Animal Damage Management Board. A special thanks to those hunter-conservationists that have invested in the DEER Project through the grass-roots fundraising efforts led by the Muley Fanatic Foundation; including all of those individuals and organizations who have "adopted-a-deer".



For More Information,

Visit our website at: www.deerproject.org or contact us:



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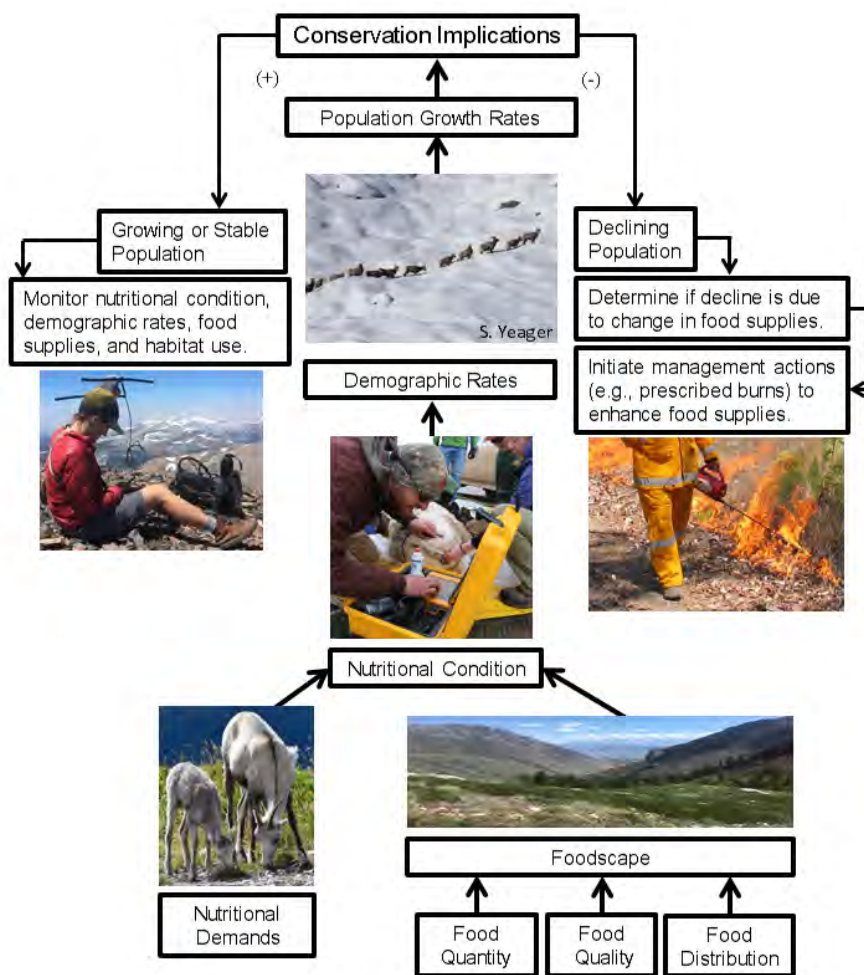
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SIERRA SHEEP NUTRITIONAL CARRYING CAPACITY PROJECT

The need to develop new tools for recovery and conservation of endangered species

The Earth is experiencing a sixth mass extinction and that immediate, intensified actions are needed to conserve endangered species. Specifically, conservation actions that support population growth and persistence are needed, as are recovery goals with a strong biological rationale. Finding conservation actions and recovery goals that are biologically sound requires thorough knowledge of the ecology and habitat requirements of endangered species and how changes in habitat affect population growth. Nutrition is the fundamental building block of populations and perhaps the

most important way through which habitat influences wildlife (Fig. 1) and thus, is the focus of our research. In this project, we will unite concepts from nutritional and population ecology to identify nutritionally valuable habitats necessary for long-term persistence of endangered species, and to better understand demographic consequences of variation in food supplies. Our work will focus on Sierra Nevada bighorn sheep, but the conceptual basis of our methodology is transferable to conservation planning and establishment of recovery goals that are biologically feasible for species around the globe.



nutritional condition scales up to influence demographic rates and population growth rates. Different growth rates (+ or -) have different implications for on-the-ground conservation.

A brief history of Sierra Nevada bighorn sheep

With an estimated population size of ~520 individuals, Sierra bighorn are one of the rarest ungulates in North America. Historic records, though incomplete, show that Sierra bighorn once ranged throughout the High Sierra, from Olancha Peak in the south to Sonora Pass in the north (Fig. 1). Following human settlement in the region during the California Gold Rush in the mid- to late-1800s, Sierra bighorn numbers decreased, likely because of the introduction of disease from domestic livestock and also potentially because of overharvest. Recovery efforts have been underway since 1999, when Sierra bighorn were listed as an endangered species by the United States Fish and Wildlife Service. The California Department of Fish and Wildlife leads the Sierra Nevada Bighorn Sheep Recovery Program and, as a result, today, 14 extant herds dispersed across four recovery regions within their historic range of Sierra bighorn are growing (Fig. 2).

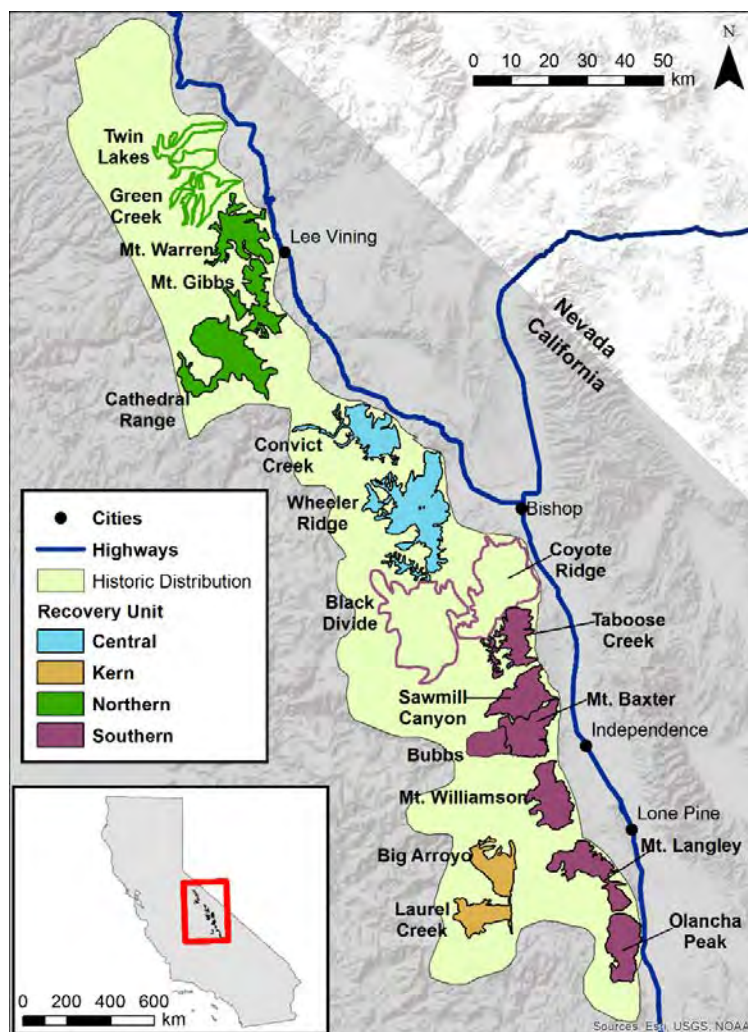


Figure 2. Map showing distributions of populations of Sierra Nevada bighorn sheep. Historic distributions likely are represented by the light green shading, whereas current distributions are represented by filled polygons throughout the recovery area; unfilled polygons represent vacant herd ranges identified in the Recovery Plan.

Nutrition, foodscapes, and populations

Implications of nutrition to conservation and management seldom have been realized, likely because of a lack of reliable methodology for collecting and analyzing data needed to link on-the-ground resources (i.e., foodscapes) with how animals assimilate those resources (i.e., nutritional condition), and how they affect demographic rates of populations (e.g., pregnancy, recruitment, survival). Uniting nutrition data with demographic rates, however, can help elucidate demographic consequences of changes in food supplies by identifying cause-and-effect relationships. In turn, those cause-and-effect relationships can produce a basis for population models capable of integrating a suite of demographic and covariate information.

Without adequate nutrition animals cannot survive, grow, or reproduce, and thus, populations cannot persist. Animals with higher quality diets and access to greater quantities of food can achieve higher intake rates, produce higher-quality milk, grow larger, and achieve greater body mass and nutritional condition than their counterparts with lower-quality diets. Nutritional condition, a measure of the proportional fat reserves an animal possesses, is a direct product of an animal's nutritional environment (e.g., foodscape). For many large mammals, fat reserves are used to finance survival and reproduction and thus, nutritional condition provides a unique lens to connect an animal's nutritional environment (foodscape) to demography.

Documenting quantity, quality, and distribution of food supplies across a landscape provides the basis for assessing population-level effects of nutrition, which can inform recovery actions. Traditionally, surrogate measures of food supplies (e.g., total vegetation biomass) have been used as coarse assessments of habitat quality, but these surrogate measures are based on researchers' perceptions, which can be diametrically different from how animals perceive their environment, and thus may not be biologically relevant. Foodscapes developed from detailed information on foraging behavior of animals can overcome limitations of traditional methods that overestimate the capacity of a landscape to support populations and consequently that fail to explain *why* animals live where they do. Further, fine-scale, animal-centric quantifications of food supplies are needed because even small differences in diet quality (e.g., ~0.3 kcal/g of food) can scale up to



have disproportionately large multiplier effects on individuals and populations. Foodscapes have utility in monitoring habitat change; estimating potential population sizes (i.e., number of animals); and, perhaps most importantly, in identifying nutritionally valuable habitats that can support growth and long-term persistence of wildlife populations — endangered or not.

Conventional population models use separate analyses of population counts and demographic rates. These separate analyses have been criticized for being inefficient, unable to account for uncertainty (i.e., variances and covariances) in parameter estimates, and producing biased estimates of population growth rates. Integrated population models are now gaining favor among population ecologists because they analyze all population count and demographic data simultaneously in a single model, and can incorporate additional covariates (e.g., nutritional condition and foodscape information), thus, overcoming limitations of conventional population models and providing more reliable estimates of population growth rates and what influences them.





Developing Foodscapes

During the summer of 2017, we produced a preliminary map of alpine habitat types to better represent available habitats for Sierra Nevada bighorn sheep (Fig. 3). The alpine habitat types classified in this approach were barren, herbaceous (dry, mesic, or wet), and shrub. At 29 locations within these habitat types, we collected information on vegetation biomass using double-sampling techniques. Beginning in 2018, we will collect samples of individual plant species consumed by Sierra Nevada bighorn sheep that will be analyzed for nutritional content (e.g., energy, protein). Vegetation biomass and quality data will be mapped across the landscape using the reclassified habitat types to produce foodscapes.

Estimating Nutritional Condition, Demography, and Potential Population Size

Since 1999, Sierra bighorn have been captured and fitted with GPS and very high frequency radio collars 1–2 times per year to enable monitoring for demography and movement. Beginning in 2018, we will also deploy a limited number ($n \leq 10$) of remote video cameras and video camera collars for additional documentation of food habits and other foraging behavior. During handling of captured animals, percent body fat will be determined via ultrasonography and manual palpation to continue building a dataset that dates back to 2001.

Demographic rates of Sierra bighorn will be estimated through the monitoring of collared and uncollared animals. Specifically, we will assess pregnancy rates based on ultrasonography data from captures and evaluate population performance based on semi-annual surveys to record sexes and ages of individuals within populations to estimate recruitment of young and population size. Monthly telemetry flights will be conducted to monitor survival of collared animals as part of the Sierra Nevada Bighorn Sheep Recovery Program.

Relevance to conservation science and practice

Links between foodscapes, nutritional condition, and demography have direct implications to conservation and recovery of endangered species. By quantifying and mapping nutritional values of habitats across foodscapes, and creating integrated population models, this research will improve our understanding of how food supplies influence nutritional condition, habitat use, and demography of Sierra bighorn. As a tool, foodscapes can be used to highlight areas on the landscape with the greatest potential to support population growth and long-term persistence of endangered species.

When anchored by available food supplies, integrated population models can provide realistic estimates of population growth rates given current foodscapes, which can be used to help guide

conservation actions to halt or reverse population declines and provide biologically justified timelines to meet specific population goals. Further, foodscapes are invaluable for conservation practitioners making decisions regarding where to focus augmentation and reintroduction efforts, which are cornerstones of the Recovery Program for Sierra bighorn. If foodscapes do not support current recovery goals, then practitioners can determine if habitat management is warranted or if recovery goals need to be re-evaluated. Further, foodscapes will be useful for monitoring effects of climate and landscape change on Sierra bighorn habitat and alpine ecosystems in the Sierra Nevada. The conceptual framework and innovative tools developed in this study will provide practitioners with the means to: identify nutritionally valuable habitats (which can be used to set land-acquisition or habitat restoration priorities); to understand cause-and-effect relationships between habitat change and population trajectories; and plan conservation actions accordingly to achieve predictable outcomes for the recovery of endangered species across the globe.

Partners

This project would not be possible without funding (including Pittman-Robertson funds) from the California Department of Fish and Wildlife (CDFW). Further, CDFW staff (T. Calfee, D. German, L. Greene, B. Hatfield, J. Leary, E. Otto, E. Siemion, A. Sturgill) have provided indispensable insights and field support for vegetation sampling in the summer of 2017 and have compiled an extensive database that will be essential to the success of this project. J. Wehausen of the Sierra Nevada Bighorn Sheep Foundation also provided helpful insights during field sampling in 2017.

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ROSE PETAL PROJECT

While seasonal migration occurs in diverse animals and habitats, large ungulate migrations are some of the most spectacular wildlife events in the world. Migration is crucial to maintaining large, robust populations of large ungulates, and the western US boasts many populations of migratory ungulates, such as pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), moose (*Alces alces*), and mule deer (*Odocoileus hemionus*). Among ungulate migrations, mule deer migrations are extraordinary because animals can migrate extensive distances (up to 260 km) over extremely rugged terrain. Despite being able to travel all over a landscape, mule deer tend to move over this rugged terrain using the same migratory routes and seasonal ranges year after year, yet the question remains: how do mule deer know how to migrate?

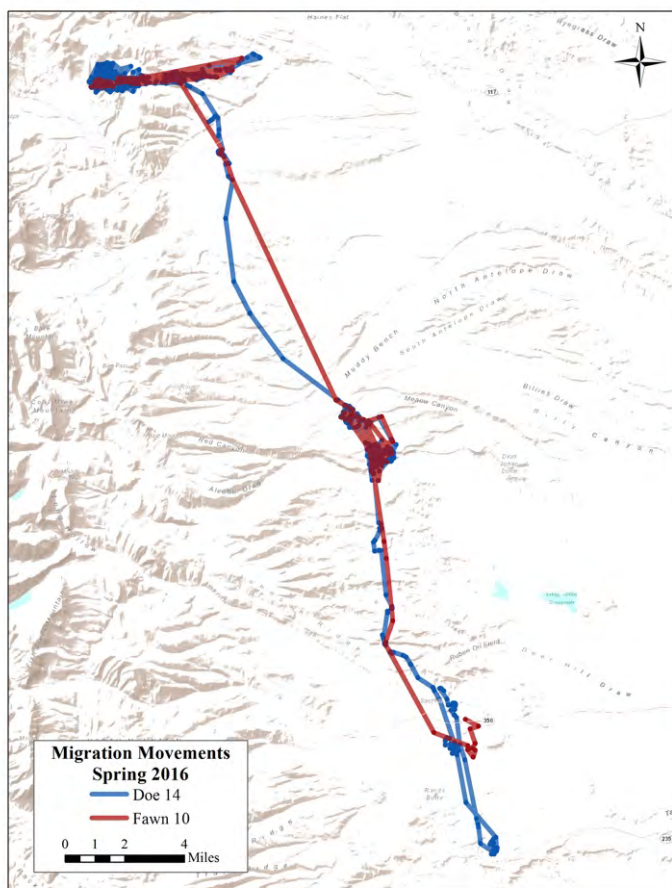


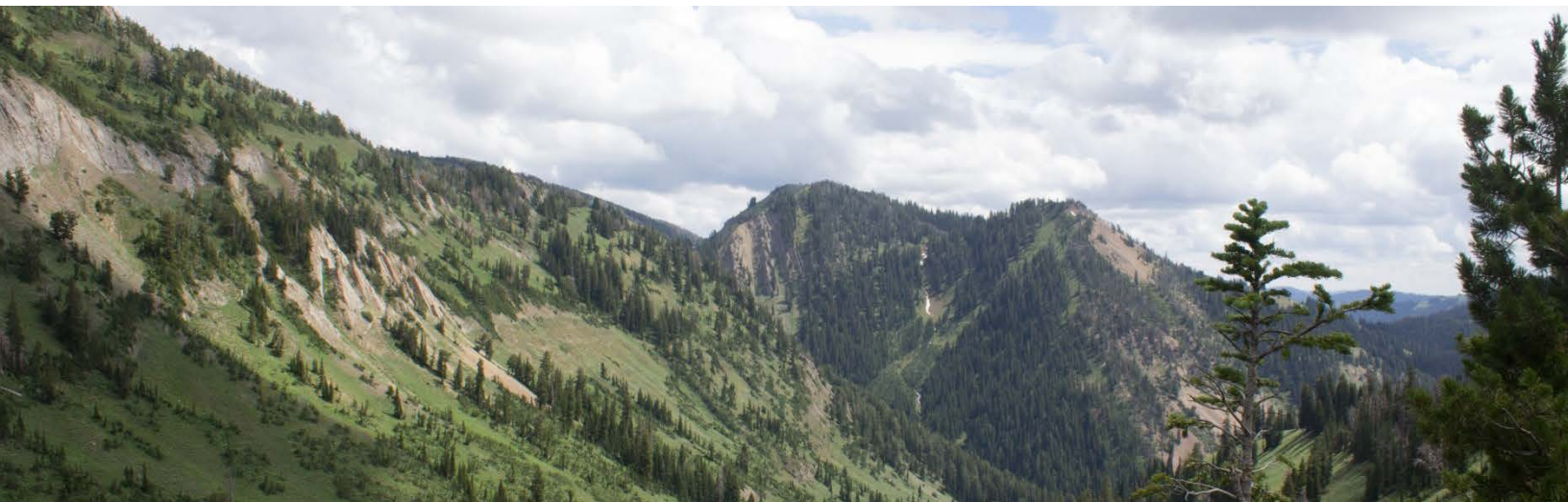
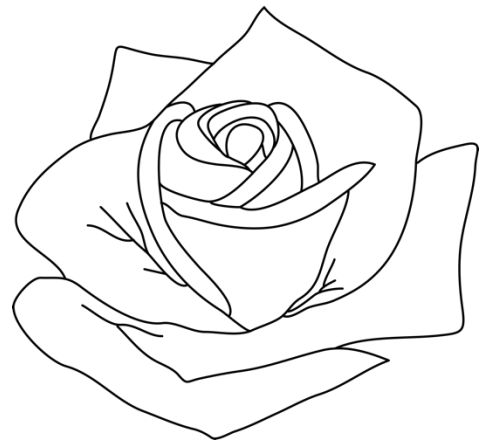
Fig 1. Paired migratory movements of mother (blue) and daughter (red) mule deer in Wyoming, USA. The migration paths of mother and daughter overlap considerably, and warrant investigation of the role of cultural inheritance in shaping migratory behaviors. Credit: S. Dwinell.

Ungulates may know how to migrate if information on migratory traits (e.g., timing to initiate migration, rate of movement, migration path, seasonal range characteristics) is passed down from parent to offspring. Two potential mechanism could facilitate this transmission from parent to offspring: genetic inheritance and cultural inheritance. While genetics may underpin migratory traits in some bird species, whether genetics underpin ungulate migration remains to be discovered. Additionally, migratory traits may be passed from mother to offspring if offspring migrate alongside and learn the behaviors of the mother – in other words, through cultural inheritance. Depending on the mechanism responsible for determining the transmission of migratory traits, we may need to alter our management strategies to ensure robust deer populations. Before we can understand these mechanisms, however, we need to test an overlooked assumption: that migration is passed from generation to generation at all, regardless of the mechanism responsible.

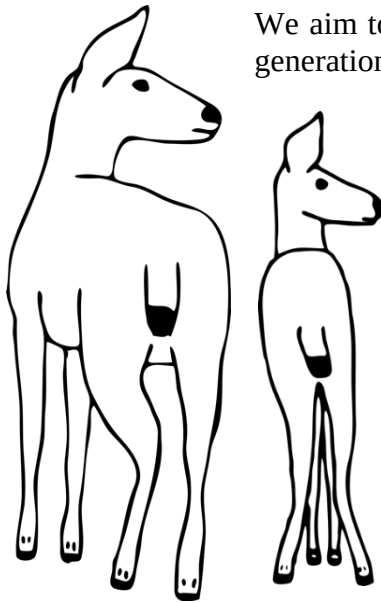


In mule deer, managers and scientists currently assume that mothers migrate with their newborn offspring from summer range to winter range, and return with their offspring to summer range the following spring (Fig. 1). The transmission of migratory traits (through either genetic or cultural inheritance) could allow parents to pass information about already successful or familiar habitats and routes to their offspring. While scientists have largely overlooked the transmission of migratory behaviors from parent to offspring, studying whether information is transmitted across generations has huge ramifications for understanding the ontogeny – or development – of migratory behaviors.

In addition to being fascinating, understanding the ontogeny of migration could change how we manage populations of migratory mule deer and other migratory ungulates. Because the females in many species of ungulates do not disperse far from their natal range, clusters of closely related females will form when mothers successfully raise offspring. This behavior of spatial arrangement is deemed the *rose petal hypothesis*, and results in clusters of mule deer families while they are on summer range. Passing migratory behaviors from parent to offspring could have population-level consequences if inherited behaviors constrain the habitat which family lineages can access. For example, if a mother mule deer transmits information about high-quality habitat to her daughter, that daughter may be more successful at having and raising offspring of her own. Alternatively, if a mother transmits information that leads her daughter to low-quality seasonal ranges, her daughter may have lower reproductive success. When combined over multiple generations, the inheritance of migratory traits of differing quality could produce differences in the sizes of these roses – potentially creating areas analogous to mule deer “hot spots” (robust rose) or “dead zones” (dilapidated rose). Identifying the migratory traits that result in these so-called “hot spots” could provide managers with information about which individuals, management areas, or behaviors to prioritize.



Are migratory traits transmitted from mother to daughter?



We aim to identify whether migratory traits are transmitted from generation to generation in mule deer. We expect that if migratory traits are transmitted, offspring will display migratory traits (e.g., migration timing, rate of movement, migration route, and quality of seasonal ranges) resembling their mothers (Fig. 2a).

To test whether migratory traits are transmitted, we will compare migration characteristics among and between mother-daughter pairs of Wyoming Range mule deer fitted with GPS collars. We began collaring efforts in 2016, and expect to collar approximately 50 mother-daughter pairs by the end of the project. We will use a suite of analyses including movement coordinate index, linear regression, and utilization distribution overlap index to quantify similarities between mother-offspring migratory traits.

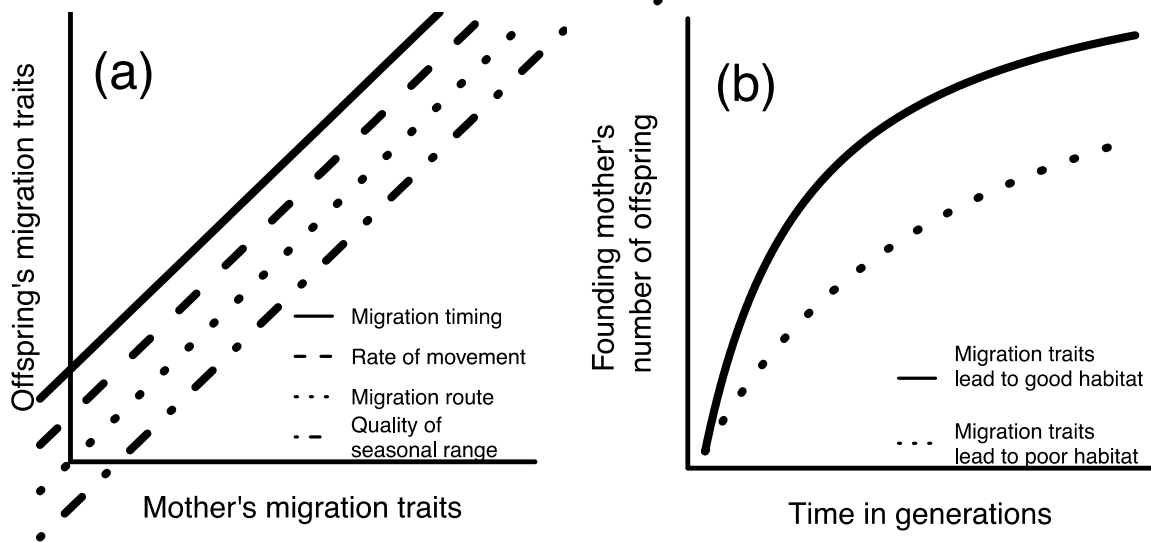


Fig. 2. Predictions associated with the cultural inheritance hypothesis (a) and the population consequences hypothesis (b).

What are the population consequences of transmitting migratory traits?

If migratory traits are transmitted, lineages may be constrained in the habitat they can occupy, such that transmission of certain combinations of migratory traits will lead to differential reproduction and local density. We expect founding mothers that inherit access to advantageous habitat will successfully raise more offspring over their lifetime, while mothers that inherit access to low-quality habitat will raise fewer offspring (Fig. 2b). Differences in reproduction, and the resulting differences in local density, may then influence landscape-scale spatial distribution.

To test whether the inheritance of migration traits has consequences of mule deer populations, we will compare local density around each collared female with mother-offspring migration trait similarities. We will determine local density by searching for fecal samples along belt transects centered around the summer range of each collared mother-daughter pair. Using genetic information extracted from fecal pellets, we will determine individual identification and genetic relatedness to the collared female. We will then test whether similarities in migration traits between mother and offspring influence local density.

Management implications

Despite the importance of migration to many ungulate species, anthropogenic change is rapidly altering landscapes and, consequently, migratory behaviors. Halting or altering migratory behaviors could impact ungulate population trajectories by rendering segments of seasonal habitats unused, ultimately constraining species abundance, occupancy, and distribution. Because migration strategies developed under past conditions, properly managing ungulates in a rapidly changing world relies on characterizing the factors shaping migratory traits and the subsequent population ramifications.



Partners

So far, this project is still in the idea and development stage, and is at the phase of hoping we can build partnerships and secure funding to make this work possible. Not only is it novel, but has enormous implications for understanding animal distribution, and for land and harvest management. Moreover, the only way for a project such as this to be possible is with work that involved following a newborn through to adulthood, which right now is possible because of ongoing work associated with the DEER Project and Wyoming Range Mule Deer Project—making now being the obvious time to initiate this work. Afterall, all projects have to start somewhere!

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BIGHORN SHEEP NUTRITION-DISEASE PROJECT

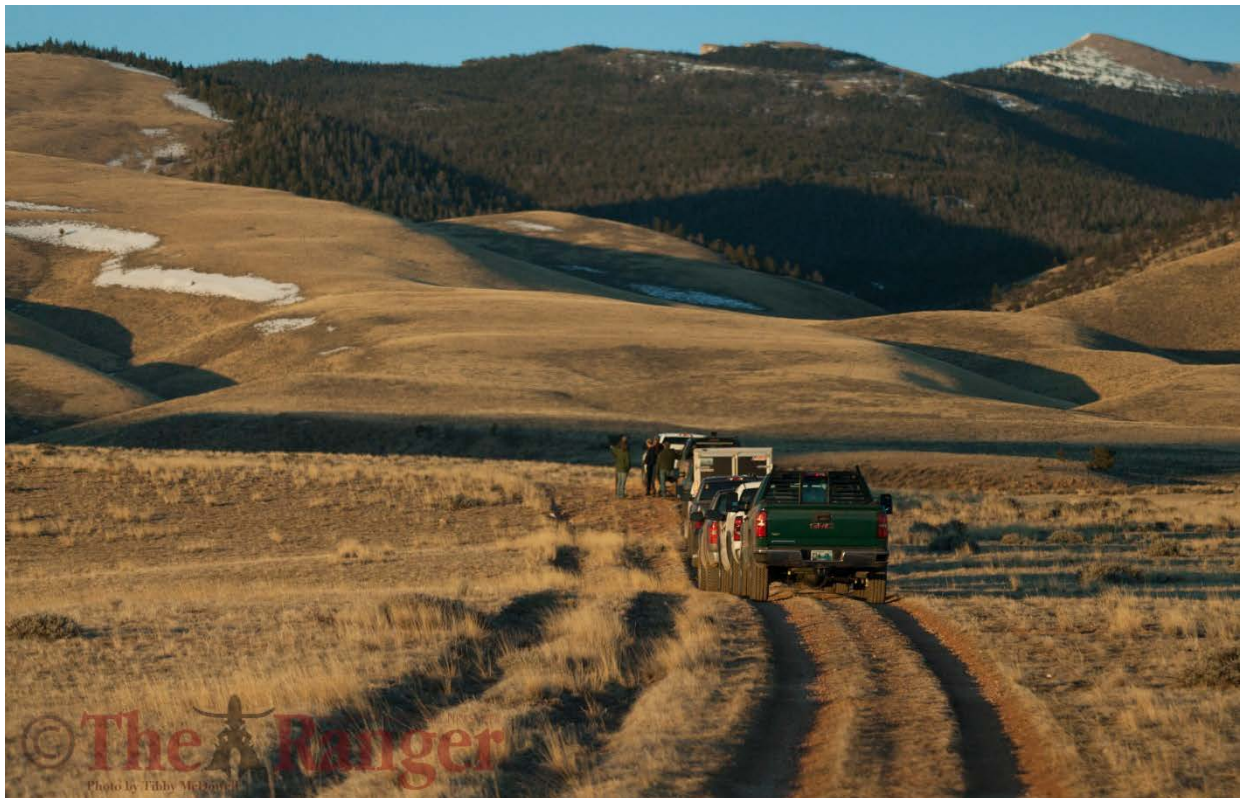
The entrance of epizootic pneumonia to bighorn sheep populations muddles the already complicated processes underlying population dynamics, and is often the culprit for massive crashes of sheep populations. Although pneumonia caused by bacterial respiratory pathogens is known to be the underlying driver of massive mortality events, the frequency and intensity of dieoffs are inconsistent, and infections are not always manifested in disease. Therefore, dieoffs may be dependent upon certain ecological or environmental conditions—the understanding of which could yield management alternatives to help reduce the frequency of outbreaks. Identifying how disease, nutrition, and population densities interact is critical in developing management options for and improving our understanding of pneumonia in bighorn sheep.

In Wyoming, the Statewide Bighorn Sheep Disease Surveillance Program, led by the Wyoming Game and Fish Department, has documented many bacterial pathogens in herds across the state. While some herds continue to do well, others have undergone repeated pneumonia outbreaks and recoveries, and others have never recovered from dieoffs. By adding long-term research on bacterial pathogens, nutritional condition, survival, pregnancy, and lamb recruitment in female bighorn sheep from three herds over time to the ongoing Disease Surveillance Program, we can work to disentangle the relative roles of each of those components on crashes and recoveries of bighorn sheep populations throughout the state.



Bighorn Sheep Captures & Disease Sampling

Starting in March 2015, the Haub School of Environment and Natural Resources, Wyoming Cooperative Fish and Wildlife Research Unit, and the Wyoming Game and Fish Department, in collaboration with the US Fish and Wildlife Service, the Shoshone and Arapaho Tribes of the Wind River Indian Reservation, and the National Elk Refuge captured adult female bighorn sheep in the Jackson, Cody, and Whiskey herds of northwest Wyoming. Each December and March thereafter, our objective was to recapture those same adult females to monitor how their recruitment status, disease status, nutritional condition and reproduction status varies seasonally. Adult females were captured via helicopter netgunning (Jackson and Whiskey herds) and ground darting (Cody herd). Each subsequent winter and spring, we have attempted to recapture those females. In the spring of 2017, we expanded the project to include the Temple Peak herd and captured 11 animals from that population.



During captures, numerous disease-related samples are collected from each animal including nasal and tonsil swabs, feces, and blood by the Wyoming Game and Fish Department Wildlife Disease Laboratory and following protocols established through the Statewide Bighorn Sheep Disease Surveillance Program. Samples are currently being analyzed by the Wildlife Disease laboratory to identify respiratory pathogens and macro-, and micro-nutrient levels. Future work will seek to assess whether previous experiences of individual animals affect their probability of becoming infected, becoming symptomatic, and their subsequent effects on vital rates.



A bighorn sheep from the Jackson herd with visible symptoms of *Ecthyma contagiosum* in the spring of 2016.



In addition to disease testing, we measured nutritional condition using a combination of ultrasonography and body condition scoring based on standardized methods developed for bighorn sheep for each captured animal. Nutritional condition of an animal is a product of its environment and therefore, represents the energetic gains and deficits experienced by an animal, as well as the nutritional reserves it carries into the upcoming season. Assessing nutritional condition of an animal is a critical step in understanding how disease, the environment, pregnancy and recruitment interact to affect bighorn sheep populations throughout the state.

We also estimate age using a combination of toothwear and replacement patterns, and by counting horn annuli. Age data are critical to understanding behavior, nutritional condition, reproductive performance, and disease exposure of individuals





Assessing Nutritional Condition

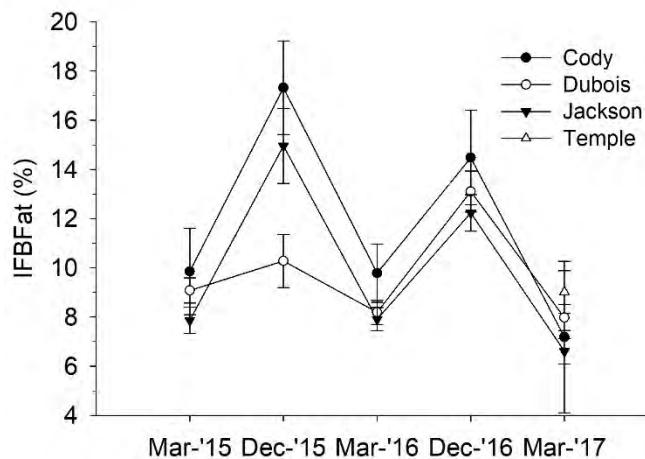


Figure 1. Ingesta-free body fat (%±SE) of adult female bighorn sheep from March 2015 to March 2017 in the Cody, Dubois, Jackson and Temple Peak herds.

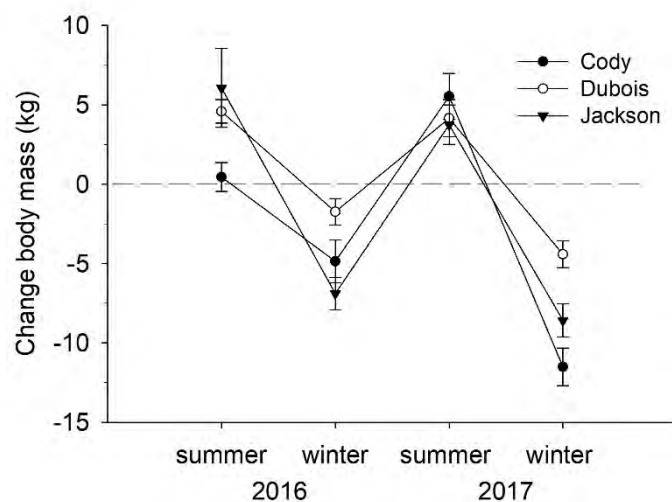


Figure 2. Change in body mass (%±SE) of adult female bighorn sheep between summer and winter in 2016 and 2017 in the Cody, Dubois and Jackson herds.



As of the summer of 2017, some of the most interesting results stem from nutritional dynamics across the different populations. The Dubois herd appears to be nutritionally limited on their summer ranges, while experiencing adequate winter conditions. Conversely, the Jackson herd appears to have robust summer ranges, but experience poorer conditions when on winter ranges than the Dubois herd. Finally, the Cody winter and summer ranges appear to fall somewhere in between those in Dubois and Jackson.

Reproduction and Recruitment

Each spring, we determine pregnancy status of captured females, and if a female is pregnant, measure the eye diameter of her fetus. Size of eye diameters allows us to estimate growth of a fetus and predict parturition dates of the mother. Interestingly, pregnancy rate of the Dubois herd has remained relatively constant across the three years of this study, while pregnancy rate of the Cody herd has steadily declined and pregnancy rate of the Jackson herd first increased slightly in 2016 and then dropped substantially in 2017.

Each fall, we conduct recruitment surveys in all three populations to determine which females successfully raised offspring through the summer. During winter captures, we also assess lactation status of females, which can provide additional evidence of recruitment (if a female is still lactating), or if she lost her offspring earlier in the summer or fall (if she is no longer lactating). Successfully recruiting young often results in females entering winter in lower body conditions, which could have important implications for survival over winter.

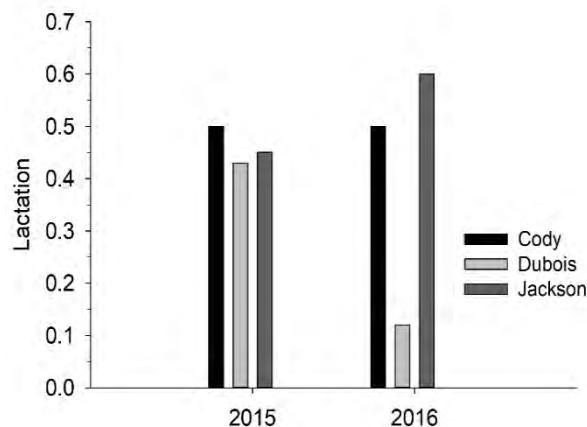


Figure 4. Proportion of adult female bighorn sheep that were lactating in December 2015 and 2016 in the Cody, Dubois, and Jackson herds of northwest Wyoming.

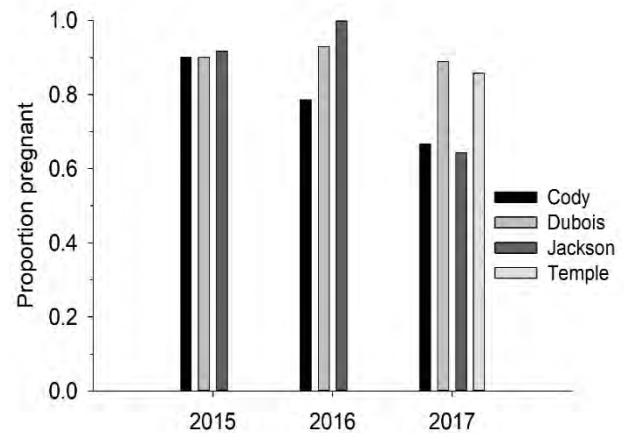


Figure 3. Proportion of pregnant adult female bighorn sheep in March 2015 -2017 in the Cody, Dubois, Jackson and Temple Peak herds of northwest Wyoming.



Disentangling the Interaction of Disease and the Environment on Bighorn Sheep Populations

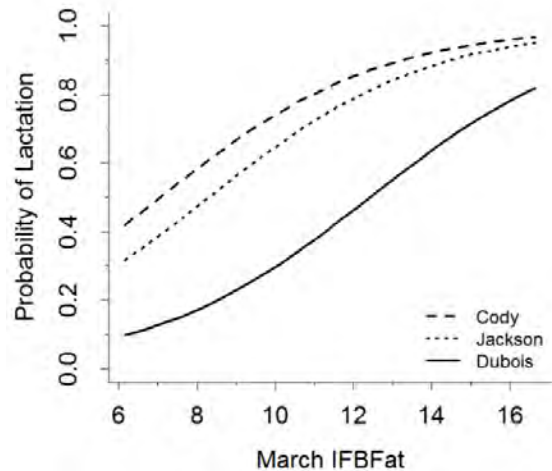


Figure 5. Probability that a female bighorn sheep was lactating (and therefore likely recruited offspring) in fall based on her ingesta-free body fat in spring for the Cody, Jackson, and Dubois herds.

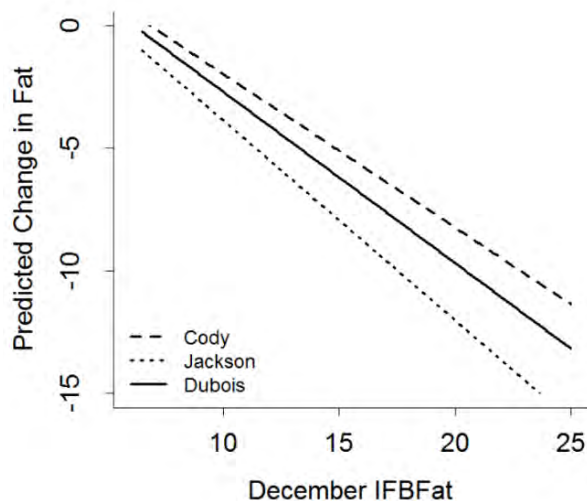


Figure 6. Predicted change in fat from fall to spring of female bighorn sheep based on her ingesta-free body fat in fall, weight in fall, age, and pregnancy status in spring, for the Cody, Jackson and Dubois herds.

Piecing together how nutrition, disease, and other vital rates of populations interact to influence the overall health and success of a herd is paramount in effective management of bighorn sheep populations. Our work thus far has demonstrated that nutrition is an important part of the equation when attempting to understand how population characteristics influence crashes and recoveries of bighorn sheep populations and may play one of the most important roles in regulating populations of bighorn sheep.

Although efforts are still underway to process and analyze current data, a few meaningful and yet, intriguing patterns have emerged. First, through the longitudinal study design, which includes recaptures in both winter and spring, we have identified potential differences in the seasonal ranges of the three herds. This is especially important in Dubois, where summer ranges appear to be lacking in nutritional quality and potentially influencing recruitment of offspring, despite a relatively high and constant rate of pregnancy. In 2016, recruitment in the Dubois herd was surprisingly low and the costs of lactation (when females did successfully recruit young) was much higher in Dubois than in the other two ranges, providing further evidence that there are differences in the summer ranges among the three populations that influence performance and the condition that a female enters winter in.

We also observed a decline in the nutritional condition (in both autumn and spring) of females in the Jackson herd through time, which is linked to a decline in pregnancy rates of that population over the past three years. That corresponding change in both nutritional condition and pregnancy could be evidence of the Jackson herd

reaching nutritional carrying capacity or, could indicate that there may be a potential dieoff occurring. Finally, despite some differences across the three ranges, seasonal nutritional condition was linked strongly to pregnancy, recruitment of young and seasonal change in condition of bighorn sheep in northwestern Wyoming.

Understanding how nutrition, disease, survival, pregnancy, and lamb recruitment in female bighorn sheep from these three herds interact to influence population dynamics is critical in developing management plans to maintain healthy populations of one of our most cherished ungulate species in Wyoming.



Looking Forward

Our efforts over the past three years of captures and monitoring of bighorn sheep in northwest Wyoming marks what we hope to be the establishment of a long-term research project to explore



the disease-nutrition interface in bighorn sheep, and to develop an understanding of the range limits (i.e., nutritional carrying capacity) of our sheep populations in northwest Wyoming. With time, our goal is to piece together each female's history to describe how she interacts with her environment, understand her success to survive and reproduce or lack thereof, and how she fits within the population in which she resides. By piecing together the histories of each female we monitor, we hope to add an important piece to the puzzle of the complex interactions of environment, disease, and dynamics of our cherished bighorn sheep populations.

Currently, we hope to continue recapturing and monitoring sheep in the Jackson, Cody, and Dubois herds until the winter of 2020, while simultaneously expanding several aspects of the study to assess the interaction of disease and the environment on success of bighorn sheep populations more carefully. First, to monitor the reproductive efforts of these populations more closely, our goal is to capture and collar neonate

bighorn sheep in the Dubois and Jackson herds in the summers of 2019 and 2020, monitor their survival, and identify causes of mortality. Furthermore, we hope to gain a better understanding of the nutritional conditions of these populations and what factors limits those conditions through diet analysis and vegetation work on the summer ranges of both the Dubois and Jackson herds.

The fundamental components underlying any large ungulate population (e.g., habitat quality and quantity, and density dependent interactions) remain operational and yet, are often neglected when considering disease dynamics. Our work to date has demonstrated that indeed, infected populations are not immune from fundamental nutritional dynamics and instead, suggests that nutrition may well be a key explanatory factor, along with disease, of the disparity in performance across sheep herds in northwest Wyoming.

Through this work, we have the opportunity to more effectively manage bighorn sheep and their habitat through science, potentially demonstrate the value of offering additional hunting opportunity if doing so may mitigate the effects of pneumonia, and demonstrate the value of hunting as a conservation and management tool. Moreover, implicit with our continued work is calibrating models of animal-indicated nutritional carrying capacity for Wyoming sheep, which will increase the toolset for managers to understand how habitat, density, and extrinsic factors such as predation or perhaps disease are regulating these and other populations of bighorn sheep.



Partners

This project would not be possible without the financial and logistical support of our research partners. Funding has been provided by the Wyoming Wildlife/Livestock Disease Research Partnership, Wyoming Governor's Big Game License Coalition, and the Wyoming Wild Sheep Foundation. We thank the Shoshone and Arapaho tribes for access to lands on the Wind River Indian Reservation, and to the US Fish and Wildlife Service for access to the National Elk Refuge for capture and research. We also thank the numerous folks who took time out of their busy schedules to assist with captures. Thanks to M. Gocke and B. Kraushaar for photographs contained herein.



Wyoming Wildlife/Livestock Disease Research Partnership

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HARVEST RECORDS PROJECT

Hunting of wild populations has been an important part of human existence since the beginning of our species. In North America, hunting has a long history as a fundamental component of wildlife management. Following the exploitation and near extirpation of many wildlife species in the 1800s, biologists, managers and sportsmen developed a set of principles that allowed them to not only sustainably harvest wild game, but also to return many of the nearly extinct populations back to robust numbers. This body of principles, better known as the North American Model of Wildlife Conservation, recognized hunting as the cornerstone of wildlife management, and is arguably one of the most successful sets of tools used for the conservation and management of wild species throughout the world.

Beyond its importance as a tool in wildlife management, hunting also provides one of the largest sources of funding for management and conservation of both game and non-game species in North America. Hunting generates billions of dollars each year through federal taxes that directly benefit the conservation and management of wildlife and their habitat throughout North America.

Without the efforts of early sportsmen and anglers in developing the North American Model of Wildlife Conservation, and the continued monetary contributions of both hunters and anglers today, many of our wild populations and the habitat upon which they rely likely would no longer exist.



Selective Harvest and Harvest-Induced Evolution

Although harvest remains a fundamental part of conservation and management of wild populations, there has been concern recently over unintended consequences of selective pressures that may result from current harvest strategies. The idea that selection for specific sizes, behaviors or characteristics of wild animals can cause an evolutionary change in those characteristics through time has garnered increased interest and concern among both researchers



and the public over the past two decades. Indeed, there can be evolutionary changes through time when harvest pressure is both highly selective and intensive, including: reduction in the average body size of a population, changes in the size of horns and antlers, increasingly early sexual maturation, and changes in behaviors such as courtship and foraging. Yet, the degree of selectivity and intensity necessary to produce such evolutionary changes remains unclear in most instances.

In ungulates, the evolutionary effects of selective harvest pressure typically are assessed through changes in the size of horns and antlers through time. Research on this subject is still relatively limited, but there is evidence that harvest can cause changes in the size of horn-like structures. The majority of the work on this topic has been focused on a single population of bighorn sheep found on Ram Mountain in Alberta, Canada. In this particular population, harvest has resulted in a genetically based reduction in the size of horns through time. The results of this research represent an important step forward in understanding the effects that selective harvest can have on the size



of horn-like structures. This population, however, possesses several unique characteristics that do not exist in most populations of wild game in North America. For the majority of the study period, harvest of bighorn sheep on Ram Mountain was regulated based solely on a size requirement, with no limit to the number of animals that could be harvested each year. During most of the study, males had a 40% probability of being harvested during the year in which they reached legal size. The high degree of both harvest selectivity and intensity of the population on Ram Mountain contributed to the genetic change in the

size of horns through time. The unique characteristics of the population on Ram Mountain, however, make it critical to understand how the results of harvest practices in this population relate to other populations of big game that are managed under more conservative harvest regulations.

Research results from the population of mountain sheep on Ram Mountain have been used in some instances to suggest that management strategies throughout North America may be causing irreversible evolutionary changes to the size of horns and antlers through time. In reality, harvest of most populations and species of big game throughout the rest of North America does not occur at the same level of severity as the harvest pressure that existed on Ram Mountain when a genetic change in horn size was detected, thereby calling into question the selective role of harvest practices more broadly. Public perception of harvest is constantly changing, and the idea that selective harvest is causing changes at the population level has received increased attention and concern. If current harvest practices are causing declines in the growth of hornlike structures in ungulates, managers and biologists would want to know and adjust harvest practices accordingly. More research is necessary on a broader spatial scale (i.e., a scale that encompasses populations that are more representative of how we harvest most populations of wild game) to help understand how harvest practices influence the size of horns and antlers through time.





Mountain Sheep as a Study System

Understanding how selective harvest influences ungulates is a highly controversial issue that can be difficult to address fully, especially because changes to horn and antler sizes in response to harvest can take decades to manifest. Furthermore, other factors such as age and nutrition can override genetic contributions to horn and antler size and can potentially confound results if not properly accounted for. Age plays the most important role in size of horn-like structures, particularly in species that cumulatively grow horns throughout their lifetime. Additionally, nutritional condition during different stages of life can have lifetime consequences for horn size, and individuals that experience poor environmental conditions may have smaller horns than individuals of the same age that are not limited by poor resources.

Mountain sheep represent an ideal system to test the question of how selective harvest influences horn size for two reasons. First, the presence of horn annuli allows biologists and managers to estimate the age of mountain sheep relatively accurately. These age data are critical for assessing changes in the age structure of the population, which can result in population-level changes in horn size through time that may mimic trends caused by selective harvest. Second, harvest of mountain sheep is highly regulated, and harvested individuals must be checked in to state and provincial agencies. In many areas, biologists and managers throughout

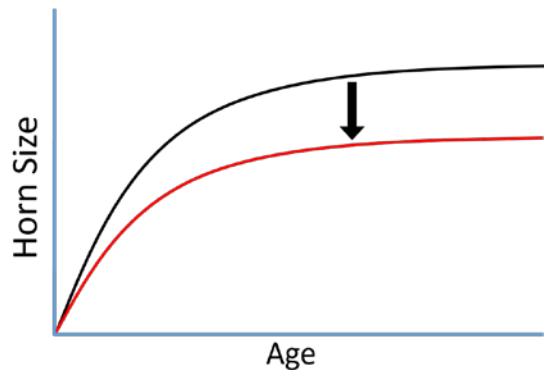
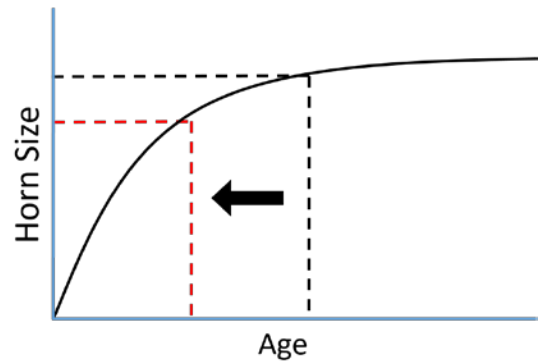


North America have collected both horn measurements and age data from wild sheep for decades. These records represent one of the few sources of empirical data that are currently available for testing the question of selective harvest at the time scale on which evolutionary processes occur in a long-lived species.

Using harvest data from four subspecies of mountain sheep (Rocky Mountain bighorn sheep, desert bighorn sheep, Stone's sheep and Dall's sheep) we will evaluate the following hypotheses for explaining how harvest influences the size of mountain sheep horns through time:

Demographic Shift Hypothesis

Through intensive removal of males in a population, there will be a shift in the overall age structure through time. Young males will become more common than old males in the population, and the mean age of harvested males will decrease through time. As a result, average horn size of the population will decrease. The shift in horn size of the population will occur solely because of the young age of harvested animals, and the mean horn size of individuals within age classes will not change through time.

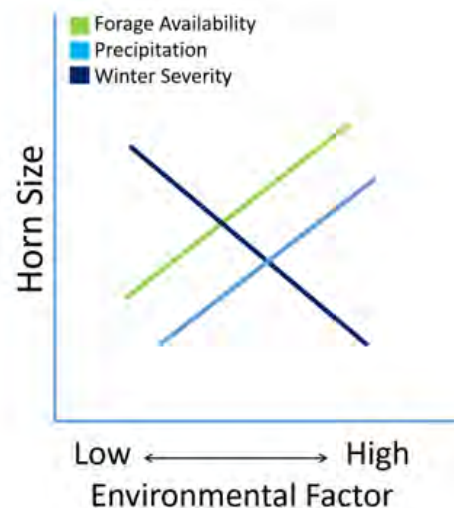


Selective Harvest Hypothesis

Selective harvest that removes fast-growing and large-horned males will favor the persistence of males with slow growing and small horns in a population. Over time, horn size relative to age class will become smaller as individuals with large horns are removed from the population.

Environmental Effects Hypothesis

Environmental conditions during different stages of life will influence horn size of males. Forage availability, precipitation and winter severity all influence the nutritional condition of an animal. Males that experience poor nutritional conditions (low precipitation, low forage availability and high winter severity) will have smaller horns than males of the same age that experience better nutritional condition.



Preliminary Results

Preliminary analysis of harvest data from 130 hunt units in 11 states throughout western North America revealed 81.5% (n= 106) of hunt units did not exhibit changes in horn size, after accounting for age, over the past 28 years. Furthermore, of the 24 hunt units that did show a temporal change, 45.8% (n=11) of those hunt units were declining, whereas 54.2% (n=13) exhibited increases in horn size through time.

Some hunt areas did not exhibit changes in horn size or changes in age at the population level, but did show changes in the size of horns of specific age classes. Accounting for age is critical when addressing the question of how harvest influences size of horns through time, because evaluating population averages alone may not tell the whole story. For example, many populations did not show a change in average horn size or average age through time, but did exhibit changes in horn size of individual age classes.

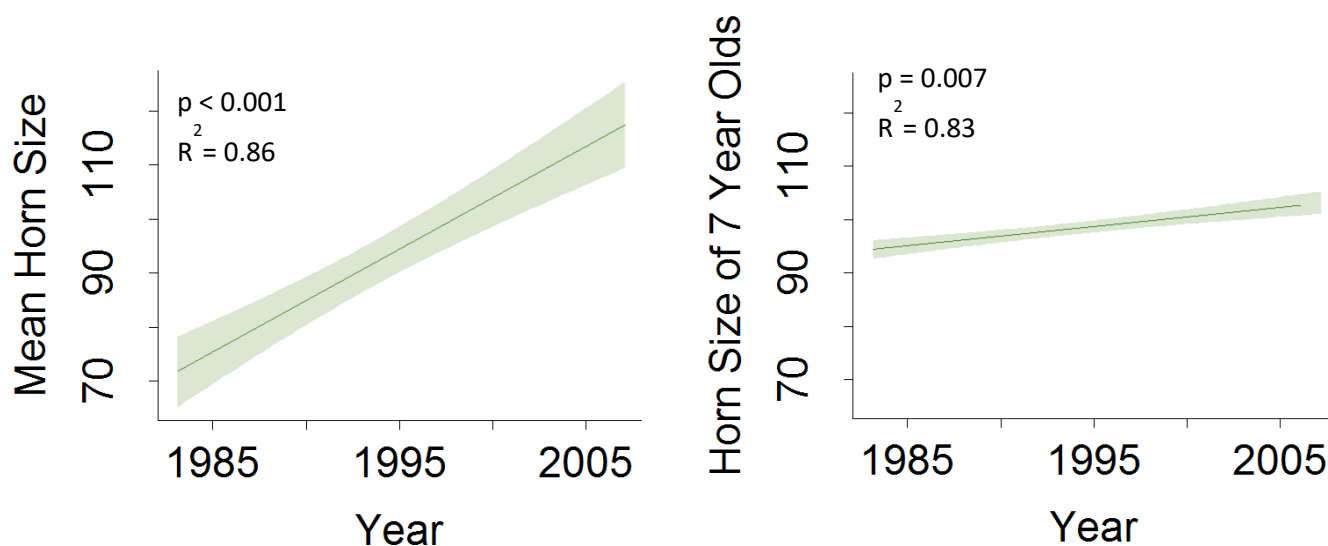


Figure 1. Average horn size (left) and horn size of 7 year olds (right) of harvest males born in Montana Hunt Unit 620 from 1984 – 2007. Population level changes can be very drastic when age is not taken into account. In this hunt area, there are increases in age-specific horn size through time, but not nearly as dramatic as the changes seen before age was taken into account.

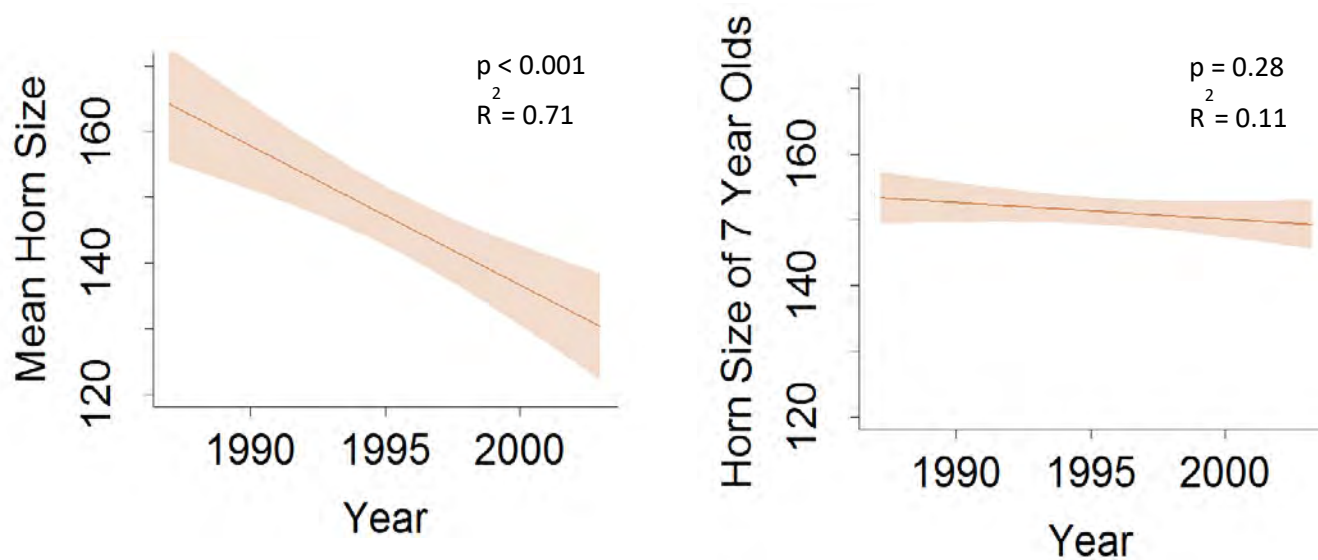


Figure 2. Average horn size (left) and horn size of 7 year olds (right) of harvest males born in Nevada Hunt Unit 13 from 1987 – 2007. The nearly 40” decrease in horn size of the population that occurred over the 20 year period was not detected after age was taken into account.



Assessing Long-Term Trends in Ungulate Species

Harvest records of mountain sheep are a valuable tool for assessing long-term trends in the size of horns, and these records are one of the few sources of empirical data that exists for testing the question of how harvest influences the size of horns and antlers through time. The Boone and Crockett Club, the first records program in North America, was created over a century ago to promote conservation and the ethical and sustainable management of one of our greatest natural resources – wildlife. To this day, that goal remains the foundation of numerous records programs throughout North America, and because of the diligence and enthusiasm of the individuals that created records programs, decades of measurement data exist for most species of big game that are harvested in North America. Consequently, the measurements of trophy animals kept by records programs may be one of the most robust and valuable tools available for understanding how harvest influences horn and antler size.

There has been recent criticism, however, of the effectiveness of trophy record books for assessing changes in the size of horns and antlers through time. This criticism stems from the idea that trophy record books are inherently providing truncated samples (i.e., they are limited by a minimum size requirement for entry). If horns and antlers must reach a minimum size to be entered into a record book, the trends seen in record books may just be exhibiting attenuated versions of trends in populations that include a wider range of horn and antler sizes. A minimum size requirement for entry will mean that all individuals have to be at least a certain size, and even if there are changes through time, the minimum size that all animals must attain to be recorded in a record book may dilute the trends seen through time.

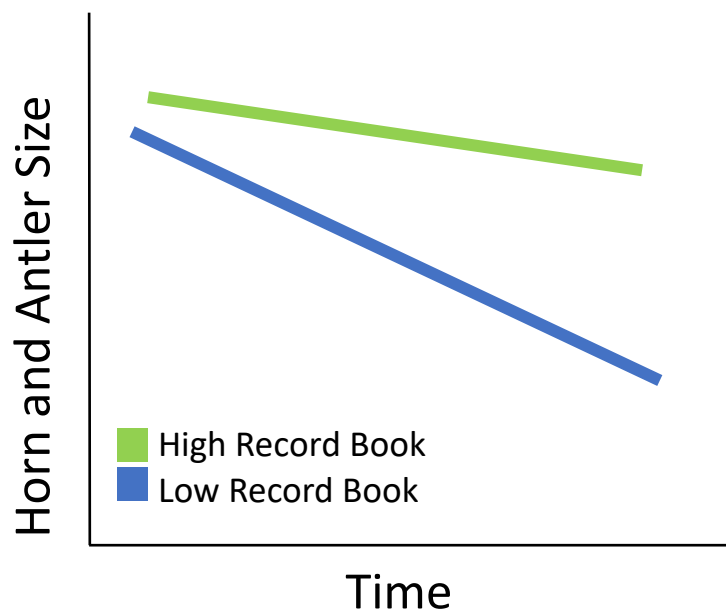


Figure 3. Expected trends in horn and antler size of a record book with high minimum size requirements (green) and a record book with lower minimum size requirements (blue) if record books do not provide a valid way to assess change through time.

To understand the usefulness of trophy record books for assessing trends in the size of horns and antlers through time, we will evaluate the prediction that lower requirements for entry into a record book (i.e. a record book that includes a wider range of horn and antler sizes) will result in a stronger temporal trend than record books with higher requirements for entry (i.e., a record book that includes a narrower ranges of horn and antler sizes).

Preliminary Results

When we compared trends in the size of horns and antlers of three different records books (Boone and Crockett Record Book, Pope and Young Record Book and Safari Club International Record Book), we found that eight of the seventeen categories differed in the direction and magnitude of temporal trends.



Our prediction that a record book with lower minimum entry requirements would exhibit trends of greater magnitude through time than a record book with higher minimum entry requirements however, was only supported in two of those trophy categories (non-typical white-tailed deer, Fig. 5H; and bighorn sheep, Fig. 4C). Furthermore, although we did observe a divergence in some categories, over half of the trophy categories that we tested did not show significant differences in trends among record books, which suggests that trends evident in trophy record books may accurately represent trends that are occurring in the size of trophy males through time and not simply resulting in watered down trends of a larger range of sizes.

As one of the longest-standing sources of data for large game that are harvested in North America, trophy record books provide a wealth of information, and their potential usefulness as a tool for assessing the effects of management strategies and conservation success was a primary goal of the founders of the records programs. These record books contain information that spans a vast range of spatial and temporal scale and that may indicate how horns and antlers of different species are changing through time. Given their truncated nature, however, care must be taken when interpreting any observed patterns in those data.

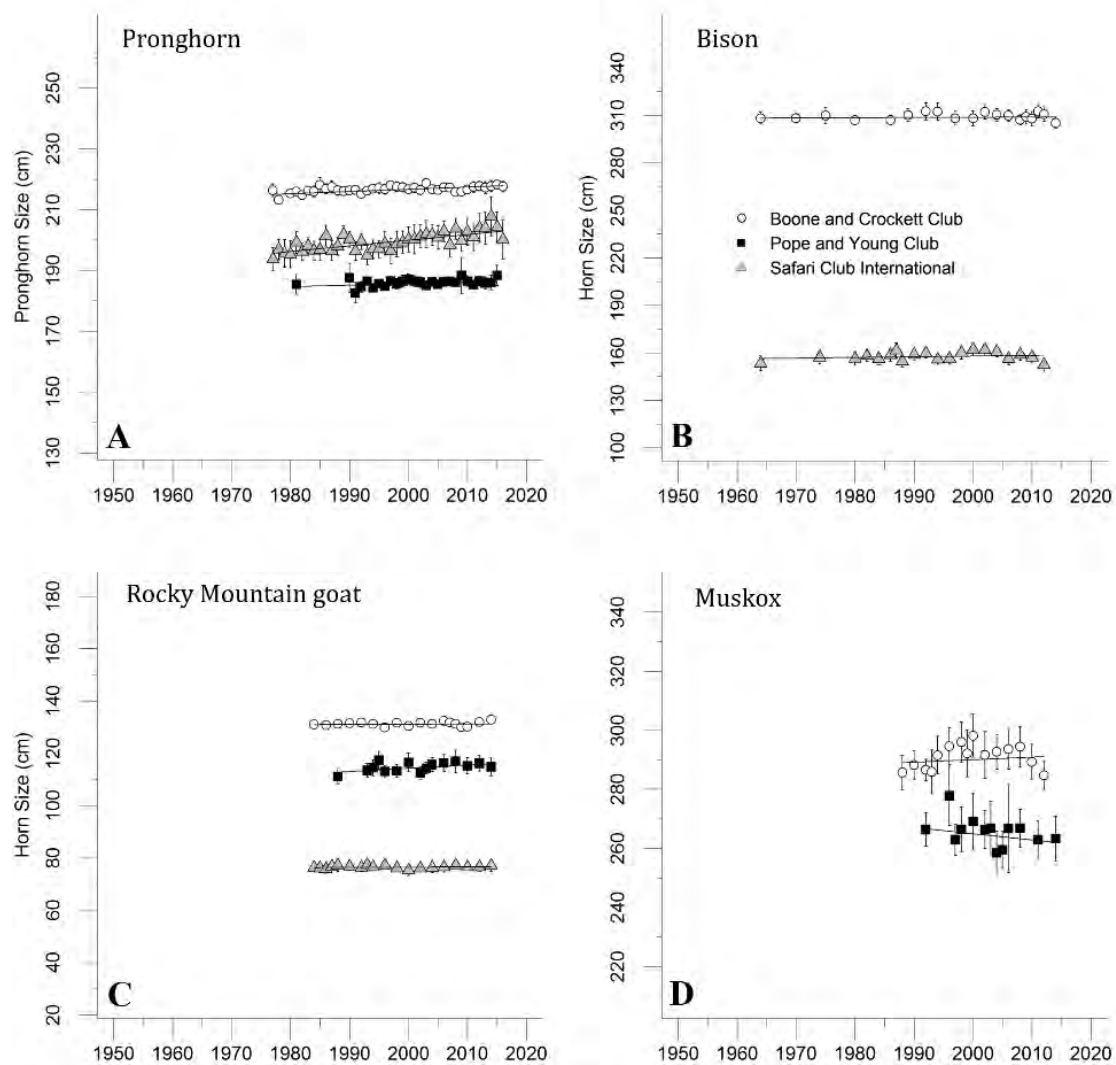


Figure 4. Trends in the size of horns in the Boone and Crockett records book, Pope and Young records book, and Safari Club International records book for pronghorn, bison, Rocky Mountain goat, and muskox through time.



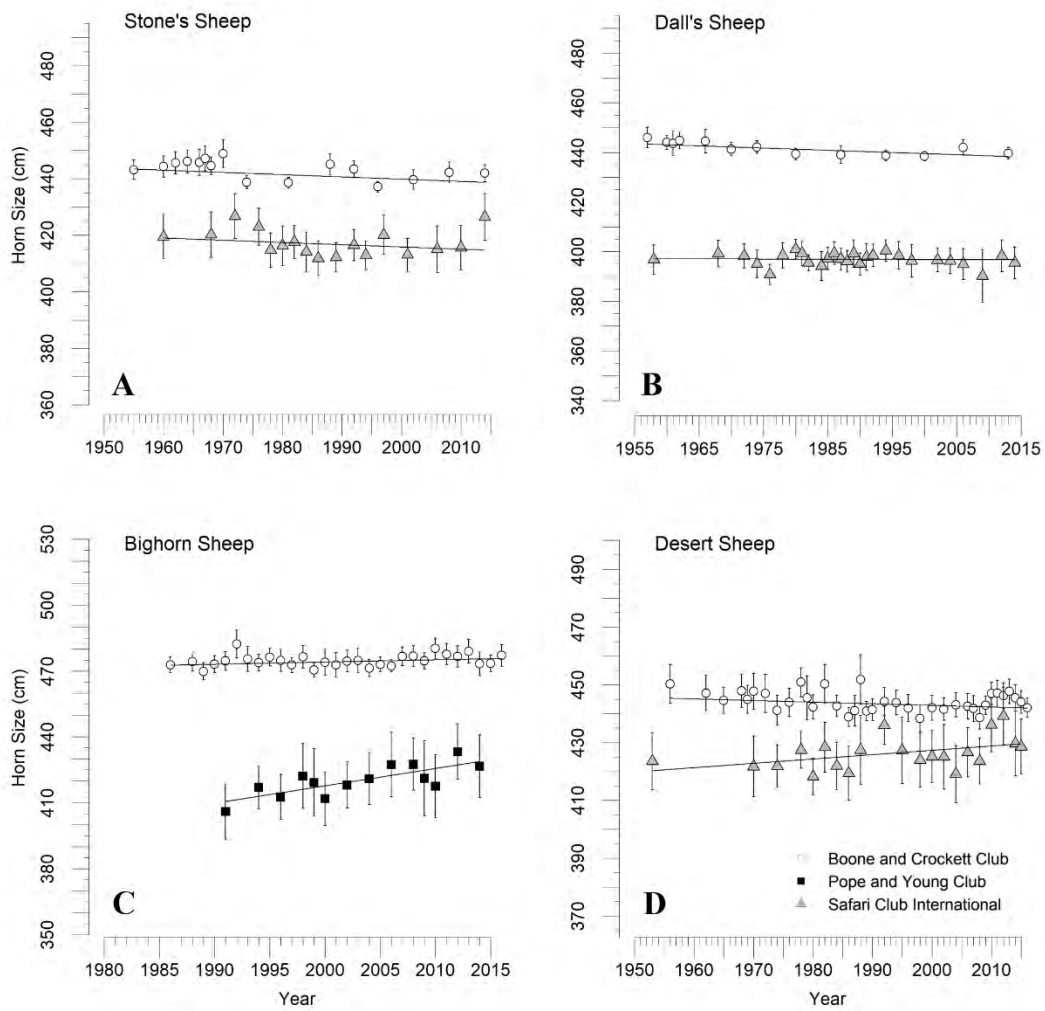


Figure 5. Trends in the size of horns in the Boone and Crockett records book, Pope and Young records book, and Safari Club International records book for Stone's sheep, Dall's sheep, bighorn sheep, and desert sheep through time.



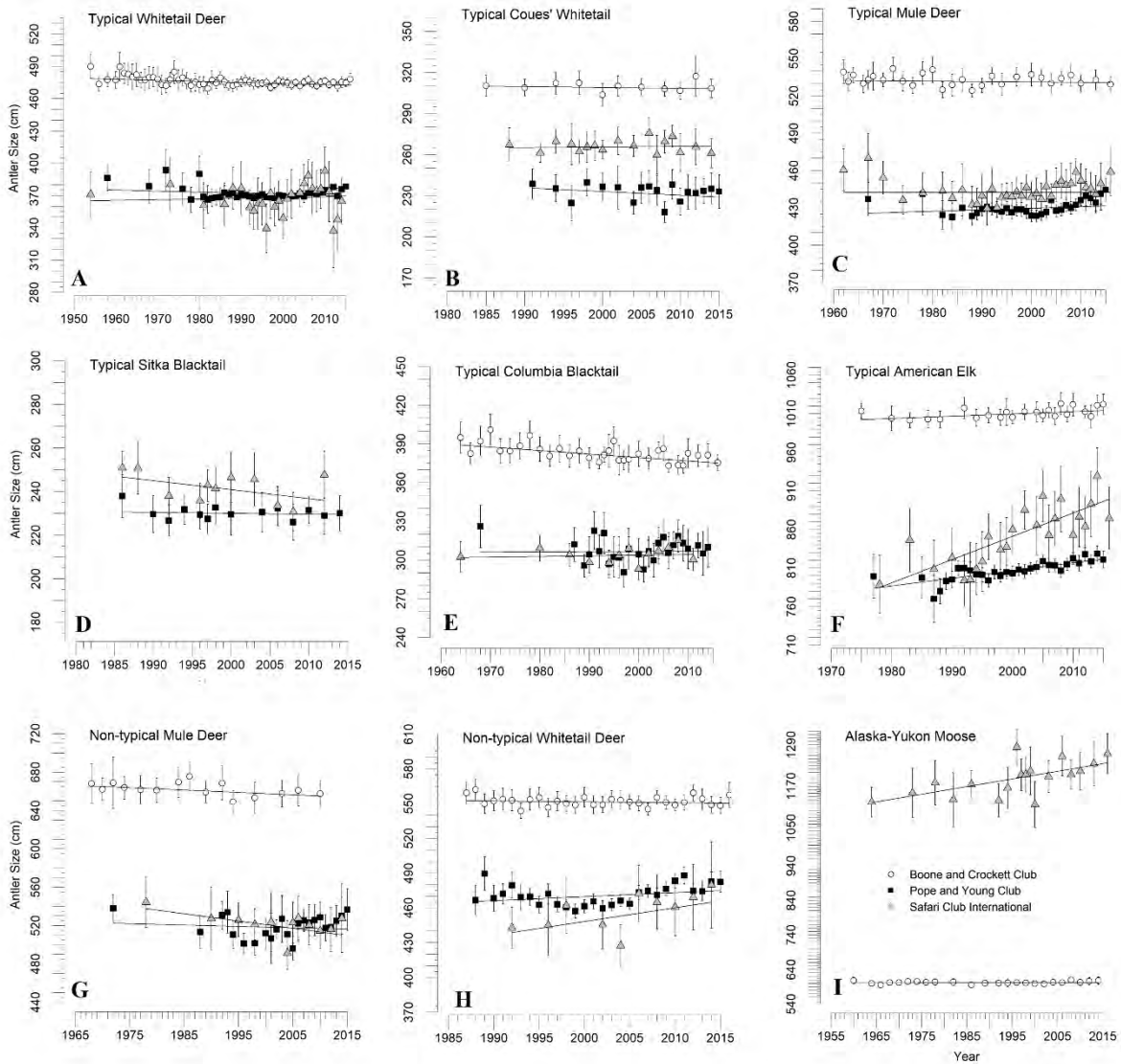


Figure 6. Trends in the size of antlers in the Boone and Crockett records book, Pope and Young records book, and Safari Club International records book for all antlered categories we tested.



Moving Forward

Preliminary results from the analysis of mountain sheep horn size using harvest records are just the beginning of our efforts to understand how harvest influences horn size through time. Currently, we have only assessed if there have been age-specific changes in horn size, and not what underlying factors might be responsible for those changes. Our next steps are to begin to understand how environmental conditions, including population size, forage quality, and climatic conditions during different stages of life influence patterns of horn growth and size. Yet, from our preliminary analyses we have seen that the majority of hunt areas in North America have not shown changes in horn size through time after accounting for age. Additionally, only 8.5% of all hunt units showed age-specific declines in horn size, while 10% exhibited age-specific increases in horn size.

Addressing questions of selective harvest is a critical step in understanding the effectiveness and value of management of big game species throughout North America, and communicating those realities to the public. Additionally, we can use these results to identify areas where there are population-level changes occurring as a result of harvest, which will provide the opportunity to reconsider harvest practices for those areas should maintenance of horn size be a management objective.

Our results from the analysis of trophy record books indicates that record programs are most likely collecting data that may be a useful tool for assessing changes in the size of horns and antlers from trophy animals through time, although those data are truncated and must be interpreted with care.

Harvest plays a critical role in the management and conservation of wild populations. Understanding how harvest practices influence populations is essential for maximizing the effectiveness of wildlife management programs throughout North America.



Partners

This project is a collaborative effort that would not be possible without the support of biologists and managers throughout the West, data contributions from Boone and Crockett, Pope and Young and Safari Club International, and financial contributions from Utah Division of Wildlife Resources, the National Wild Sheep Foundation, Wyoming Wild Sheep Foundation, Alberta Wild Sheep Foundation, California Wild Sheep Foundation, Arizona Desert Bighorn Sheep Society, Wyoming Governor's Big Game License Coalition, Iowa Foundation for North American Wild Sheep, Utah Foundation for North American Wild Sheep and the Pope and Young Club.



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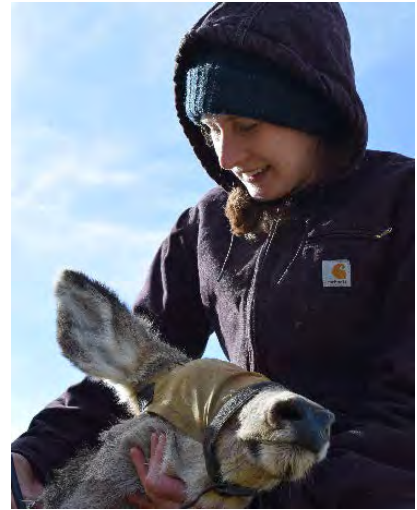
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Ellen Aikens

Ellen is a PhD candidate in the Program in Ecology at the University of Wyoming. Ellen is fascinated by animal movement, especially migration. Ellen plans to pursue a career in research, with a focus on the interface between fundamental research and applied conservation and management. Before coming to Wyoming, Ellen worked at the Smithsonian Conservation Biology Institute's GIS lab, where she analyzed remote sensing and GPS telemetry data for conservation research projects across the globe. Ellen is a recipient of the National Science Foundation Graduate Research Fellowship and the Berry Fellowship. Ellen earned her bachelor's degree in Biology and Environmental Studies from Ursinus College.



Kristin Denryter

Kristin is a Postdoctoral Research Scientist in the Haub School of Environment and Natural Resources at the University of Wyoming. For her PhD research at the University of Northern British Columbia, Kristin quantified nutritional values of plant communities across the landscape of northeastern British Columbia during summer for woodland caribou. Her intensive field work focused on collecting direct observations of foraging by tame caribou using traditional bite-count methods. Kristin currently leads a project aimed at integrating nutrition, resource use, and population ecology to better inform conservation and management for endangered Sierra Nevada bighorn sheep.



Samantha Dwinnell

Samantha Dwinnell is a Research Scientist with the Haub School of Environment and Natural Resources. Samantha is the first student to miraculously graduate (May 2017) with a MSc from the Monteith Shop. Immediately following her defense that was made successful through bribery, she foolishly convinced Dr. Monteith to hire her as a Research Scientist to manage the Wyoming Range Mule Deer Project. Samantha's graduate research was focused on the nutritional relationships among mule deer behavior, forage, and human disturbance. Currently, her research is focused on disentangling the relative influence of various factors that affect fawn survival. Although Samantha is most interested in research aimed at informing management and conservation of wildlife, she also dedicates research efforts into finding ways to mountain bike and ski without her boss knowing.



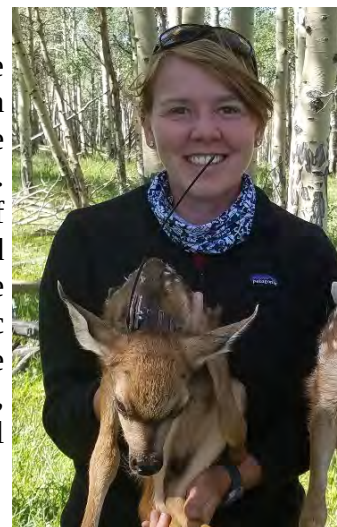
Matthew Hayes

Matt is a research scientist and PhD student in the Haub School of Environment and Natural Resources and Cooperative Fish and Wildlife Research Unit. Following his enlistment in the United States Marine Corps, he completed his BSc and MSc in wildlife biology and management in 2012. Since that time, Matt has worked as a spatial analyst investigating dynamics of large ungulates from Wyoming to Alaska. Matt began working on the DEER project as a PhD student starting in the winter of 2015. His research interests are based on the merging of new techniques to address complex research and conservation problems in large mammals.



Katey Huggler

Katey is currently a MSc student in the Cooperative Fish and Wildlife Research Unit at the University of Wyoming. She grew up in northern Idaho and attended the University of Idaho for her undergraduate degree and graduated with a BSc in Wildlife Resources in May 2016. During her time at the University of Idaho, she worked on a variety of projects ranging from harvester ant colony research to elk survival and recruitment. After graduating from the University of Idaho, she worked as a technician on the DEER Project before she began her MSc in the fall of 2016. Her project focuses on nutritional and reproductive ecology of elk, including calf survival and cause-specific mortality, while examining contributions of habitat selection, nutritional condition, diet, female harvest, and predation.



Rhiannon Jakopak

Rhiannon is currently a MSc student in the Cooperative Fish and Wildlife Research Unit at the University of Wyoming. She received dual bachelor's degrees in Wildlife and Fisheries Biology and Management and Religious Studies at the University of Wyoming in 2016. She is broadly interested in population ecology and mammalogy, and more specifically interested in the processes regulating the distribution of species. Her master's project seeks to identify the factors which influence the development of migration and the subsequent population consequences.



Tayler LaSharr

Tayler LaSharr is a MSc student in the Cooperative Fish and Wildlife Research Unit. Tayler grew up in Phoenix, AZ and attended the University of Arizona where she obtained a BSc in Natural Resources with an emphasis in Conservation Biology and a minor in Chemistry in May of 2015. During her time at the University of Arizona, she studied life history tradeoffs in Western and Mountain Bluebirds and the effects of aggression in closely related species on habitat and range dynamics. In the summer of 2015, she began work in the Wyoming Cooperative Fish and Wildlife Research Unit as a technician on a fawn survival study of mule deer in the Wyoming Range. In the fall of 2015, she began work on her own research, which focuses on understanding the effects of harvest on horn size of mountain sheep, identifying the relevancy and use of trophy record books to assess biological trends, and understanding the influence of nutrition and the environment on annual growth of horns in mountain sheep.



Bryan Lamont

Bryan is pursuing a MSc in Zoology from the University of Wyoming. While Bryan's past professional endeavors are varied, his interests have always been focused on wildlife ecology and management, and education. Bryan grew up in North Carolina and earned his first BSc from Appalachian State University. After moving west to Colorado and working in the outdoor education arena he realized that working in the wildlife field is where his passion fell. He returned to school to earn a BSc in Wildlife Biology from Colorado State University. He then gained a great deal of wildlife experience working with the Rocky Mountain Elk Foundation in Nevada, and through several wildlife research field positions working with bighorn sheep and mule deer. Bryan's interests lie in using sound science to make informed management decisions to conserve and enhance wildlife populations for future generations.



Alex May

Alex is a MSc student in the Cooperative Fish and Wildlife Research Unit. Alex enjoys the trials and elation from wildlife research, having been seasonally employed for six years prior to beginning his Master's project. He has worked with insects, cougars, marten, Kodiak bears, wolves, pikas, bald eagles, peregrine falcons, osprey, sage grouse, great blue herons, trumpeter swans, leopards, black bears, pronghorn, mule deer, and wolverines. Moose are now the central component of his fieldwork and computer menagerie. He enjoys that his project has both applied management and ecology components. Alex likes hiking, birding, hiking on skis, reading, and vegetable fermentation.



Tana Verzuh

Tana Verzuh joined the Monteith lab in the fall of 2017 and will be continuing the Snowy Range moose project, specifically looking at cause-specific mortality of adult female moose. She earned her BSc in Zoology from Colorado State University in 2005 and her MSc in Science Education from Montana State University in 2009. For the past 4 years, Tana worked on a variety of research projects in Colorado including a black bear study investigating the influence of human development on behavior and population dynamics and projects evaluating factors associated with mule deer fawn and elk calf survival. Tana seeks to not only conduct relevant science, but to be able to communicate that science effectively to diverse groups of people. Other than wildlife research, she enjoys rafting, mountain biking, splitboarding, surfing, fly fishing, gardening, cooking, and international travel.



Kevin Monteith

Kevin Monteith is an Assistant Professor of the Haub School of Environment and Natural Resources and the Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology at the University of Wyoming. After receiving his BSc and MSc in Wildlife and Fisheries Sciences from South Dakota State University, he went on to obtain his PhD in Biology from Idaho State University in 2011. Kevin's research program is focused on integrating nutritional ecology with intensive field studies of large ungulates to elucidate the mechanisms that underpin behavior, growth, reproductive allocation, predator-prey dynamics, and ultimately, the factors affecting population growth. Kevin and his graduate students are currently conducting research on most of Wyoming's large ungulates; topics are centered on establishing a protocol for habitat-based, sustainable management of ungulate populations, while investigating the effects of predation, habitat alteration, climate change, migration tactics, and novel disturbance





Mark Gock









THANKS TO OUR PROJECT PARTNERS

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