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Ungulate Migrations of the Western United States

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Outline

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
barrel (bbl; petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m^3)
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic inch (in^3)	0.01639	cubic decimeter (dm^3)
cubic inch (in^3)	0.01639	liter (L)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per hour (ft/h)	0.3048	meter per hour (m/h)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ([ft^3/s]/mi^2)	0.01093	cubic meter per second per square kilometer ([m^3/s]/km^2)

cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minte (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile ($[gal/d]/mi^2$)	0.001461	cubic meter per day per square kilometer ($[m^3/d)]/km^2$)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile ($[Mgal/d]/mi^2$)	1,461	cubic meter per day per square kilometer ($[m^3/d]/km^2$)
inch per hour (in/h)	0.0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
ton, long (2,240 lb)	1.016	metric ton (t)
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
bar	100	kilopascal (kPa)
inch of mercury at 60 °F (in Hg)	3.377	kilopascal (kPa)
pound-force per square inch (lbf/in^2)	6.895	kilopascal (kPa)
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)
	Energy	
kilowatthour (kWh)	3,600,000	joule (J)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Specific capacity	
gallon per minute per foot ([gal/min]/ft)	0.2070	liter per second per meter ([L/s]/m)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Application rate	
pound per acre per year ([lb/acre]/yr)	1.121	kilogram per hectare per year ([kg/ha]/yr)
	Leakance	
foot per day per foot ([ft/d]/ft)	1	meter per day per meter ([m/d]/m)
inch per year per foot ([in/yr]/ft)	83.33	millimeter per year per meter ([mm/yr]/m)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)

	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
cubic decimeter (dm^3)	0.2642	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic decimeter (dm^3)	61.02	cubic inch (in^3)
liter (L)	61.02	cubic inch (in^3)
cubic decimeter (dm^3)	0.03531	cubic foot (ft^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
cubic hectometer (hm^3)	810.7	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per year (m^3/yr)	0.000811	acre-foot per year (acre-ft/yr)
cubic hectometer per year (hm^3/yr)	811.03	acre-foot per year (acre-ft/yr)
meter per second (m/s)	3.281	foot per second (ft/s)
meter per minute (m/min)	3.281	foot per minute (ft/min)
meter per hour (m/h)	3.281	foot per hour (ft/h)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per year (m/yr)	3.281	foot per year ft/yr)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer ($[m^3/s]/km^2$)	91.49	cubic foot per second per square mile ($[ft^3/s]/mi^2$)
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
liter per second (L/s)	15.85	gallon per minute (gal/min)
cubic meter per day (m^3/d)	264.2	gallon per day (gal/d)
cubic meter per day per square kilometer ($[m^3/d]/km^2$)	684.28	gallon per day per square mile ($[gal/d]/mi^2$)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
cubic meter per day per square kilometer ($[m^3/d]/km^2$)	0.0006844	million gallons per day per square mile ($[Mgal/d]/mi^2$)
meter per hour (m/h)	39.37	inch per hour (in/h)
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short [2,000 lb]

metric ton (t)	0.9842	ton, long [2,240 lb]
	Pressure	
kilopascal (kPa)	0.009869	atmosphere, standard (atm)
kilopascal (kPa)	0.01	bar
kilopascal (kPa)	0.2961	inch of mercury at 60°F (in Hg)
kilopascal (kPa)	0.1450	pound-force per inch (lbf/in)
kilopascal (kPa)	20.88	pound per square foot (lb/ft^2)
kilopascal (kPa)	0.1450	pound per square inch (lb/ft^2)
	Density	
kilogram per cubic meter (kg/m^3)	0.06242	pound per cubic foot (lb/ft^3)
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
	Energy	
joule (J)	0.0000002	kilowatthour (kWh)
	Radioactivity	
becquerel per liter (Bq/L)	27.027	picocurie per liter (pCi/L)
	Specific capacity	
liter per second per meter ([L/s]/m)	4.831	gallon per minute per foot ([gal/min]/ft)
	Hydraulic conductivity	
meter per day (m/d)	3.281	foot per day (ft/d)
	Hydraulic gradient	
meter per kilometer (m/km)	5.27983	foot per mile (ft/mi)
	Transmissivity	
meter squared per day (m^2/d)	10.76	foot squared per day (ft^2/d)
	Application rate	
kilogram per hectare per year ([kg/ha]/yr)	0.8921	pound per acre per year ([lb/acre]/yr)
	Leakance	
meter per day per meter ([m/d]/m)	1	foot per day per foot ([ft/d]/ft)
millimeter per year per meter ([mm/yr]/m)	0.012	inch per year per foot ([in/yr]/ft)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the [insert datum name (and abbreviation) here; for example, North American Vertical Datum of 1988 (NAVD 88)].
Horizontal coordinate information is referenced to the [insert datum name (and abbreviation) here; for example, North American Datum of 1983 (NAD 83)].
Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).
Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).
Activities for radioactive constituents in water are given in picocuries per liter (pCi/L).
Results for measurements of stable isotopes of an element (with symbol E) in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope (iE) to the number of the more abundant isotope of a sample with respect to a measurement standard.

Abbreviations

DOD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
ppm	parts per million
USGS	U.S. Geological Survey

Abstract

Across the western U.S., many ungulate herds must migrate seasonally to access resource and avoid harsh winter conditions. Because these corridors traverse vast landscapes (i.e., up to 150 miles), they are increasingly threatened by roads, fencing, subdivisions and other development on public lands. Over the last decade, many new tracking studies have been conducted on migratory herds, and analytical methods have been developed that allow for population-level corridors and stopovers to be mapped and prioritized. In 2018, prompted by the signing of Secretarial Order 3362, the U.S. Geological Survey assembled a Corridor Mapping Team to provide technical assistance to western states working to map elk, mule deer, and pronghorn corridors using existing GPS data. Based out of the Wyoming Cooperative Fish and Wildlife Research Unit, the team consists of USGS scientists working alongside spatial analysts embedded within participating state agencies. In its first year, the team has worked to develop a standardized analytical and computational methods and a workflow applicable to data sets typically collected by state agencies. In 2019, the team completed analyses necessary to map corridors, stopovers, and winter ranges in Arizona, Idaho, Nevada, Utah, and Wyoming. A total of 26 corridors, 16 migration routes, 25 stopovers, and 9 winter ranges, were mapped across these states and are included in this report. This report and associated map archive provides the means for corridors to be taken into account by state wildlife managers, federal land managers, and other conservationists working to maintain big game corridors in the western states.

Introduction

Across the American West, many ungulate herds migrate to exploit key resources that shift seasonally across topographically diverse landscapes (Kauffman et al. 2018). Migration promotes abundant populations by enhancing foraging opportunities and reducing risk of exposure to adverse conditions (Bolger et al. 2008). Evidence of the importance of migration can be found throughout western landscapes as well as more broadly across the globe. For example, migratory herds of wildebeest (*Connochaetes taurinus*) in east Africa often outnumber resident counterparts by an order of magnitude (Fryxell et al. 1988). Many western landscapes are a juxtaposition of mountains and plains or sagebrush basins, wherein the best forage is produced in mountain habitats fed by winter snow melt and summer precipitation. Thus, many herds migrate into the mountains in spring in search of high-quality forage (Albon and Langvatn 1992). The mountains become largely inhospitable, however, once winter advances and blankets the high country with snow. All ungulates suffer elevated energy costs when forced to move through deep snow (reviewed in Parker et al. 2009). The migratory cycle is complete when animals move out of the high country in early winter and head for low-elevation basins, where snow levels are relatively low and some forage remains accessible. Migration is recognized as a ubiquitous behavior that allows ungulates to survive and thrive in seasonal landscapes that characterize the American West.

Mapping Migration

Wildlife managers have recognized the importance of migration for a long time. Early trappers and explorers commonly made observations about the seasonal movements of the ungulate herds. Comments such as "In the spring, as the snows disappears and the young grass starts, they return by the same route." can easily be found in early records (Kauffman et al. 2018). American Indians had seasonal hunting circuits that were timed to access the pulse of animals coming in and out of the mountains. Although the knowledge of these movements existed, maps of historical migrations are mostly non-existent.

The first detailed maps of ungulate migrations were of elk (*Cervus canadensis*) migrating in and out of Yellowstone National Park in the 1960s, conducted by Frank and John Craighead (Craighead et al. 1972a, Craighead et al. 1972b). The Craigheads caught elk in clover traps and fit them with color-banded neckbands, allowing them to be resighted up in the mountains on summer range (Craighead et al. 1972a). Such studies only gave a broad understanding of general movements between winter and summer ranges. Starting in the 1970s, VHF radio collars allowed animals to be relocated infrequently by ground or air via triangulation (Kays et al. 2015). VHF studies often provided an animal location every 1-2 weeks depending on the field effort involved; such methods provided the first coarse-scale maps of migratory movements. In the 2000s, GPS technology became widely available to wildlife researchers. Currently, tracking technology continues to evolve with longer lasting batteries, better data storage, and satellite transmission options. With the ability to record locations every 1-2 hours for several years, modern-day GPS collars provide a detailed path of the year-round movements of ungulates and other large-bodied animals (Kays et al. 2015).

The use of GPS collars on ungulate taxa has brought about a renaissance in animal tracking, and along with it, the discovery and delineation of migrations across the West (Sawyer et al. 2009). In many cases, wildlife managers knew that specific herds were migratory, but lacked detailed delineation of the migrations. Some herds have been found to migrate farther than anyone had imagined. This was the case for Wyoming's Sublette mule deer (*Odocoileus hemionus*) herd in south-central Wyoming. The remarkable 150-mile migratory journey was recently discovered, revealing that many of the animals migrate from their Red Desert winter range near the town of Superior, WY, to lush and productive summer ranges in the headwaters of the Hoback River (Sawyer et al. 2016). This is just one example of new data on the migration routes of mule deer, elk and pronghorn (*Antilocapro americana*) that has been collected by state wildlife agencies in the West. Detailed location data from unmapped herds is being collected each year.

Migration Ecology

In addition to the delineation of migration routes, fine-scale GPS data has enabled new scientific discoveries. For example, although it has been known for some time that migratory ungulates move into the mountains in spring to access higher-quality forage, it has been predicted that migratory herbivores — including waterfowl (Drent et al. 1978) — should time their movements in spring to seek out new forage that is reasonably abundant yet still young enough to be highly digestible. Tracking waves of spring green-up is referred to as "surfing the green wave" (van der Graaf et al. 2006). Sawyer and Kauffman (2011) showed that mule deer spend nearly 95% of their time during spring migration held up in stopovers used primarily for foraging. To empirically test the idea that ungulates surf the green wave in Norwegian red deer (*Cervus elaphus*), Bischof et al. (2012) first developed the means of measuring spring green up using remotely sensed measures of plant growth (the Normalized Difference Vegetation Index [NDVI]). When this method was applied to migratory mule deer in Wyoming, researchers found strong evidence of surfing in a migratory ungulate; in a two-month long migration, nearly 1/3 of collared mule deer moved in nearly complete coordination with green-up as it moved up in elevation in spring (Aikens et al. 2017). Although less work has been conducted on the timing of the fall migration, it is clear that the onset of snow and cold temperatures cause animals to initiate their fall movements out of the high country (Monteith et al. 2011, Jones and Carter 2016). These studies, combined with recent work documenting the nutritional benefit of surfing in elk (Middleton et al. 2018), indicate that animals require the ability to freely move along their corridors in order to derive the foraging benefits of migration.

Ungulates can migrate hundreds of kilometers along the same migratory routes year after year, and studies are beginning to identify how they know how to make these journeys. In general, migratory taxa navigate along their routes using either learned or genetic information. For example, common-garden experiments in migratory birds have shown that both timing and compass direction of migration are heritable traits (reviewed in Merlin and Liedvogel 2019). But in mammals, it has been thought that migrations must be learned, and presumably passed on from mother to young (Nelson 1998). A breakthrough came in 2018, when Jesmer et al. (2018) showed that reintroduced bighorn sheep (*Ovis canadensis*) and re-established moose (*Alces alces*) populations failed to migrate in their new habitats, indicating the lack of a genetic program to do so. Reintroduced animals did not surf well either – but they learned. Their ability to surf increased over multiple generations, as did their propensity to migrate. Notably, animals required 30-80 years of learning a new landscape to develop migratory behavior, suggesting that a complete loss of migratory behavior can have dire consequences for populations (Jesmer et al. 2018). Numerous studies have shown that animals must learn complex behaviors, such as the migrations of whooping cranes (Mueller et al. 2013), or the homing of pigeons (Sasaki and Biro 2017). In elephants (*Loxodonta africana*), the older matriarchs possess knowledge about resource distribution (e.g., water sources) that younger animals have not yet learned (McComb et al. 2001). Increasingly, researchers understand that the detailed knowledge required to make seasonal migrations is best thought of as a form of animal culture, built up through time, and transmitted between generations (Whiten 2019). This is a cautionary tale for the conservation of migration corridors, because it means that not only must the corridors be kept intact, but the specific animals that retain the knowledge of these journeys must be conserved as well (Brakes et al. 2019). The decades that it will take for the culture of migration to return once lost, suggests that restoring lost migrations is likely to be a nearly impossible task.

At the same time that mapping of migrations has proliferated, so too has our understanding of the threats that many migrating animals now face. Freely moving across large landscapes is a requirement of migrations, but western landscapes are increasingly fragmented by many types of barriers. Fences are a persistent feature of many habitats; they are often navigable by migrating big game but remain a source of direct mortality (Harrington and Conover 2006). For some species (like pronghorn) and some fence types (tall, woven wire), the stretch of fences across public and private rangelands can constrain movements, including long-distance migration (Gates et al. 2012, Jones et al. 2019). Housing development in the West is a constant and growing impact to migration corridors, because subdivisions and other housing are permanent (Kauffman et al. 2018, Monteith et al. 2018). For example, migrating mule deer avoided stopping over near housing developments (Wyckoff et al. 2018). Roads are an additional source of mortality, which also constrain connectivity in the western U.S. (Huijser et al. 2017) and worldwide (Brown and Ross 1994). Each year, 1000s of animals are killed on the nation's roadways (Conover et al. 1995), many during their spring or fall migrations (Sawyer et al. 2012). Perhaps more importantly, roads — especially those with high traffic — represent an increasingly formidable barrier to movement, capable of truncating or causing loss of migration (Kauffman et al. 2018). Finally, the rapid pace of energy development represents a new challenge for migrating big game. Mule deer have been found to avoid energy development in various ways (Lendrum et al. 2012, Sawyer et al. 2013, Wyckoff et al. 2018) including speeding up, stopping over less, or detouring around gas development areas during migration. Such behavioral modifications cause animals to miss out on peak green up, which diminishes the foraging benefit of migration (Wyckoff et al. 2017).

Applying Migration Science to Conservation and Wildlife Management

The identification and mapping of migration corridors has proven to be a powerful means to advance science-based conservation and wildlife management (Kauffman et al. 2018). Studying and mapping corridors helps managers and researchers alike better understand the unique habitat needs of big game herds (Berger et al. 2008, Monteith et al. 2018), which has long been a goal of applied wildlife research. Moreover, state wildlife managers, federal land managers, and other conservation groups have demonstrated for over a decade that corridor identification can facilitate critical on-the-ground management and conservation (e.g., Sawyer et al. 2014). Modern methods of corridor mapping provide a polygon with defined width and intensity of use by marked animals, which can be simply overlayed with threats and conservation actions (Sawyer et al. 2009). In Wyoming alone, conservation groups, wildlife, and land managers have worked to convert hundreds of miles of fence within identified corridors to be wildlife friendly. In the Greater Yellowstone Ecosystem, encompassing Montana, Idaho and Wyoming, land trusts are currently working to secure conservation easements on private ranches within identified corridors, with investments in the tens of millions of dollars.

There are a growing number of successful highway crossing structures built across western states, which were informed by migration corridors (e.g., Sawyer et al. 2012) or otherwise guided by the seasonal movement needs of big game, such as two recently built overpasses on I-80 in Nevada and five crossing structures on US Highway 93 (Simpson et al. 2016). In summary, the identification and mapping of big game migration corridors is an effective tool for science-based wildlife management that will allow western states to sustain the migration corridors of their big game herds by identifying barriers to movements and other conservation opportunities.

In 2019, the US Geological Survey assembled a Corridor Mapping Team consisting of USGS researchers and state wildlife managers from western states. In response to DOI Secretarial Order 3362, this team was formed to facilitate the mapping of mule deer, elk, and pronghorn migration corridors, using existing data collected by participating states. In 2019, the Corridor Mapping Team worked to identify and prioritize state data sets for analyses to map corridors of mule deer, elk and pronghorn. This collaborative approach allowed individual states to set their own priorities for corridor mapping, while making use of technical support and expertise from the broader mapping team. This report is a first effort to document the big game migration corridors of participating states, using standardized methods (Sawyer et al. 2009). Our hope is that this work can provide a common methodology and a common platform to enable corridor delineations to be incorporated into conservation planning and wildlife management efforts.

Mule Deer

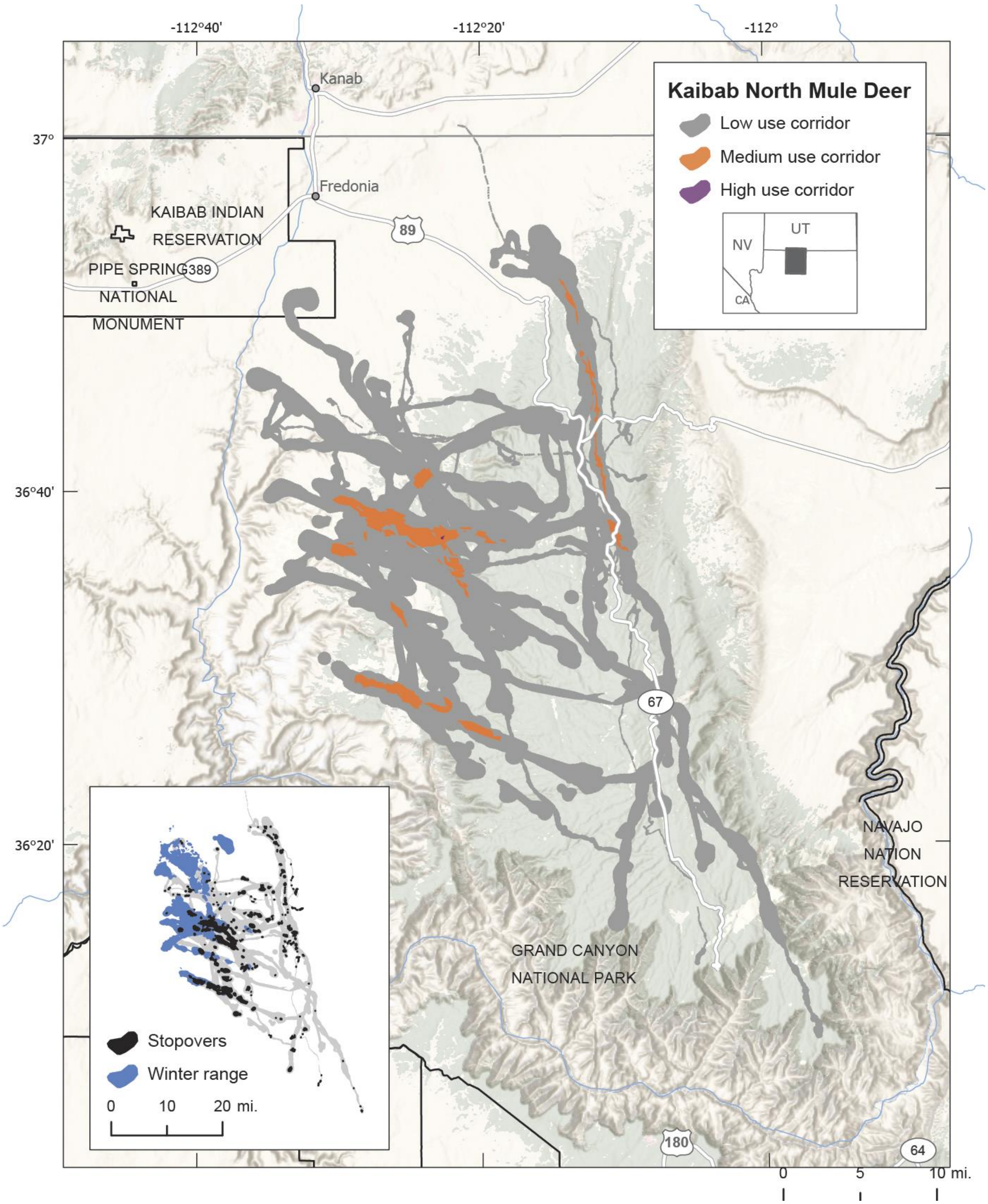
Mule deer have a large geographic range that covers the western half of North America, extending from the Yukon to Mexico (Fig. 1). The scientific name "hemionus" means half-mule, and refers to the large ears of mule deer that help distinguish them from their cousin, the white-tailed deer (*Odocoileus virginianus*). Within their expansive geographic range, mule deer have adapted to a variety of different ecoregions, including the coastal rainforests, the Great Plains, the deserts of the Southwest, and the Rocky Mountain basin and range (Kie and Czech 2000).

Larger ungulates like moose and elk can ingest significant amounts of coarse forage that may not have high nutrional value. In contrast, mule deer are selective feeders that forage on plants that provide concentrated and highly digestible nutrients (Short 1981). Mule deer are generally considered browsers rather than grazers, but they do prefer herbaceous forage when it is seasonally available in the spring and summer. When herbaceous forage is not available, mule deer often rely on native shrub species like sagebrush (*Artemisia tridentata)*, bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus ledifolius)*, cliffrose (*Purshia stansburyana)*, and serviceberry (*Amelanchier utahensis)*.

Mule deer show strong fidelity to their seasonal ranges and migration routes (Sawyer et al. 2019). Although some populations are resident, the largest and most productive mule deer herds tend to be migratory and may travel anywhere from 10 to 150 miles between seasonal ranges. Like other ungulates, mule deer usually migrate along elevational or moisture gradients that enable access to seasonal peaks in high-quality forage (Sawyer and Kauffman 2011). Spring migrations tend to be synchronized with vegetation green-up, whereas autumn migrations often correspond with snow events or vegetation senescence (Monteith et al. 2011). The breeding season or 'rut' usually occurs in November, and females give birth the following June to one or two fawns, depending on habitat productivity and their body condition

Fig. 1. Current and historic range of mule deer

Mule deer and other big game were scarce by the early 1900s because of unrestricted hunting. However, by the 1930s, hunting restrictions and wildlife management practices allowed mule deer populations to recover and by the 1950s and 60s, mule deer populations flourished. Beginning in the early 1970s and 80s, mule deer populations across the western US began to gradually decline (Kauffman et al. 2018). Today, the trajectory of mule deer populations varies regionally, with some stable or increasing, while others continue to decline. As of 2019, the Western Association of Fish and Wildlife Agencies estimated mule deer numbers totaled approximately three million across their range (Mule Deer Working Group 2019). The key threats and challenges to mule deer conservation also vary by region, but generally include habitat loss, disease (e.g., chronic wasting disease), habitat fragmentation and loss of connectivity (e.g., roadways, fences, dense development), and changing environmental conditions (e.g., vegetation succession, drought, climate change).



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37°
36°40'
36°20'
Kanab
Fredonia
89
KAIBAB INDIAN
RESERVATION
PIPE SPRING
389
NATIONAL
MONUMENT
67
GRAND CANYON
NATIONAL PARK
NAVAJO
NATION
RESERVATION
180
64
0
5
10 mi.
Kaibab North Mule Deer
Low use corridor
Medium use corridor
High use corridor
NV
UT
CA
Stopovers
Winter range
0
10
20 mi.

Arizona | Mule Deer

Kaibab North Mule Deer Migration Corridors

Mule deer of the Kaibab North herd on the Kaibab Plateau are treasured for their historic and contemporary significance in North America. They are the densest population of mule deer in Arizona. This report compiles two research efforts, the first completed by Arizona Game and Fish Department in 2014, and the second from Utah Division of Wildlife's ongoing research started in 2017. The Kaibab Plateau is bound on the east, south, and west by vertical canyon walls which run along the Colorado River and Kanab Creek. The Kaibab North Deer herd winters among pinyon-juniper, sagebrush, and cliffrose landscapes along the west, east, and northern extents of the plateau. Portions of the Kaibab North herd in Arizona and the Paunsaugunt Plateau herd in Utah share a common winter range along the Arizona and Utah border. Their summer range consists of habitat dominated by ponderosa pine, mixed conifer, and aspen. There are currently few impediments to mule deer migration on the Kaibab Plateau. Water availability throughout seasonal ranges may be the limiting factor for this population.

Animal Capture and Data Collection

Sample size: 46 mule deer
Relocation frequency: ~ 6 hours (AZ study); ~2 hours (UT study)
Project duration: 2012 – 2014 (AZ study); 2017 – present (UT study)

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009); corridor analysis used FMV=1,000 for Arizona Study

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:
- **Migration:** 96 sequences from 41 individuals (55 spring sequences, 41 fall sequences)
- **Winter:** 44 sequences from 30 individuals

Corridor and Stopover Summary

Migration start and end date (median):
- **Spring:** April 21 to May 3
- **Fall:** October 21 to November 13

Average number of days migrating:
- **Spring:** 15 days
- **Fall:** 23 days

Migration corridor length:
- **Min**: 11 miles
- **Mean**: 28 miles
- **Max**: 93 miles

Migration corridor area:
- 359,530 acres (low use)
- 12,923 acres (medium use)
- 25 acres (high use)

Stopover area: 25,105 acres

Winter Range Summary

Winter start and end date (median):
- December 15 to April 9

Winter length (mean): 105 days
Winter range (50% contour) area: 83,915 acres

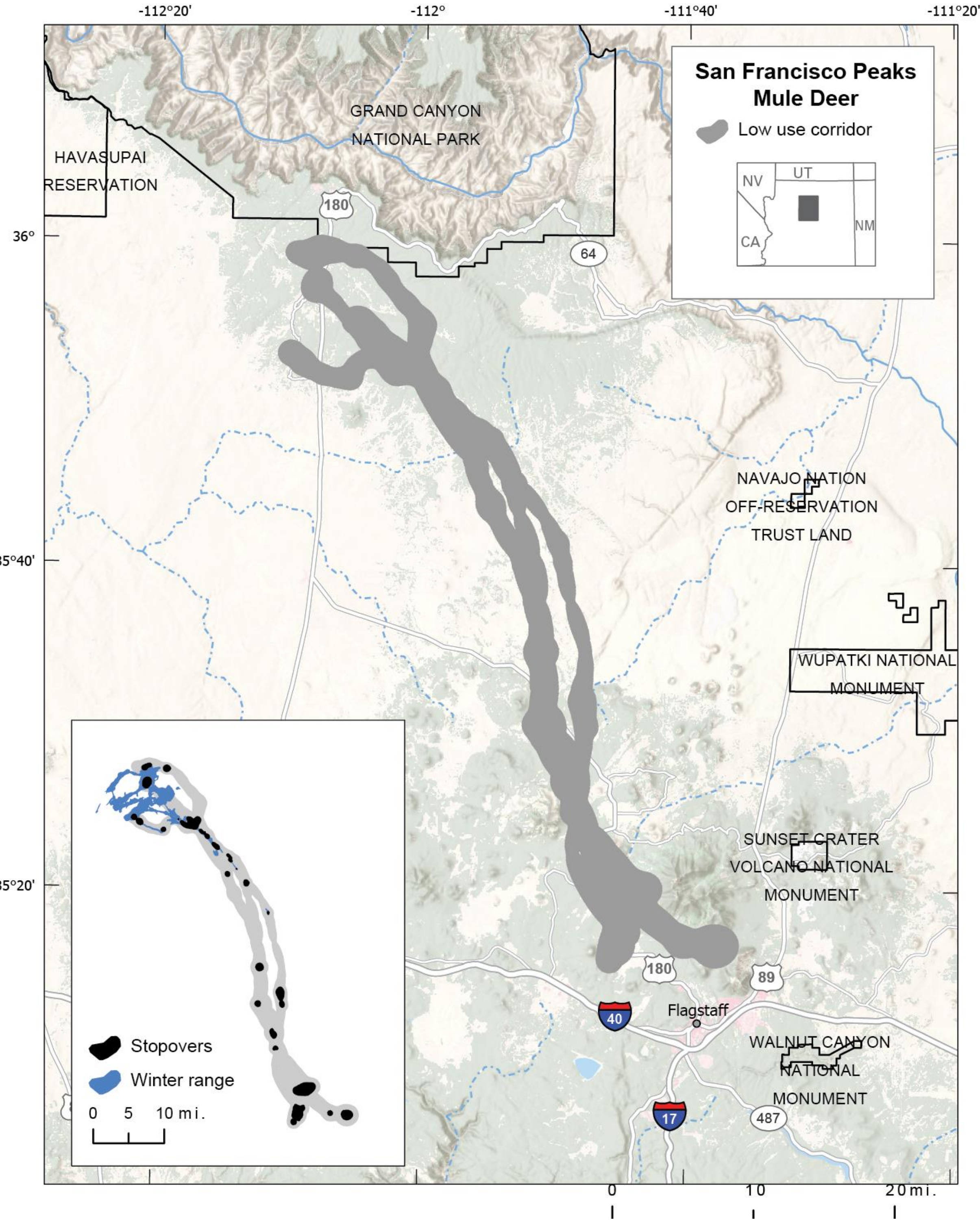
Other Information

Project contacts:
- Dan Olson (danielolson@utah.gov), Wildlife Migration Initiative Coordinator, Utah Department of Natural Resouces
- Jeff Gagnon (jgagnon@azgfd.gov), Wildlife Specialist Regional Supervisor, Arizona Game and Fish Department

Data analyst:
- Lucas Olson, Cooperative Mule Deer Biologist, Arizona Game and Fish Department

Reports and publications:

- Carrel, W. K., R. A. Ockenfels, and R. E. Schweinsburg. 1999. An evaluation of annual migration patterns of the Paunsaugunt mule deer herd between Utah and Arizona. Research Branch Tech. Rep. No. 29. Arizona Game and Fish Department, Phoenix. 44 pp.



-112°20'
-112°
-111°40'
-111°20'
36°
35°40'
35°20'
San Francisco Peaks
Mule Deer
Low use corridor
NV
UT
CA
NM
GRAND CANYON
NATIONAL PARK
HAVASUPAI
RESERVATION
180
64
NAVAJO NATION
OFF-RESERVATION
TRUST LAND
WUPATKI NATIONAL
MONUMENT
SUNSET CRATER
VOLCANO NATIONAL
MONUMENT
180
89
40
Flagstaff
WALNUT CANYON
NATIONAL
MONUMENT
17
487
Stopovers
Winter range
0 5 10 mi.
0 10 20 mi.

Arizona | Mule Deer

San Francisco Peaks Mule Deer Migration Corridors

In 2008, 13 mule deer were GPS collared near the South Rim of the Grand Canyon to understand the impact of Arizona's State Route 64 on mule deer movement. Unexpectedly, 4 individuals migrated over 50 miles to summer range near the San Francisco Peaks, north of Flagstaff, containing alpine, subalpine, and ponderosa pine habitats. The GPS collars dropped in 2009, but questions surrounding this long-distance migration remained. In June of 2019, the Arizona Game and Fish Department GPS collared 20 additional mule deer from the San Francisco Peaks herd on their summer range. The primary challenges to mule deer in this migration corridor are related to navigating highways. These deer must traverse two major highways, State Route 180 and State Route 64, which experience high traffic volumes from tourists visiting the Grand Canyon.

Animal Capture and Data Collection

Sample size: 9 adult mule deer
Relocation frequency: ~ 2 hours
Project duration: March 2008 – November 2009

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 6 sequences from 4 individuals (4 spring sequences, 2 fall sequences)
- **Winter:** 8 sequences from 7 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** April 23 to April 28
- **Fall:** October 10 to October 15

Average number of days migrating:

- **Spring:** 8 days
- **Fall:** 6 days

Migration corridor length:

- **Min**: 52 miles
- **Mean**: 54 miles
- **Max**: 56 miles

Migration corridor area:

- 195,728 acres (low use)

Stopover area: 14,950 acres

Winter Range Summary

Winter start and end date (median):

- October 25 to October 23

Winter length (mean): 86 days
Winter range (50% contour) area: 25,649 acres

Other Information

Project contacts:

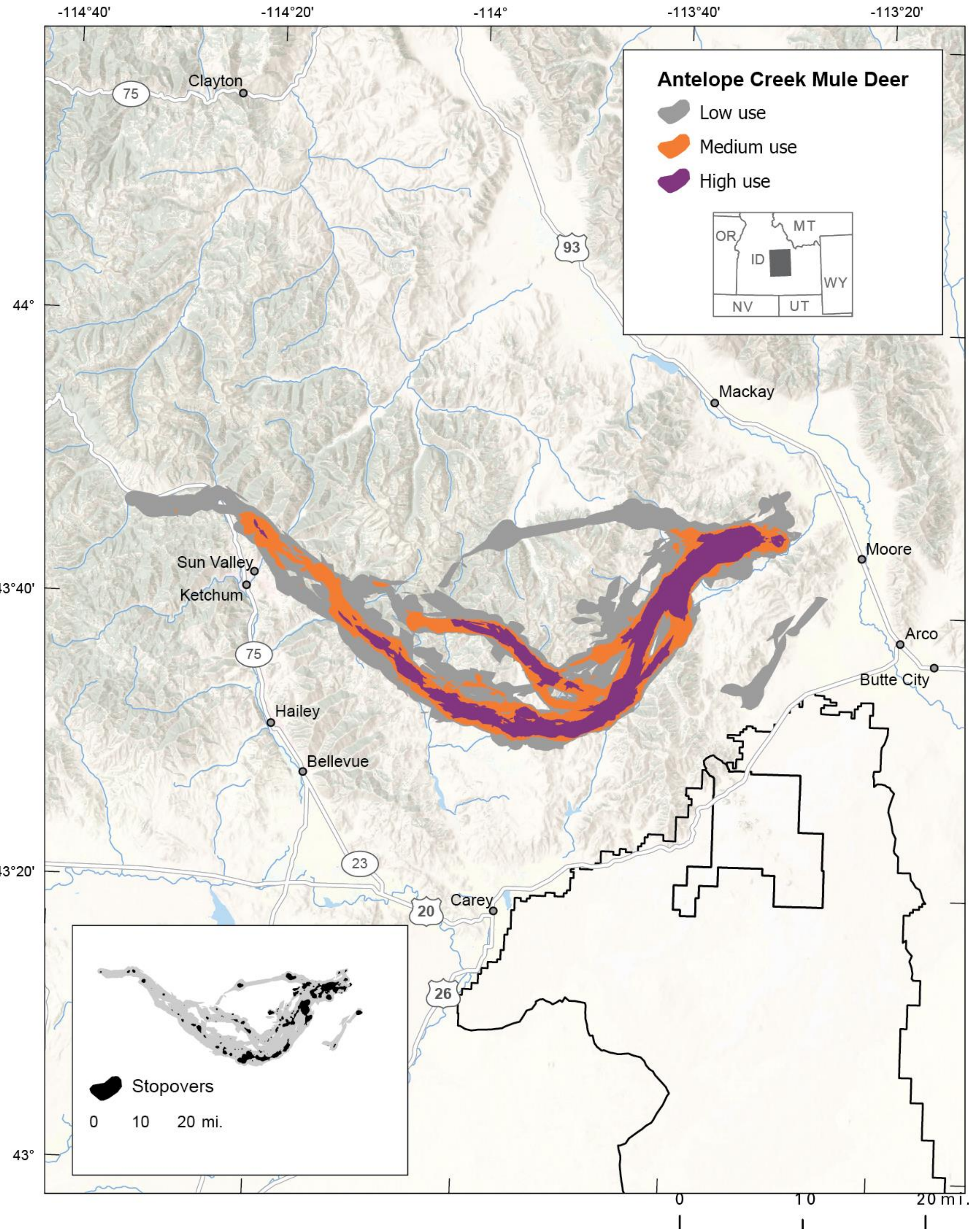
- Jeff Gagnon (jgagnon@azgfd.gov), Wildlife Specialist Regional Supervisor, Arizona Game and Fish Department

Data analyst:

- Lucas Olson, Cooperative Mule Deer Biologist, Mule Deer Foundation

Reports and publications:

- Dodd, N., Gagnon, J., Sprague, S., Boe, S., & Schweinsburg, R. (2012). Wildlife Accident Reduction Study and Monitoring: Arizona State Route 64. Arizona Game and Fish Department. Phoenix, AZ.


-114°40'
-114°20'
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-113°40'
-113°20'
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43°20'
43°
Antelope Creek Mule Deer
Low use
Medium use
High use
OR
MT
ID
WY
NV
UT
Clayton
75
93
Mackay
Moore
Sun Valley
Ketchum
Arco
Butte City
Hailey
Bellevue
23
20
Carey
26
Stopovers
0 10 20 mi.
0 10 20 mi.

Idaho | Mule Deer

Antelope Creek Mule Deer Migration Routes

Antelope Creek mule deer winter along Antelope Creek, west of Big Lost River. The area provides crucial forage and habitat for mule deer, especially when winters are more severe. The rolling hills and steep, rocky slopes of Antelope Creek hold between 1,300 and 1,850 mule deer during winter (based on aerial surveys in 2006 and 2010). These mule deer migrate westward through the White and Pioneer Mountains towards Ketchum and the northern portions of Game Management Units (GMUs) 49 and 50. On average, Antelope Creek mule deer travel over 42 miles to migrate between summer and winter range with the farthest individuals traveling close to 110 miles. The Antelope Creek mule deer are adjacent to the Appendicitis Hills deer herd (950 – 2,120 deer). Individuals may move between these two areas during winter and often share migration routes and summer ranges. Currently, there are no known significant migration challenges for this deer herd, but continued development of infrastructure and loss of native habitat across their range could result in cumulative impacts over time.

Animal Capture and Data Collection

Sample size: 99 adult female mule deer
Mean relocation frequency: ~16 hours
Project duration: April 20, 2011 – December 22, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 99 sequences from 41 individuals (59 spring sequences, 40 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 8 to May 16
- **Fall:** October 14 to November 20

Days migrating (mean):

- **Spring:** 38 days
- **Fall:** 37 days

Migration length:

- **Min:** 5.6 miles
- **Mean:** 42.4 miles
- **Max:** 109.8 miles

Migration area:

- 376,335 acres (low use)
- 152,462 acres (medium use)
- 49,854 acres (high use)

Stopover area: 35,984 acres

Other Information

Project contacts:

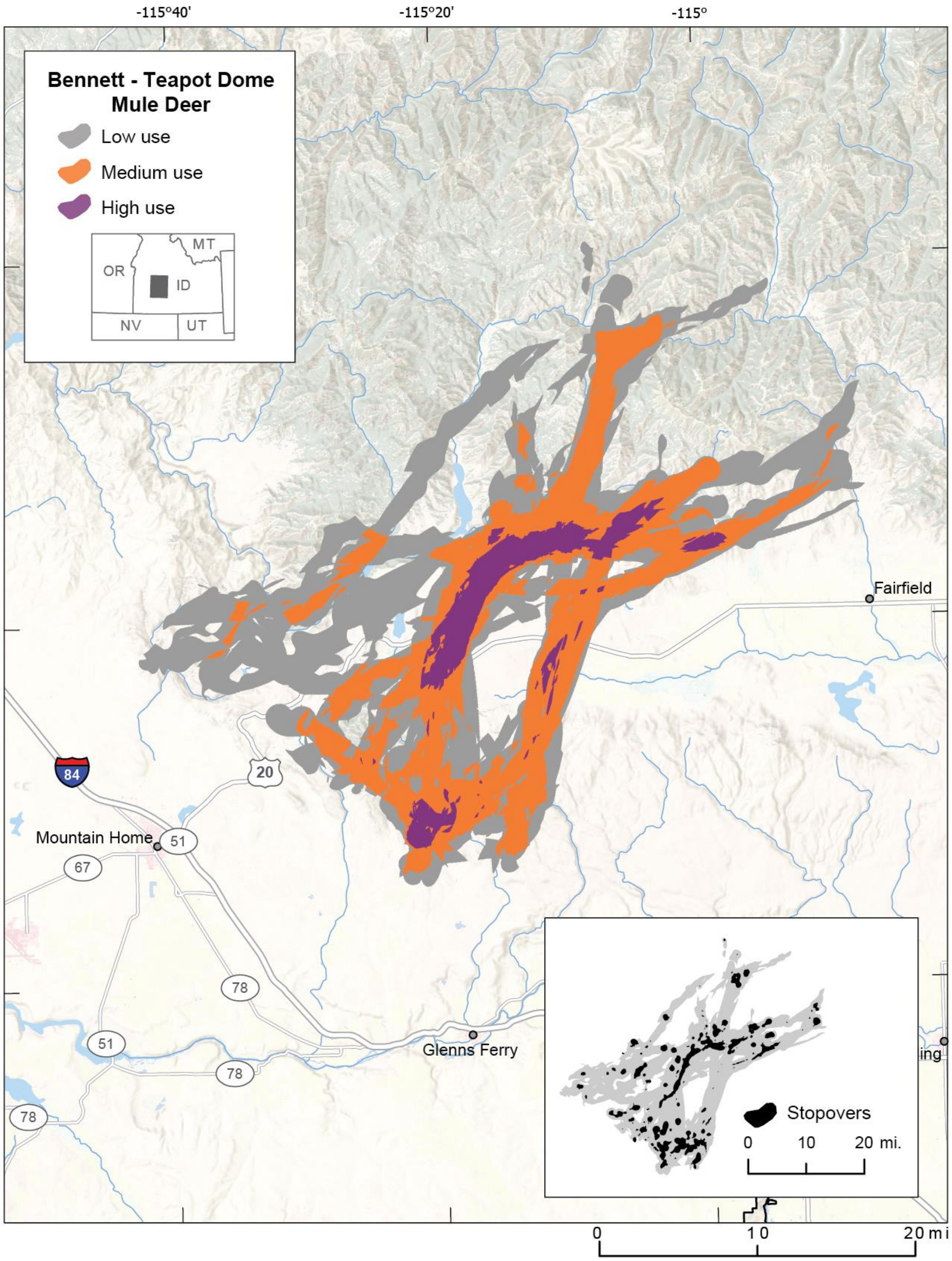
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Curtis Hendricks (curtis.hendricks@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game
- Mike McDonald (mike.mcdonald@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



Bennett - Teapot Dome
Mule Deer
Low use
Medium use
High use
MT
OR
ID
NV
UT
-115°40'
-115°20'
-115°
43°40'
43°20'
43°
Fairfield
Mountain Home
Glenns Ferry
84
20
51
67
78
Stopovers
0
10
20 mi.
0
10
20 mi

Idaho | Mule Deer

Bennett-Teapot Dome Mule Deer Migration Routes

Bennett mule deer inhabit the foothills between Mountain Home and the Bennett Mountain front, north of King Hill and west of King Hill Creek. Mule deer wintering in this area typically traverse the Bennett Mountains using several migration pathways (2 major, 1 moderate, and several low-use) to reach summer ranges across Camas Prairie and in the Soldier and Smoky Mountains. Bennett-Teapot Dome mule deer migrate on average 38 miles between summer and winter range, with the longest routes reaching more than 60 miles. Deer used for this analysis winter in two Population Management Units (PMUs): Smoky-Bennett (Game Management Units 43, 44, 45, 48, and 52) and Boise (GMU 39). The 2018 population estimates for mule deer in the Smoky-Bennett and Boise PMUs was 16,358 and 28,600, respectively.

Animal Capture and Data Collection

Sample size: 40 adult female mule deer
Mean relocation frequency: ~15 hours
Project duration: March 28, 2013 – December 2, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 105 sequences from 40 individuals (57 spring sequences, 48 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 16 to May 12
- **Fall:** October 4 to October 30

Days migrating (mean):

- **Spring:** 26 days
- **Fall:** 26 days

Migration length:

- **Min:** 20.6 miles
- **Mean:** 38.5 miles
- **Max:** 62.4 miles

Migration area:

- 520,267 acres (low use)
- 183,095 acres (medium use)
- 27,722 acres (high use)

Stopover area: 52,960 acres

Other Information

Project contacts:

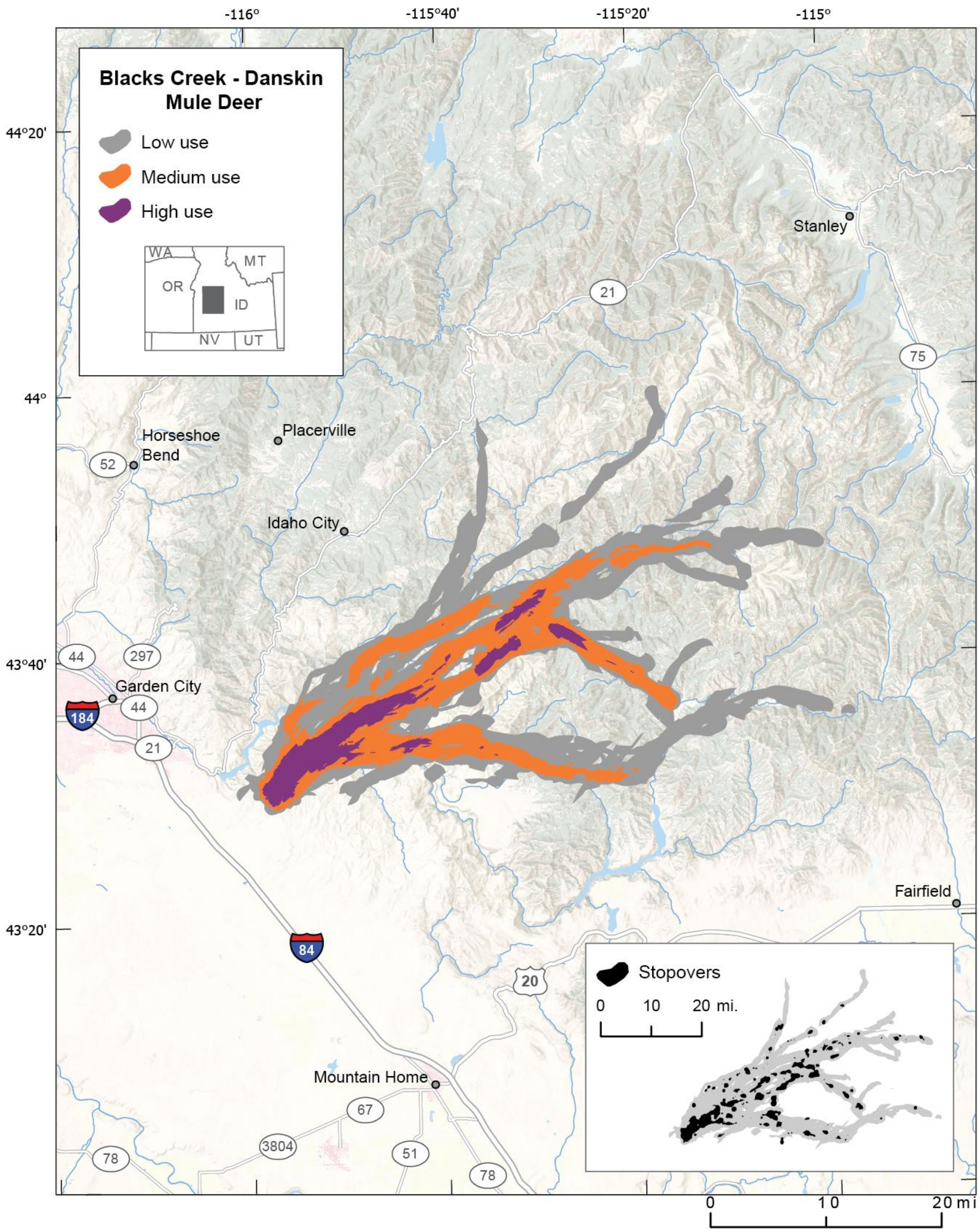
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Mike McDonald (mike.mcdonald@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



-116°
-115°40'
-115°20'
-115°
44°20'
44°
43°40'
43°20'
Blacks Creek - Danskin
Mule Deer
Low use
Medium use
High use
WA
MT
OR
ID
NV
UT
Stanley
21
75
Horseshoe
Bend
52
Placerville
Idaho City
44
297
Garden City
184
44
21
Fairfield
84
20
Stopovers
0
10
20 mi.
Mountain Home
67
3804
51
78
78
0
10
20 mi

Idaho | Mule Deer

Blacks Creek-Danskin Mule Deer Migration Routes

Blacks Creek-Danskin mule deer winter in the foothills southeast of Lucky Peak Reservoir. During their spring migration, these mule deer typically traverse the Boise River Valley into reaches much farther up the valley. They may also travel as far as the Sawtooth Valley. On average, Blacks Creek-Danskin mule deer migrate over 40 miles between winter and summer range, with some individuals migrating up to 75 miles.

Animal Capture and Data Collection

Sample size: 48 adult female mule deer
Mean relocation frequency: ~16 hours
Project duration: March 15, 2015 – December 17, 2018

Data Analysis

Migration and stopover analysis: Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 119 sequences from 48 individuals (73 spring sequences, 46 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 8 to May 4
- **Fall:** October 9 to November 20

Days migrating (mean):

- **Spring:** 25 days
- **Fall:** 42 days

Migration length:

- **Min**: 8.7 miles
- **Mean**: 40.4 miles
- **Max**: 76.3 miles

Migration area:

- 485,901 acres (low use)
  158,857 acres (medium use)
  29,801 acres (high use)

Stopover area: 50,933 acres

Other Information

Project contacts:

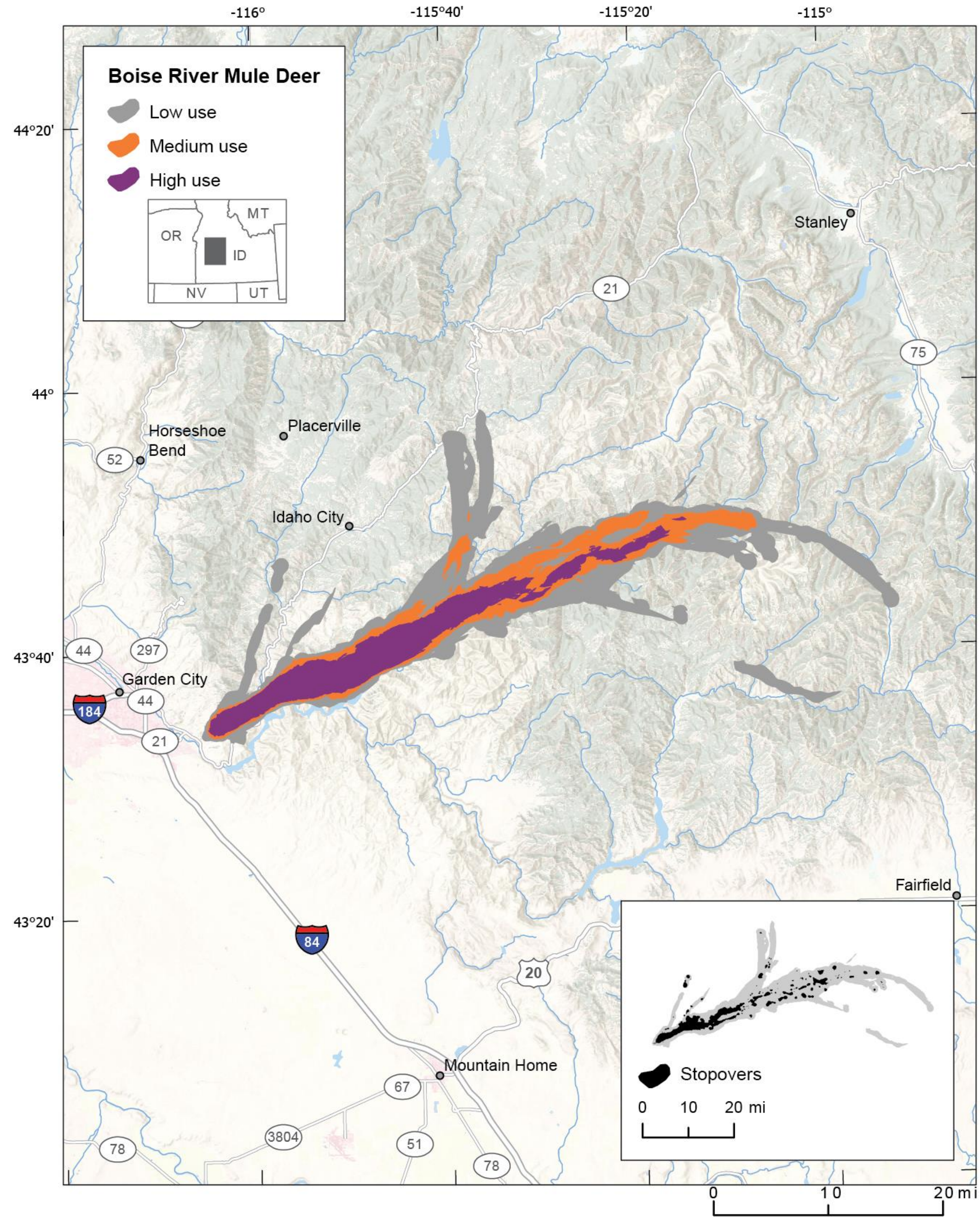
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Rick Ward (rick.ward@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.


-116°
-115°40'
-115°20'
-115°
44°20'
44°
43°40'
43°20'
Boise River Mule Deer
Low use
Medium use
High use
OR
MT
ID
NV
UT
Stanley
21
75
Horseshoe Bend
Placerville
52
Idaho City
44
297
Garden City
44
184
21
84
20
Fairfield
Mountain Home
67
3804
51
78
78
Stopovers
0
10
20 mi
0
10
20 mi

Idaho | Mule Deer

Boise River Mule Deer Migration Routes

Boise River mule deer inhabit the foothills west of Lucky Peak Reservoir in winter. Mule deer wintering in this area typically traverse the Boise River Valley into reaches much farther up the valley, and may travel as far as the Sawtooth Mountains. On average, Boise River mule deer migrate over 45 miles between summer and winter range, while the longest migrations are close to 96 miles.

Animal Capture and Data Collection

Sample size: 52 adult female mule deer
Mean relocation frequency: ~17 hours
Project duration: April 20, 2011 – December 10, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 119 sequences from 52 individuals (76 spring sequences, 43 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 1 to May 7
- **Fall:** October 11 to November 11

Days migrating (mean):

- **Spring:** 36 days
- **Fall:** 31 days

Migration length:

- **Min**: 12.7 miles
- **Mean**: 45.7 miles
- **Max**: 96.2 miles

Migration area:

- 370,616 acres (low use)
- 150,911 acres (medium use)
- 52,888 acres (high use)

Stopover area: 38,564 acres

Other Information

Project contacts:

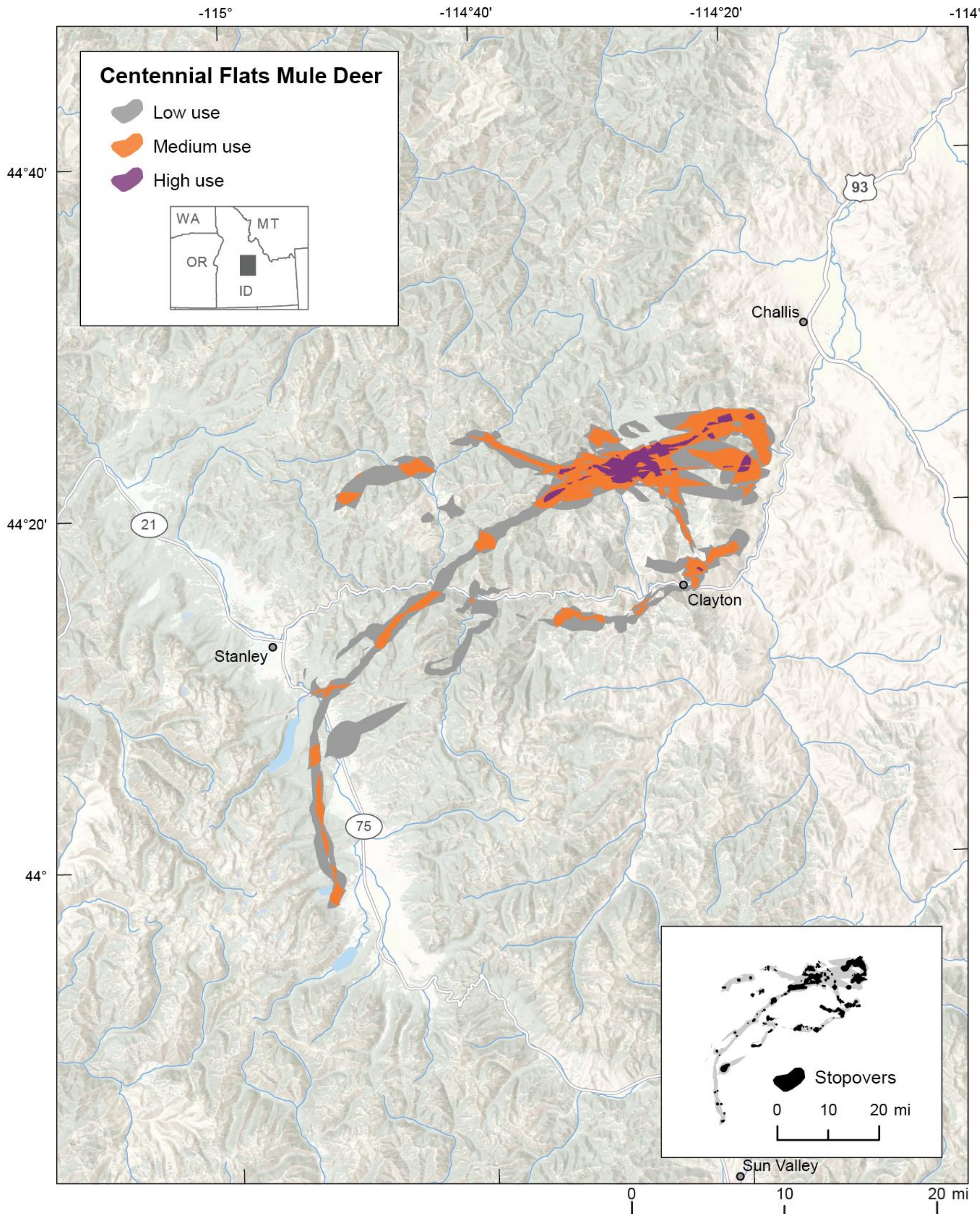
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Rick Ward (rick.ward@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



-115°
-114°40'
-114°20'
-114°
44°40'
44°20'
44°
Centennial Flats Mule Deer
Low use
Medium use
High use
WA
MT
OR
ID
93
Challis
21
Clayton
Stanley
75
Stopovers
0
10
20 mi
Sun Valley
0
10
20 mi

Idaho | Mule Deer

Centennial Flats Mule Deer Migration Routes

Centennial Flat's mule deer inhabit the foothills southwest of Challis, adjacent to the Salmon River in winter. After the snow melts, mule deer migrate to the southwest. The western migration crosses rural areas of the Challis National Forest, with some deer traveling through the Stanley Basin to summer range in the Sawtooth Mountains. On average, Centennial Flat's mule deer migrate over 30 miles between summer and winter ranges. The wintering population of deer used for this analysis is approximately 3,370.

Animal Capture and Data Collection

Sample size: 21 adult female mule deer
Mean relocation frequency: ~13 hours
Project duration: May 27, 2003 – December 3, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 35 sequences from 21 individuals (22 spring sequences, 13 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** May 19 to June 1
- **Fall:** October 11 to November 3

Days migrating (mean):

- **Spring:** 14 days
- **Fall:** 23 days

Migration length:

- **Min**: 5.6 miles
- **Mean**: 32.9 miles
- **Max**: 51.2 miles

Migration area:

- 132,267 acres (low use)
- 42,774 acres (medium use)
- 5,645 acres (high use)

Stopover area: 22,286 acres

Other Information

Project contacts:

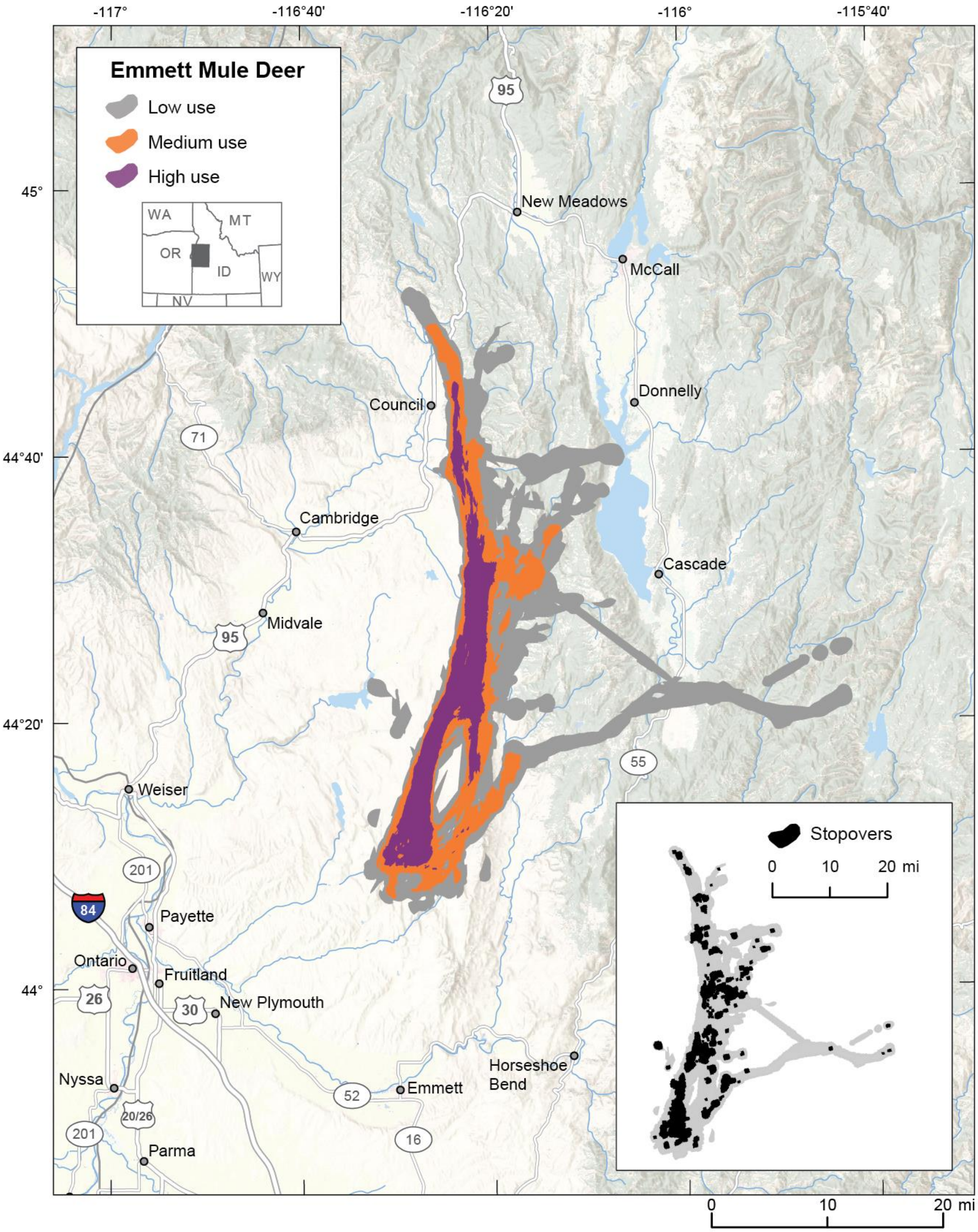
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Dennis Newman (dennis.newman@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game
- Jessie Shallow (jessie.shallow@idfg.idaho.gov), Regional Wildlife Biologist, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.


Emmett Mule Deer
Low use
Medium use
High use
WA
MT
OR
ID
WY
NV
-117°
-116°40'
-116°20'
-116°
-115°40'
45°
44°40'
44°20'
44°
New Meadows
McCall
Donnelly
Council
Cambridge
Cascade
Midvale
Weiser
Payette
Ontario
Fruitland
New Plymouth
Nyssa
Parma
Emmett
Horseshoe Bend
95
71
55
201
84
26
30
20/26
52
16
Stopovers
0 10 20 mi
0 10 20 mi

Idaho | Mule Deer

Emmett Mule Deer Migration Routes

Emmett mule deer winter on a mix of private and public land northeast of the towns of Payette and Emmett, ID in vicinity of Paddock Valley Reservoir. Repeated fires have left winter range in relatively poor condition, with significant presence of annual grasses and noxious weeds. The majority of these mule deer migrate northward to summer on public land west of Cascade Reservoir. A small segment of the herd migrates eastward. Deer that do summer east of the North Fork of the Payette River and the Cascade Reservoir must cross State Highway 55. On average, Emmett mule deer migrate over 42 miles between summer and winter ranges. The Emmett mule deer wintering population is estimated at 24,000 mule deer.

Animal Capture and Data Collection

Sample size: 60 adult female mule deer
Mean relocation frequency: ~21 hours
Project duration: March 16, 2003 – December 28, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 146 sequences from 60 individuals (85 spring sequences, 61 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** March 25 to May 2
- **Fall:** October 17 to November 1

Days migrating (mean):

- **Spring:** 31 days
- **Fall:** 20 days

Migration length:

- **Min**: 12.8 miles
- **Mean**: 42.0 miles
- **Max**: 85.8 miles

Migration area:

- 449,683 acres (low use)
- 169,584 acres (medium use)
- 52,248 acres (high use)

Stopover area: 51,224 acres

Other Information

Project contacts:

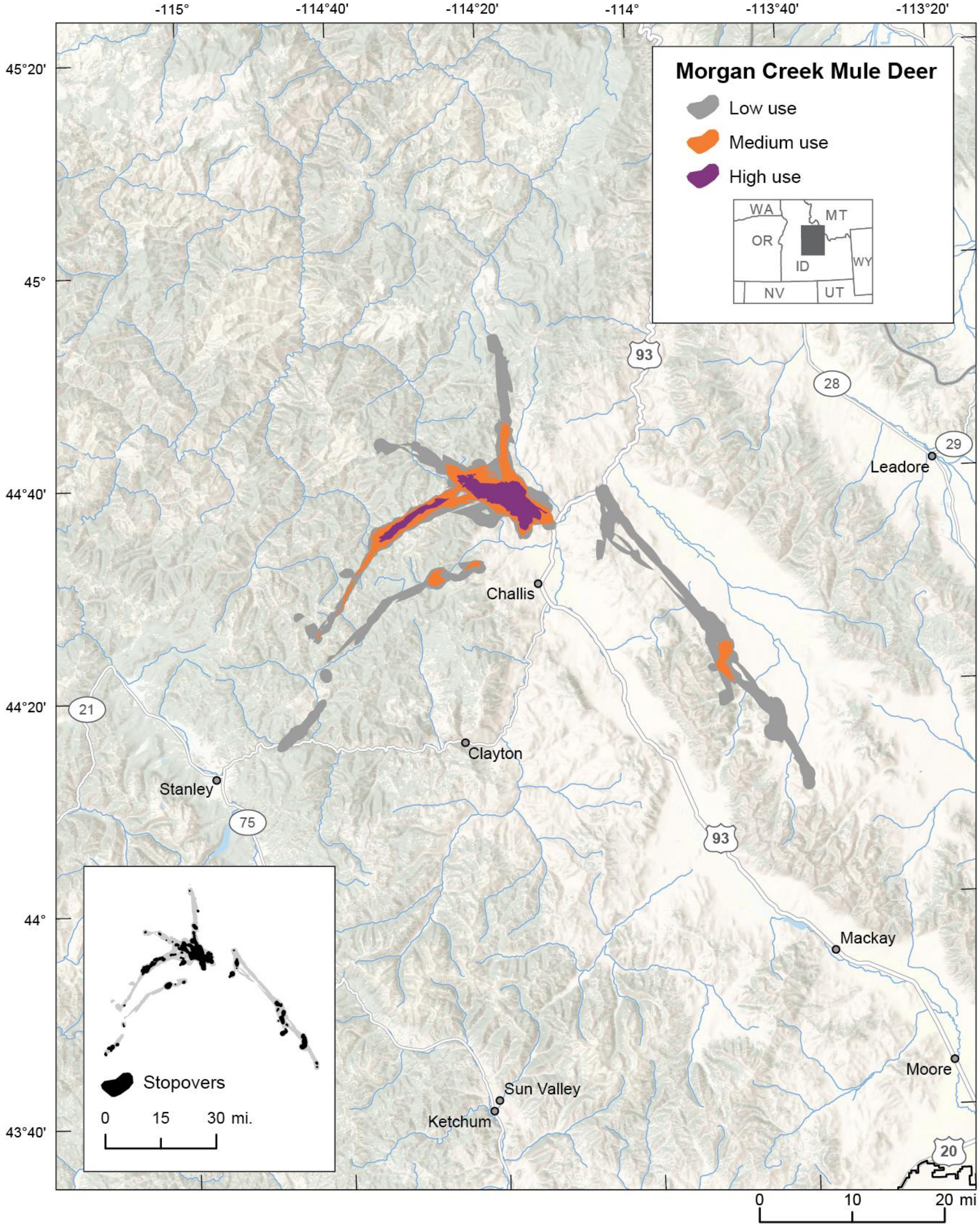
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Regan Berkley (regan.berkley@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.


Morgan Creek Mule Deer
Low use
Medium use
High use
WA
MT
OR
ID
WY
NV
UT
-115°
-114°40'
-114°20'
-114°
-113°40'
-113°20'
45°20'
45°
44°40'
44°20'
44°
43°40'
93
28
29
Leadore
Challis
21
Clayton
Stanley
75
93
Mackay
Moore
Sun Valley
Ketchum
20
Stopovers
0 15 30 mi.
0 10 20 mi

Idaho | Mule Deer

Morgan Creek Mule Deer Migration Routes

Morgan Creek's mule deer inhabit the foothills north of Challis in winter. After the snow melts, a handful of mule deer migrate to the east (Pahsimeroi Valley), while the majority migrate to the west. The western migration fans out across rural and wilderness areas, whereas the eastern migration mainly follows the Pahsimeroi Mountains. On average, Morgan Creek mule deer migrate 25 miles between summer and winter ranges, with more extensive migrations occurring to the west that reach over 85 miles. The Morgan Creek population of wintering mule deer is approximately 2,650.

Animal Capture and Data Collection

Sample size: 39 adult female mule deer

Mean relocation frequency: ~17 hours

Project duration: May 13, 2012 – December 31, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 114 sequences from 39 individuals (66 spring sequences, 48 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 30 to May 16
- **Fall:** October 29 to December 23

Days migrating (mean):

- **Spring:** 16 days
- **Fall:** 55 days

Migration length:

- **Min**: 5.5 miles
- **Mean**: 25.4 miles
- **Max**: 87.1 miles

Migration area:

- 208,658 acres (low use)
- 61,523 acres (medium use)
- 16,898 acres (high use)

Stopover area: 34,660 acres

Other Information

Project contacts:

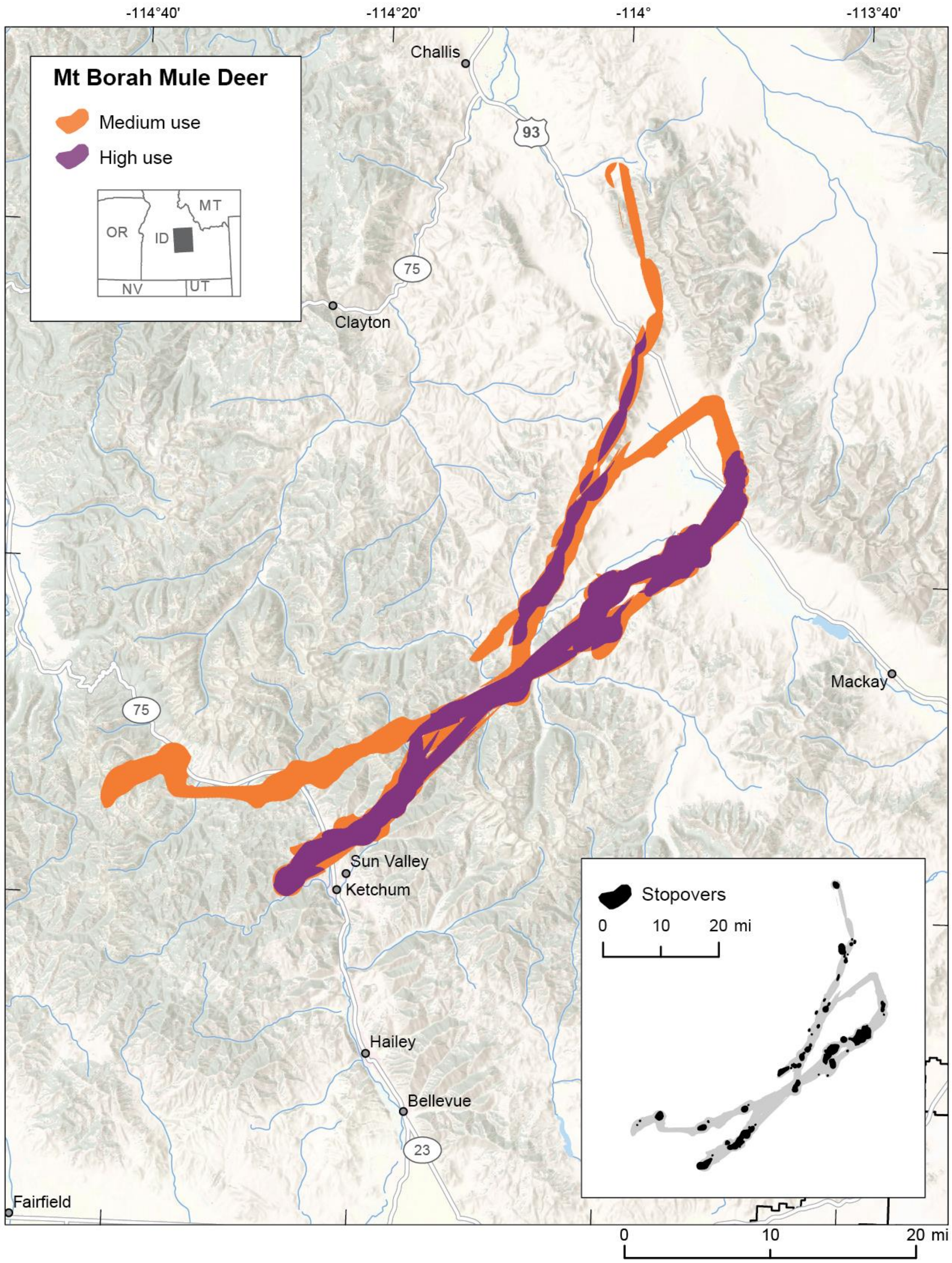
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Dennis Newman (dennis.newman@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game
- Jessie Shallow (jessie.shallow@idfg.idaho.gov), Regional Wildlife Biologist, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



Mt Borah Mule Deer
Medium use
High use
OR
ID
MT
NV
UT
-114°40'
-114°20'
-114°
-113°40'
44°20'
44°
43°40'
Challis
93
75
Clayton
75
Mackay
Sun Valley
Ketchum
Hailey
Bellevue
23
Fairfield
Stopovers
0
10
20 mi
0
10
20 mi

Idaho | Mule Deer

Mt. Borah Mule Deer Migration Routes

The Mt. Borah mule deer winter on the western flats at the base of the Lost River Range between the Vance Canyon area in the south and Lime Creek in the north. Winter habitat, which is shared by elk, pronghorn, and bighorn sheep, is limited by steep, rocky slopes and deep snow. As snow subsides in the spring, mule deer migrate to the west and converge past Thousand Springs Valley and Trail Creek Summit, reaching their summer range north of Ketchum in the Smoky Mountains. On average, these mule deer migrate nearly 50 miles, and some migrate as far as 73 miles. Continued improvements to Trail Creek Road and associated infrastructure development could result in deer mortalities due to increased traffic as the migration route follows the roadway quite closely. In addition, human development, particularly in Game Management Unit (GMU) 49, could prove detrimental for migrating and summering mule deer. The Mt. Borah population consists of roughly 400 – 500 individuals (based on aerial surveys in 2010).

Animal Capture and Data Collection

Sample size: 12 adult female mule deer

Mean relocation frequency: ~16 hours

Project duration: April 2017 – December 2018

Data Analysis

Migration and stopover analysis: Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 27 sequences from 12 individuals (18 spring sequences, 9 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 17 to May 27
- **Fall:** November 22 to December 23

Days migrating (mean):

- **Spring:** 39 days
- **Fall:** 31 days

Migration length:

- **Min**: 27.8 miles
- **Mean**: 48.9 miles
- **Max**: 73.4 miles

Migration area:

- 197,921 acres (medium use)
- 67,087 acres (high use)

Stopover area: 21,745 acres

Other Information

Project contacts:

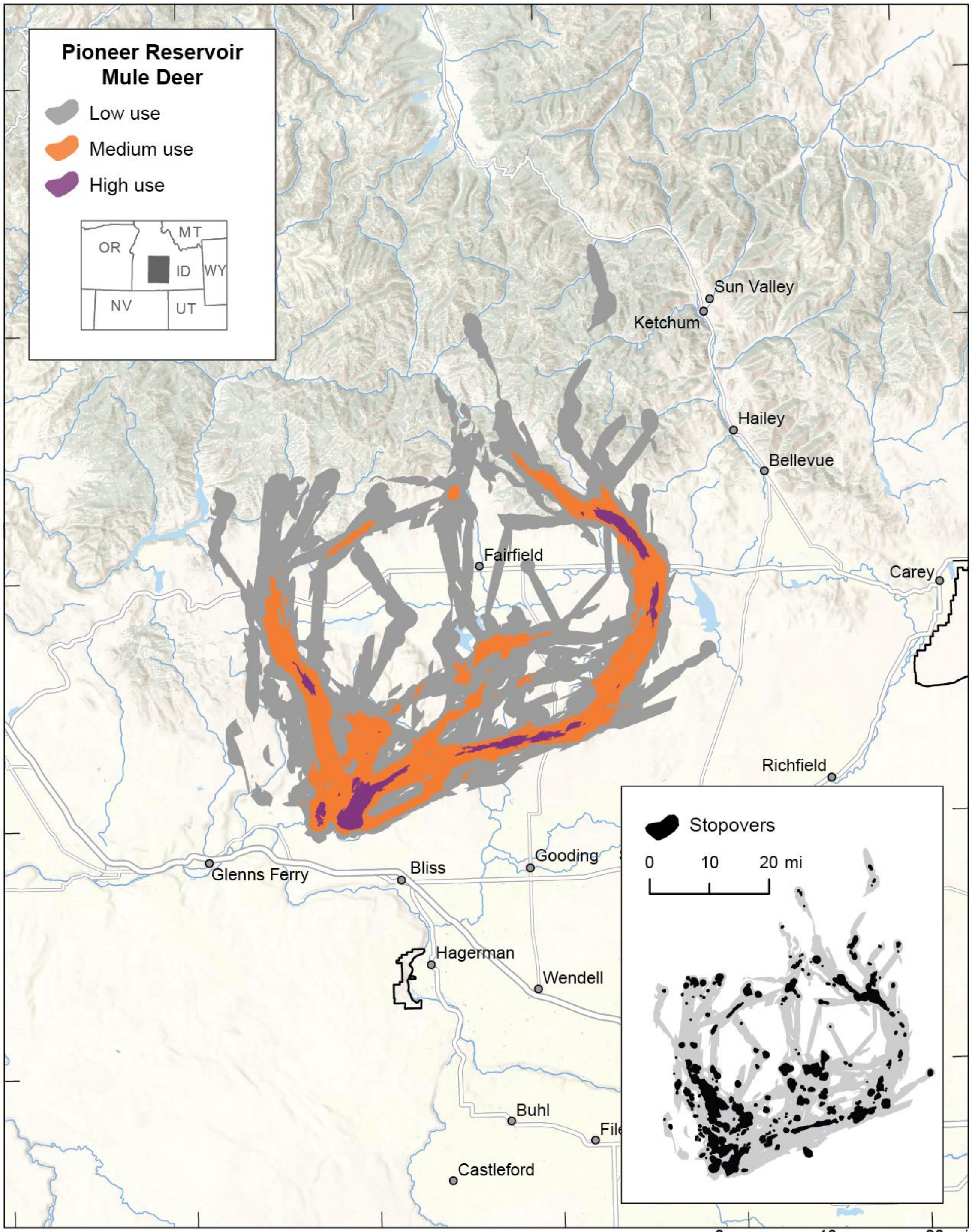
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Curtis Hendricks (curtis.hendricks@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game
- Mike McDonald (mike.mcdonald@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.


Pioneer Reservoir Mule Deer
Low use
Medium use
High use
OR
MT
ID
WY
NV
UT
-115°20'
-115°
-114°40'
-114°20'
-114°
44°
43°40'
43°20'
43°
42°40'
Sun Valley
Ketchum
Hailey
Bellevue
Fairfield
Carey
Richfield
Glenns Ferry
Bliss
Gooding
Hagerman
Wendell
Buhl
Castleford
Stopovers
0
10
20 mi
0
10
20 mi

Idaho | Mule Deer

Pioneer Reservoir Mule Deer Migration Routes

Pioneer Reservoir mule deer winter east of Mountain Home, in vicinity of the junction between Clover Creek and the Snake River. They migrate north-northeast past Anderson Ranch, Mormon, and Magic Reservoirs to summer west of Hailey and Ketchum. On average, these mule deer migrate over 46 miles between summer and winter ranges. The population of wintering mule deer in the greater Smoky-Bennett Population Management Unit (including the Bennett-Teapot Dome population) was estimated at 16,358 in 2018.

Animal Capture and Data Collection

Sample size: 66 adult female mule deer
Mean relocation frequency: ~17 hours
Project duration: April 8, 2012 – December 15, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 153 sequences from 66 individuals (93 spring sequences, 60 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 4 to May 3
- **Fall:** October 10 to October 27

Days migrating (mean):

- **Spring:** 26 days
- **Fall:** 24 days

Migration length:

- **Min**: 13.9 miles
- **Mean**: 46.7 miles
- **Max**: 125.3 miles

Migration area:

- 696,451 acres (low use)
- 160,361 acres (medium use)
- 17,447 acres (high use)

Stopover area: 84,410 acres

Other Information

Project contacts:

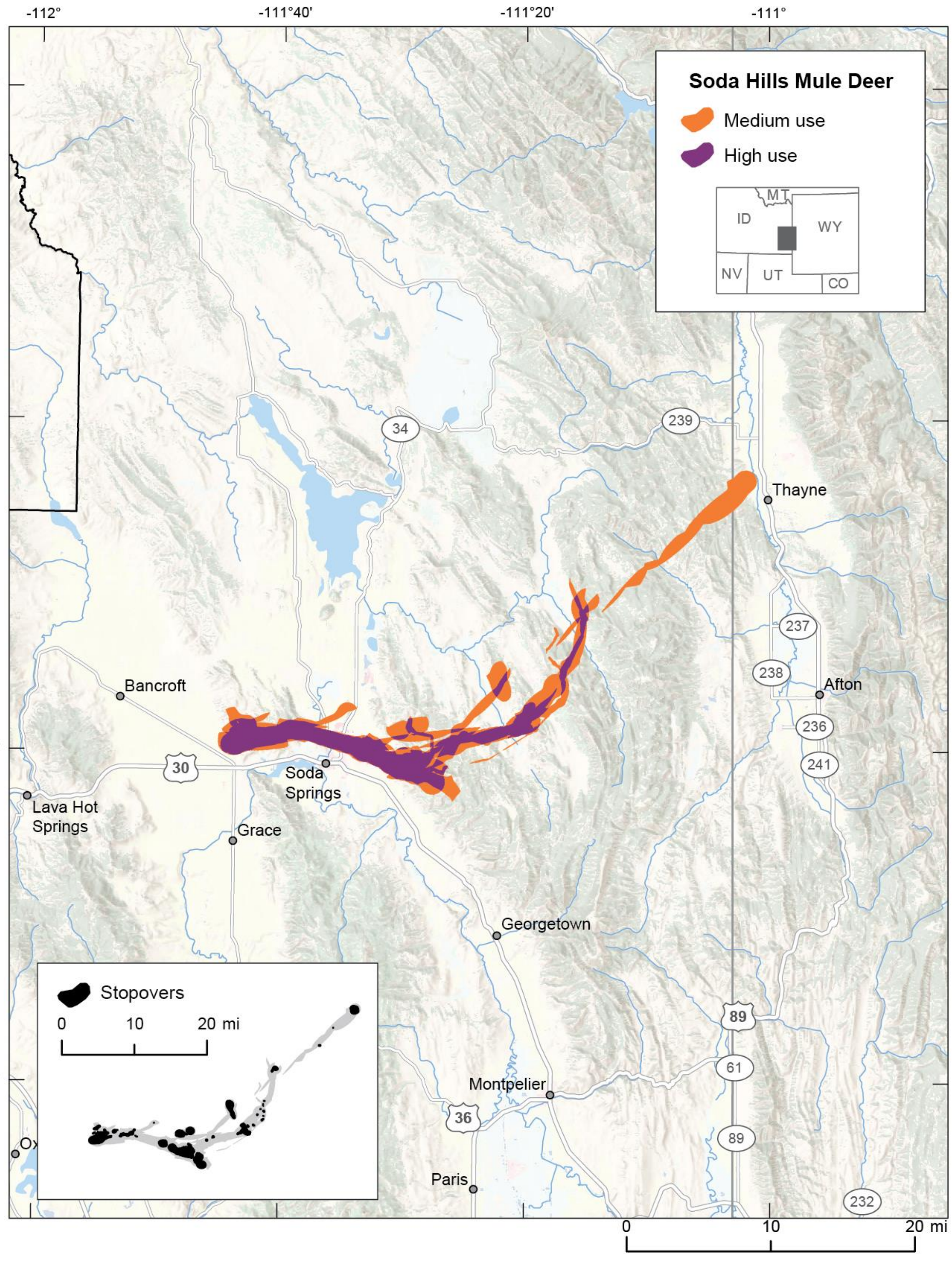
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Mike McDonald (mike.mcdonald@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



Soda Hills Mule Deer
Medium use
High use
ID
MT
WY
NV
UT
CO
Stopovers
0
10
20 mi
-112°
-111°40'
-111°20'
-111°
43°20'
43°
42°40'
42°20'
Thayne
Afton
Bancroft
Soda Springs
Lava Hot Springs
Grace
Georgetown
Montpelier
Paris
34
239
237
238
236
241
30
89
61
36
232

Idaho | Mule Deer

Soda Hills Mule Deer Migration Routes

Soda Hills mule deer winter near the town of Soda Springs in vicinity of Alexander Reservoir. These mule deer migrate northeast to summer ranges, typically located in the Blackfoot Mountains or the Caribou Range along the Idaho-Wyoming border. On average, Soda Hills mule deer migrate 32 miles between summer and winter ranges. The Soda Hills wintering population numbers 3,500 – 5,000 animals.

Animal Capture and Data Collection

Sample size: 15 adult female mule deer
Relocation frequency: ~30 hours
Project duration: April 24, 2013 – December 4, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 23 sequences from 15 individuals (15 spring sequences, 8 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 27 to May 15
- **Fall:** October 15 to October 30

Days migrating (mean):

- **Spring:** 25 days
- **Fall:** 32 days

Migration length:

- **Min**: 13.3 miles
- **Mean**: 32.1 miles
- **Max**: 47.3 miles

Migration area:

- 75,030 acres (medium use)
- 24,130 acres (high use)

Stopover area: 12,235 acres

Other Information

Project contacts:

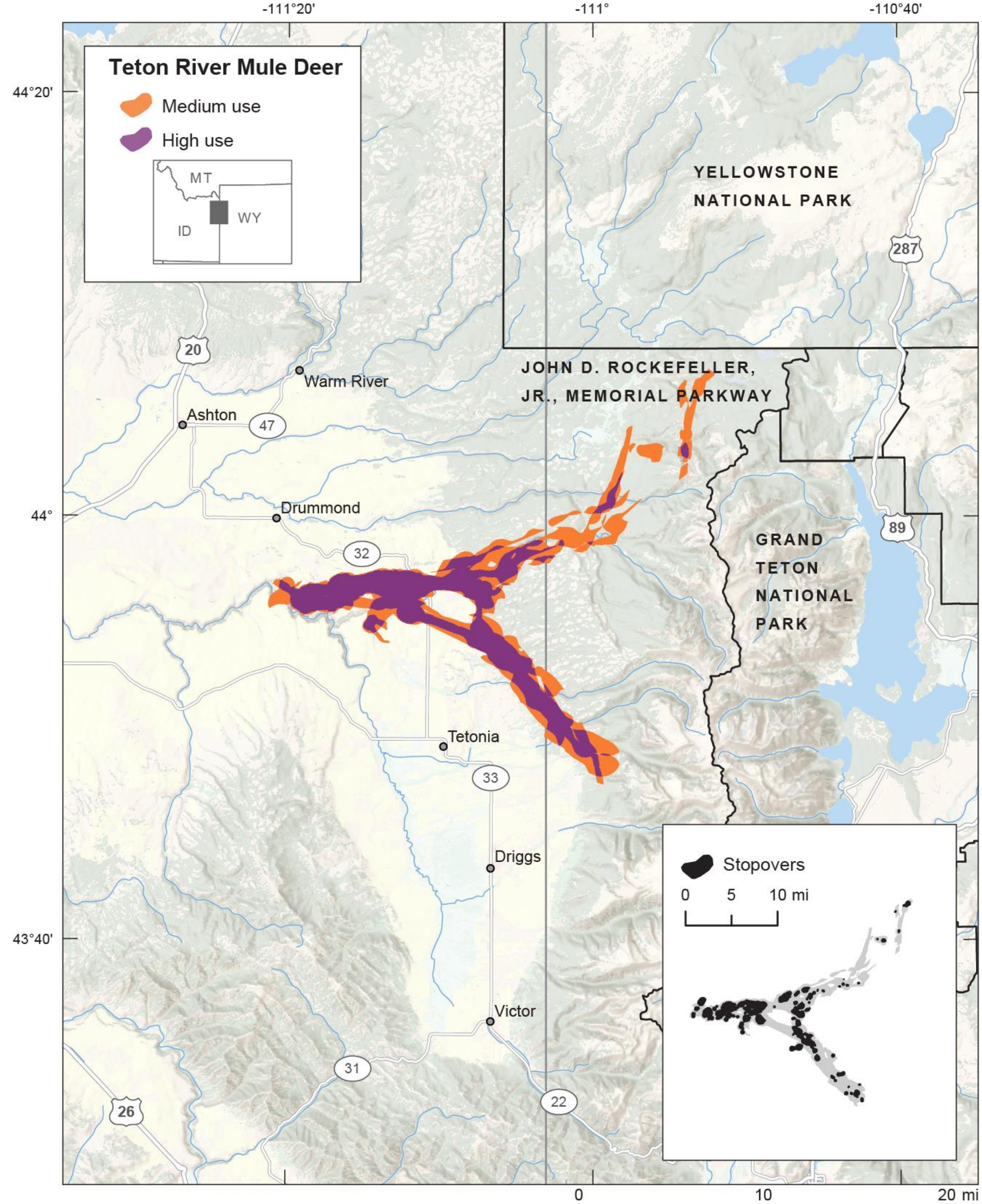
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Zach Lockyer (zach.lockyer@idfh.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.


Teton River Mule Deer
Medium use
High use
MT
WY
ID
-111°20'
-111°
-110°40'
44°20'
44°
43°40'
YELLOWSTONE
NATIONAL PARK
JOHN D. ROCKEFELLER,
JR., MEMORIAL PARKWAY
GRAND
TETON
NATIONAL
PARK
Warm River
Ashton
Drummond
Tetonia
Driggs
Victor
20
47
32
33
31
26
22
287
89
Stopovers
0 5 10 mi
0 10 20 mi

Idaho | Mule Deer

Teton River Mule Deer Migration Routes

Teton River mule deer winter adjacent to the Teton River in eastern Idaho. Due to limited quality and quantity of winter habitat, the 1,000 – 2,500 individuals within this population are greatly influenced by winter severity. They experience dramatic swings in productivity and mortality, especially of fawns. Teton River mule deer migrate eastward across the Idaho-Wyoming border to two areas west of the Teton Range: the northern summer range southwest of Pitchstone Plateau and the southern summer range in the western foothills of the Teton Range. On average, Teton River mule deer migrate 25 miles between summer and winter ranges, with the longest migration spanning over 70 miles. Challenges to Teton River deer migration include human activity related to residential subdivision development and recreation in Teton Canyon.

Animal Capture and Data Collection

Sample size: 15 adult female mule deer
Mean relocation frequency: ~3 hours
Project duration: April 2018 – December 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 30 sequences from 15 individuals (15 spring sequences, 15 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** May 4 to May 16
- **Fall:** November 7 to November 13

Days migrating (mean):

- **Spring:** 19 days
- **Fall:** 14 days

Migration length:

- **Min**: 8.2 miles
- **Mean**: 25.4 miles
- **Max**: 70.1 miles

Migration area:

- 66,395 acres (medium use)
- 23,608 acres (high use)

Stopover area: 10,544 acres

Other Information

Project contacts:

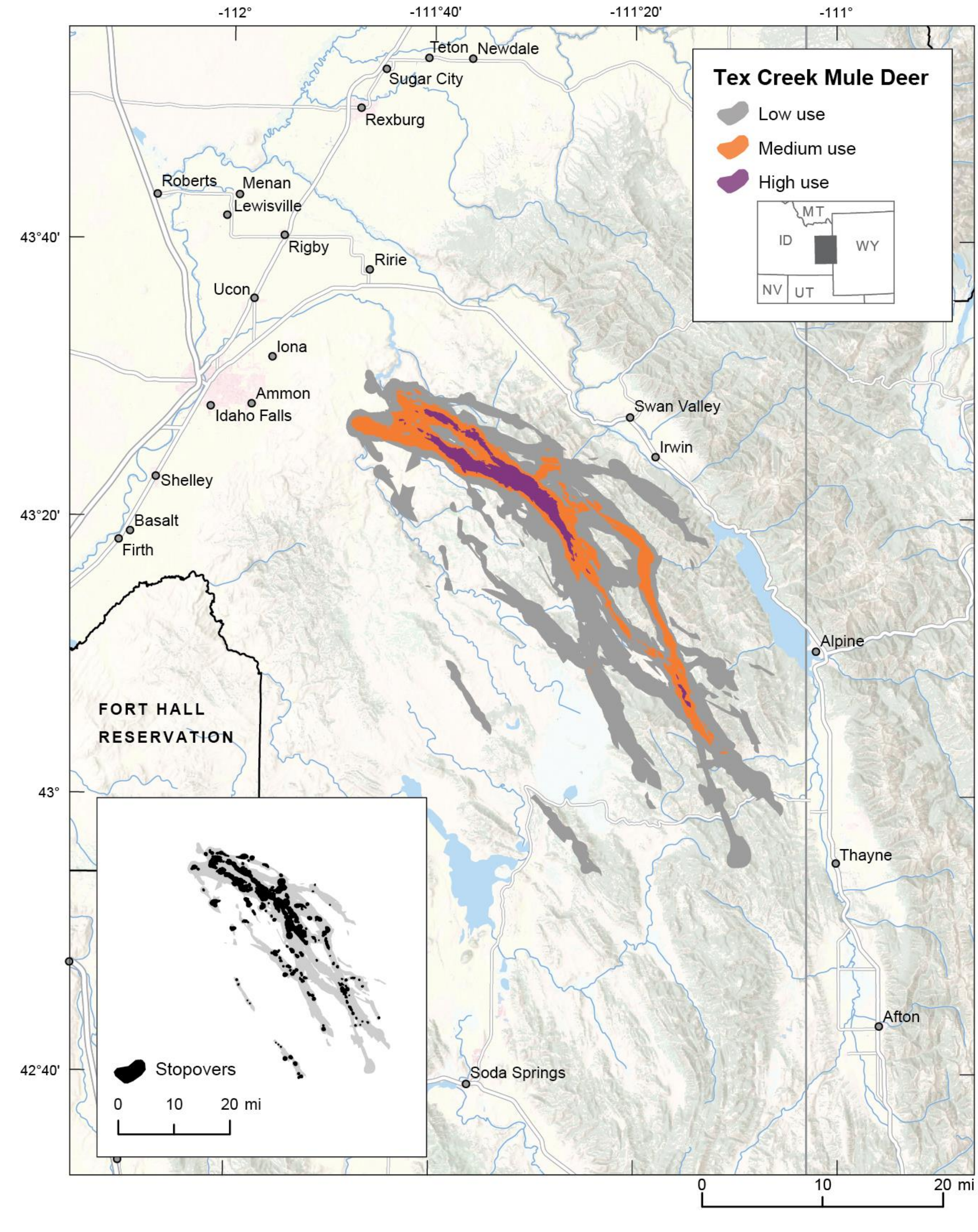
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Curtis Hendricks (curtis.hendricks@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game
- Sarah Dewey (sarah_dewey@nps.gov), Wildlife Biologist, Grand Teton National Park

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



Tex Creek Mule Deer
Low use
Medium use
High use
MT
ID
WY
NV
UT
-112°
-111°40'
-111°20'
-111°
43°40'
43°20'
43°
42°40'
Teton
Newdale
Sugar City
Rexburg
Roberts
Menan
Lewisville
Rigby
Ririe
Ucon
Iona
Ammon
Idaho Falls
Swan Valley
Irwin
Shelley
Basalt
Firth
Alpine
FORT HALL
RESERVATION
Thayne
Afton
Soda Springs
Stopovers
0
10
20 mi
0
10
20 mi

Idaho | Mule Deer

Tex Creek Mule Deer Migration Routes

Tex Creek mule deer winter in the valleys surrounding the Ririe Reservoir (Tex Creek, Willow Creek, Grays Lake Outlet, Meadow Creek). This habitat is varied, consisting of steep, rocky canyon walls, small drainages, and open flats. They migrate across the Caribou Range to summer ranges spread across Game Management Units (GMUs) 66 and 66A, with some deer extending southward into GMU 76. On average, Tex Creek mule deer migrate 35 miles, with the longest migration recorded at 65 miles. The wintering herd historically numbered approximately 4,500 individuals, but the Henry's Creek fire in 2016 burned 52,000 acres. - areas used by 80% of the wintering deer. The fire was followed by heavy snow accumulations in winter. The combination dramatically altered the 2016 winter range and impacted subsequent deer densities. The 2019 population estimate indicated a 40% population decline in the northern portion of Caribou Data Analysis Unit (DAU) and a 75% decline within the fire footprint. The impacts of the fire, along with human recreation (particularly motorized vehicles), changing land management, and human development, continues to challenge this mule deer herd.

Animal Capture and Data Collection

Sample size: 63 adult female mule deer
Mean relocation frequency: ~13 hours
Project duration: March 16, 2007 – December 23, 2018

Data Analysis

Migration and stopover analysis: Brownian bridge (Sawyer et al. 2009) and Forced Motion Variance movement models (see further description of methods in appendix)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 108 sequences from 63 individuals (76 spring sequences, 32 fall sequences)

Migration and Stopover Summary

Migration start and end date (median):

- **Spring:** April 18 to May 9
- **Fall:** November 3 to December 20

Days migrating (mean):

- **Spring:** 20 days
- **Fall:** 41 days

Migration length:

- **Min**: 2.3 miles
- **Mean**: 35.2 miles
- **Max**: 64.9 miles

Migration area:

- 281,636 acres (low use)
- 66,399 acres (medium use)
- 12,781 acres (high use)

Stopover area: 39,970 acres

Other Information

Project contacts:

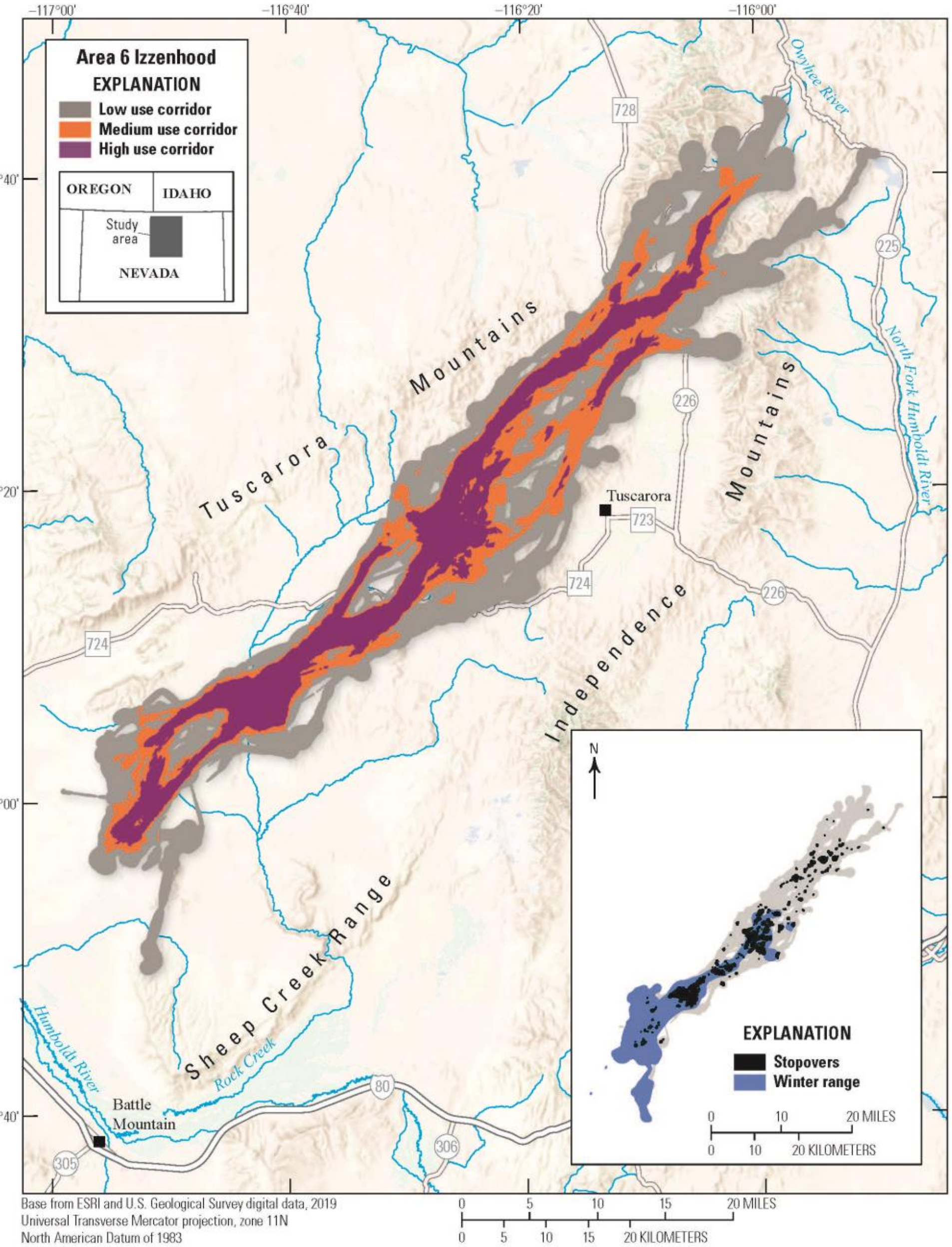
- Mark Hurley (mark.hurley@idfg.idaho.gov), Wildlife Research Supervisor, Idaho Department of Fish and Game
- Curtis Hendricks (curtis.hendricks@idfg.idaho.gov), Regional Wildlife Manager, Idaho Department of Fish and Game

Data analyst:

- Jodi Berg, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming
- Scott Bergen, Sr. Research Biologist, Idaho Department of Fish and Game

Reports and publications:

- Ellstrom et al. 2019. Mule deer surveys and inventories statewide report 2018 seasons. D. R. Meints, editor. Idaho Department of Fish and Game, Boise, ID, USA.
- Hurley, M. and S. Roberts. 2019. F16AF00908 statewide wildlife research final performance report. Idaho Department of Fish and Game, Boise, ID, USA.



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Nevada | Mule Deer

Izzenhood Mule Deer Migration Corridors

Mule deer in the Izzenhood population are part of the larger Area 6 mule deer herd. They primarily reside on winter ranges in the Izzenhood Basin and upper Rock Creek drainages in western Elko County and northern Lander County. From their winter range, mule deer in this population migrate approximately 70 miles to summer ranges in the northern Independence Mountains and Bull Run Basin. Some of the most important stopover areas are located near upper Rock Creek, Toe Jam Mountain, and Chicken Creek Summit. Challenges faced by this population include historic wildfires on winter range, conversion of native shrub habitats to exotic annual grasses, and lower forage production in some stopover sites.

Animal Capture and Data Collection

Sample size: 35 adult female mule deer

Relocation frequency: 1 – 25 hours

Project duration: 2015 – 2019

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 87 sequences from 35 individuals
- **Winter:** 69 sequences from 35 individuals

Corridor and Stopover Summary

Migration start and end date (median):

Spring: March 17 to April 23

Fall: November 12 to December 10

Average number of days migrating:

- **Spring:** 36 days
- **Fall:** 41 days

Migration corridor length:

- **Min**: 25 miles
- **Mean**: 59 miles
- **Max**: 83 miles

Migration corridor area:

- 371,564 acres (low use)
- 168,282 acres (medium use)
- 91,584 acres (high use)

Stopover area: 38,391 acres

Winter Range Summary

Winter start and end date (median):

- December 15 to March 1

Winter length (mean): 75 days

Winter range (30% contour) area: 109,088 acres

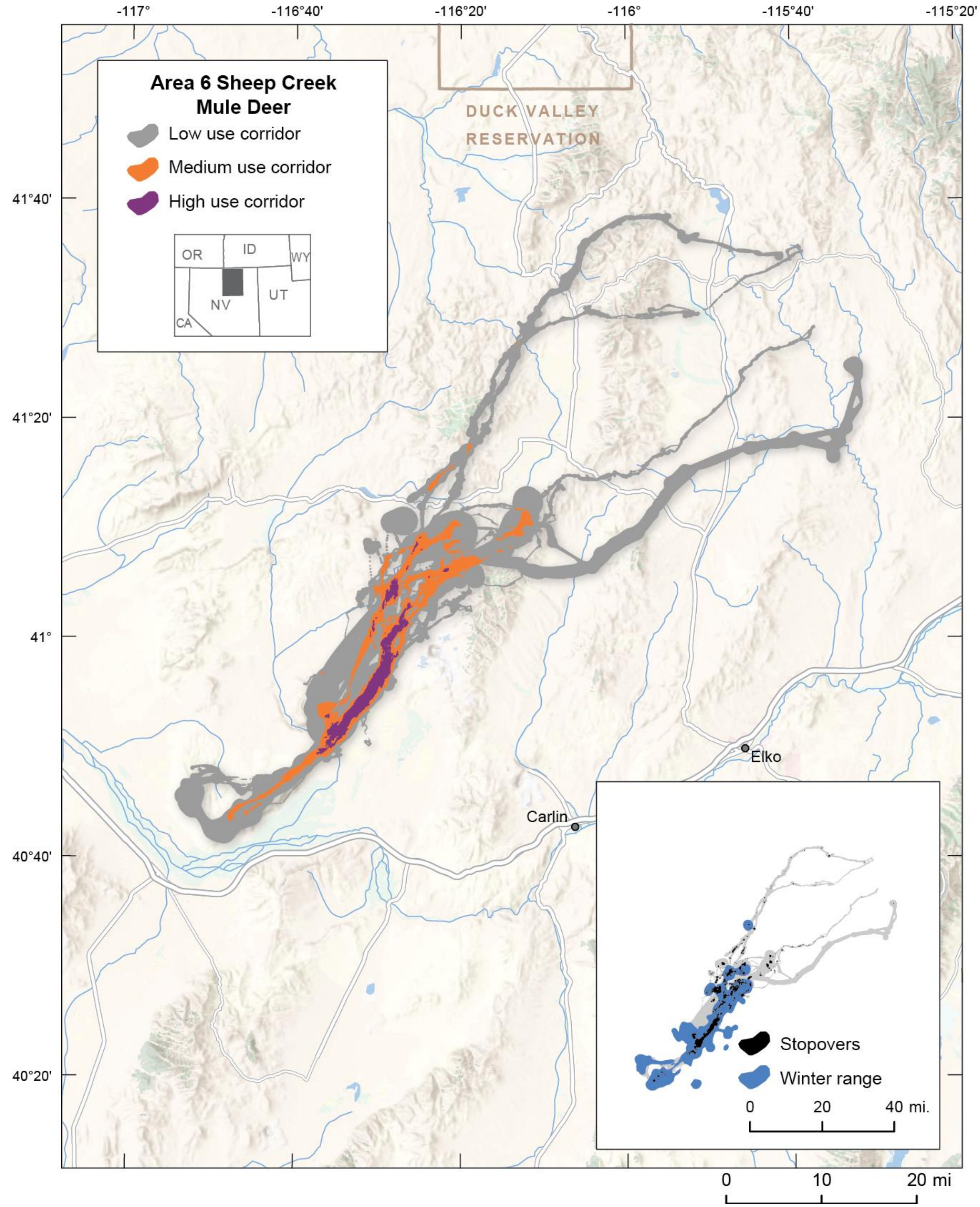
Other Information

Project contacts:

- Cody Schroeder (cschroeder@ndow.org), Wildlife Staff Specialist, Nevada Department of Wildlife

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.



Area 6 Sheep Creek
Mule Deer
Low use corridor
Medium use corridor
High use corridor
OR
ID
WY
NV
UT
CA
DUCK VALLEY
RESERVATION
Elko
Carlin
Stopovers
Winter range
0
20
40 mi.
-117°
-116°40'
-116°20'
-116°
-115°40'
-115°20'
41°40'
41°20'
41°
40°40'
40°20'
0
10
20 mi

Nevada | Mule Deer

Sheep Creek Mule Deer Migration Corridors

Mule deer in the Sheep Creek population are part of the larger Area 6 herd that occupies portions of Elko, Lander, and Eureka counties. The primary winter range of this population is located along the eastern flank of the Sheep Creek Range and the west side of Boulder Valley. Most deer migrate approximately 30 miles from winter ranges in upper Boulder Creek and Antelope Creek drainages to summer ranges on the west side of the Tuscarora Mountains. However, some deer in this population migrate much farther – approximately 80 miles – and connect with mule deer that summer east of the Humboldt River. This deer herd faces several challenges, including migration routes that pass through increased mineral extraction activities in the Carlin Mine area, invasion of exotic annual grasses on winter range, increased wildfires on winter range, and deteriorated range conditions on many stopover sites and winter range due to overgrazing by livestock.

Animal Capture and Data Collection

Sample size: 36 adult female mule deer
Relocation frequency: 1 – 25 hours
Project duration: 2012 – 2019

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 68 sequences from 36 individuals
- **Winter:** 58 sequences from 34 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** March 22 to April 9
- **Fall:** December 7 to December 18

Average number of days migrating:

- **Spring:** 16 days
- **Fall:** 11 days

Migration corridor length:

- **Min**: 13 miles
- **Mean**: 37 miles
- **Max**: 98 miles

Migration corridor area:

- 284,400 acres (low use)
- 54,123 acres (medium use)
- 13,352 acres (high use)

Stopover area: 29,430 acres

Winter Range Summary

Winter start and end date (median):

- December 15 to March 1

Winter length (mean): 75 days
Winter range (30% contour) area: 108,973 acres

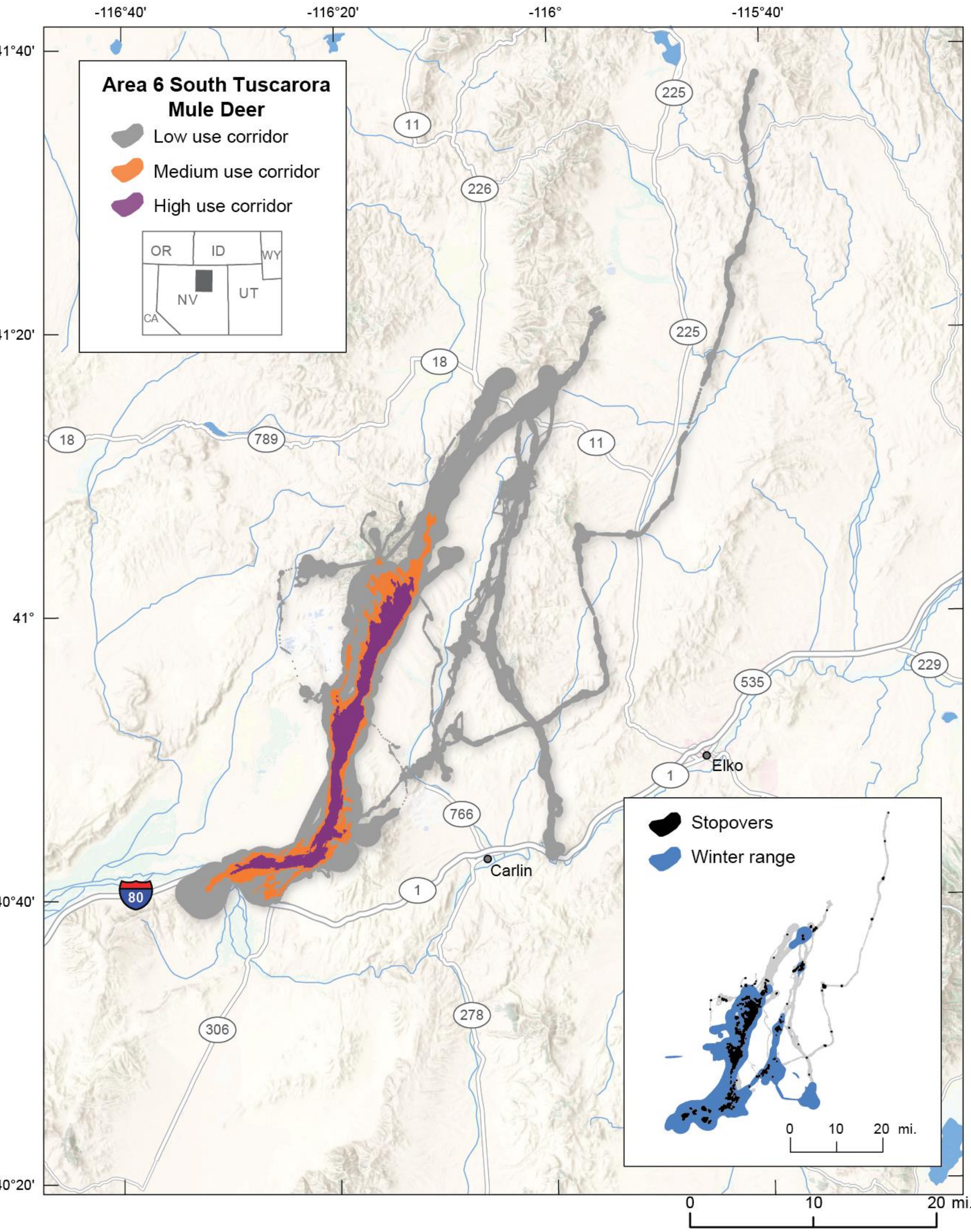
Other Information

Project contacts:

- Cody Schroeder (cschroeder@ndow.org), Wildlife Staff Specialist, Nevada Department of Wildlife

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.



Area 6 South Tuscarora Mule Deer
Low use corridor
Medium use corridor
High use corridor
OR
ID
WY
NV
UT
CA
-116°40'
-116°20'
-116°
-115°40'
41°40'
41°20'
41°
40°40'
40°20'
225
11
226
18
789
11
535
229
1
Elko
766
Carlin
80
306
278
Stopovers
Winter range
0
10
20 mi.

Nevada | Mule Deer

South Tuscarora Mule Deer Migration Corridors

Mule deer in the South Tuscarora population reside in the most southern and eastern portion of the larger Management Area 6. The winter range for this population is located along the western slopes of the Tuscarora Mountains and the Dunphy Hills. The spring migration route for this deer herd traverses north along the toe slopes of the Tuscarora Mountains on the east side and narrows to approximately 600 meters at one pinch point near the Carlin-Pete Mine area. The migration route generally spans 30 miles to the northeast, with summer ranges at higher elevations in the northern Tuscarora Mountains. Important stopover areas include Richmond Mountain, Jack and Little Jack Creeks, and Coyote Creek on the east side of the Tuscarora Mountains. Challenges to this deer herd include constrictions in the migration corridor from large-scale gold mining operations and multiple wildfires on winter ranges in the Dunphy Hills. Interstate traffic also poses a challenge to some deer that continue to migrate south and experience a high rate of mortality and a complex network of fences along the Interstate 80 corridor.

Animal Capture and Data Collection

Sample size: 35 adult female mule deer
Relocation frequency: 1 – 25 hours
Project duration: 2012 – 2019

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)
Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 63 sequences from 31 individuals
- **Winter:** 60 sequences from 35 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** March 14 to April 3
- **Fall:** December 15 to December 25

Average number of days migrating:

- **Spring:** 18 days
- **Fall:** 10 days

Migration corridor length:

- **Min**: 9 miles
- **Mean**: 34 miles
- **Max**: 70 miles

Migration corridor area:

- 201,624 acres (low use)
- 44,404 acres (medium use)
- 22,153 acres (high use)

Stopover area: 20,685 acres

Winter Range Summary

Winter start and end date (median):

- December 15 to March 1

Winter length (mean): 75 days
Winter range (30% contour) area: 124,992 acres

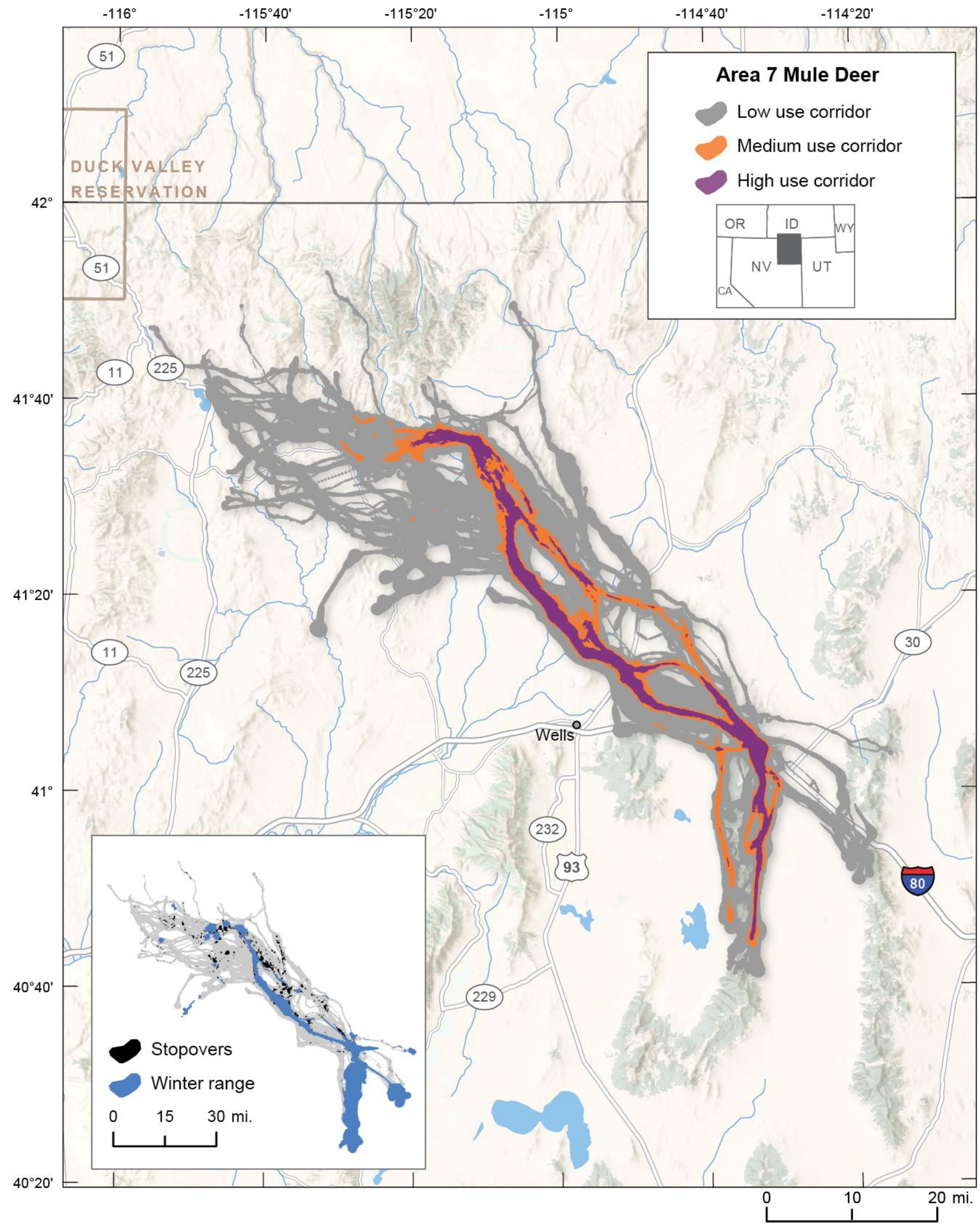
Other Information

Project contacts:

- Cody Schroeder (cschroeder@ndow.org), Wildlife Staff Specialist, Nevada Department of Wildlife

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.



-116°
-115°40'
-115°20'
-115°
-114°40'
-114°20'
Area 7 Mule Deer
Low use corridor
Medium use corridor
High use corridor
OR
ID
WY
NV
UT
CA
DUCK VALLEY
RESERVATION
42°
41°40'
41°20'
41°
40°40'
40°20'
51
11
225
30
Wells
232
93
80
229
Stopovers
Winter range
0 15 30 mi.
0 10 20 mi.

Nevada | Mule Deer

Pequop Mule Deer Migration Corridors

The Area 7 Pequop mule deer population is one of Nevada's largest deer herds with an estimated population size of 11,000 in 2019. This deer herd is highly important from an economic and ecological perspective. These deer make one of the longest known deer migrations in the state, with some animals travelling over 120 miles one way. Winter range for this deer herd occurs primarily along the east side of the Pequop Mountains from Sixmile Creek to Ninemile Canyon. The largest stopovers occur along the west side of the Snake Mountains near Tabor Creek, Antelope Peak, and Bishop Creek, north and south of Interstate 80 near Pequop Summit, and in the Pequop Mountains between Sixmile Creek and Long Canyon. This herd primarily summers between the Owyhee and Bruneau Rivers east of Wildhorse Reservoir. A subset of this population, known as the "Pequop" herd, crosses both US Highway 93 and Interstate 80 twice annually during their seasonal migrations. Several million dollars in wildlife crossing structures have been constructed to help these deer during their migration, yet they still face challenges to connectivity between winter and summer ranges, including miles of livestock fencing and a large-scale gold mine operation in close proximity a large stopover site near Long Canyon.

Animal Capture and Data Collection

Sample size: 86 adult female mule deer
Relocation frequency: 1 – 25 hours
Project duration: 2011 – 2017

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 218 sequences from 79 individuals
- **Winter:** 193 sequences from 86 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** March 15 to April 5
- **Fall:** October 7 to October 31

Average number of days migrating:

- **Spring:** 21 days
- **Fall:** 23 days

Migration corridor length:

- **Min**: 37 miles
- **Mean**: 77 miles
- **Max**: 120 miles

Migration corridor area:

- 714,671 acres (low use)
- 154,578 acres (medium use)
- 71,355 acres (high use)

Stopover area: 73,232 acres

Winter Range Summary

Winter start and end date (median):

- December 15 to March 1

Winter length (mean): 75 days
Winter range (30% contour) area: 181,671 acres

Other Information

Project contacts:

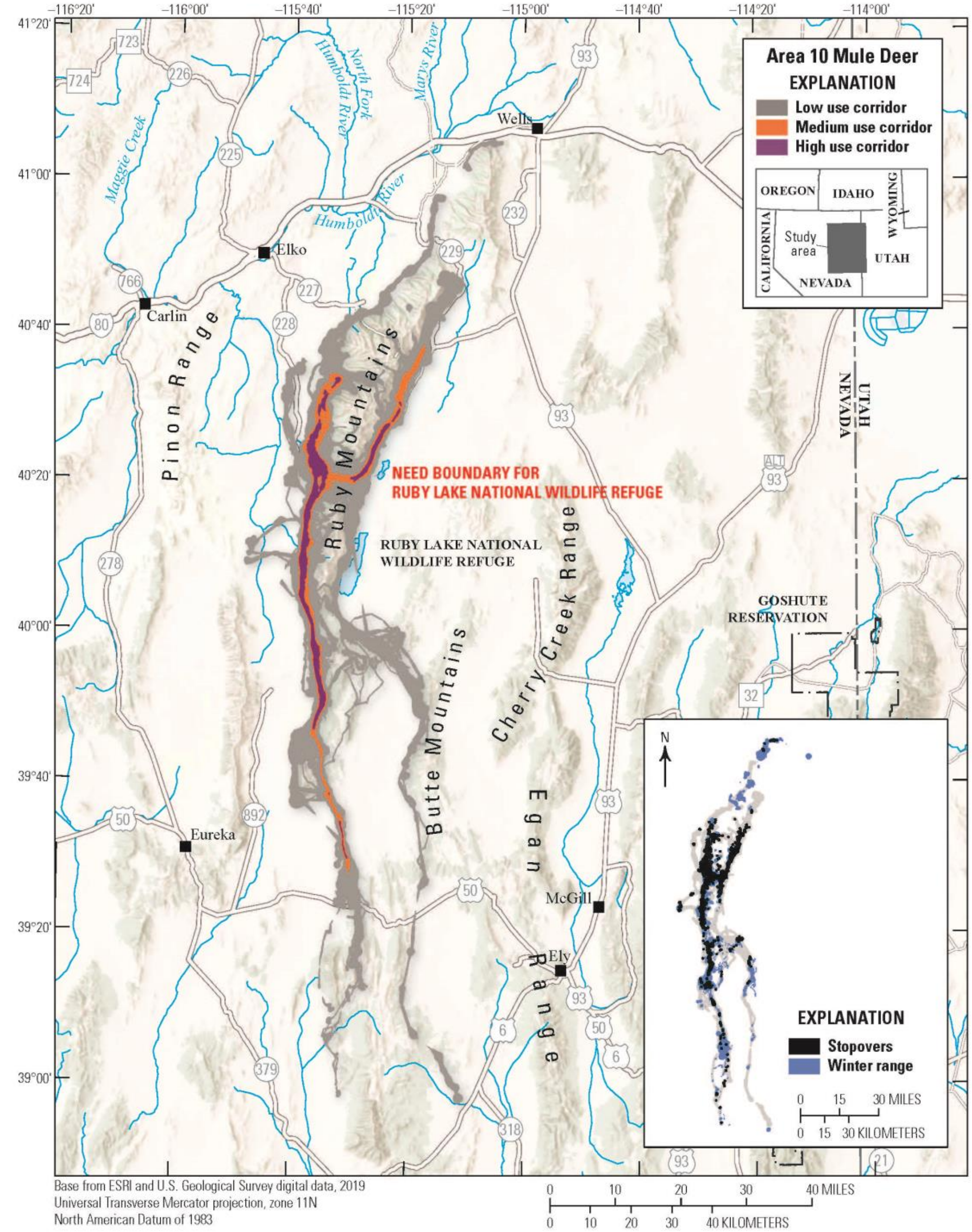
- Cody Schroeder (cschroeder@ndow.org), Wildlife Staff Specialist, Nevada Division of Wildlife

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Shoemaker, K. T., Heffelfinger, L. J., Jackson, N. J., Blum, M. E., Wasley, T., & Stewart, K. M. (2018). A machine-learning approach for extending classical wildlife resource selection analyses. *Ecology and evolution*, *8*(6), 3556-3569.
- Simpson, N.O., Stewart, K.M., Schroeder, C., Cox, M., Huebner, K., & Wasley, T. (2016) Overpasses and underpasses: effectiveness of crossing structures for migratory ungulates. Journal of Wildlife Management 80:1370-1378.



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Nevada | Mule Deer

Ruby Mountains Mule Deer Migration Corridors

The Ruby Mountains (Area 10) mule deer population is one of the state's largest deer herds, accounting for nearly 20% of mule deer in Nevada. This herd is comprised of several subpopulations that occupy the Ruby Mountains and tend to migrate long distances, 40 to 100 miles, between summer and winter ranges. Several key stopover areas occur within this herd's migration corridor. The largest stopover areas are located along the Harrison Pass Road on both sides of Toyn Creek, the west side of Pearl Peak and Sherman Mountain, Little and Big Bald Mountains near the Bald Mountain Mine complex, and Bourne to Orchard Canyons west of Warm Spring Ranch. The expansive winter range spans approximately 120 miles along the lower elevations of the Ruby Mountains from Interstate 80 south to US Highway 50. Some migrations extend even farther south in extreme winters, while some animals may continue migrating another 30-40 miles to lower elevations in the White Pine Range. Several migration routes in this herd face challenges to permeability, including livestock fences, impediments to the migration path from mineral extraction, competition from wild horses, and increased highway traffic.

Animal Capture and Data Collection

Sample size: 155 adult female mule deer
Relocation frequency: 1 – 25 hours
Project duration: 2011-2017

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 290 sequences from 117 individuals
- **Winter:** 333 sequences from 155 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** March 21 to April 18
- **Fall:** November 17 to December 5

Average number of days migrating:

- **Spring:** 23 days
- **Fall:** 24 days

Migration corridor length:

- **Min**: 8 miles
- **Mean**: 45 miles
- **Max**: 134 miles

Migration corridor area:

- 474,989 acres (low use)
- 76,883 acres (medium use)
- 32,806 acres (high use)

Stopover area: 50,998 acres

Winter Range Summary

Winter start and end date (median):

- December 15 to March 1

Winter length (mean): 75 days
Winter range (30% contour) area: 288,323 acres

Other Information

Project contacts:

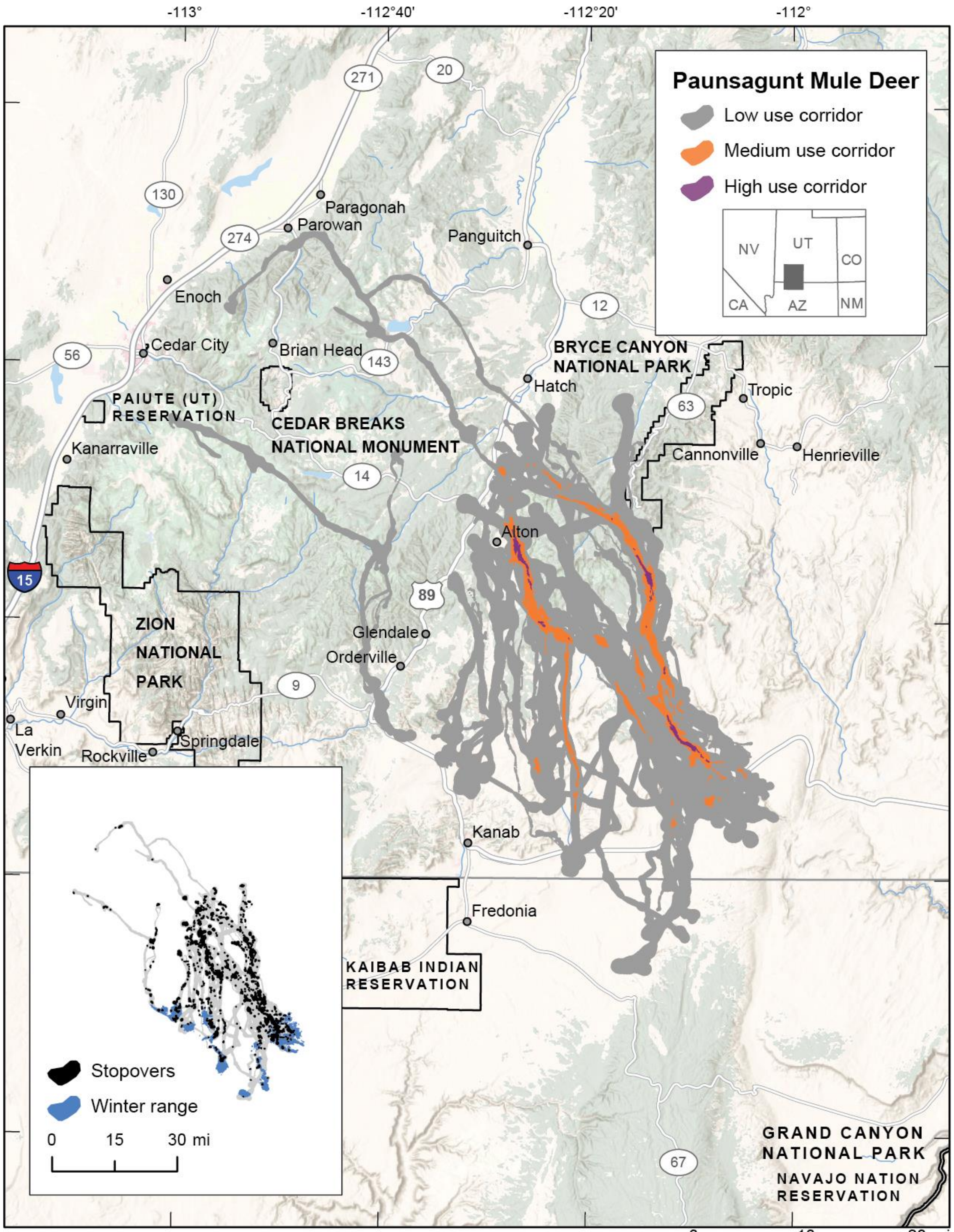
- Cody Schroeder (cschroeder@ndow.org), Wildlife Staff Specialist, Nevada Division of Wildlife

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Blum, M. E., Stewart, K. M., & Schroeder, C. (2015). Effects of large-scale gold mining on migratory behavior of a large herbivore. *Ecosphere*, *6*(5), 1-18.
- Sawyer, H., & Brittell, M. (2014). Mule Deer Migration and Bald Mountain Mine-a Summary of Baseline Data. Western Ecosystems Technology, Laramie, WY.
- Wolff, P. L., Schroeder, C., McAdoo, C., Cox, M., Nelson, D. D., Evermann, J. F., & Ridpath, J. F. (2016). Evidence of bovine viral diarrhea virus infection in three species of sympatric wild ungulates in Nevada: life history strategies may maintain endemic infections in wild populations. *Frontiers in microbiology*, *7*, 292.


Paunsagunt Mule Deer
Low use corridor
Medium use corridor
High use corridor
NV
UT
CO
CA
AZ
NM
-113°
-112°40'
-112°20'
-112°
38°
37°40'
37°20'
37°
36°40'
Paragonah
Parowan
Panguitch
Enoch
Cedar City
Brian Head
Hatch
Tropic
Cannonville
Henrieville
Kanarraville
Alton
Glendale
Orderville
Virgin
La Verkin
Springdale
Rockville
Kanab
Fredonia
BRYCE CANYON NATIONAL PARK
PAIUTE (UT) RESERVATION
CEDAR BREAKS NATIONAL MONUMENT
ZION NATIONAL PARK
KAIBAB INDIAN RESERVATION
GRAND CANYON NATIONAL PARK
NAVAJO NATION RESERVATION
271
20
130
274
12
56
143
63
14
15
89
9
67
Stopovers
Winter range
0 15 30 mi
0 10 20 mi

Utah | Mule Deer

Paunsaugunt Plateau Mule Deer Migration Corridors

The Paunsaugunt Plateau in southern Utah is home to a prolific mule deer herd. In early October, these mule deer begin their migration from the Plateau traveling south distances up to 78 miles to winter range in the Buckskin Mountains near the Utah-Arizona border. Approximately 20-30% of the Paunsaugunt Plateau herd reside in northern Arizona during the winter, sharing winter range also used by deer from the Kaibab Plateau herd. Beginning in late April, deer reverse their migration to summer range on the Plateau. The most significant challenge for these deer is US Highway 89 which bisects this migration corridor and winter range, where deer-vehicle collisions have historically been a problem. In 2012, the Utah Department of Transportation and partners placed 12.5 miles of wildlife exclusion fence between existing and new crossing structures to reduce deer-vehicle collisions and provide connectivity for deer and other wildlife across the highway. These mitigation measures have been a tremendous success, facilitating over 78,600 successful mule deer crossings and a 77% crossing success rate.

Animal Capture and Data Collection

Sample size: 54 adult mule deer
Relocation frequency: ~ 2 hours
Project duration: 2018 – 2019

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)
Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 117 sequences from 54 individuals (75 spring sequences, 42 fall sequences)
- **Winter:** 36 sequences from 36 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** April 23 to April 30
- **Fall:** October 6 to October 21

Average number of days migrating:

- **Spring:** 11 days
- **Fall:** 16 days

Migration corridor length:

- **Min**: 13 miles
- **Mean**: 35 miles
- **Max**: 79 miles

Migration corridor area:

- 633,589 acres (low use)
- 30,146 acres (medium use)
- 2,397 acres (high use)

Stopover area: 40,030 acres

Winter Range Summary

Winter start and end date (median):

- November 5 to April 17

Winter length (mean): 153 days
Winter range (50% contour) area: 58,760 acres

Other Information

Project contacts:

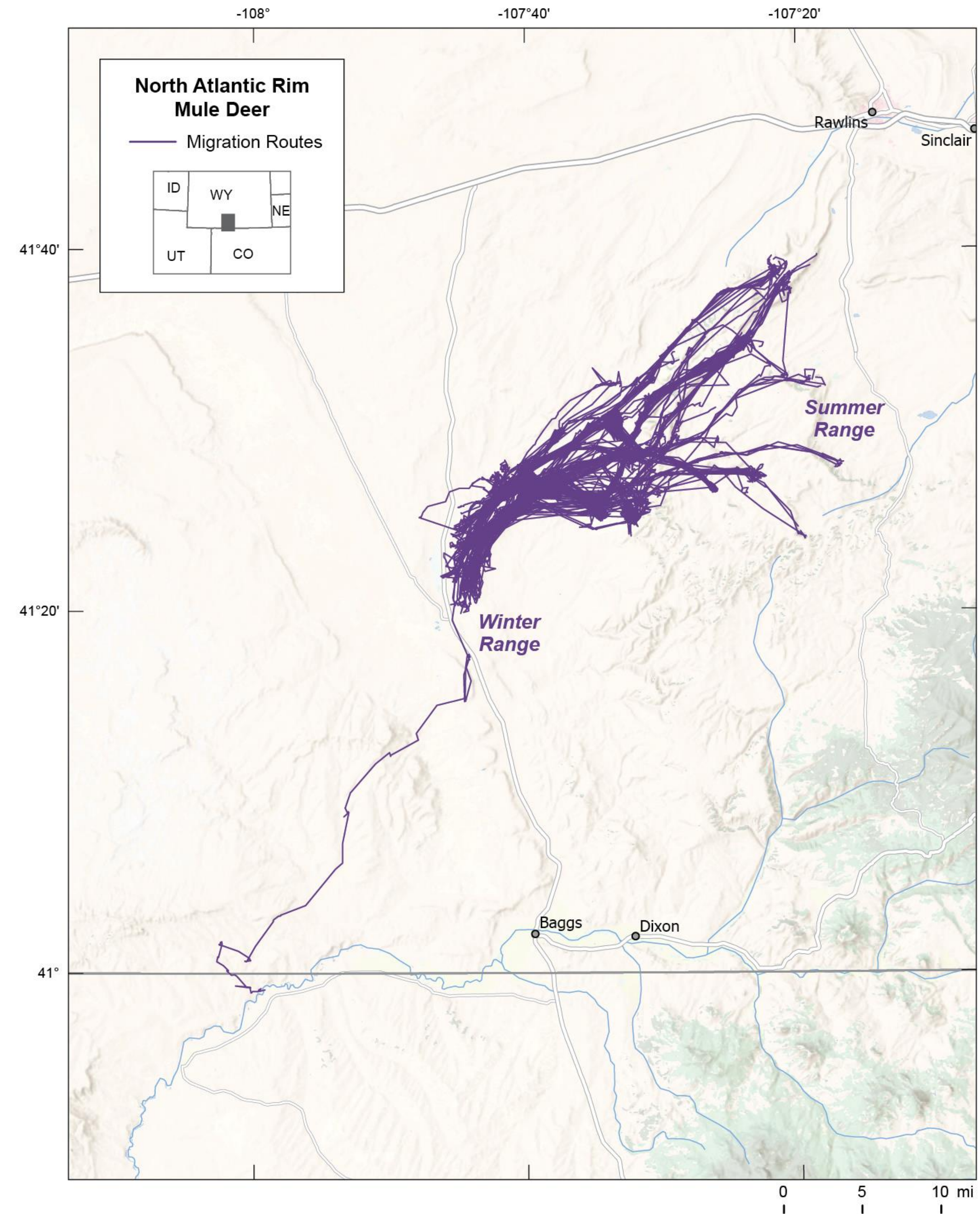
- Daniel Olson (danielolson@utah.gov), Wildlife Migration Initiative Coordinator

Data analyst:

- Lucas Olson (lolson@azgfd.gov), Arizona Game & Fish/Mule Deer Foundation

Reports and publications:

- Carrel, W. K., R. A. Ockenfels, and R. E. Schweinsburg. 1999. An evaluation of annual migration patterns of the Paunsaugunt mule deer herd between Utah and Arizona. Research Branch Tech. Rep. No. 29. Arizona Game and Fish Department, Phoenix. 44 pp.
- Cramer, P. & Hamlin, R. 2019. US 89 Kanab-Paunsaugunt Wildlife Crossing and Existing Structures Research Project. Final Report. Utah Department of Transportation. Taylorsville, UT.
- Messmer, T., & Klimack, P. 1999. Summer Habitat Use and Migration Movements of the Paunsaugunt Plateau Mule Deer Herd. Final Report. Arizona Game and Fish Department, Phoenix, AZ. Utah Division of Wildlife Resources, Salt Lake City, UT.


North Atlantic Rim
Mule Deer
Migration Routes
ID
WY
NE
UT
CO
-108°
-107°40'
-107°20'
41°40'
41°20'
41°
Rawlins
Sinclair
Summer Range
Winter Range
Baggs
Dixon
0
5
10 mi

Wyoming | Mule Deer

Baggs Herd: Atlantic Rim North Mule Deer Migration Routes

Mule deer in the Atlantic Rim North population are part of the Baggs herd unit that is managed for approximately 19,000 animals. These mule deer winter in the pinyon/juniper and sagebrush badlands near Dad, Wyoming and migrate north and east 10 to 35 miles to various summer ranges. Many of these deer must navigate coal-bed methane development that is situated along the migration route between their seasonal ranges. In addition to gas development, portions of their summer range overlap with areas of wind energy development.

Animal Capture and Data Collection

Sample size: 55 adult female mule deer
Relocation frequency: 2 – 3 hours
Project duration: 2005 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 147 sequences from 47 individuals
- **Winter:** 115 sequences from 55 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 24 to May 1
- **Fall:** October 27 to December 2

Days migrating (mean):

- **Spring:** 12 days
- **Fall:** 29 days

Migration route length:

- **Min**: 9 miles
- **Mean**: 23 miles
- **Max**: 57 miles

Winter Use Summary

Winter use start and end date (median):

- January 1 to March 15

Days of winter use (mean): 74 days

Other Information

Project contacts:

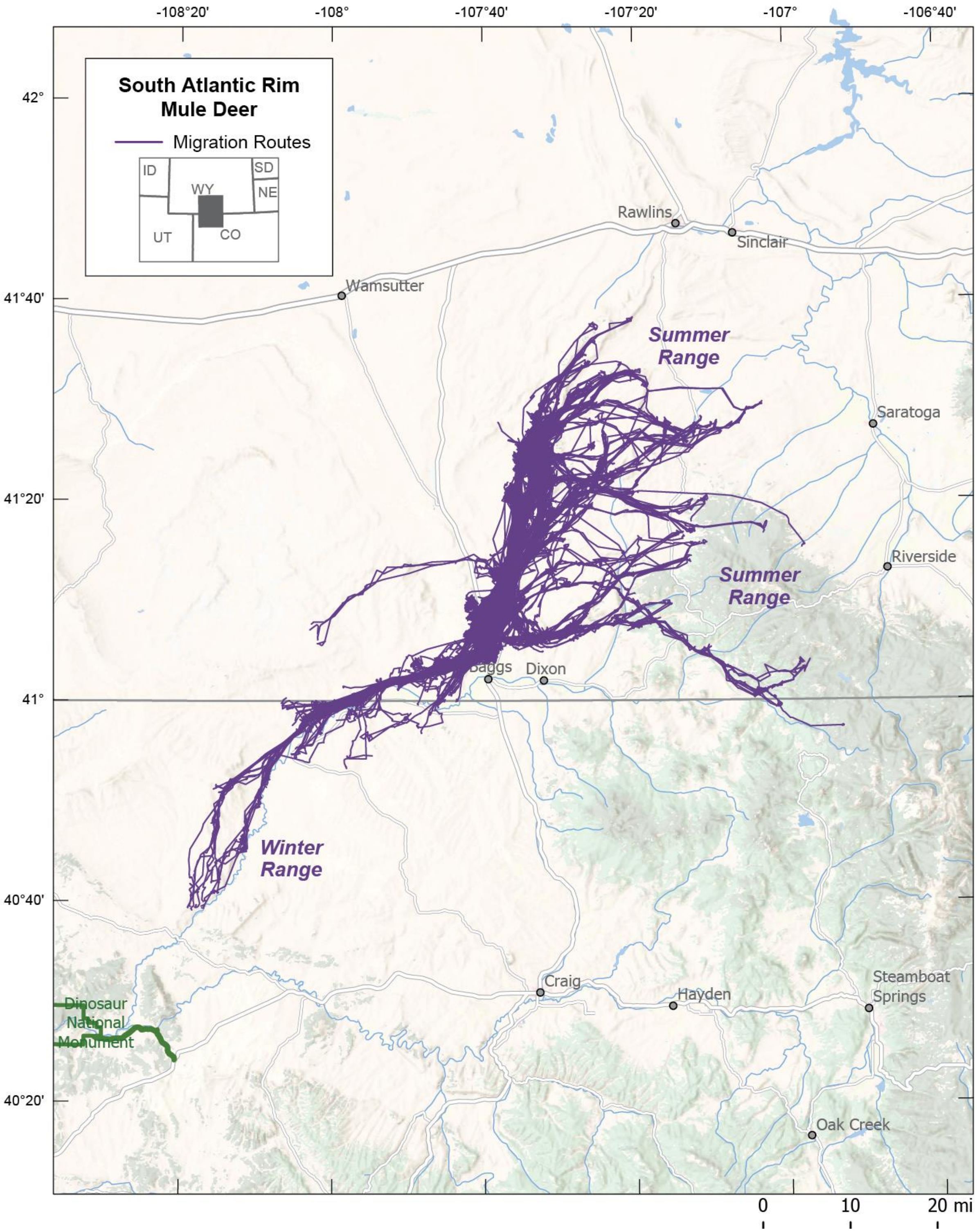
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST Inc.
- Philip Damm (philip.damm@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST Inc.

Reports and publications:

- Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016-2025.
- Sawyer, H., and M. J. Kauffman. 2011. Stopover ecology of a migratory ungulate. Journal of Animal Ecology 80:1078-1087.
- Sawyer, H., M. J. Kauffman, A. Middleton, T. Morrison, R. Nielson, and T. Wyckoff. 2013. A framework for understanding semi-permeable barrier effects on migratory ungulates. Journal of Applied Ecology 50:68-78.



South Atlantic Rim
Mule Deer
Migration Routes
ID
SD
WY
NE
UT
CO
-108°20'
-108°
-107°40'
-107°20'
-107°
-106°40'
42°
41°40'
41°20'
41°
40°40'
40°20'
Rawlins
Sinclair
Wamsutter
Summer Range
Saratoga
Riverside
Summer Range
Baggs
Dixon
Winter Range
Craig
Hayden
Steamboat Springs
Oak Creek
Dinosaur National Monument
0
10
20 mi

Wyoming | Mule Deer

Baggs Herd: Atlantic Rim South Mule Deer Migration Routes

Mule deer in the Atlantic Rim South population are part of the Baggs herd unit that is managed for approximately 19,000 animals. These mule deer winter in the sagebrush canyons and basins north and west of Baggs, Wyoming and migrate north and east 20 to 50 miles to various summer ranges. Many of these deer must navigate coal-bed methane development situated along the migration route between their seasonal ranges. In addition to gas development, many of these deer cross Highway 789 during winter and migration. WYDOT recently installed two underpasses and several miles of game-proof fencing to facilitate highway crossings across Highway 789 and help minimize wildlife-vehicle collisions and maintain corridor connectivity.

Animal Capture and Data Collection

Sample size: 104 adult female mule deer
Relocation frequency: 2 – 3 hours
Project duration: 2005 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 277 sequences from 89 individuals
- **Winter:** 215 sequences from 104 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 9 to May 1
- **Fall:** October 23 to December 9

Days migrating (mean):

- **Spring:** 26 days
- **Fall:** 38 days

Migration route length:

- **Min**: 6 miles
- **Mean**: 41 miles
- **Max**: 89 miles

Winter Use Summary

Winter use start and end date (median):

- January 1 to March 15

Days of winter use (mean): 74 days

Other Information

Project contacts:

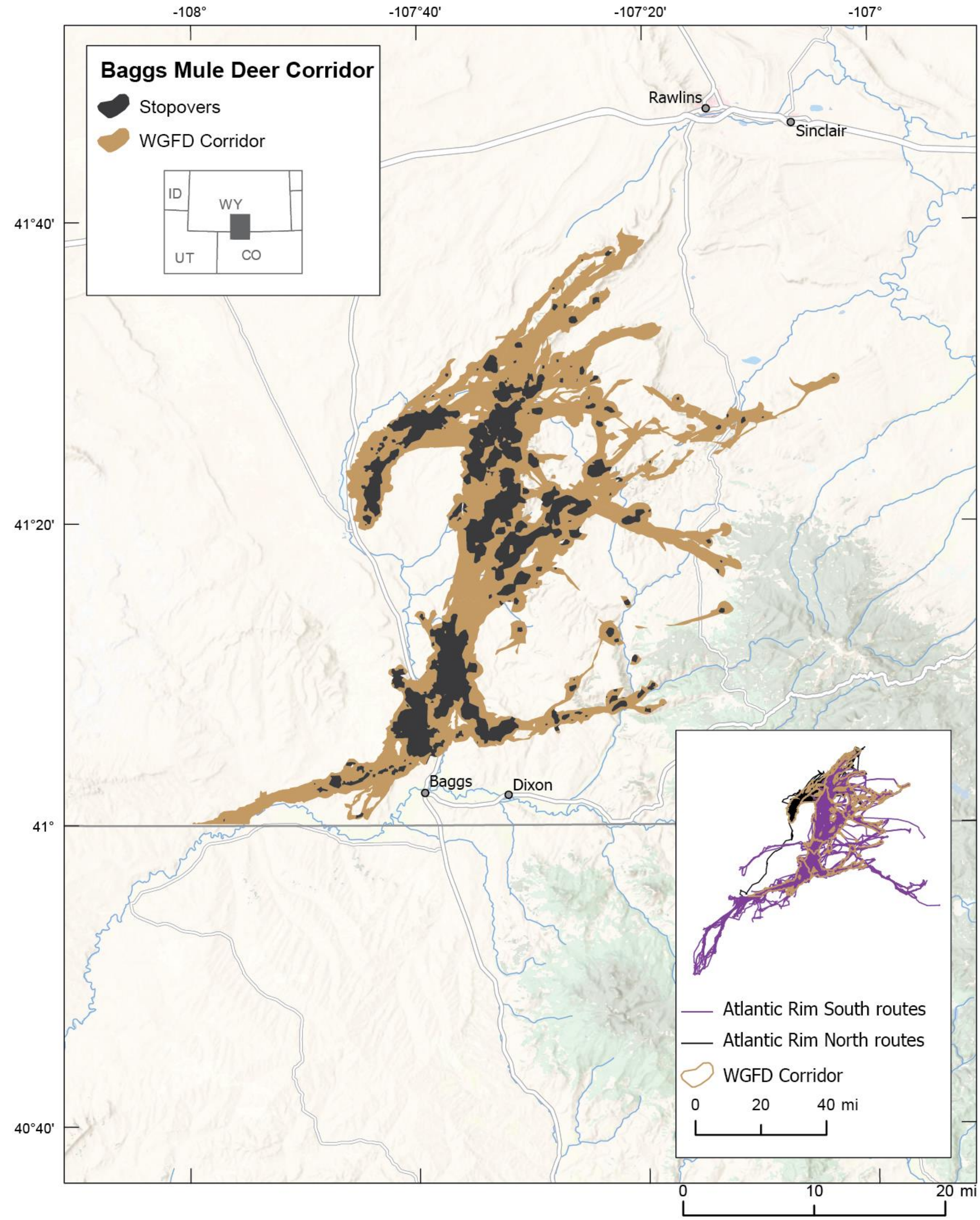
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST Inc.
- Philip Damm (philip.damm@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST Inc.

Reports and publications:

- Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016-2025.
- Sawyer, H., and M. J. Kauffman. 2011. Stopover ecology of a migratory ungulate. Journal of Animal Ecology 80:1078-1087.
- Sawyer, H., M. J. Kauffman, A. Middleton, T. Morrison, R. Nielson, and T. Wyckoff. 2013. A framework for understanding semi-permeable barrier effects on migratory ungulates. Journal of Applied Ecology 50:68-78.



-108°
-107°40'
-107°20'
-107°
41°40'
41°20'
41°
40°40'
Baggs Mule Deer Corridor
Stopovers
WGFD Corridor
ID
WY
UT
CO
Rawlins
Sinclair
Baggs
Dixon
Atlantic Rim South routes
Atlantic Rim North routes
WGFD Corridor
0
20
40 mi
0
10
20 mi

Wyoming | Mule Deer

Baggs Herd: WGFD Designated Corridor

The Baggs Mule Deer Corridor was officially designated by the Wyoming Game and Fish Department in 2018. The Baggs Herd is managed for approximatley 20,000 animals and the corridor is based on two wintering deer populations – a northern and southern segment. Animals in the north segment occupy a relative small winter range along a pinyon-juniper ridge that runs along the east side of highway 789. From there, deer migrate north and west to summer ranges on Atlantic Rim, Miller Hill, and the Sand Hills. The southern segment occupies a larger sagebrush winter range on both sides of highway 789, some of which extends into Colorado. These animals migrate north and west to summer ranges in and around the Sierra Madre Mountains.

Corridor and Stopover Summary

Migration corridor area: 252,050 (WGFD designation)

Stopover area: 69,209 acres

Other Information

Agency contacts:

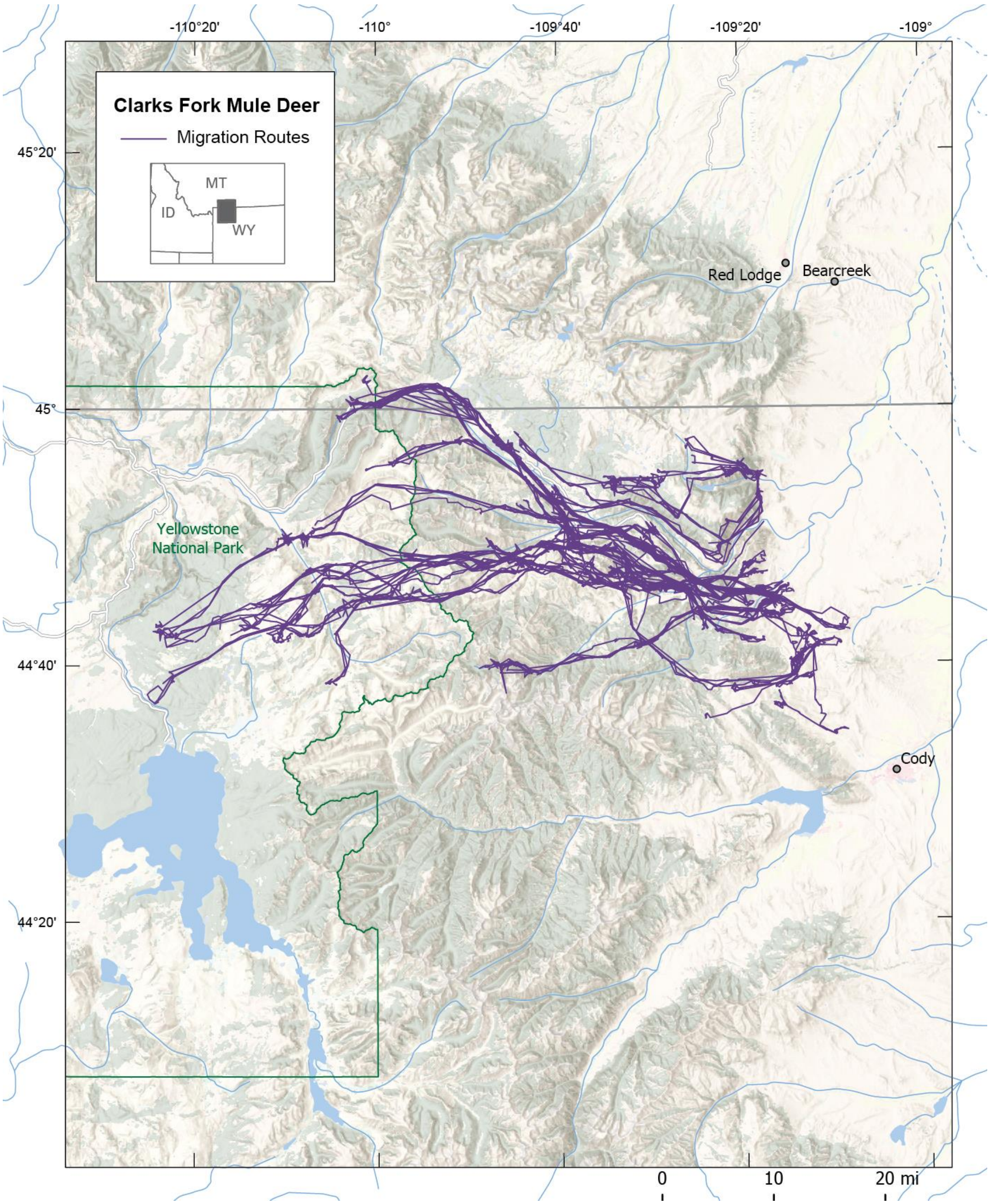
- Mark Zornes (mark.zornes@wyo.gov), Wildlife Management Coordinator, Green River Region, Wyoming Game and Fish Department
- Philip Damm (philip.damm@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc

Reports and publications:

- Sawyer, H. and A. Telander. 2019. Atlantic Rim Mule Deer Study – Phase 3 Final Report. Western Ecosystems Technology, Inc. Laramie, WY.
- Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016-2025.
- Sawyer, H., M. J. Kauffman, A. Middleton, T. Morrison, R. Nielson, and T. Wyckoff. 2013. A framework for understanding semi-permeable barrier effects on migratory ungulates. Journal of Applied Ecology 50:68-78.



Clarks Fork Mule Deer
Migration Routes
MT
ID
WY
-110°20'
-110°
-109°40'
-109°20'
-109°
45°20'
45°
44°40'
44°20'
Red Lodge
Bearcreek
Yellowstone
National Park
Cody
0
10
20 mi

Wyoming | Mule Deer

Clarks Fork Mule Deer Migration Routes

Mule deer within the Clarks Fork herd make a number of significant westward long-distance migrations. These migrations originate north of Cody, near Heart Mountain and along the foothills of Absaroka Front. There, deer winter in the lower elevation sagebrush valleys, and in spring an estimated 2,700 deer head west into the high elevation mountain valleys of the Absaroka Range and Yellowstone National Park. This herd summers along the Lamar River, Cache Creek, and the Clarks Fork of the Yellowstone. The longest migration is 68 miles and ends just north of Yellowstone Lake along the Yellowstone River in the Hayden Valley. These challenging journeys, an average of 38 miles long, cross rugged terrain and steep mountain passes such as those at the head of Sunlight Creek at 11,400 feet in elevation. Deer must also navigate human-created obstacles such as fences and the Beartooth Highway (US Highway 212).

Animal Capture and Data Collection

Sample size: 31 adult female mule deer
Relocation frequency: ~2 hours
Project duration: 2016 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 79 sequences from 29 individuals (43 spring sequences, 36 fall sequences)
- **Winter:** 41 sequences from 28 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 11 to May 30
- **Fall:** October 6 to October 25

Days migrating (mean):

- **Spring:** 20 days
- **Fall:** 20 days

Migration route length:

- **Min**: 6.2 miles
- **Mean**: 37.5 miles
- **Max**: 68.1 miles

Winter Use Summary

Winter use start and end date (median):

- December 1 day to March 25

Days of winter use (mean): 102 days

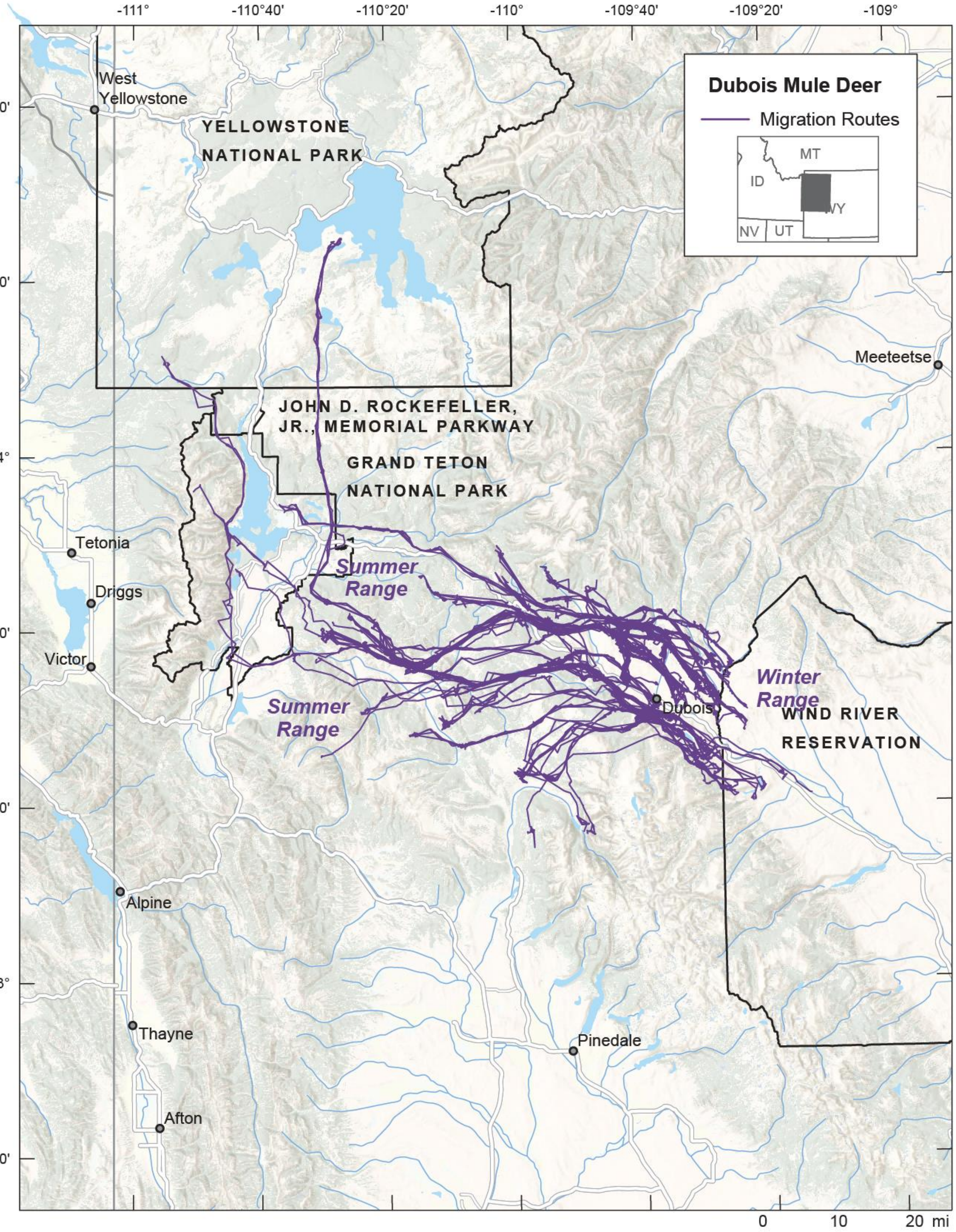
Other Information

Project contacts:

- Matthew Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Corey Class (corey.class@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department
- Tony Mong (tony.mong@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Julien Fattebert, Post Doctoral Researcher, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming



Dubois Mule Deer
Migration Routes
MT
ID
WY
NV
UT
-111°
-110°40'
-110°20'
-110°
-109°40'
-109°20'
-109°
44°40'
44°20'
44°
43°40'
43°20'
43°
42°40'
West Yellowstone
YELLOWSTONE NATIONAL PARK
JOHN D. ROCKEFELLER, JR., MEMORIAL PARKWAY
GRAND TETON NATIONAL PARK
Meeteetse
Tetonia
Driggs
Victor
Summer Range
Summer Range
Winter Range
Dubois
WIND RIVER RESERVATION
Alpine
Thayne
Pinedale
Afton
0
10
20 mi

Wyoming | Mule Deer

Dubois Mule Deer Migration Routes

Mule deer within the Dubois herd make a number of long-distance migrations into the heart of the Greater Yellowstone Ecosystem. These migrations originate from winter range in the warm, protected sagebrush valley surrounding the small town of Dubois, Wyoming and extending to the southeast on the Wind River Indian Reservation. Each spring, an estimated 6,000-7,000 deer leave this valley and the Reservation and head northwest. These journeys, averaging 44 miles one-way, begin as deer ascend Togwotee Pass (9,658 feet in elevation). From there, they cross challenging natural terrain with high mountain passes and disperse into the north Wind River Range, Gros Ventre Wilderness, Absaroka Wilderness, Grand Teton National Park, and deep into Yellowstone National Park. The longest migration is 105-miles and ends in Yellowstone National Park. This deer herd encounters a number of challeges related to human activity such as housing developments on the outskirts of Dubois, roads and fences. Deer-vehicle collisions along US Highway 287/US Route 26 are a particular concern and a priority for mitigation measures that reduce mortality and improve motorist safety.

Animal Capture and Data Collection

Sample size: 49 adult female mule deer
Relocation frequency: 2 – 24 hours
Project duration: 2014 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 108 sequences from 41 individuals (56 spring sequences, 52 fall sequences)
- **Winter:** 94 sequences from 46 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 14 to June 5
- **Fall:** October 14 to November 5

Days migrating (mean):

- **Spring:** 22 days
- **Fall:** 26 days

Migration route length:

- **Min**: 12 miles
- **Mean**: 44 miles
- **Max**: 105 miles

Winter Use Summary

Winter use start and end date (median):

- December 28 to April 24

Days of winter use (mean): 74 days

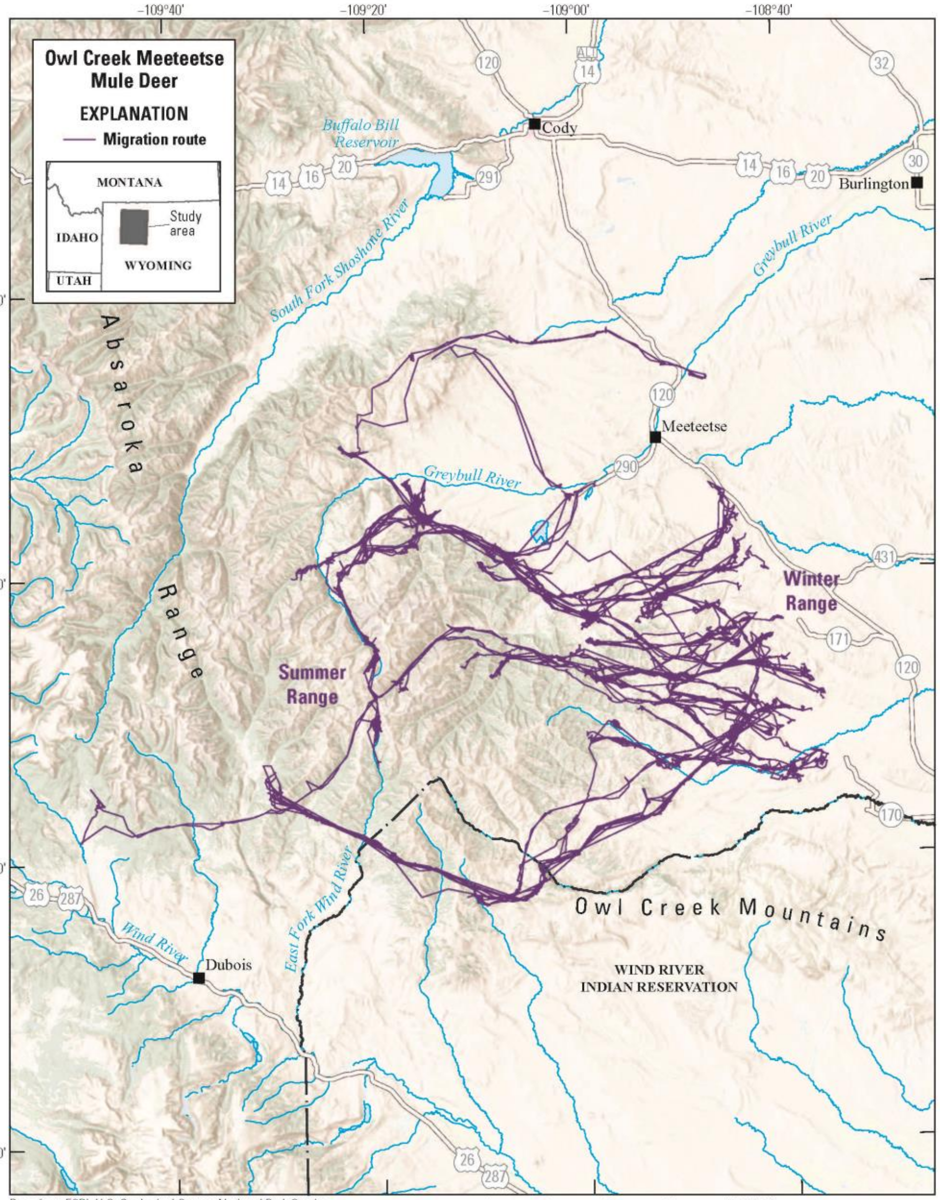
Other Information

Project contacts:

- Matt Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Greg Anderson (gregory.anderson@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department
- Pat Hnilicka (pat_hnilicka@fws.gov), Wildlife Biologist, US Fish and Wildlife Service

Data analyst:

- Holly Copeland, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming



Base from ESRI, U.S. Geological Survey, National Park Service, and U.S. Census Bureau digital data, 2019
Universal Transverse Mercator projection, zone 12N
North American Datum of 1983

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Wyoming | Mule Deer

Owl Creek/Meeteetse Mule Deer Migration Routes

Mule deer within the Owl Creek/Meeteetse herd make a number of medium- to long-distance migrations west into the Shoshone National Forest. These migrations originate on the sagebrush grasslands just southwest and west of Meeteetse, Wyoming, where this population winters. In spring, an estimated 4,100 deer leave these foothills and travel into the rugged Absaroka mountain range. These journeys, across challenging natural terrain, range an average of 27 miles and include navigating fast moving rivers, such as the Greybull River, and over high mountains passes like Bear Creek and East Fork Pass—the highest at 12,230 feet in elevation. The longest migration is 70 miles to the Dunoir Valley northwest of Dubois. Although the private lands that comprise winter range and low-eleveation route segments are at risk of residential development, once deer cross onto the National Forest they encounter few human-created obstacles in this remote wilderness environment.

Animal Capture and Data Collection

Sample size: 37 adult female mule deer
Relocation frequency: ~ 2 hours
Project duration: 2016 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 86 sequences from 32 individuals (45 spring sequences, 41 fall sequences)
- **Winter:** 46 sequences from 29 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 4 to May 25
- **Fall:** October 3 to October 13

Days migrating (mean):

- **Spring:** 20.2 days
- **Fall:** 12.3 days

Migration route length:

- **Min**: 9.8 miles
- **Mean**: 27.2 miles
- **Max**: 69.9 miles

Winter Use Summary

Winter use start and end date (median):

- November 20 to April 06

Days of winter use (mean): 119 days

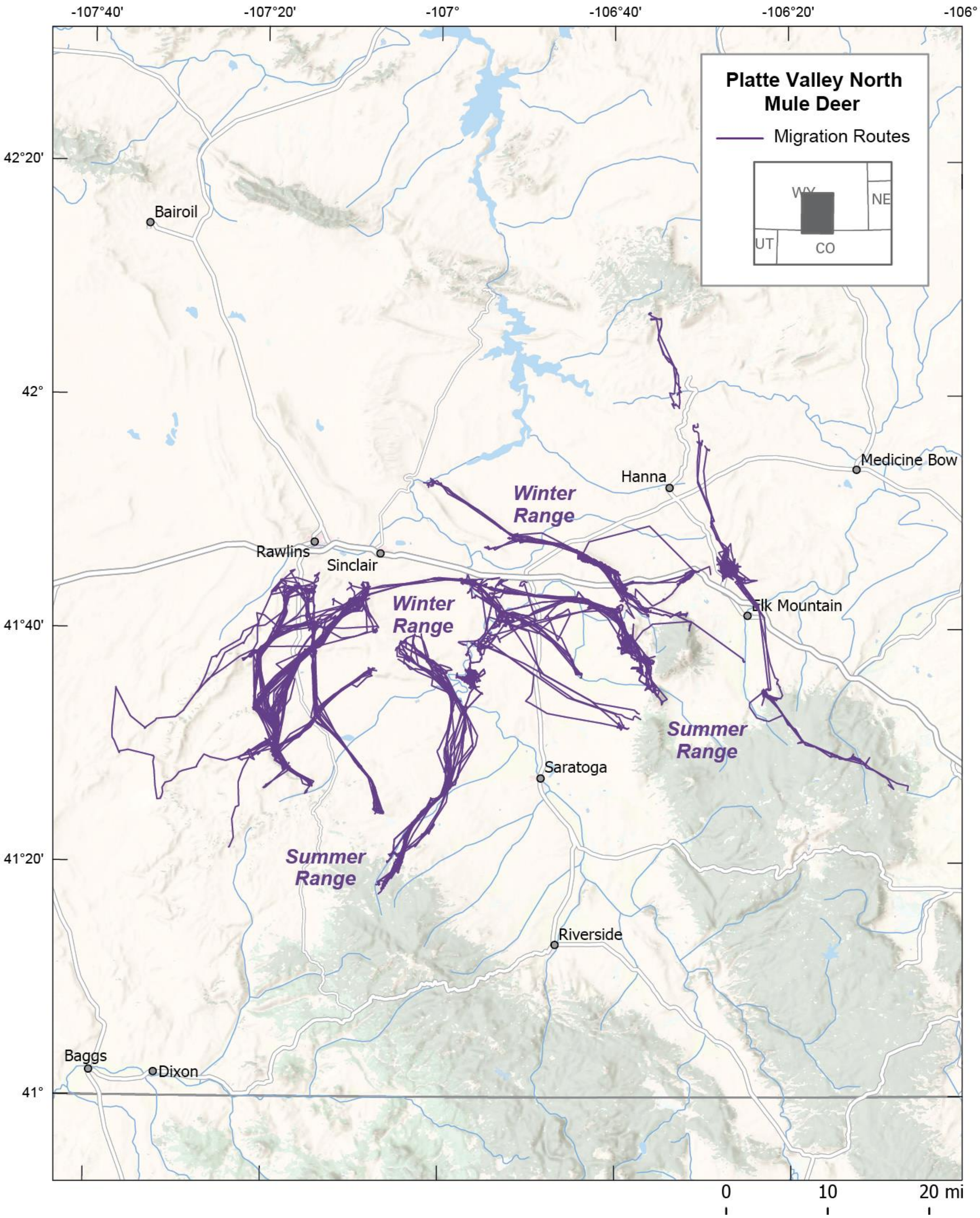
Other Information

Project contacts:

- Matthew Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Corey Class (corey.class@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department
- Bart Kroger (bart.kroger@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Emily Gelzer, University of Wyoming, Department of Zoology and Physiology


Platte Valley North Mule Deer
Migration Routes
WY
NE
UT
CO
-107°40'
-107°20'
-107°
-106°40'
-106°20'
-106°
42°20'
42°
41°40'
41°20'
41°
Bairoil
Medicine Bow
Hanna
Rawlins
Sinclair
Elk Mountain
Saratoga
Riverside
Baggs
Dixon
Winter Range
Winter Range
Summer Range
Summer Range
0
10
20 mi

Wyoming | Mule Deer

Platte Valley Herd: Platte Valley North Mule Deer Migration Routes

Mule deer in the Platte Valley North population are part of the larger Platte Valley herd unit that is managed for approximately 11,000 animals. These mule deer winter in the sagebrush canyons and basins near the Platte River north of Saratoga, Wyoming. Other segments of this population winter in the Chokecherry Knob area, south of Sinclair, and the Dana Ridge area just north of Interstate 80. The migratory patterns of these deer are diverse and vary with each winter range. Deer in this part of the Platte Valley have a noticeably higher proportion of resident animals compared to Platte Valley South. For example, half of the mule deer near Interstate 80 are residents. Improving connectivity of Interstate 80 has become a management priority to reduce wildlife-vehicle collisions and provide deer access to more habitat. Wind energy development is a major concern for the northwest part of the Platte Valley, where 1,000 turbines are slated for construction beginning in 2022. The potential impacts of wind development on mule deer are generally unknown.

Animal Capture and Data Collection

Sample size: 104 adult female mule deer
Relocation frequency: ~2 hours
Project duration: 2011 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 131 sequences from 32 individuals
- **Winter:** 113 sequences from 40 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 7 to May 15
- **Fall:** October 20 to October 27

Days migrating (mean):

- **Spring:** 8 days
- **Fall:** 9 days

Migration route length:

- **Min**: 9 miles
- **Mean**: 23 miles
- **Max**: 60 miles

Winter Use Summary

Winter use start and end date (median):

- December 1 to March 15

Days of winter use (mean): 103 days

Other Information

Project contacts:

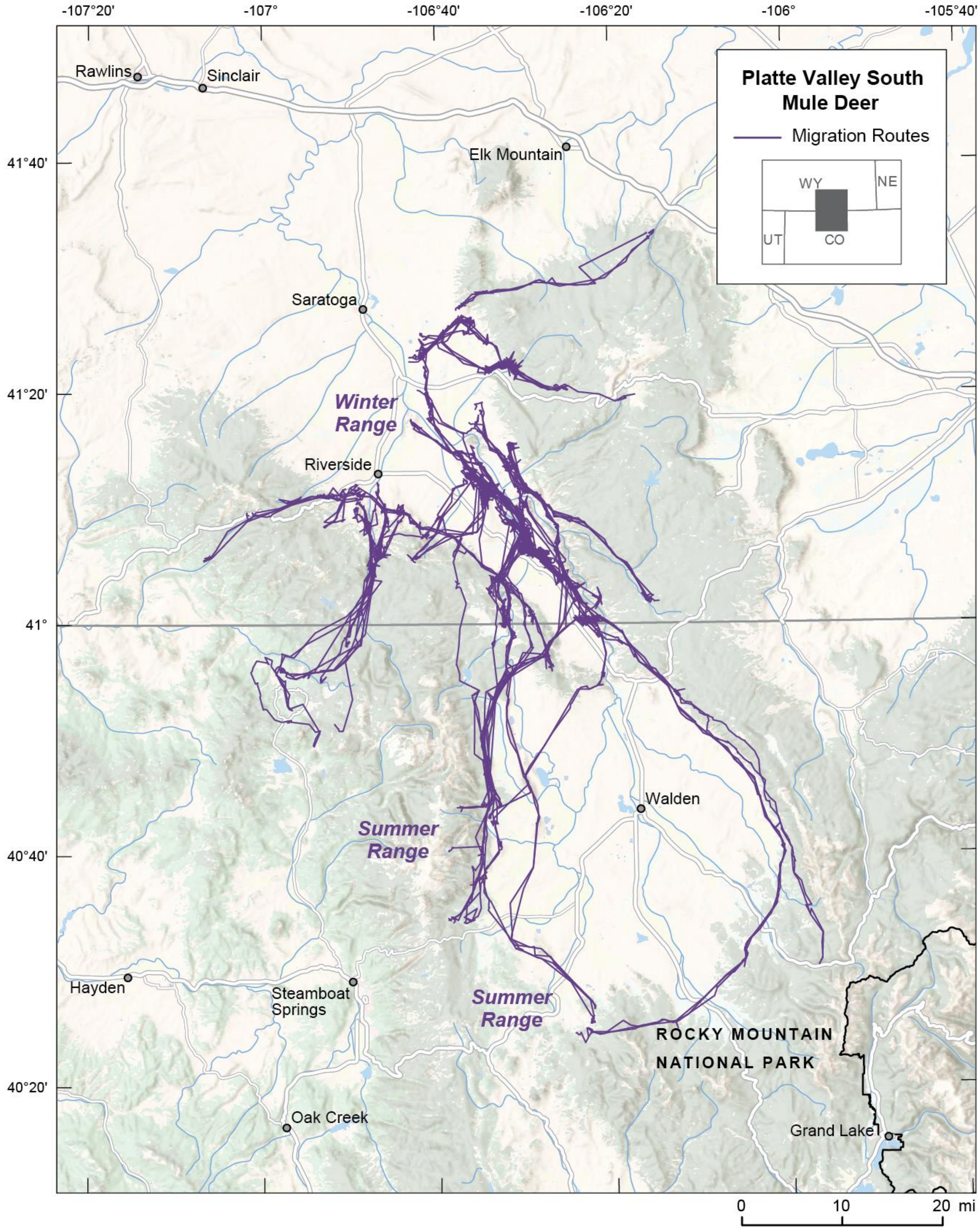
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST Inc.
- Teal Cufaude (teal.cufaude@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST Inc.

Reports and publications:

- Kauffman, M.J., H. Sawyer. W. Schultz, and M. Hayes. 2015. Seasonal ranges, migration and habitat use of the Platte Valley Mule Deer Herd. Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie.


Platte Valley South Mule Deer
Migration Routes
WY
NE
UT
CO
-107°20'
-107°
-106°40'
-106°20'
-106°
-105°40'
41°40'
41°20'
41°
40°40'
40°20'
Rawlins
Sinclair
Elk Mountain
Saratoga
Winter Range
Riverside
Walden
Summer Range
Summer Range
Hayden
Steamboat Springs
Oak Creek
ROCKY MOUNTAIN NATIONAL PARK
Grand Lake
0
10
20 mi

Wyoming | Mule Deer

Platte Valley Herd: Platte Valley South Mule Deer Migration Routes

Mule deer in the Platte Valley South population are part of the larger Platte Valley herd unit that is managed for approximately 11,000 animals. These mule deer winter in the sagebrush canyons and basins near the Platte and Encampment Rivers, south of Saratoga, Wyoming. Most of these deer migrate southerly 20 to 70 miles to portions of the Sierra Madre, Medicine Bow and Park Ranges in northern Colorado and southern Wyoming. Some of these deer move as far south as Rabbit Ears Pass and must negotiate numerous fences, highways, and residential development to complete their migrations.

Animal Capture and Data Collection

Sample size: 35 adult female mule deer
Relocation frequency: ~2 hours
Project duration: 2011 – 2013

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 81 sequences from 28 individuals
- **Winter:** 80 sequences from 35 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 27 to May 21
- **Fall:** October 16 to November 17

Days migrating (mean):

- **Spring:** 24 days
- **Fall:** 21 days

Migration route length:

- **Min**: 4 miles
- **Mean**: 30 miles
- **Max**: 83 miles

Winter Use Summary

Winter use start and end date (median):

- December 1 to March 15

Days of winter use (mean): 103 days

Other Information

Project contacts:

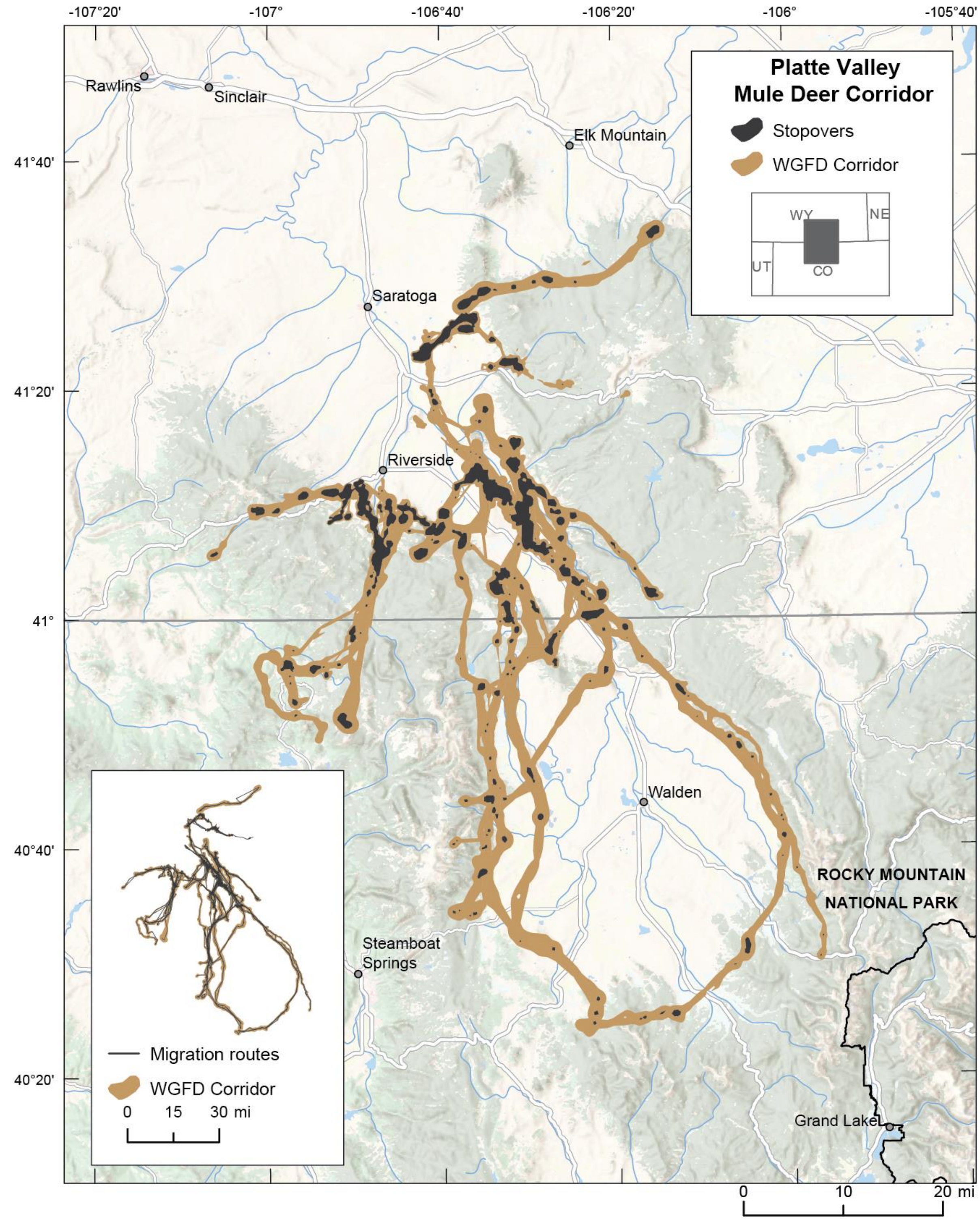
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST Inc.
- Matt Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Teal Cufaude (teal.cufaude@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST Inc.

Reports and publications:

- Kauffman, M.J., H. Sawyer. W. Schultz, and M. Hayes. 2015. Seasonal ranges, migration and habitat use of the Platte Valley Mule Deer Herd. Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie.



-107°20'
-107°
-106°40'
-106°20'
-106°
-105°40'
41°40'
41°20'
41°
40°40'
40°20'
Platte Valley
Mule Deer Corridor
Stopovers
WGFD Corridor
WY
NE
UT
CO
Rawlins
Sinclair
Elk Mountain
Saratoga
Riverside
Walden
Steamboat Springs
ROCKY MOUNTAIN NATIONAL PARK
Grand Lake
Migration routes
WGFD Corridor
0 15 30 mi
0 10 20 mi

Wyoming | Mule Deer

Platte Valley Herd: WGFD Designated Corridor

The Platte Valley Herd Corridor was designated by the Wyoming Game and Fish Department in 2018. The Platte Valley herd supports approximately 11,000 mule deer. The corridor is based on two wintering populations, including a south segment from Saratoga to Colorado state line, and a north segment from Saratoga to Dana Ridge area north of Interstate 80. Winter ranges in the Platte Valley are more dispersed than other parts of the state, so deer migrate in many different directions. Most animals in the herd use a corridor in the south segment that follows the Platte River south to summer ranges in Colorado. Most deer migrations in the north radiate south and east from winter ranges along Interstate 80. The WGFD collared 30-40 additional mule deer in 2020 to help refine corridor delineations for this herd unit.

Corridor and Stopover Summary

Migration corridor area: 162,562 acres (WGFD designation)

Stopover area: 54,649 acres

Other Information

Agency contacts:

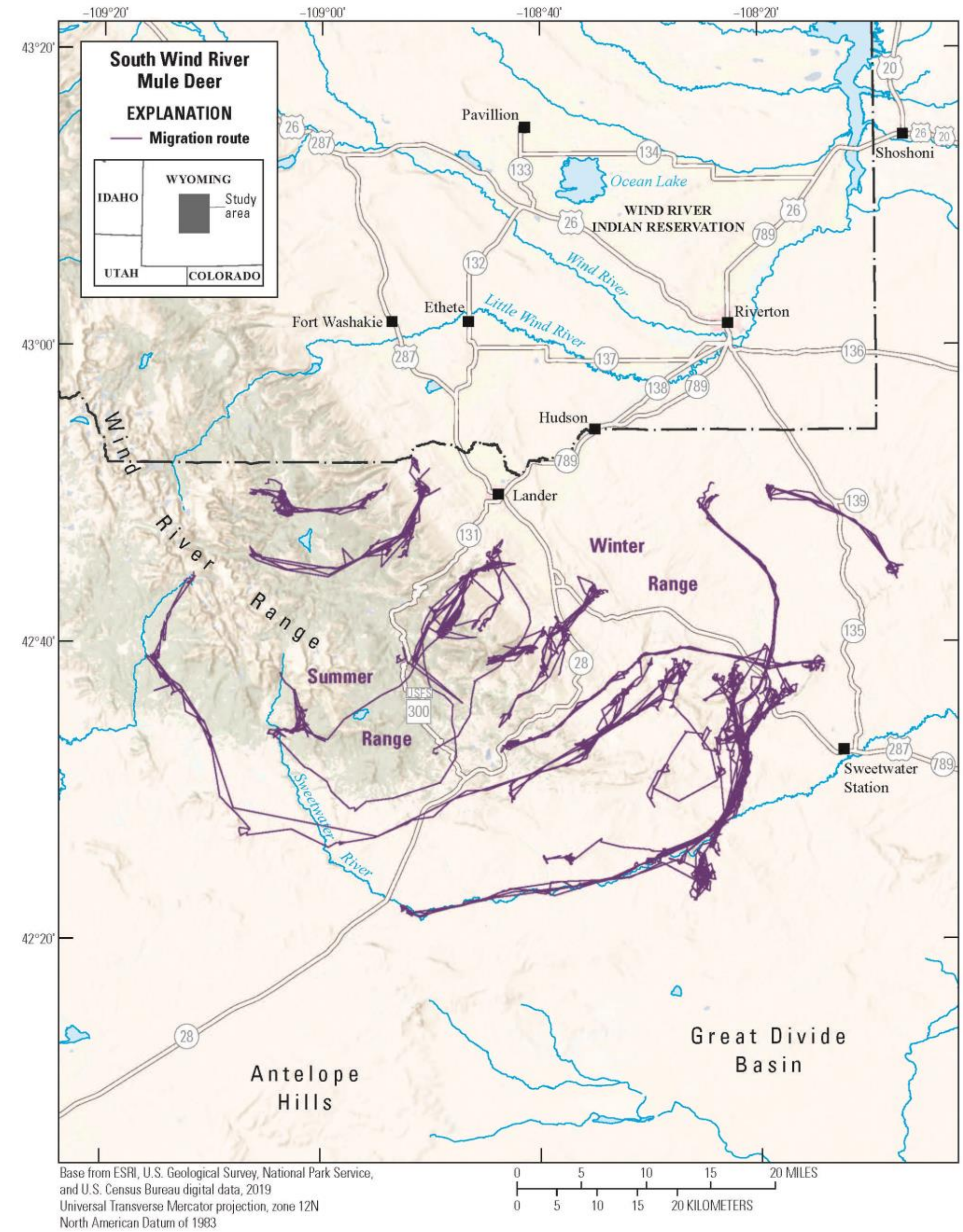
- Embere Hall (embere.hall@wyo.gov), Wildlife Management Coordinator, Laramie Region, Wyoming Game and Fish Department
- Teal Cufaude (teal.cufaude@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Kauffman, M., H. Sawyer, W. Shultz, and M. Hayes. 2015. Seasonal ranges, migration and habitat use of the Platte Valley Mule Deer Herd. Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, WY.



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Wyoming | Mule Deer

South Wind River Migration Routes

Mule deer within the South Wind River herd make short- and medium-distance migrations from the foothills near the town of Lander, Wyoming into the Wind River Range and around its southern flanks. The longest migration in this herd is a 75-mile route originating south of Lander near Twin Creek. Deer following this long-distance route traverse the southern edge of the Winds and summer in the mountainous terrain at the head of the Big Sandy River. Some deer make medium-distance migrations, traveling 14 to 51 miles from Beaver Rim along the Sweetwater River to summer range in the northern Red Desert. Meanwhile, other deer in this population make short- and medium-distance migrations of 7 to 59 miles, moving along the Lander foothills and up into the Wind River Mountains. Challenges for South Wind River deer include rugged terrain, crossing US Highways 789 and 28, and navigating development in and around the town of Lander.

Animal Capture and Data Collection

Sample size: 42 adult female mule deer
Relocation frequency: 2 – 24 hours
Project duration: 2012 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 65 sequences from 28 individuals (32 spring and 33 fall sequences)
- **Winter:** 78 sequences from 42 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 4 to May 13
- **Fall:** October 7 to October 16

Days migrating (mean):

- **Spring:** 13 days
- **Fall:** 11 days

Migration route length:

- **Min**: 7 miles
- **Mean**: 21 miles
- **Max**: 75 miles

Winter Use Summary

Winter use start and end date (median):

- Dec 28 to April 11

Days of winter use (mean): 70 days

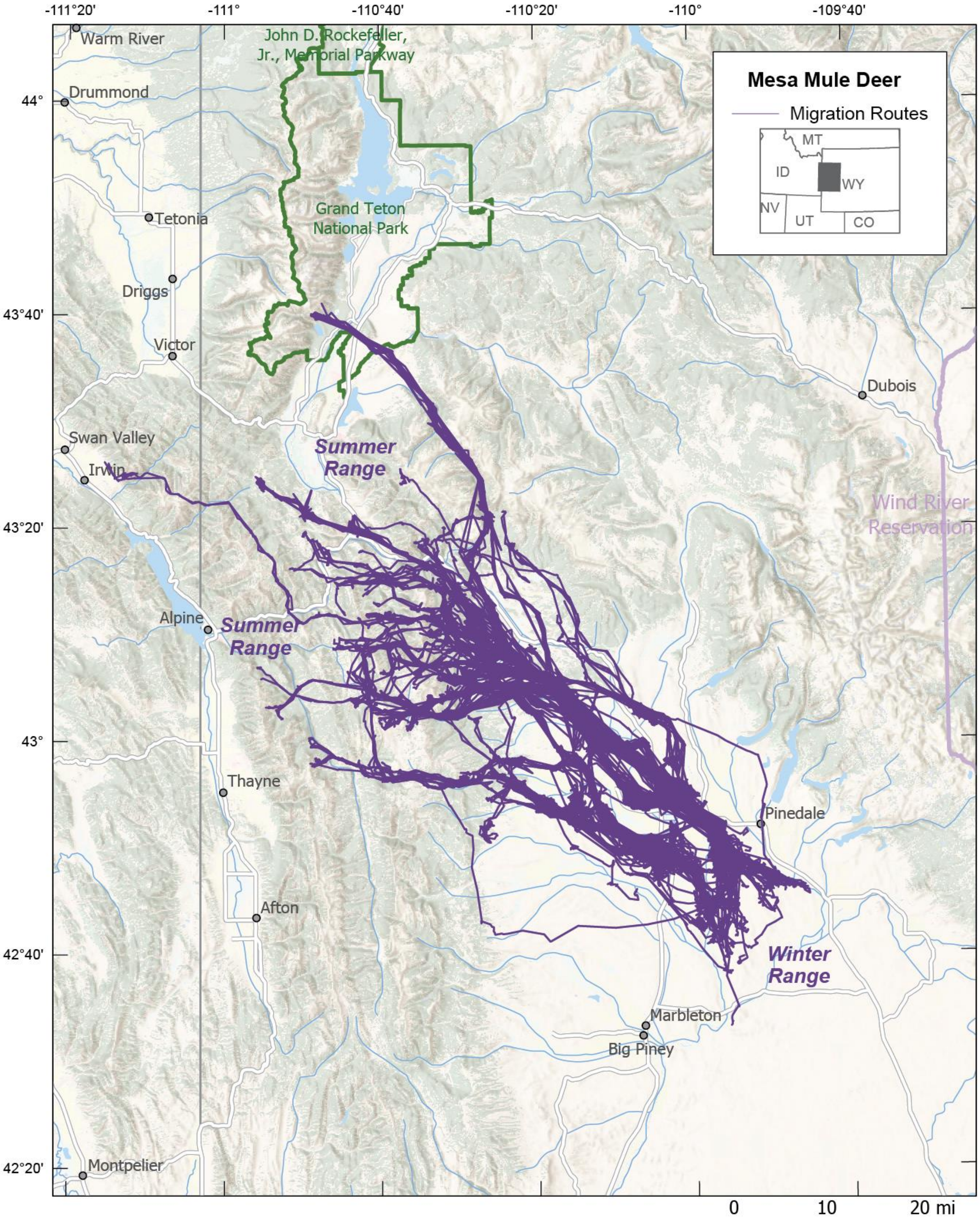
Other Information

Project contacts:

- Matt Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Stan Harter (stan.harter@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department

Data analyst:

- Holly Copeland, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming


Mesa Mule Deer
Migration Routes
MT
ID
WY
NV
UT
CO
John D. Rockefeller, Jr., Memorial Parkway
Grand Teton National Park
Summer Range
Summer Range
Winter Range
Wind River Reservation
Warm River
Drummond
Tetonia
Driggs
Victor
Swan Valley
Irwin
Alpine
Thayne
Afton
Montpelier
Dubois
Pinedale
Marbleton
Big Piney
-111°20'
-111°
-110°40'
-110°20'
-110°
-109°40'
44°
43°40'
43°20'
43°
42°40'
42°20'
0
10
20 mi

Wyoming | Mule Deer

Sublette Herd: Mesa Mule Deer Migration Routes

The Mesa mule deer population is part of the larger Sublette herd that winters in north-central portion of the Green River Basin, east of the Green River and west of US Highway 191. The Mesa wintering area supports 3,000 to 5,000 deer that migrate northwest to summer ranges in the Wyoming Range, Gros Ventre Range, and Snake River Range. The Mesa winter range, which has been fragmented by the Pinedale Anticline natural gas field, has experienced 30-40% declines in deer abundance since development began. Mitigating winter range impacts continues to be a challenge for managers. These migratory deer have benefited from six underpasses and two overpasses constructed along US Highway 191 in 2012; a project that has reduced wildlife-vehicle collisions by 85%.

Animal Capture and Data Collection

Sample size: 143 adult female mule deer
Relocation frequency: 2 – 3 hours
Project duration: 2003 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 263 sequences from 83 individuals
- **Winter:** 291 sequences from 143 individuals

Route Summary

Migration start and end date (median):

- **Spring:** March 31 to May 20
- **Fall:** November 6 to November 25

Days migrating (mean):

- **Spring:** 56 days
- **Fall:** 22 days

Migration route length:

- **Min**: 21 miles
- **Mean**: 52 miles
- **Max**: 107 miles

Winter Range Summary

Winter start and end date (median):

- December 15 to March 15

Days of winter use (mean): 87 days
Winter range (50% contour) area: 116,287 acres

Other Information

Project contacts:

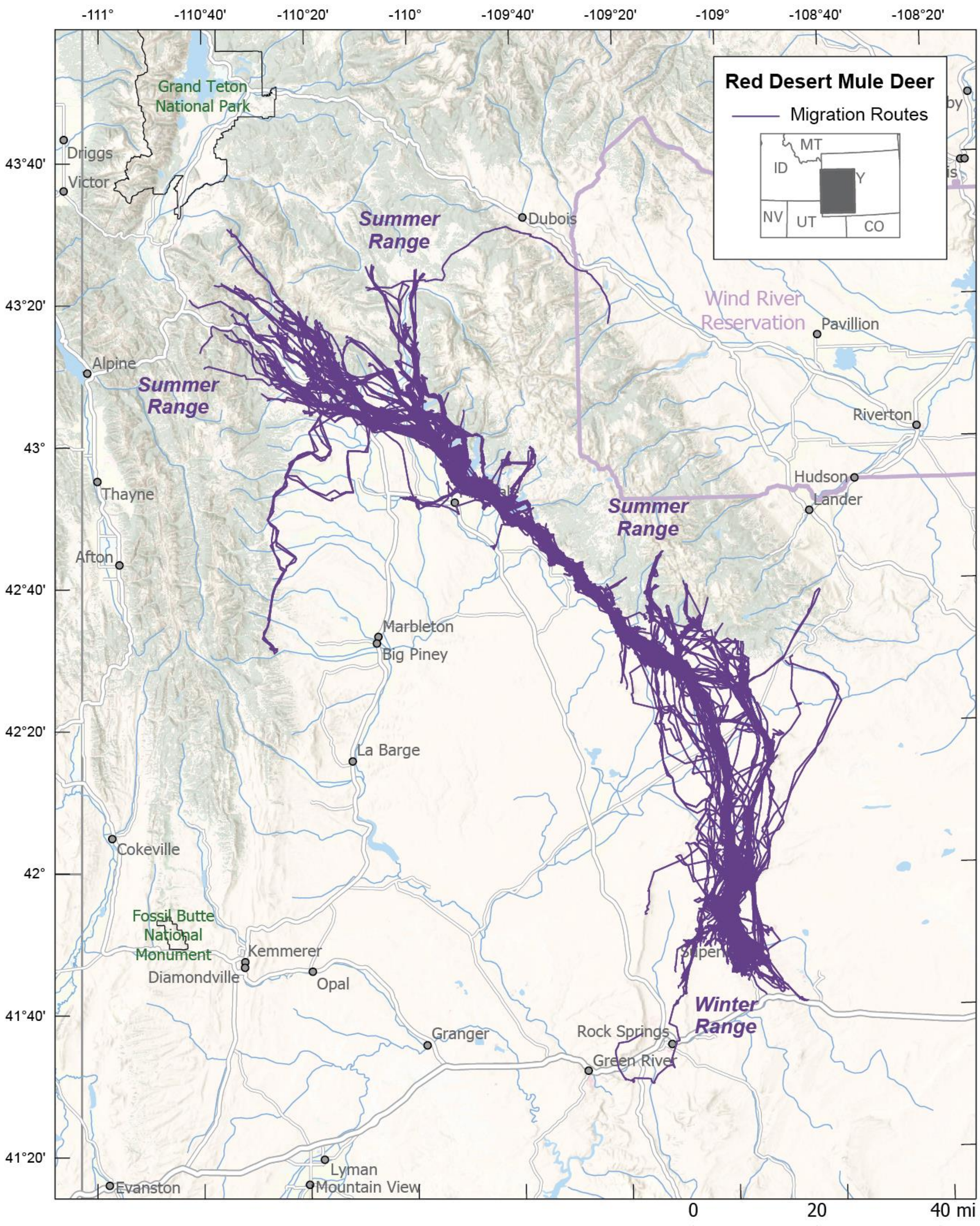
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST, Inc.
- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department

Data analysts:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.
- Andrew Telander, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Sawyer, H., N. Korfanta, R. Nielson, K. Monteith, and D. Strickland. 2017. Mule deer and energy development – long term trends in habituation and abundance. Global Change Biology 23:4521-4529.
- Sawyer, H., M. J. Kauffman, and R. M. Nielson. 2009. Influence of well pad activity on the winter habitat selection patterns of mule deer. Journal of Wildlife Management 73:1052-1061.
- Sawyer, H., C. Lebeau and T. Hart. 2012. Mitigating roadway impacts to migratory mule deer—a case study with underpasses and continuous fencing. Wildlife Society Bulletin 36(3): 492-498.


Red Desert Mule Deer
Migration Routes
MT
ID
NV
UT
CO
-111°
-110°40'
-110°20'
-110°
-109°40'
-109°20'
-109°
-108°40'
-108°20'
43°40'
43°20'
43°
42°40'
42°20'
42°
41°40'
41°20'
Grand Teton National Park
Driggs
Victor
Dubois
Summer Range
Summer Range
Summer Range
Wind River Reservation
Pavillion
Alpine
Riverton
Hudson
Lander
Thayne
Afton
Marbleton
Big Piney
La Barge
Cokeville
Fossil Butte National Monument
Kemmerer
Diamondville
Opal
Winter Range
Rock Springs
Green River
Granger
Lyman
Mountain View
Evanston
0
20
40 mi

Wyoming | Mule Deer

Sublette Herd: Red Desert Mule Deer Migration Routes

Mule deer within the Red Desert population, part of the larger Sublette herd, make the longest ungulate migration ever recorded in the lower 48 states. Here, mule deer travel a one-way distance of 150 miles from the Red Desert in the south to the Hoback Basin and surrounding mountain ranges in the north. This migration originates in the desert sagebrush basins of the Red Desert/Steamboat Mountain area of southwest Wyoming where deer winter. In spring, an estimated 500 deer travel 50 miles north across the desert to the west side of the Wind River Range. From there they merge with 4,000 to 5,000 other deer that winter in the foothills of the Wind River Range and then travel a narrow corridor along the base of the Winds for 60 miles before crossing the upper Green River Basin. Deer must navigate several bottlenecks, one as narrow as 50 meters wide, at the outlets of Fremont, Willow, and Boulder Lakes. In the final leg of the journey, they travel another 30-50 miles to individual summer ranges in the Hoback Basin.

Animal Capture and Data Collection

Sample size: 172 adult female mule deer

Relocation frequency: ~2 hours

Project duration: 2011 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 374 sequences from 138 individuals (234 spring sequences, 140 fall sequences)
- **Winter:** 367 sequences from 172 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 25 to May 22
- **Fall:** October 14 to November 16

Average number of days migrating:

- **Spring:** 33 days
- **Fall:** 31 days

Migration route length:

- **Min:** 7.9 miles
- **Mean:** 94.0 miles
- **Max:** 209.0 miles

Winter Use Summary

Winter use median start and end date:

- Nov 15 to Apr 15

Winter use length (mean): 98 days

Other Information

Project contacts:

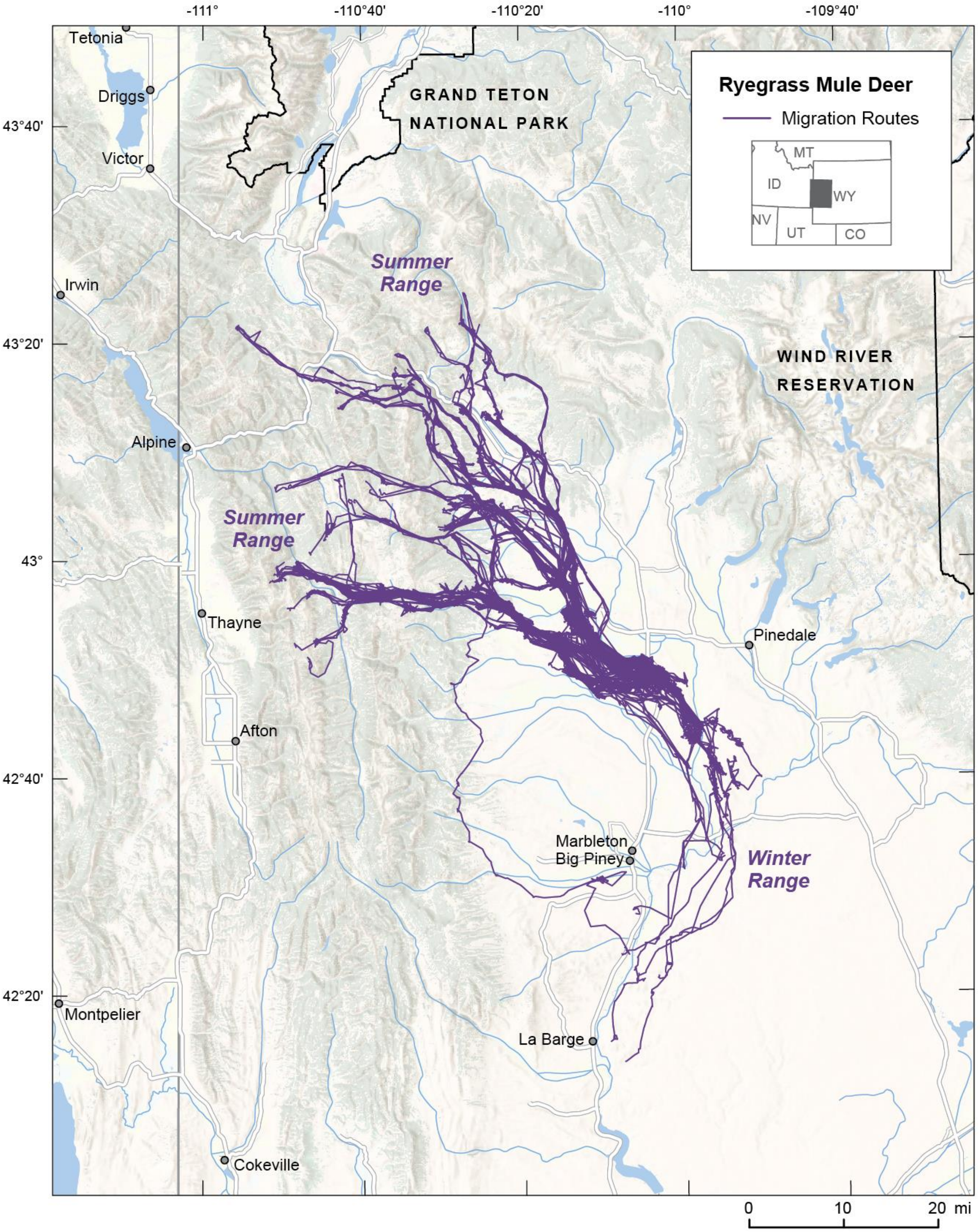
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST, Inc.
- Matt Kauffman (mkauff1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator Pinedale Region, Wyoming Game and Fish Department
- Mark Zornes (mark.zornes@wyo.gov), Wildlife Management Coordinator Green River Region, Wyoming Game and Fish Department

Data analysts:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.
- Andrew Telander, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Sawyer, H., et al. (2014). The Red Desert to Hoback Mule Deer Migration Assessment. W. M. Initiative. Laramie, WY, University of Wyoming.
- Sawyer, H., A. D. Middleton, M. H. Hayes, M. J. Kauffman, and K. L. Monteith. 2016. The extra mile: ungulate migration distance alters the use of seasonal range and exposure to anthropogenic risk. Ecosphere 7(10):e01534.10.1002/ecs2.1534.



Ryegrass Mule Deer
Migration Routes
MT
ID
WY
NV
UT
CO
GRAND TETON
NATIONAL PARK
WIND RIVER
RESERVATION
Summer Range
Summer Range
Winter Range
Tetonia
Driggs
Victor
Irwin
Alpine
Thayne
Afton
Pinedale
Marbleton
Big Piney
La Barge
Montpelier
Cokeville
-111°
-110°40'
-110°20'
-110°
-109°40'
43°40'
43°20'
43°
42°40'
42°20'
0
10
20 mi

Wyoming | Mule Deer

Sublette Herd: Ryegrass Migration Routes

The Ryegrass mule deer population is part of the larger Sublette herd that winters in northwest portion of the Green River Basin, west of the Green River and north of Cottonwood Creek. In severe winters, these deer may travel southeast to the Mesa, Ross Ridge, or Reardon Draw areas. The Ryegrass region supports approximately 1,500 to 2,000 deer that migrate northwest to summer ranges in the Wyoming Range and Salt River Range. Many of these deer must traverse US Highway 189, where deer–vehicle collisions are problematic. This stretch of highway is a top priority for underpass installation to improve both wildlife permeability and motorist safety.

Animal Capture and Data Collection

Sample size: 41 adult female mule deer
Relocation frequency: 2 – 3 hours
Project duration: 2007 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 133 sequences from 33 individuals
- **Winter:** 96 sequences from 41 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 7 to May 23
- **Fall:** November 2 to November 26

Days migrating (mean):

- **Spring:** 48 days
- **Fall:** 26 days

Migration corridor length:

- **Min**: 23 miles
- **Mean**: 47 miles
- **Max**: 97 miles

Winter Range Summary

Winter start and end date (median):

- December 15 to March 15

Days of winter use (mean): 87 days
Winter range (50% contour) area: 74,875 acres

Other Information

Project contacts:

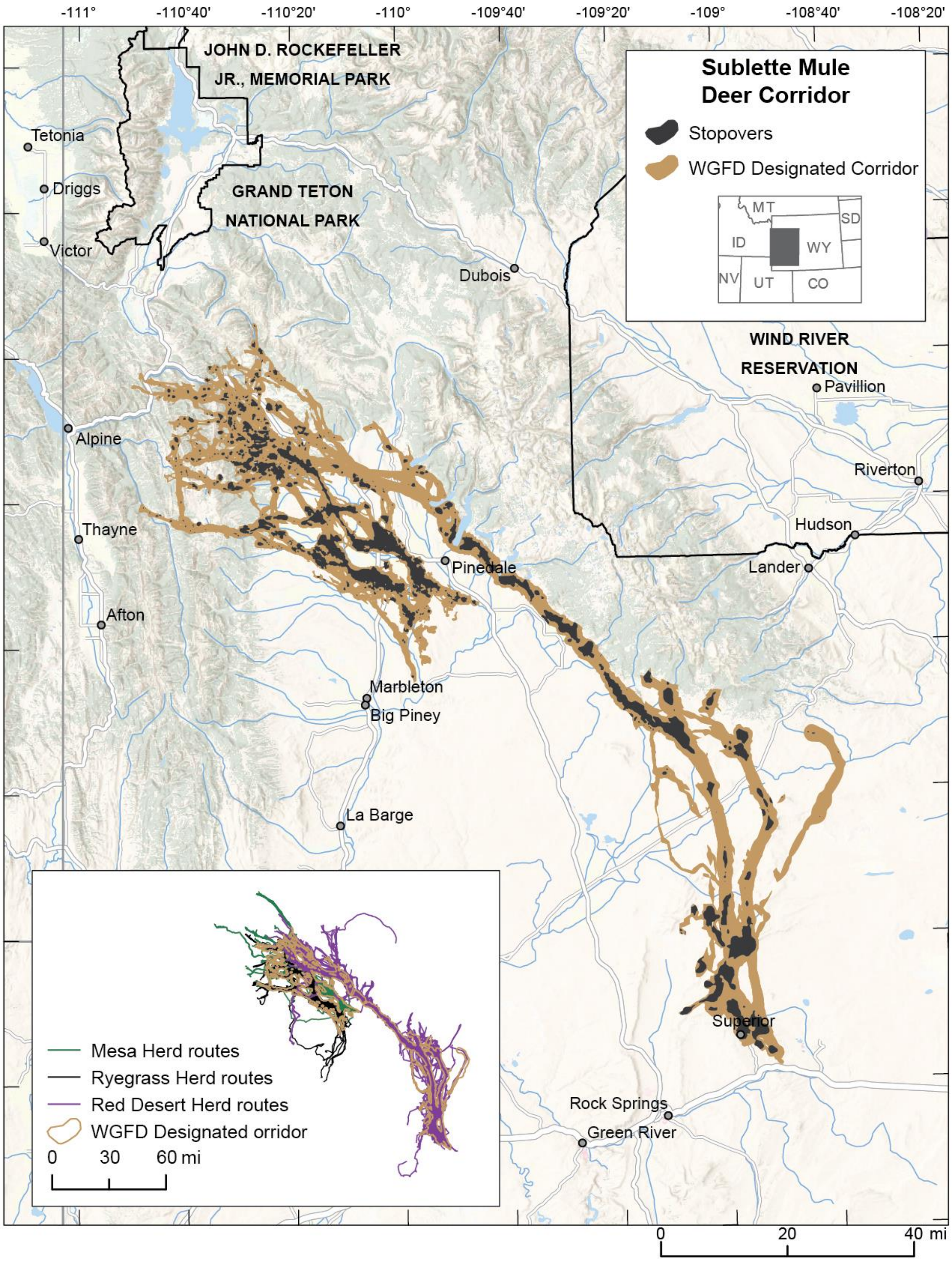
- Hall Sawyer (hsawyer@west-inc.com), Wildlife Biologist, WEST, Inc.
- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Pinedale Region, Wyoming Game and Fish Department

Data analysts:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.
- Andrew Telander, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Sawyer, H., J.A. Merkle, A.D. Middleton, S.P.H. Dwinnell, and K.L. Monteith. 2019. Migratory plasticity is not ubiquitous among large herbivores. Journal of Animal Ecology 88:450-460.
- Copeland, H. E., H. Sawyer, K. L. Monteith, D. E. Naugle, A. Pocewicz, N. Graf, and M. J. Kauffman. 2014. Conservation migratory mule deer through the umbrella of sage-grouse. Ecosphere 5:17



Sublette Mule Deer Corridor
Stopovers
WGFD Designated Corridor
MT
SD
ID
WY
NV
UT
CO
JOHN D. ROCKEFELLER JR., MEMORIAL PARK
GRAND TETON NATIONAL PARK
WIND RIVER RESERVATION
Tetonia
Driggs
Victor
Dubois
Pavillion
Alpine
Riverton
Thayne
Hudson
Pinedale
Lander
Afton
Marbleton
Big Piney
La Barge
Superior
Rock Springs
Green River
-111°
-110°40'
-110°20'
-110°
-109°40'
-109°20'
-109°
-108°40'
-108°20'
44°
43°40'
43°20'
43°
42°40'
42°20'
42°
41°40'
Mesa Herd routes
Ryegrass Herd routes
Red Desert Herd routes
WGFD Designated orridor
0 30 60 mi
0 20 40 mi

Wyoming | Mule Deer

Sublette Herd: WGFD Designated Corridor

The Sublette Herd Corridor was designated by the Wyoming Game and Fish Department in 2016. The Sublette Herd supports an estimated 20,000 - 25,000 animals and the corridors represent movements from three sub-populations, including the Ryegrass, Mesa, and Red Desert segments. Deer from the Ryegrass winter west of the Green River and migrate northwest into portions of the Wyoming Range, Salt River Range, and Hoback Basin. Deer from the Mesa segment winter east of the Green River and migrate northwest to summer ranges in the Wyoming Range, Snake River Range, Hoback Basin, and Gros Ventre Ranges. Deer in the Red Desert occupy winter ranges near Superior, WY just north of Interstate 80. These animals migrate nearly 150 miles between seasonal ranges, along a narrow corridor that leads across the Red Desert, along the base of the Wind River Range, and eventually into summer ranges around the Hoback Basin.

Corridor and Stopover Summary

Migration corridor area: 834,143 acres (WGFD designation)

Stopover area: 206,358 acres

Other Information

Agency contacts:

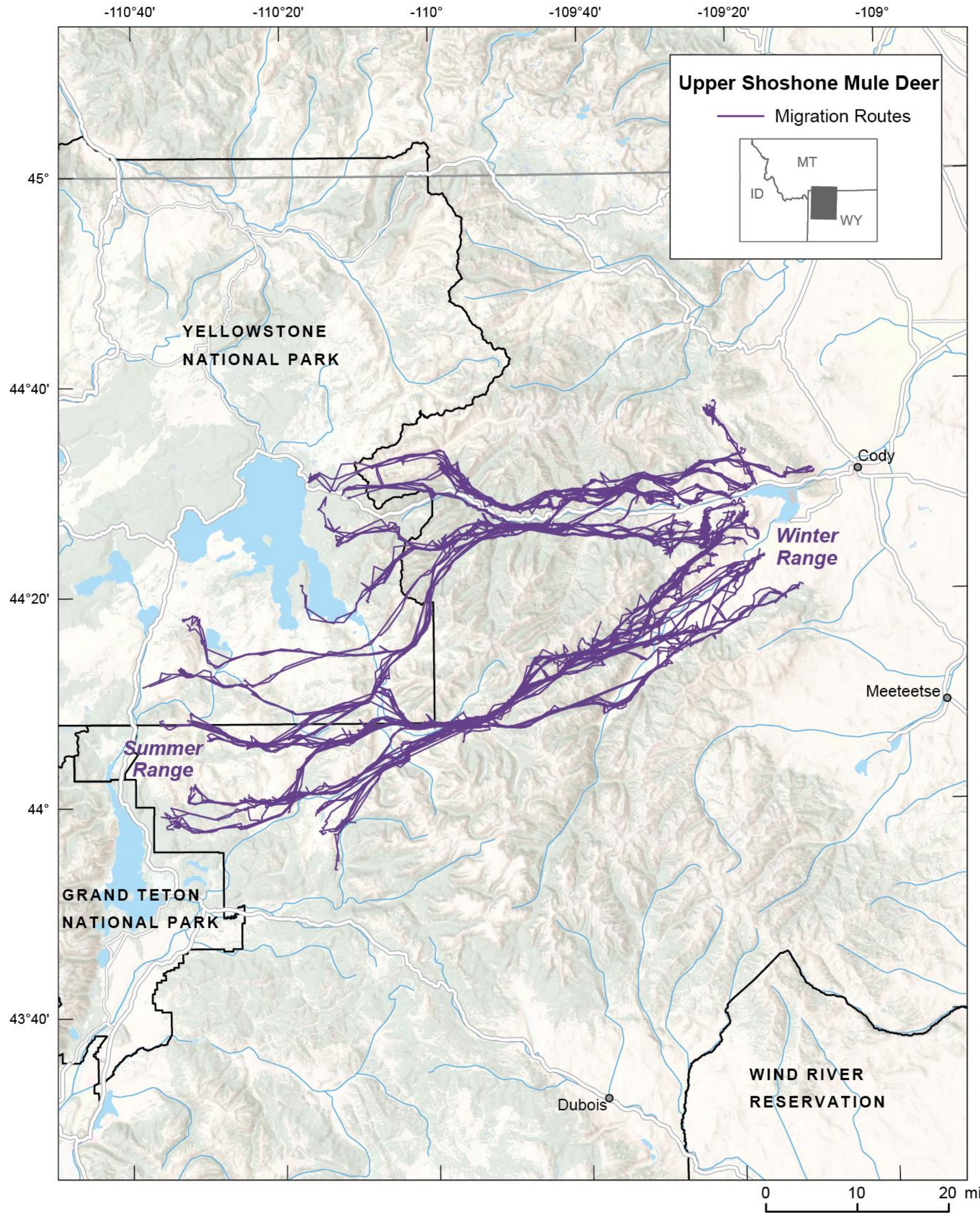
- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Pinedale Region, Wyoming Game and Fish Department
- Mark Zornes (mark.zornes@wyo.gov), Wildlife Management Coordinator, Green River Region, Wyoming Game and Fish Department

Data analyst:

- Hall Sawyer, Wildlife Biologist, WEST, Inc.

Reports and publications:

- Wyoming Game and Fish Department. 2017. Sublette Mule Deer Migration Corridor Assessment. Cheyenne, Wyoming, USA.
- Sawyer, H., A. D. Middleton, M. H. Hayes, M. J. Kauffman, and K. L. Monteith. 2016. The extra mile: ungulate migration distance alters the use of seasonal range and exposure to anthropogenic risk. Ecosphere 7(10):e01534.10.1002/ecs2.1534



-110°40'
-110°20'
-110°
-109°40'
-109°20'
-109°
45°
44°40'
44°20'
44°
43°40'
Upper Shoshone Mule Deer
Migration Routes
MT
ID
WY
YELLOWSTONE
NATIONAL PARK
Cody
Winter
Range
Meeteetse
Summer
Range
GRAND TETON
NATIONAL PARK
WIND RIVER
RESERVATION
Dubois
0
10
20 mi

Wyoming | Mule Deer

Upper Shoshone Mule Deer Migration Routes

Mule deer within the Upper Shoshone herd make a number of significant, long-distance migrations west into the core of the Greater Yellowstone Ecosystem. The longest is a 94-mile migration that originates at the mouth of the South Fork of the Shoshone River near Buffalo Bill Reservoir and ends at Jenny Lake in Grand Teton National Park. Deer in the Upper Shoshone herd winter in the lower-elevation sagebrush valleys of the South and North Fork of the Shoshone River. Each spring, an estimated 6,700 deer head west into the high-elevation, mountainous country of the Absaroka Range and then into Yellowstone National Park or Grand Teton National Park. These challenging journeys, an average of 53 miles long, cross rugged terrain with fast-moving rivers and steep mountain passes such as Deer Creek Pass (the highest) at 10,800 feet in elevation. These deer also navigate human-created obstacles, such as fences, housing developments, and US Highway 16, a major road into Yellowstone National Park.

Animal Capture and Data Collection

Sample size: 59 adult female mule deer
Relocation frequency: ~2 hours
Project duration: 2016 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 142 sequences from 55 individuals (69 spring sequences, 73 fall sequences)
- **Winter:** 142 sequences from 55 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 20 to June 7
- **Fall:** October 9 to October 29

Days migrating (mean):

- **Spring:** 21 days
- **Fall:** 23 days

Migration route length:

- **Min**: 11.8 miles
- **Mean**: 53.2 miles
- **Max**: 94.4 miles

Winter Use Summary

Winter use start and end date (median):

- December 28 to May 3

Days of winter use (mean): 96 days

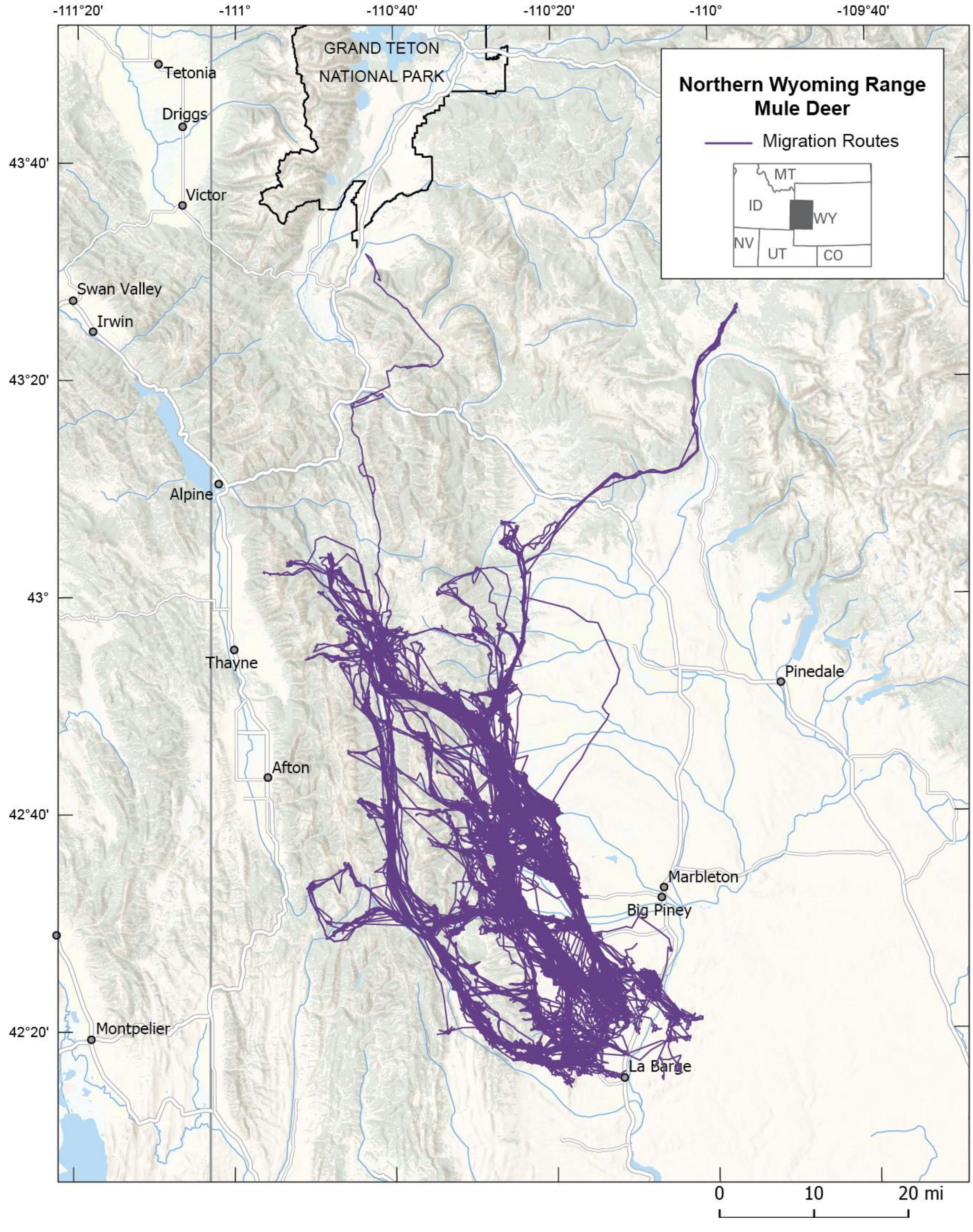
Other Information

Project contacts:

- Matthew Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming
- Corey Class (corey.class@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department
- Tony Mong (tony.mong@wyo.gov), Wildlife Biologist, Wyoming Game and Fish Department
- Sarah Dewey (sarah_dewey@nps.gov) , Wildlife Biologist, National Park Service

Data analyst:

- Julien Fattebert, Post Doctoral Researcher, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming



Northern Wyoming Range Mule Deer
Migration Routes
MT
ID
WY
NV
UT
CO
GRAND TETON
NATIONAL PARK
-111°20'
-111°
-110°40'
-110°20'
-110°
-109°40'
43°40'
43°20'
43°
42°40'
42°20'
Tetonia
Driggs
Victor
Swan Valley
Irwin
Alpine
Thayne
Afton
Montpelier
Pinedale
Marbleton
Big Piney
La Barge
0
10
20 mi

Wyoming | Mule Deer

Wyoming Range North Mule Deer Migration Routes

Mule deer in the northern Wyoming Range population use winter ranges in the Calpet area between the towns of Big Piney and LaBarge. These deer generally move northwesterly during spring to high-elevation summer ranges in the Salt River and Wyoming Ranges. Interchange with deer in the Sublette herd unit has been documented, with individuals migrating northwest into the Upper Green River and Upper Fish Creek drainages. At least one individual migrated 85 miles north and summered near the National Elk Refuge in Jackson. Challenges for Wyoming Range mule deer include energy development on winter ranges, vehicle collisions on US Highway 189 between LaBarge and Big Piney, severe winters leading to high episodic mortality, and disease.

Animal Capture and Data Collection

Sample size: 63 adult female mule deer
Relocation frequency: 2 – 5 hours
Project duration: 2013 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 271 sequences from 63 individuals (144 spring sequences, 127 fall sequences)
- **Winter:** 136 sequences from 65 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 22 to May 30
- **Fall:** October 17 to November 21

Days migrating (mean):

- **Spring:** 44 days
- **Fall:** 30 days

Migration route length:

- **Min**: 7 miles
- **Mean**: 40 miles
- **Max**: 85 miles

Winter Use Summary

Winter use start and end date (median):

- Nov 21 to March 22

Days of winter use (mean): 121 days

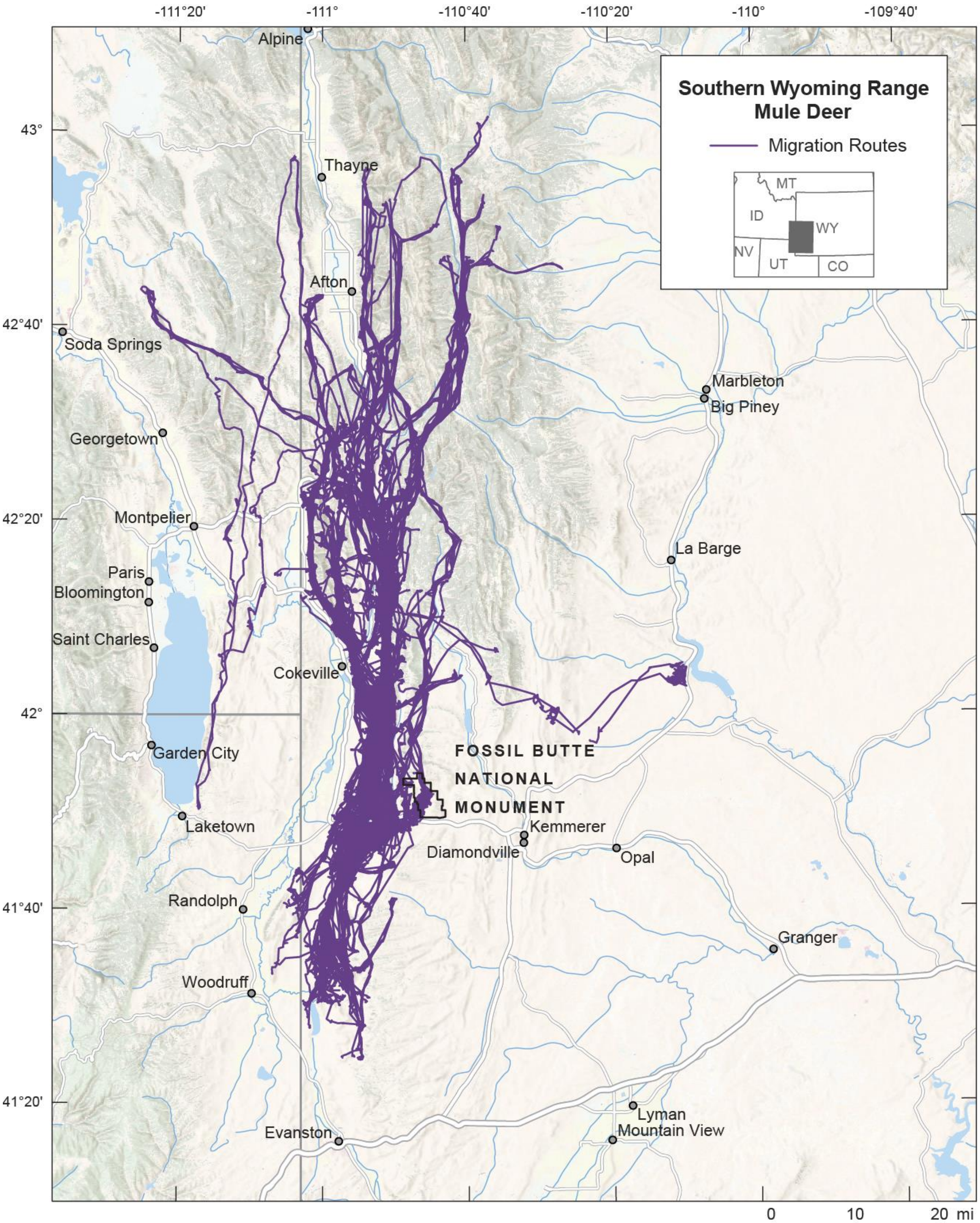
Other Information

Project contacts:

- Kevin Monteith (kevin.monteith@uwyo.edu), Associate Professor, University of Wyoming
- Gary Fralick (gary.fralick@wyo.gov) Wildife Biologist, Wyoming Game and Fish Department

Reports and publications:

- Dwinnell, S. P., Sawyer, H., Randall, J. E., Beck, J. L., Forbey, J. S., Fralick, G. L., & Monteith, K. L. (2019). Where to forage when afraid: Does perceived risk impair use of the foodscape?. *Ecological Applications 29(7),* e01972.
- Jakopak, R. P., Lasharr, T. N., Dwinnell, S. P., Fralick, G. L., & Monteith, K. L. (2019). Rapid acquisition of memory in a complex landscape by a mule deer. *Ecology 100(12),* e02854.
- Aikens, E. O., Kauffman, M. J., Merkle, J. A., Dwinnell, S. P., Fralick, G. L., & Monteith, K. L. (2017). The greenscape shapes surfing of resource waves in a large migratory herbivore. *Ecology Letters*, *20*(6), 741-750.



Southern Wyoming Range Mule Deer
Migration Routes
MT
ID
WY
NV
UT
CO
-111°20'
-111°
-110°40'
-110°20'
-110°
-109°40'
43°
42°40'
42°20'
42°
41°40'
41°20'
Alpine
Thayne
Afton
Soda Springs
Marbleton
Big Piney
Georgetown
Montpelier
La Barge
Paris
Bloomington
Saint Charles
Cokeville
Garden City
FOSSIL BUTTE
NATIONAL
MONUMENT
Laketown
Kemmerer
Diamondville
Opal
Randolph
Granger
Woodruff
Lyman
Mountain View
Evanston
0
10
20 mi

Wyoming | Mule Deer

Wyoming Range South Mule Deer Migration Routes

Mule deer in the southern Wyoming Range population winter north of Evanston in the relatively low mountains between the town of Kemmerer, Wyoming and Woodruff Narrows Reservoir along the Utah border. Many deer in this population migrate north over 100 miles to summer ranges in the Wyoming Range surrounding the town of Afton, Wyoming. Migrations in this population are not limited to Wyoming, with at least one deer summering in the Caribou Range in Idaho. Challenges for this population include highway and train mortality, especially along US Highway 30. A number of highway underpasses were constructed between 2001 to 2008 along US Highway 30 at Nugget Canyon, which has significantly reduced vehicle-caused mortality.

Animal Capture and Data Collection

Sample size: 63 adult female mule deer
Relocation frequency: 2 – 5 hours
Project duration: 2013 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)
Models derived from:

- **Migration:** 237 sequences from 63 individuals (129 spring sequences, 108 fall sequences)
- **Winter:** 140 sequences from 68 individuals

Route Summary

Migration start and end date (median):

- **Spring:** March 27 to May 17
- **Fall:** October 18 to December 5

Days migrating (mean):

- **Spring:** 50 days
- **Fall:** 37 days

Migration route length:

- **Min**: 9 miles
- **Mean**: 50 miles
- **Max**: 108 miles

Winter Use Summary

Winter use start and end date (median):

- Nov 7 to Mar 19

Days of winter use (mean): 132 days

Other Information

Project contacts:

- Kevin Monteith (kevin.monteith@uwyo.edu), Assistant Professor, University of Wyoming
- Gary Fralick (gary.fralick@wyo.gov), Wildife Biologist, Wyoming Game and Fish Department

Reports and publications:

- Dwinnell, S. P., Sawyer, H., Randall, J. E., Beck, J. L., Forbey, J. S., Fralick, G. L., & Monteith, K. L. 2019. Where to forage when afraid: Does perceived risk impair use of the foodscape? *Ecological Applications* 29: e01972.
- Jakopak, R. P., Lasharr, T. N., Dwinnell, S. P., Fralick, G. L., & Monteith, K. L. 2019. Rapid acquisition of memory in a complex landscape by a mule deer. *Ecology* 100:e02854.
- Aikens, E. O., Kauffman, M. J., Merkle, J. A., Dwinnell, S. P., Fralick, G. L., & Monteith, K. L. 2017. The greenscape shapes surfing of resource waves in a large migratory herbivore. *Ecology Letters* 20:741-750.

Pronghorn

Pronghorn (*Antilocapra americana*) are the only living ungulate endemic to North America. Their name means "American goat antelope" though they are neither from the goat or antelope family. Rather, they are the lone surviving member of the family Antilocapridae from the Pleistocene epoch (lasting from 2.6 million years to 11,700 years ago). They are uniquely suited to inhabit the open grasslands and sagebrush expanses of the American West. In these open environments, pronghorn evolved with now extinct saber toothed cat (*Smilodon spp*) and cheetahs (*Miracinonyx trumani),* evading predation by running at speeds up to 55 mph. Consequently, they are still the fastest land mammal in the western hemisphere.

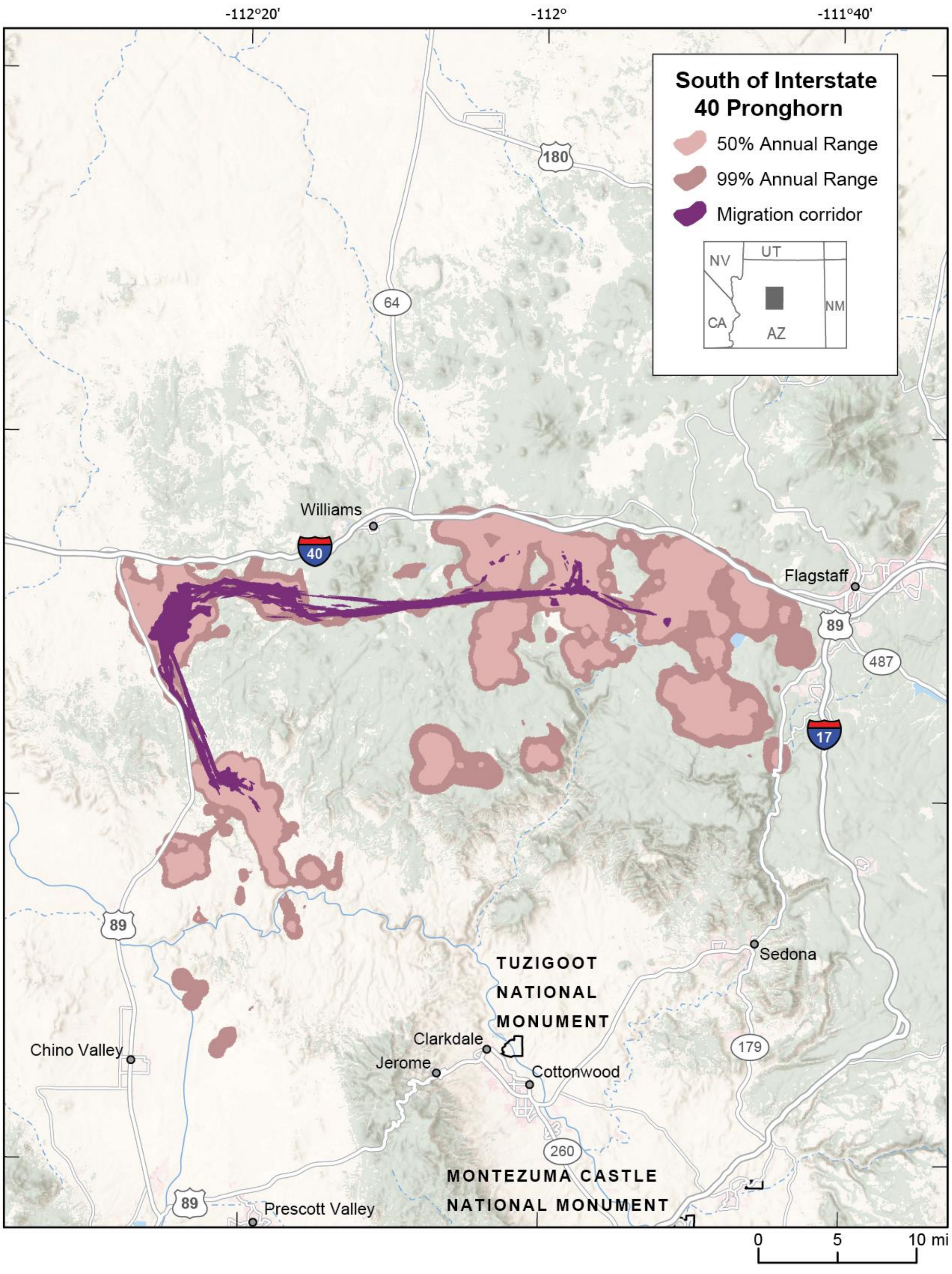
Pronghorn have specific habitat requirements and rely on open grasslands and sagebrush systems with a variety of grasses, forbs (flowering plants), and shrubs. In Wyoming, the quality of winter range is important to survival (Sawyer et al. 2005). There, pronghorn occupy low-elevation sagebrush basins, preferring areas with high sagebrush density, as sagebrush is their primary winter forage (Sawyer et al. 2005). In the southwest, moisture is an important component of habitat quality and is necessary for adequate forage and successful recruitment of fawns (Brown and Ockenfels 2007). Pronghorn mate in late summer and early fall. Females give birth to one or two fawns in late May or early June.

Figure 2. Current and historic range of pronghorn.

The movement patterns of pronghorn tend to be much broader and less predictable than other ungulate species. Pronghorn have a limited ability to navigate deep snow. Thus, they leave high-elevation summer ranges earlier than other ungulates to avoid getting caught in an early snowfall. In contrast to mule deer, which generally tend to use the same migratory routes year after year, pronghorn are facultative migrants, more like bison. Depending on factors such as snow depth, forage quality, and disturbance, pronghorn may migrate one year but not the next (Sawyer et al. 2005, Reinking et al. 2019). Further, many pronghorn populations contain a mix of resident, migratory, and nomadic individuals. Some of the more notable migratory populations include: i) the "Path of the Pronghorn", where animals move 150 miles between Grand Teton National Park and the Upper Green River Basin (Berger 2004), ii) the Northern Great Plains, where some pronghorn move nearly 250 miles between seasonal ranges in Montana and Canada (Tack et al. 2019), and iii) the Southwest, where pronghorn in Arizona migrate up to 189 km between Garland Prairie and the Verde River Valley.

Pronghorn historically ranged across western North America from Canada to central Mexico and numbered in the millions (Fig. 2). During the early 1900s, unregulated hunting drove their numbers to as low as 13,000. By the 1980s, sustained conservation and translocation efforts allowed their numbers to rebound to an estimated 800,000 pronghorn in western North America. Although still widely distributed, modern populations are smaller and more fragmented. Approximately 10,000 pronghorn inhabit Arizona and 400,000 reside in Wyoming. Pronghorn populations are struggling in some locations, and in Wyoming, population trends show local declines of up to 20% (Reinking et al. 2019).

Pronghorn face several conservation challenges. Increasing human development has restricted movement and connectivity, forcing pronghorn to navigate a web of fences, roads, and other anthropogenic disturbances (*e.g*., energy development). Recent research has documented the negative impacts that fencing and energy development can have on pronghorn populations, including avoidance, winter range abandonment, and loss of connectivity (Sawyer et al. 2005, Jones et al. 2019, Reinking et al. 2019). Fences are the densest anthropogenic feature of the western landscapes and can present a significant movement barrier for pronghorn because they rarely jump them (Jones et al. 2018). Habitat loss also threatens pronghorn populations. In the southwest, for example, moisture regimes and historic land-use practices have allowed juniper tree encroachment into former grasslands and savannahs, resulting in more fragmented blocks of pronghorn habitat (McKinney et al. 2008).



-112°20'
-112°
-111°40'
35°40'
35°20'
35°
34°40'
South of Interstate 40 Pronghorn
50% Annual Range
99% Annual Range
Migration corridor
NV
UT
CA
AZ
NM
180
64
Williams
40
Flagstaff
89
487
17
89
Sedona
TUZIGOOT NATIONAL MONUMENT
Clarkdale
Jerome
Cottonwood
Chino Valley
179
260
MONTEZUMA CASTLE NATIONAL MONUMENT
89
Prescott Valley
0
5
10 mi

Arizona | Pronghorn

South of Interstate 40 Pronghorn Migration Routes

Interest in the movement of pronghorn south of Arizona's Interstate 40 (I-40) began when telemetry data from 1999 – 2004 showed seasonal round-trip movements upwards of 100 miles. In 2018, high-resolution GPS location data confirmed persistence of this remarkable pronghorn migration. Unlike traditional summer-winter range dynamics, this pronghorn population uses a complex of several important seasonal ranges during their annual movements, which are connected by narrow corridors. The herd has high fidelity to these corridors, which elevates the importance of research and management efforts to conserve them. During the summer, these pronghorn inhabit large grasslands in the Garland Prairie area. During migration, animals parallel I-40 westward moving through densely forested habitat, then grasslands near Ash Fork, and finally moving south to winter range near Drake, AZ. In late March the migration is reversed. High-volume roads including I-40 and State Route 89 present the largest impediments to movement for this migration. These roads also appear to determine the herd's movement patterns along this corridor, as pronghorn rarely cross them.

Animal Capture and Data Collection

Sample size: 21 adult pronghorn
Relocation frequency: ~ 3 hours
Project duration: 2018 – 2019

Data Analysis

Annual range analysis: Brownian bridge movement models (Horne et al. 2007)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 34 sequences from 21 individuals (21 spring sequences, 13 fall sequences)

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** March 17 to March 31
- **Fall:** November 4 to December 22

Days migrating (mean):

- **Spring:** 18 days
- **Fall:** 80 days

Migration corridor length:

- **Min**: 20 miles
- **Mean**: 60 miles
- **Max**: 118 miles

Migration corridor area:

- 24,774 acres (high use)

Annual Range Summary

Start and end date (median):

- October 24, 2018 to November 1, 2019

Annual range (50% contour) area: 106,875 acres
Annual range (99% contour) area: 212,350 acres

Other Information

Project contacts:

- Jeff Gagnon (jgagnon@azgfd.gov), Wildlife Specialist Regional Supervisor, Arizona Game and Fish Department

Data analyst:

- Lucas Olson, Cooperative Mule Deer Biologist, Mule Deer Foundation

Reports and publications:

- Dodd, N., Gagnon, J., Sprague, S., Boe, S., Schweinsburg, R. (2010). Assessment of Pronghorn Movements and Strategies to Promote Highway Permeability: US Highway 89. Arizona Department of Transportation. Phoenix, AZ.
- Horne, J. S., Garton, E. O., Krone, S. M., & Lewis, J. S. (2007). Analyzing animal movements using Brownian bridges. Ecology.
- Theimer, T., Sprague, S. C., Eddy, E., & Benford, R. (2012). Genetic Variation of Pronghorn across US Route 89 and State Route 64. Final Report 659. Arizona Department of Transportation. Phoenix, AZ.

Elk

Elk currently range from Canada to the southern U.S. border and have also been reintroduced in small parts of their historic range across the eastern U.S. (Fig. 3). They are one of the largest terrestrial mammals in North America. Native American tribes refered to elk as ‘waapiti’ meaning “white rump.”

Elk prefer a mix of forested habitat that provides cover, and large, open areas for foraging. Elk are primarily grazers, consuming an average of 20 pounds of food per day. Elk feed preferentially on grasses and forbs, though they often switch to woody shrubs in winter (Toweill et al. 2002). Forests provide security cover that protects elk from predators and hunting. These habitats are especially important during the very early calf-rearing period. At this time, maternal elk with their calves are solitary before forming nursery groups with other adult females and their calves (Altmann 1952). Older females have also been documented seeking out heavy forest cover during hunting season (Thurfjell et al. 2017).

The breeding season occurs during late summer or early fall, when elk gather in mixed groups of females with calves and a few males. Males are renowned for their complex vocalizations, called bugling, they make during breeding (Rocky Mountain Elk Foundation 2020). In the fall, these haunting sounds echo through the landscape.

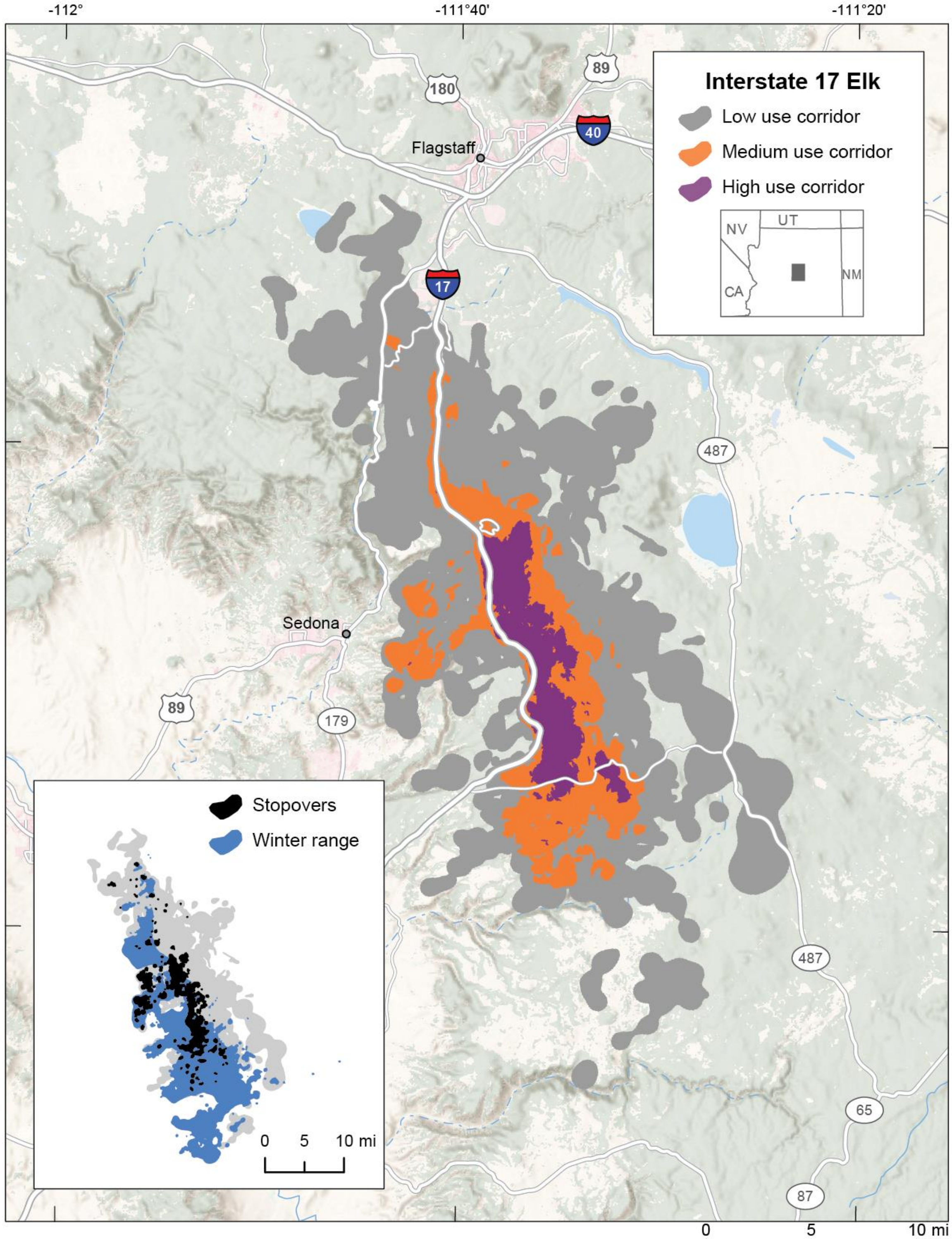
While most elk are seasonally migratory, the tule elk of coastal California and the Roosevelt elk of Oregon and Washington generally do not migrate (or migrate comparatively less than Rocky Mountain elk). They have less need to migrate, because their preferred habitat and weather conditions remain relatively constant year-round (Toweill et al. 2002). In regions that experience high snowfall and more severe winter conditions, Rocky Mountain elk typically winter in consolidated groups at lower elevations and migrate in various-sized groups to higher elevations once the snow melts (Altmann 1952, Morgantini and Hudson 1988).

Figure 3. Current and historic range of elk

Loss and fragmentation of winter range due to development, fencing, agriculture, and other intensive land uses threaten elk populations, and some states have implemented winter feeding programs as a result. Like many other large herbivores worldwide, these human influences have also impacted natural migratory behaviors of elk. Some populations have changed the patterns and timing or lost their migratory behavior altogether (Berg et al. 2019). As is observed in other elk subspecies, some Rocky Mountain elk have more recently developed resident behavior in habitats where it is more beneficial for them to do so. For example, irrigated crops and supplemental feeding can entice animals to stay longer or even year-round on low-elevation winter range rather than needing to migrate to their traditional summer range (Barker et al. 2018).

Prior to European settlement, an estimated 10 million elk ranged across the U.S. and parts of Canada – the largest range of any cervid in North America (Kauffman M. J. et al. 2018). European settlement, unregulated hunting, and habitat destruction severely reduced elk numbers to less than 100,000 individuals in the early 1900s. Only four subspecies have survived: Roosevelt elk (*C. c. roosevelti*), Rocky Mountain elk (*C. c. nelsoni*), tule elk (*C. c. nannodes*), and Manitoban elk (*C. c. manitobensis*). Two other subspecies, the Eastern elk (*C. c. canadensis*) and Merriam's elk (*C. c. merriami*), became extinct. Yellowstone National Park harbored one of the few remaining viable populations, and as early as 1912, Rocky Mountain elk from the park were reintroduced to locations all across the West.

Protection from hunting and near-eradication of large predators enabled a rapid recovery of elk populations (Mac et al. 1998). Today, approximately one million elk inhabit the western U.S., a handful of central and eastern states, and Canada (Rocky Mountain Elk Foundation 2020). Colorado is home to the largest elk population, followed by Montana, Idaho, and Oregon (Colorado Parks & Wildlife 2020, Idaho Department of Fish and Game 2020, Montana Fish Wildlife & Parks and 2020. 2020, Oregon Department of Fish & Wildlife 2020).



-112°
-111°40'
-111°20'
35°
34°40'
Interstate 17 Elk
Low use corridor
Medium use corridor
High use corridor
NV
UT
CA
NM
Flagstaff
Sedona
180
89
40
17
487
179
65
87
Stopovers
Winter range
0 5 10 mi
0 5 10 mi

Arizona | Elk

Interstate 17 Elk Herd Migration Routes

The Interstate 17 (I-17) elk herd primarily resides in Arizona's Game Management Units 6A and 11M south of Flagstaff. Their summer range consists of gentle topography with ponderosa pine forest and interspersed riparian-meadow habitat. Annually, the I-17 elk herd migrates an average of 24 miles to lower-elevation winter range dominated by pinyon-juniper habitat. This winter habitat is located along Oak Creek Canyon to the west and Wet Beaver Creek to the south. The I-17 elk herd faces high road mortality, averaging around 80 mortalities from vehicles per year and accounting for 75% of all wildlife-vehicle collisions in Arizona (Gagnon et al 2013). Despite the high incidence of elk-vehicle collisions along I-17, road crossings are generally prevented from the highway's high traffic volumes.

Animal Capture and Data Collection

Sample size: 47 elk

Relocation frequency: ~ 2 hours

Project duration: 2006 – 2014

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 106 sequences from 47 individuals (55 spring sequences, 51 fall sequences)
- **Winter:** 60 sequences from 44 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** March 14 to March /27
- **Fall:** Decemeber 5 to December 19

Average number of days migrating:

- **Spring:** 18 days
- **Fall:** 18 days

Migration corridor length:

- **Min**: 7 miles
- **Mean**: 24 miles
- **Max**: 58 miles

Migration corridor area:

- 429,139 acres (low use)
- 72,672 acres (medium use)
- 17,890 acres (high use)

Stopover area: 22,165 acres

Winter Range Summary

Winter start and end date (median):

- December 19 to December 13

Winter length (mean): 88 days

Winter range (50% contour) area: 122,290 acres

Other Information

Project contact:

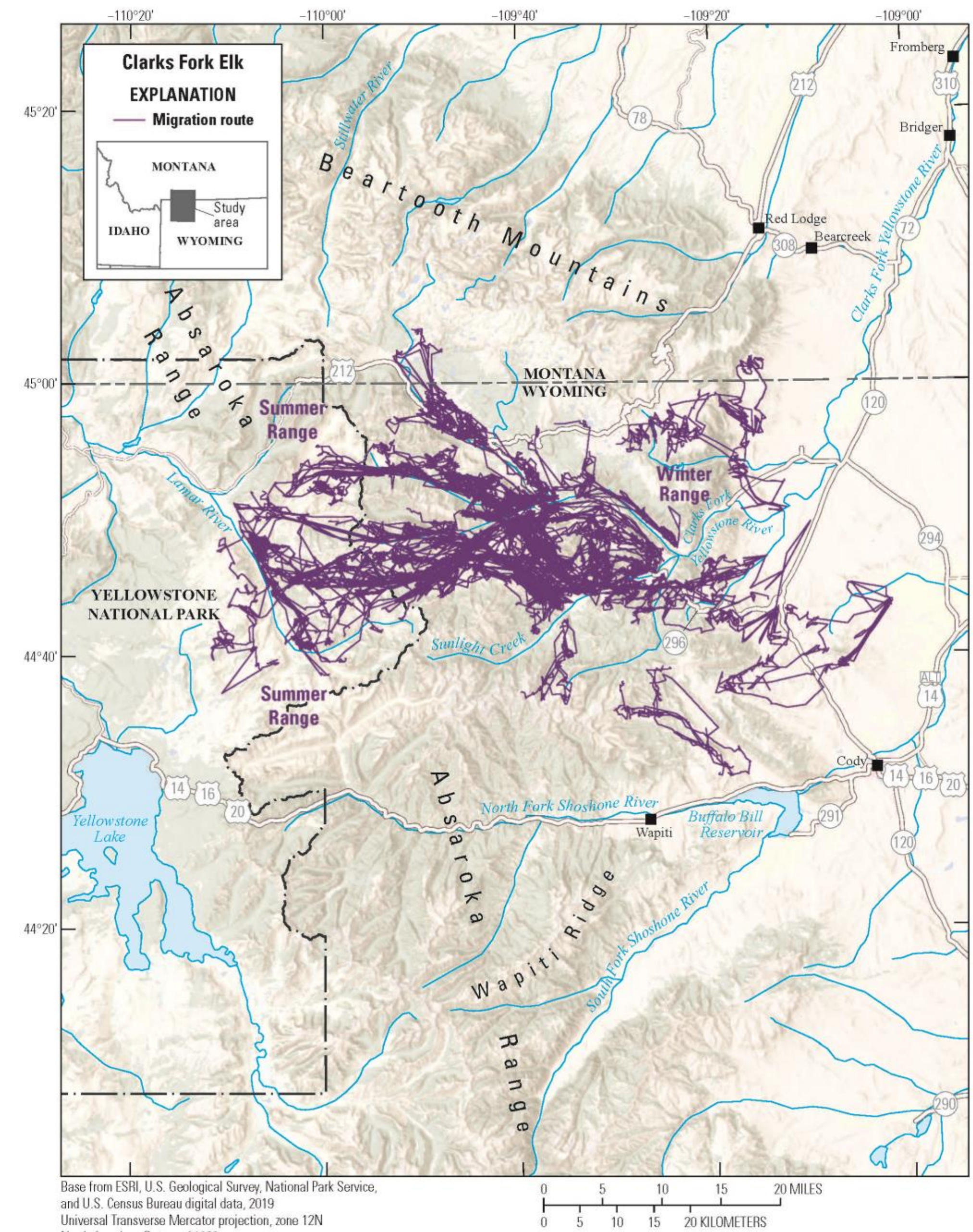
- Jeff Gagnon (jgagnon@azgfd.gov), Wildlife Specialist Regional Supervisor, Arizona Game and Fish Department

Data analyst:

- Lucas Olson, Cooperative Mule Deer Biologist, Mule Deer Foundation

Reports and publications:

- Gagnon, J. W., Dodd, N. L., Sprague, S. C., Nelson, R., Loberger, C., Boe, S., & Schweinsburg, R. E. (2013). Elk Movements Associated with a High-traffic Highway: Interstate 17. Arizona Game and Fish Department. Phoenix, AZ.
- Gagnon, J. W., Loberger, C. D., Sprague, S. C., Ogren, K. S., Boe, S. L., & Schweinsburg, R. E. (2015). Cost-effective approach to reducing collisions with elk by fencing between existing highway structures. Human-Wildlife Interactions, 9(2), 248–264.



Base from ESRI, U.S. Geological Survey, National Park Service, and U.S. Census Bureau digital data, 2019
Universal Transverse Mercator projection, zone 12N
North American Datum of 1983

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Wyoming | Elk

Clarks Fork Elk Migration Routes

Elk within the Clarks Fork herd migrate though some of the most rugged and remote terrain in the lower 48 states. The herd, which numbers around 3,000, winters in the Sunlight Basin and the Absaroka foothills just west of Cody, WY. Winter ranges are a mix of sagebrush hills and lodgepole pine forests, within expansive private ranchlands. During migration, animals travel an average one-way distance of 33 miles, with some animals migrating as far as 67 miles. Spring migrations off of winter range head west towards Yellowstone National Park, up several drainages that flow out of the Absaroka Mountains, including the Clarks Fork of the Yellowstone, Crandall Creek, and smaller creeks to the south. Summer ranges consist of alpine and subalpine meadows embedded within spruce-fir and lodgepole pine forest that are predominately within the Park. The Clarks Fork herd is partially migratory, with migrants and resident animals mixing on winter range (residents tend to winter along the foothills further east). Over the last decade, the migratory segment has seen poor recruitment due to drought and increased rates of predation by grizzly bears and wolves, while resident animals have been more productive and continue to expand to the east. Aside from the poor recruitment, the migrations are relatively safe because most of the routes traverse lands within the National Forest or National Park system.

Animal Capture and Data Collection

Sample size: 69 adult female elk

Relocation frequency: ~3 hours

Project duration: 2007 – 2010

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 107 sequences from 46 individuals (35 spring sequences, 72 fall sequences)
- **Winter:** 136 sequences from 66 individuals

Route Summary

Migration start and end date (median):

- **Spring:** June 2 to June 30
- **Fall:** October 21 to November 23

Days migrating (mean):

- **Spring:** 25 days
- **Fall:** 36 days

Migration route length:

- **Min**: 12 miles
- **Mean**: 33 miles
- **Max**: 67 miles

Winter Use Summary

Winter use start and end date (median):

- January 16 to April 16

Days of winter use (mean): 85 days

Other Information

Project contacts:

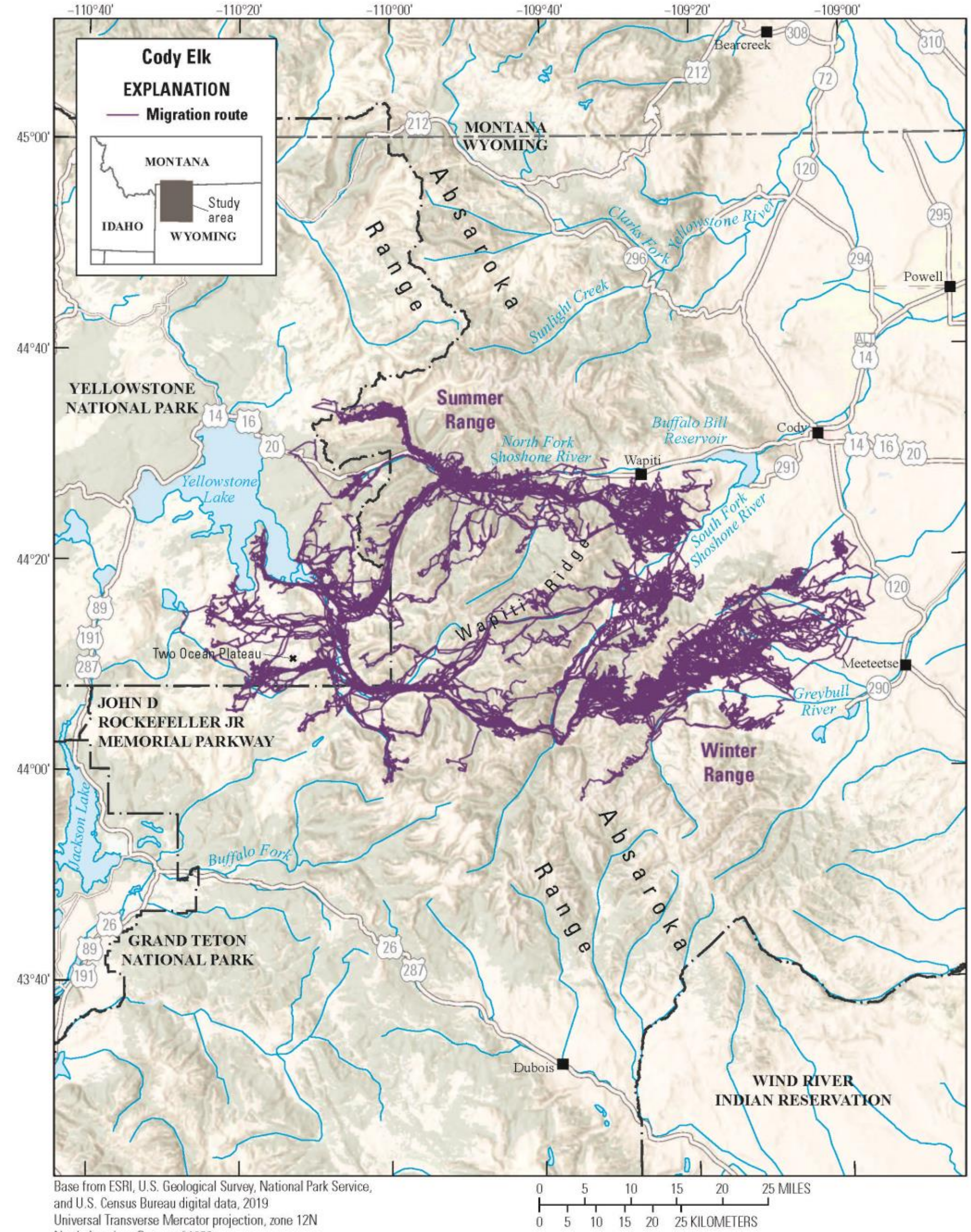
- Arthur Middleton (amiddleton@berkeley.edu), University of California Berkeley

Data analyst:

- Matthew Cuzzocreo, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Reports and publications:

- Middleton, A. D., Kauffman, M. J., McWhirter, D. E., Cook, J. G., Cook, R. C., Nelson, A. A., Jimenez, M. D. and Klaver, R. W. (2013). Animal migration amid shifting patterns of phenology and predation: lessons from a Yellowstone elk herd. *Ecology, 94*: 1245-1256. doi:10.1890/11-2298.1
- Nelson, A. A., Kauffman, M. J., Middleton, A. D., Jimenez, M. D., McWhirter, D. E., Barber, J. and Gerow, K. (2012). Elk migration patterns and human activity influence wolf habitat use in the Greater Yellowstone Ecosystem. *Ecological Applications, 22*: 2293-2307. doi:10.1890/11-1829.1



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Wyoming | Elk

Cody Elk Migration Routes

The Cody elk herd migrates across rugged country on the eastern side of the Absaroka Mountains near Cody, WY. This large herd of 6,000-7,000 animals winters in foothill habitat to the south and west of Cody. There are three core winter areas, namely the valleys formed by the North and South Fork of the Shoshone River and the headwaters of the Greybull River north to Meeteetse creek. In spring, the elk that winter along the North Fork of the Shoshone generally follow the river west towards the park, some of them branching up Eagle Creek and other tributaries. The elk that winter in the South Fork of the Shoshone follow it upstream in spring, eventually heading west up Ishawooa Creek and into the Thorofare and Yellowstone National Park. The elk the winter in the upper Greybull River drainage also summer in the Thorofare, but their journey is more arduous. From winter range, they climb nearly 3,000 vertical feet, up and over Needle Mountain, before descending down to the Shoshone River, only to climb again out of the river up to the Thorofare for summer. Some animals in this herd make migrations as far as 117 miles, while others make shorter migration; the mean migration length is 58 miles. Like the Clarks Fork herd, this herd is also partially migratory, with resident animals typically exhibiting higher levels of calf recruitment. Since most of the migrations of this herd cross public forest and park land, the most pressing management issue is to maintain strong collaborative relationships with the large landowners that privately manage much of the winter range these elk return to each autumn.

Animal Capture and Data Collection

Sample size: 29 adult female elk

Relocation frequency: ~1 hour

Project duration: 2014 – 2017

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 109 sequences from 28 individuals (63 spring sequences, 46 fall sequences)
- **Winter:** 46 sequences from 20 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 14 to June 24
- **Fall:** October 26 to November 29

Days migrating (mean):

- **Spring:** 41 days
- **Fall:** 46 days

Migration route length:

- **Min**: 19 miles
- **Mean**: 58 miles
- **Max**: 117 miles

Winter Use Summary

Winter use start and end date (median):

- January 14 to April 10

Days of winter use (mean): 64 days

Other Information

Project contacts:

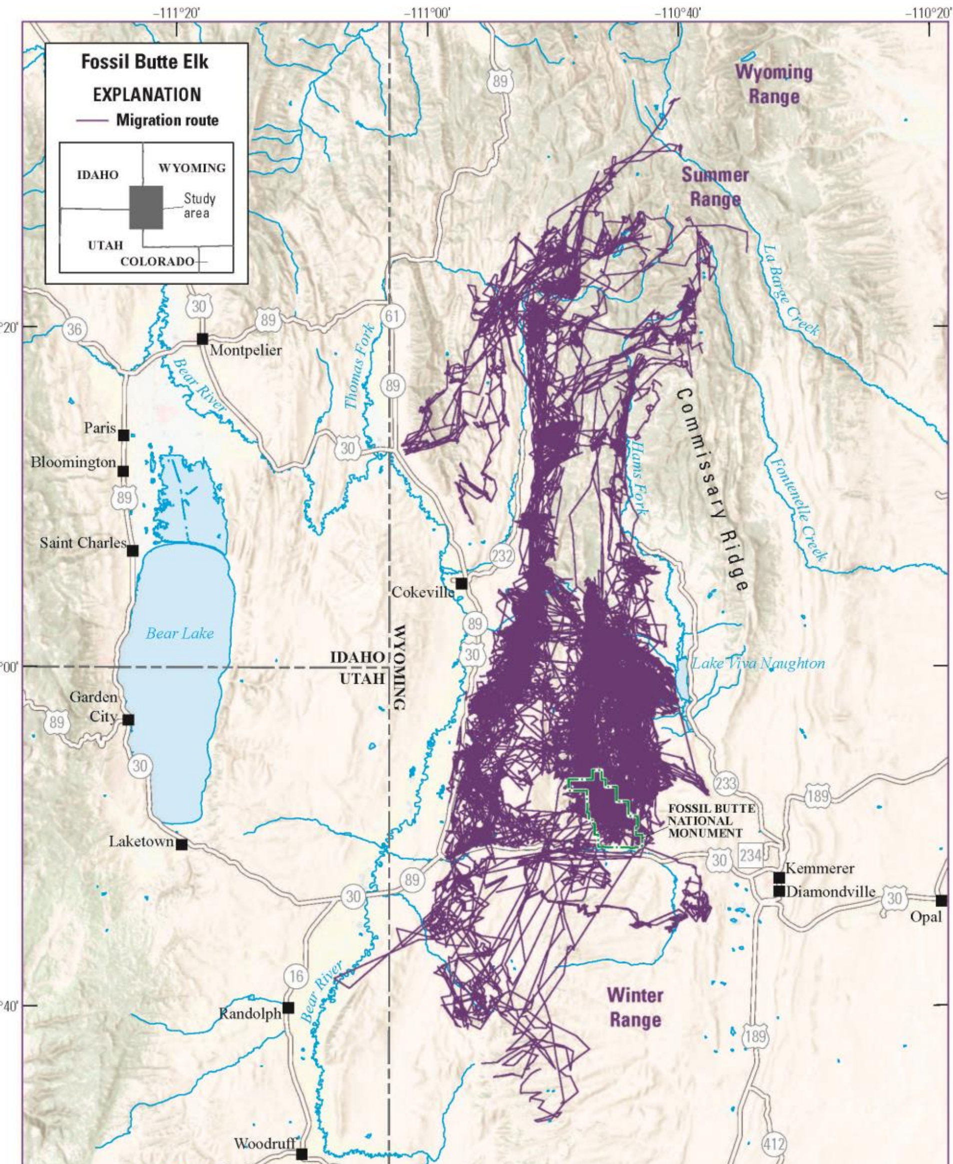
- Arthur Middleton (amiddleton@berkeley.edu), University of California Berkeley
- Matt Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Data analyst:

- Matthew Cuzzocreo, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Reports and publications:

- Nelson, A. A, Kauffman, M., Middleton, A., Jimenez, M., McWhirter, D., & Gerow, K. (2016). Native prey distribution and migration mediates wolf (*Canis lupus*) predation on domestic livestock in the Greater Yellowstone Ecosystem. *Canadian Journal of Zoology, 94*, 291-299. doi: 10.1139/cjz-2015-0094



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Wyoming | Elk

Fossil Butte Elk Migration Routes

The Fossil Butte elk population winters in the southern Wyoming Range between Fossil Butte National Monument and Cokeville. During spring, they migrate north short (11 miles) to medium (74 miles) distances. The segment of the elk population that winters near the Monument migrates into the Wyoming Range at the head of the Hams Fork and LaBarge Creek. This population tends to depart their summer ranges earlier in the fall, coincident with the beginning of archery season, where no hunting is allowed. Elk wintering closer to Cokeville migrate north in the spring along the western edge of the mountains into the Bridger Teton National Forest. Cokeville collared elk departed their summer ranges later, timed with weather events and vegetation senescence. Challenges to this elk herd include crossing US Highway 89.

Animal Capture and Data Collection

Sample size: 75 adult female elk

Relocation frequency: ~ 5 hours

Project duration: 2005 – 2010

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 207 sequences from 72 individuals (117 spring sequences, 90 fall sequences)
- **Winter:** 164 sequences from 75 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 15 to May 11
- **Fall:** August 11 to October 2

Days migrating (mean):

- **Spring:** 35 days
- **Fall:** 17 days

Migration route length:

- **Min**: 11.0 miles
- **Mean**: 29.6 miles
- **Max**: 74.9 miles

Winter Use Summary

Winter use start and end date (median):

- January 6 to March 8

Days of winter use (mean): 61 days

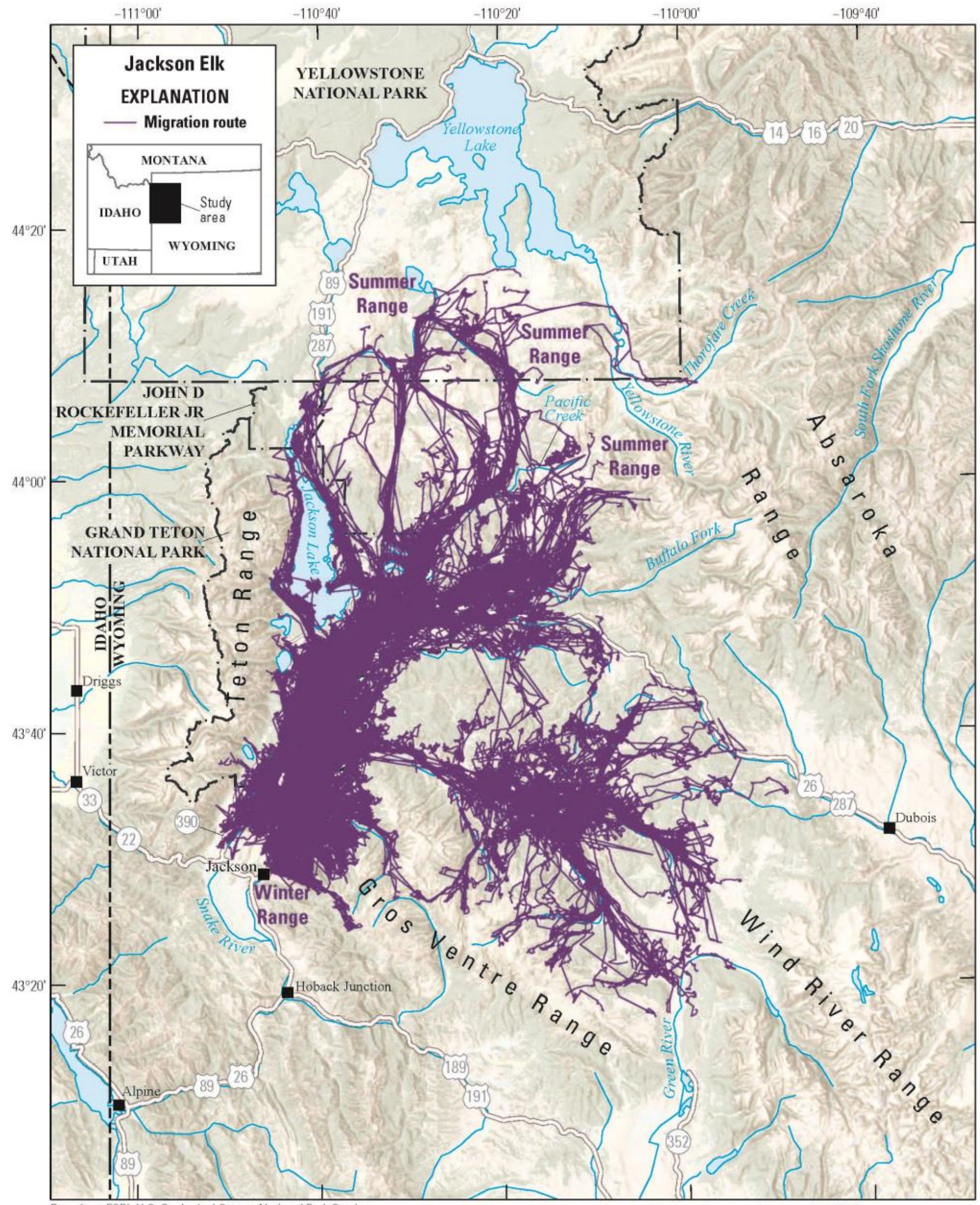
Other Information

Project contacts:

- Tabitha Graves (tgraves@usgs.gov), Research Ecologist, US Geological Survey, Northern Rocky Mountain Science Center, West Glacier, Montana
- Gary Fralick (gary.fralick@wyo.gov), Wildife Biologist, Wyoming Game and Fish Department

Data analyst:

- Julien Fattebert, Post Doctoral Researcher, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming



Base from ESRI, U.S. Geological Survey, National Park Service, and U.S. Census Bureau digital data, 2019
Universal Transverse Mercator projection, zone 12N
North American Datum of 1983

0 5 10 15 20 25 MILES
0 5 10 15 20 25 KILOMETERS

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Wyoming | Elk

Jackson Elk Migration Routes

Elk within the Jackson herd have been the focus of management for over a century. The herd, which numbers between 9,000 -13,000, winters in Jackson Hole. Most of the herd winters in the sagebrush basins and irrigated fields of the National Elk Refuge, with less than a quarter of the herd winters in the Gros Ventre drainage to the east. Migrating animals travel an average one-way distance of 39 miles, with some migrating as far as 168 miles. The herd is partially migratory, containing both migrant and residents. In spring, the migrants move north on either side of Jackson Lake, into the eastern foothills of the Teton Range and into the upper drainages of the Snake River and the southern portion of Yellowstone National Park. A smaller segment migrates east up the Gros Ventre River drainage and its upper tributaries. A study by the National Elk Refuge documented a long-term reduction in the migratory segment of the herd between 1978 and 2012. This trend is thought to be driven by declining calf recruitment of the migratory segment. Few obstacles to migration exist for this herd, which moves through a vast expanse of habitats managed by either the National Forest or National Park system.

Animal Capture and Data Collection

Sample size: 269 adult female elk

Relocation frequency: ~2 hours

Project duration: 2006 – 2018

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 595 sequences from 247 individuals (344 spring sequences, 251 fall sequences)
- **Winter:** 402 sequences from 261 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 25 to May 19
- **Fall:** November 1 to November 25

Days migrating (mean):

- **Spring:** 26 days
- **Fall:** 27 days

Migration route length:

- **Min**: 5 miles
- **Mean**: 39 miles
- **Max**: 168 miles

Winter Use Summary

Winter use start and end date (median):

- January 5 to April 6

Days of winter use (mean): 77 days

Other Information

Project contacts:

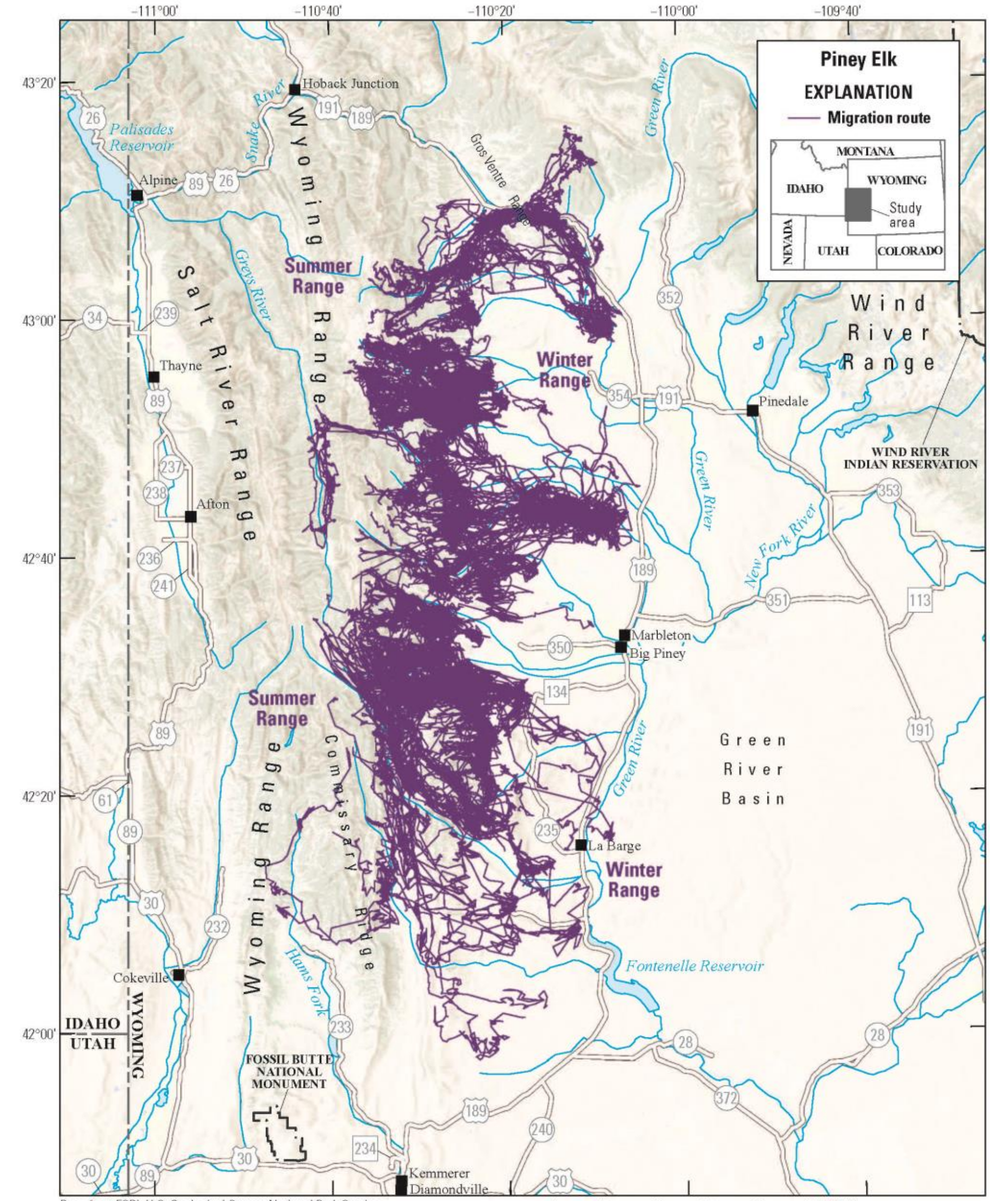
- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department
- Alyson Courtemanch (alyson.courtemanch@wyo.gov), Regional Biologist, Wyoming Game and Fish Department

Data analyst:

- Matthew Cuzzocreo, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Reports and publications:

- Cole, E. K., Foley, A. M., Warren, J. M., Smith, B. L., Dewey, S. R., Brimeyer, D. G., Fairbanks, W. S., Sawyer, H. and Cross, P. C. (2015), Changing migratory patterns in the Jackson elk herd. Journal of Wildlife Management, 79: 886.



Base from ESRI, U.S. Geological Survey, National Park Service, and U.S. Census Bureau digital data, 2019
Universal Transverse Mercator projection, zone 12N
North American Datum of 1983

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0 5 10 15 20 25 KILOMETERS

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Wyoming | Elk

Piney Elk Migration Routes

Migratory movements of elk within the Piney herd unit, a large area encompassing the eastern side of the Wyoming, include short (i.e., 10 miles) to medium (i.e., 30 miles) distance migrations. These elk migrate from low elevation elk feedgrounds and native winter ranges in the Upper Green River Basin to high elevation summer ranges in the Wyoming Range. In summer, some elk head further west into the Grey's River Basin from the Bench Corral and Forest Park feedgrounds. Challenges for Piney elk include energy development, especially in the southern portion of the herd unit.

Animal Capture and Data Collection

Sample size: 167 adult female elk

Relocation frequency: ~2 hours

Project duration: 1999 – 2001 and 2006 – 2019

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 306 sequences from 158 individuals (186 spring sequences, 120 fall sequences)
- **Winter:** 286 sequences from 166 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 17 to May 28
- **Fall:** November 5 to December 8

Days migrating (mean):

- **Spring:** 40 days
- **Fall:** 35 days

Migration route length:

- **Min**: 7 miles
- **Mean**: 47 miles
- **Max**: 164 miles

Winter Use Summary

Winter use start and end date (median):

- January 5 to April 8

Days of winter use (mean): 88 days

Other Information

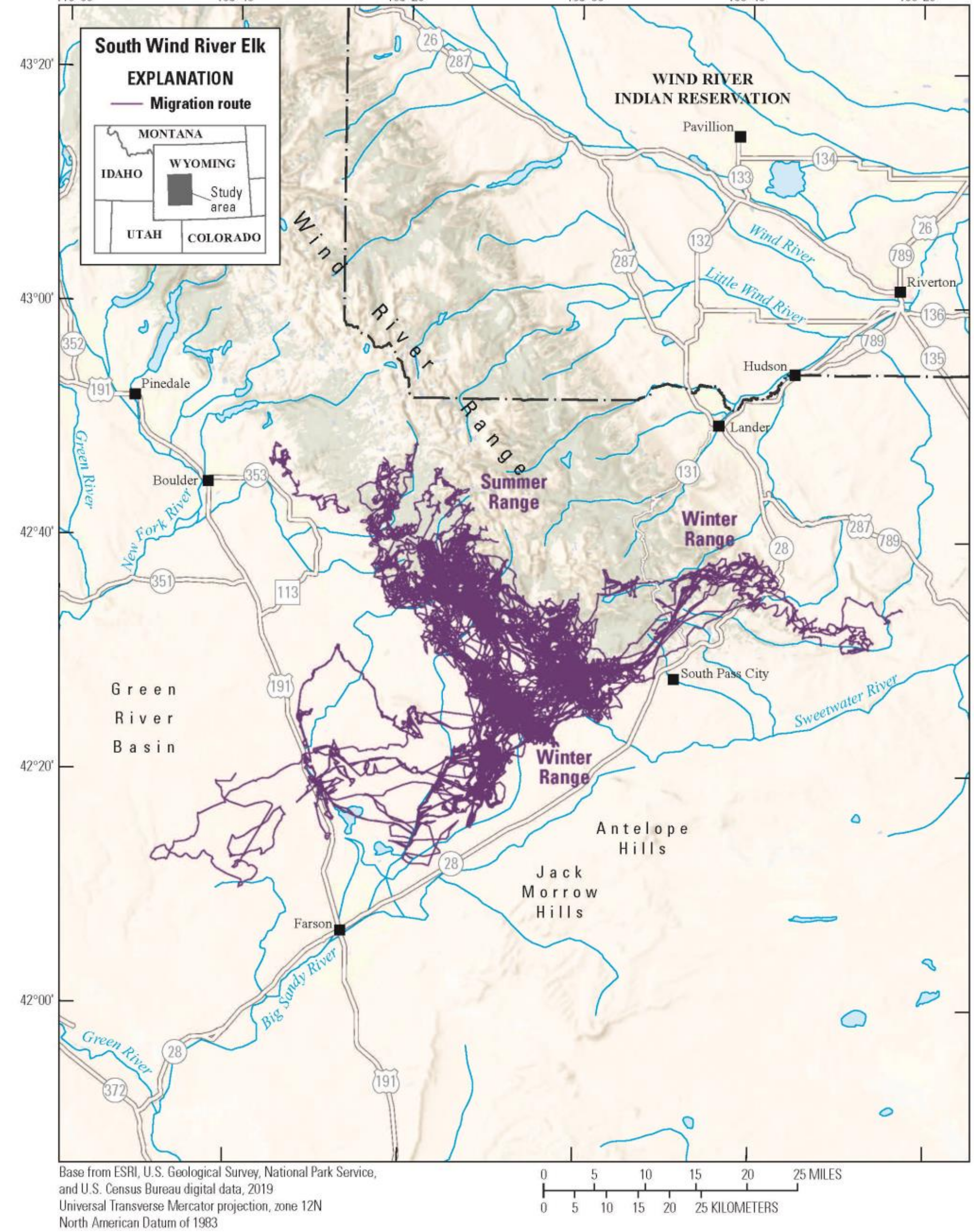
Project contacts:

- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department

Data analysts:

- Matthew Cuzzocreo, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

- Julien Fattebert, Post Doctoral Researcher, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming



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Wyoming | Elk

South Wind River Elk Migration Routes

Migratory movements of elk within the South Wind River herd include short (i.e., 10 miles) to medium (i.e., 40 miles) distance migrations generally from low elevation winter ranges along the foothills to high elevation summer ranges within the Wind River Range. Elk movements along the west side of the Winds trend southwesterly from summer ranges to winter ranges, largely dependent upon winter severity. Some individuals traverse the Winds and winter in Red Canyon. There are a number of challenges for South Wind River elk. These include increasing vehicle collisions on US Highways 287 and 789 from Twin Creek to Beaver Rim and over South Pass and potential future energy development along the western side of the Wind River Range where recent oil and gas leasing has occurred on Bureau of Land Management and State of Wyoming managed lands.

Animal Capture and Data Collection

Sample size: 24 adult female elk

Relocation frequency: ~2 hours

Project duration: 2008 – 2014

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 60 sequences from 24 individuals (30 spring sequences, 30 fall sequences)
- **Winter:** 21 sequences from 17 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 23 to June 23
- **Fall:** November 4 to December 10

Days migrating (mean):

- **Spring:** 51 days
- **Fall:** 42 days

Migration route length:

- **Min**: 14 miles
- **Mean**: 56 miles
- **Max**: 116 miles

Winter Use Summary

Winter use start and end date (median):

- January 27 to March 18

Days of winter use (mean): 56 days

Other Information

Project contacts:

- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department

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Data analyst:

- Matthew Cuzzocreo, Sr. Research Scientist, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Moose

As the second-largest mammal in North America, moose still occupy much of their historical range throughout Canada, Alaska, and some mainland U.S. states close to the Canadian border. The word, "moose" originates from an Algonquin term, "moosu", meaning, "he strips off". Throughout the U.S. Rocky Mountains, moose are considered relatively recent immigrants. They dispersed from northern Idaho and northwestern Montana during the mid-1800s to colonize areas of southern Idaho, Wyoming, and Utah. Wildlife officials in Colorado have reintroduced moose in four areas of the state since 1978 (Fig. 4).

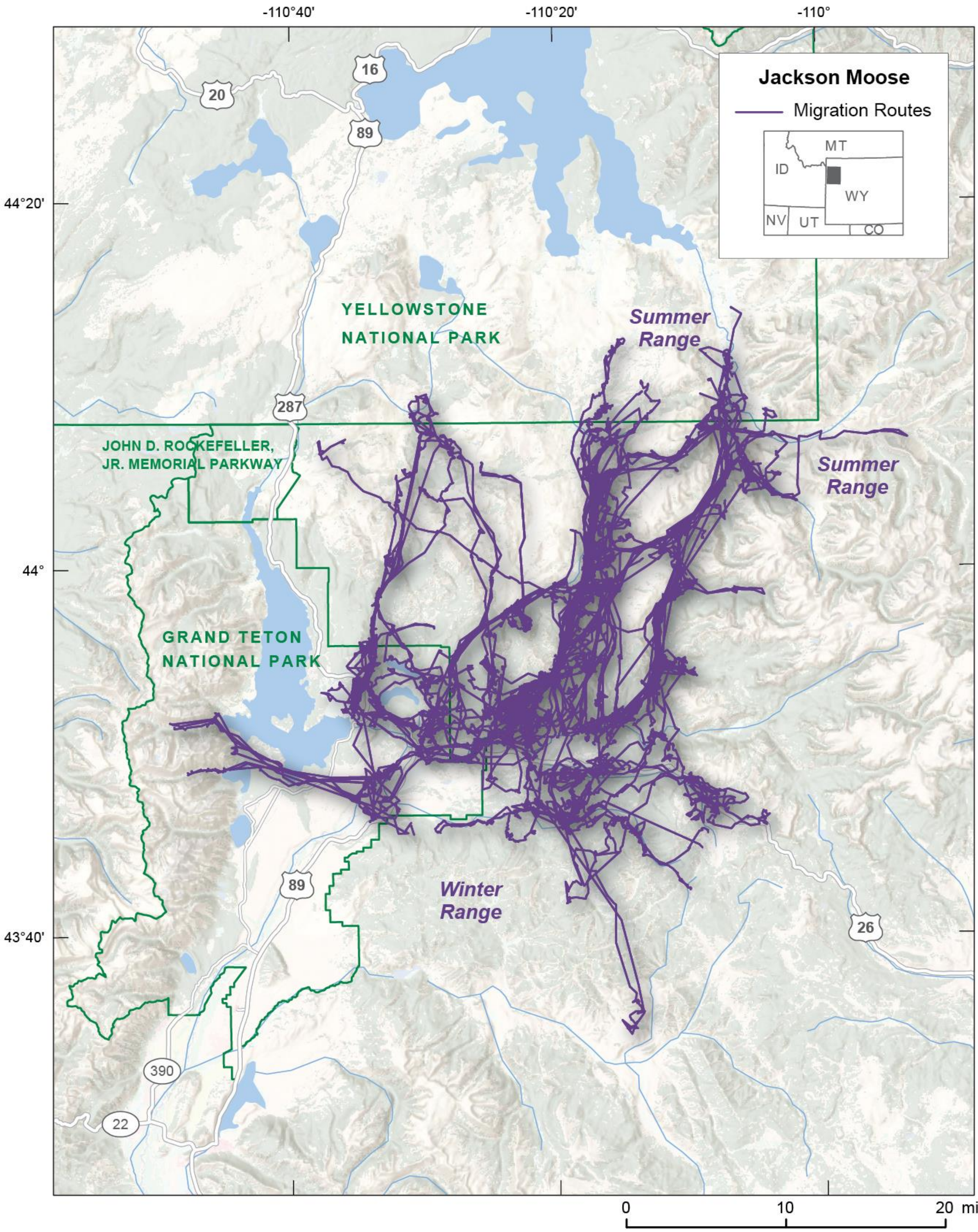
Figure 4. Current and historic range of moose.

Moose are browsing ruminants that typically occupy riparian and adjacent forested habitat. As a generalist browser, moose have specific salivary proteins that aid digestion of up to 40 pounds of forage a day (Randel 2009). They primarily forage on shrubs, young trees, and forbs. Moose are often observed feeding in habitat recently disturbed from fire or logging (i.e., 2 to 26 years), as regeneration stimulates the production of palatable and digestible plants (Nelson et al. 2008). Moose also forage in lakes and ponds to access mineral-rich aquatic plants, such as water lilies (*Nymphaea* spp.) and pond weed (*Potamogeton* spp.). Moose are excellent swimmers, and can dive up to 20 feet underwater (de Vos 1958). They use their long nasal passage to blow away mud burying aquatic plants they want to eat. During winter, moose shift their diets to the woody stems of willow (*Salix* spp.), aspen (*Populus tremuloides*), cottonwood (*Populus* spp.), and needles of fir (*Abies* spp.) trees. In some areas of the western U.S. (e.g., Utah and Wyoming), moose will forage in open areas containing bitterbrush (*Purshia tridentata*), oak (*Quercus* spp.), and chokecherry (*Prunus virginiana*).

Throughout the western U.S., moose migratory behavior ranges from entirely resident with overlapping summer and winter ranges (e.g., in northern Idaho), to largely migratory (e.g., Jackson population in northwest Wyoming). During spring and fall, migratory individuals will travel relatively short distances (5-30 miles) along drainages to their corresponding seasonal range (Becker 2008, Vartanian 2011, Oates 2016). Their large body size, long legs, and splaying hooves, combined with their dietary niche allow moose to survive harsh winter environments along a broad elevation range that deters most ungulate species. Consequently, moose can be facultative migrants, choosing whether to migrate relative to weather conditions, food availability, and vulnerability to predation.

Moose are sensitive to parasites and disease, especially during warm years (Samuel 2007). Winter ticks can aggregate by the thousands on a single moose, decreasing nutritional condition over winter through the loss of blood. Henningsen et al. (2012) documented the presence of a nematode parasite, *Elaeophora schneideri*, which is transmitted by horse flies and appears to have been at high prevalence near the Greater Yellowstone Ecosystem. Chronic wasting disease in moose has also been detected in western Wyoming, northwest Montana, and Colorado. Despite their impressive size and defensive capabilities, moose are also prey for a suite of large carnivores. Grizzly, and to a lesser extent, black bears, will prey on young moose calves during early summer (Ballard and Miller 1990, Gasaway et al. 1992), and wolves (Peterson 1977) and cougars (Ross and Jalkotzy 1996) will prey on all age classes year round.

Moose populations throughout the lower 48 states are thought to be in decline, due to a combination of interacting factors such as parasites, disease, predators, habitat change and warming temperatures (DeCesare et al. 2014, Timmermann and Rodgers 2017). Relative to elk and deer, moose are much less common throughout the Rocky Mountains. Nadeau et al. (2017) reported that population estimates of moose were 2,400 in Colorado, 10,000 in Idaho, 4,000 in Montana, 20 in Nevada, 70 in Oregon, 2,625 in Utah, 5,169 in Washington (as of 2017; Oyster et al. 2018), and 4,650 in Wyoming.



Jackson Moose
Migration Routes
MT
ID
WY
NV
UT
CO
-110°40'
-110°20'
-110°
44°20'
44°
43°40'
YELLOWSTONE NATIONAL PARK
JOHN D. ROCKEFELLER, JR. MEMORIAL PARKWAY
GRAND TETON NATIONAL PARK
Summer Range
Summer Range
Winter Range
16
20
89
287
89
26
390
22
0
10
20 mi

Wyoming | Moose

Jackson Moose Migration Routes

Moose in the Jackson herd make an elevational migration in the southern portion of the Greater Yellowstone Ecosystem. This small herd of approximately 500 animals winters primarily in the Buffalo Valley just east of Jackson Lake. During migration, animals travel an average one-way distance of 33 miles, with some animals migrating as far as 67 miles. In the spring, most moose migrate north into the Teton Wilderness or the southern extent of Yellowstone National Park. Summer ranges consist of a mix of conifers and riparian habitats along the upper watersheds that flow into the Snake River. Nearly all moose in this herd are migratory, with the herd sharing a common winter range then branching out in the spring to summer ranges to the north and west. Over the last decade or so, Jackson moose have experienced poor recruitment due to lingering effects of the 1988 fires, prolonged drought, and increased rates of predation by grizzly bears and wolves, although recruitment rates have been improving over the last five years or so. Despite the poor demographic performance, the migrations are relatively intact because most routes overlap public lands.

Animal Capture and Data Collection

Sample size: 41 adult moose

Relocation frequency: ~1 hour

Project duration: 2005 – 2010

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 94 sequences from 33 individuals (47 spring sequences, 47 fall sequences)
- **Winter:** 86 sequences from 41 individuals

Route Summary

Migration start and end date (median):

- **Spring:** May 11 to June 6
- **Fall:** November 7 to December 6

Days migrating (mean):

- **Spring:** 32 days
- **Fall:** 25 days

Migration route length:

- **Min**: 4.1 miles
- **Mean**: 25.2 miles
- **Max**: 68.5 miles

Winter Use Summary

Winter use start and end date (median):

- January 1 to March 18

Days of winter use (mean): 61 days

Other Information

Project contacts:

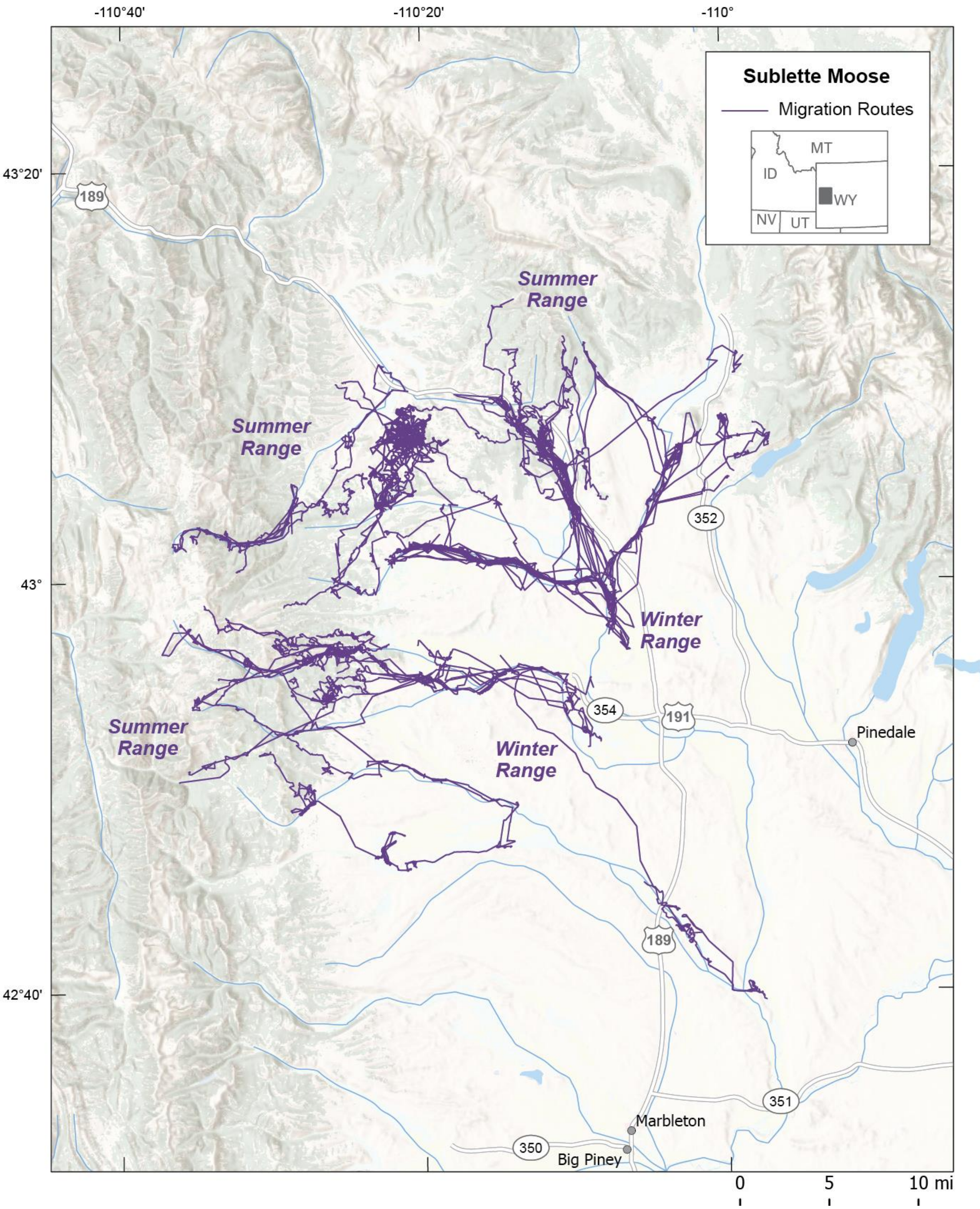
- Doug McWhirter (doug.mcwhirter@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department
- Alyson Courtemanch (alyson.courtemanch@wyo.gov), Regional Biologist, Wyoming Game and Fish Department
- Matthew Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Data analyst:

- Julien Fattebert, Post Doctoral Researcher, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Reports and publications:

- Oates, B.A., J.A. Merkle, M.J. Kauffman, S.R. Dewey, M.D. Jimenez, J.M. Vartanian, S.A. Becker, and J.R. Goheen. 2019. Antipredator response diminishes during periods of resource deficit for a large herbivore. Ecology 100: e02618.


-110°40'
-110°20'
-110°
43°20'
43°
42°40'
Sublette Moose
Migration Routes
MT
ID
WY
NV
UT
189
Summer Range
Summer Range
Summer Range
352
Winter Range
Winter Range
354
191
Pinedale
189
351
Marbleton
350
Big Piney
0
5
10 mi

Wyoming | Moose

Sublette Moose Migration Routes

The Sublette herd is the largest moose population in Wyoming, numbering approximately 1,000 individuals. This herd winters among the willow-dominated floodplains of the Green River Basin, primarily the eastern foothills of the Wyoming Range; some animals winter also in the Hoback Basin. As a partially migratory population, approximately half of the moose are resident, while migratory individuals travel short distances (14 miles on average, max 45 miles) primarily to tributaries of the Green and Hoback rivers. During spring, most migration routes originate on private ranchlands within the expansive willow bottoms of Beaver, Horse, Cottonwood, and Piney Creeks, as well as the aspen-conifer forests of the Hoback Basin. Migratory individuals typically travel upstream, within or near the same drainage that they spent the winter. During migration, moose encounter many fences, low-use county roads, and some must cross Highway 191 to reach their summer ranges. Migratory moose often arrive on summer ranges within the Bridger-Teton National Forest along the Wyoming Range front. Most summer ranges used by moose on the forest were withdrawn from oil and gas development due to the Wyoming Range Legacy Act passed by the U.S. Congress in 2009.

Animal Capture and Data Collection

Sample size: 54 adult moose

Relocation frequency: ~1 hour

Project duration: 2011 – 2014

Data Analysis

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 91 sequences from 41 individuals (54 spring sequences, 37 fall sequences)
- **Winter:** 42 sequences from 41 individuals

Route Summary

Migration start and end date (median):

- **Spring:** April 4 to April 24
- **Fall:** November 28 to Decemeber 13

Days migrating (mean):

- **Spring:** 36 days
- **Fall:** 25 days

Migration route length:

- **Min**: 3.7 miles
- **Mean**: 14.4 miles
- **Max**: 45.7 miles

Winter Use Summary

Winter use start and end date (median):

- January 15 to March 2

Days of winter use (mean): 39 days

Other Information

Project contacts:

- Brandon Scurlock (brandon.scurlock@wyo.gov), Wildlife Management Coordinator, Wyoming Game and Fish Department
- Matthew Kauffman (mkauffm1@uwyo.edu), US Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Data analyst:

- Julien Fattebert, Post Doctoral Researcher, Wyoming Cooperative Fish and Wildlife Research Unit, Department of Zoology and Physiology, University of Wyoming

Reports and Publications:

- Oates, B. A., K. L. Monteith, J. R. Goheen, J. A. Merkle, G. L. Fralick, A. B. Courtemanch, S. R. Dewey, M. D. Jimenez, D. W. Smith, D. R. Stahler, J. M. Vartanian, S. A. Becker, and M. J. Kauffman. In review. Spatiotemporal variability in resource limitation and predator density limits population growth of a large herbivore. Frontiers in Ecology and Evolution

Bison

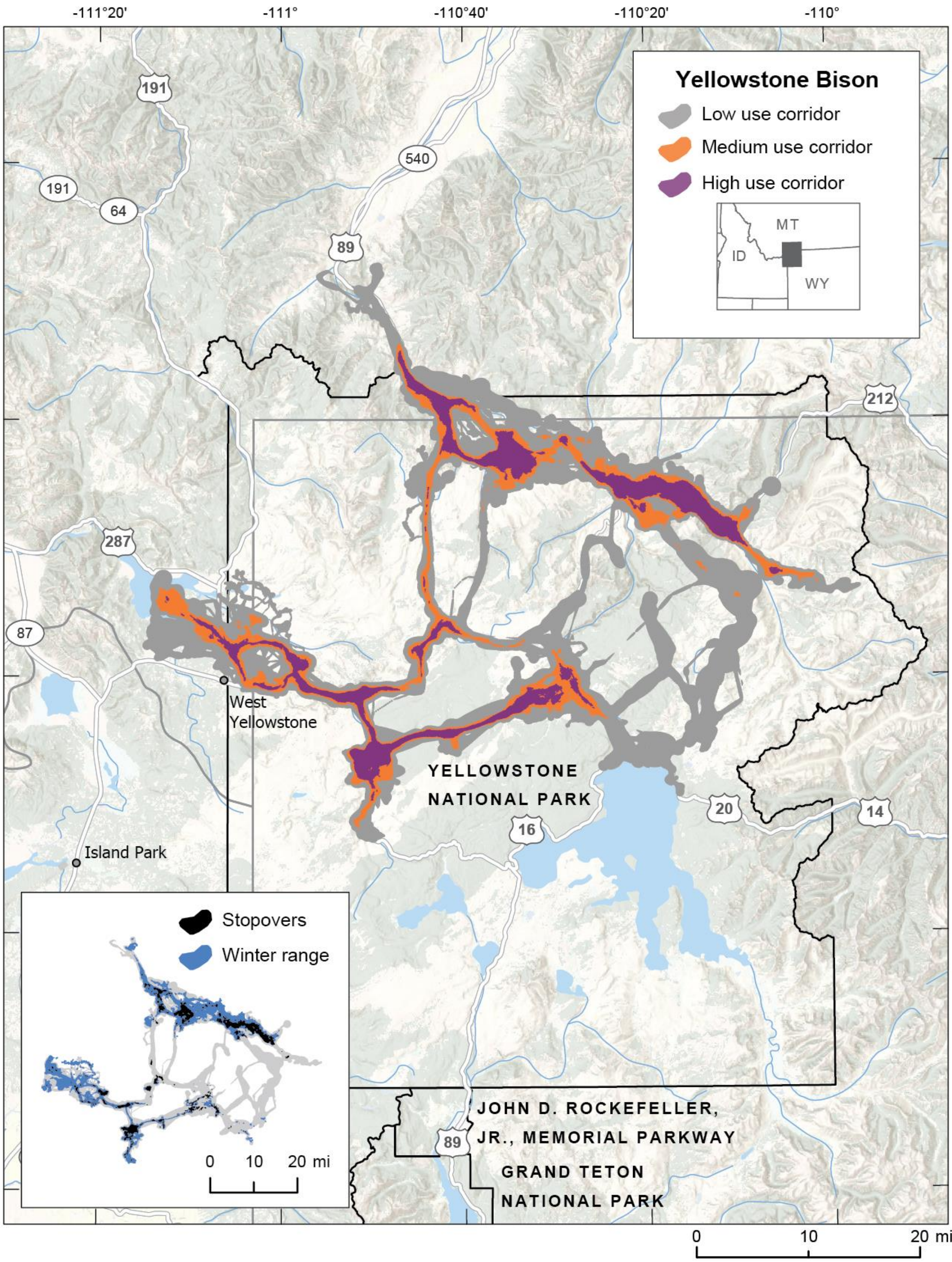
Bison (*Bison bison*) are the largest terrestrial mammal in North America. Males can weigh 2,000 lbs, reaching nearly double the size of females (U.S. Department of the Interior 2016). Thirty to 50 million plains bison once ranged over nine million km^2, encompassing the largest area of any large herbivore native to North America. Just 200 years ago, bison moved across the Great Plains and montane grasslands in vast herds of up to 10,000 individuals, serving as a major ecological keystone species (Wildlife Conservation Society 2007).

When good forage is available, bison prefer highly nutritious sedges and grasses. Such forage may be available in some ecosystems or become occasionally available through regeneration after fire and during spring green-up. In addition, bison can create their own 'grazing lawns'. By continuously foraging, urinating, defecating, and removing older, dead plants in an area, they essentially cultivate their own lawns of high-quality grasses (McNaughton 1984, Geremia et al. 2019). Like other ungulate species, migratory bison follow the wave of emerging green forage that moves up in elevation as spring progresses, snow melts, and temperatures warm. They then move back to low elevations when snow accumulates in the mountains in late winter. These behaviors are limited, however, by the area that most bison are allowed to occupy in the modern era. Thus, many bison, wild and in captivity, have become bulk feeders which spend 9-11 hours each day eating large amounts of weeds and low-quality grasses.

Figure 5. Current and historic range of bison.

Currently, intense management constrains most bison herds to relatively small, fenced-in areas, restricting natural migratory behavior. Some exceptions include the free-roaming Henry Mountains herd in Utah and the Wind Cave herd in South Dakota. There are also several free-roaming herds in Canada, including Prince Albert National Park (Saskatchewan), Wood Buffalo National Park (Alberta and Northwest Territories), and Banff and Elk Island National Parks (Alberta). The most iconic free-roaming bison are the 5,000 animals that reside mostly within Yellowstone National Park. Over the last century, individuals in this population have learned to migrate up to 60 miles (Geremia et al. 2019) and can now be considered the last truly migratory herd. The migratory movements of Yellowstone bison are also truncated, however. They are not allowed to move freely outside the park over concerns about human safety, disease transmission, conflicts with domestic livestock, and protection of property (National Park Service 2020).

Overhunting virtually eliminated bison, and by 1900 only a few hundred individuals remained. Although bison numbers are generally increasing, with over half a million alive today, the number of bison in herds that still serve a functional role in ecosystems has not changed for decades. Many biologists (including geneticists) agree that bison herds should be large (thousands of individuals), allowed to move over thousands of square kilometers, and be exposed to natural predators such as wolves, in order to serve their ecological role on the landscape. However, only a small fraction of the bison alive today reside in what are called conservation herds – small herds that were saved and protected and that are managed at less than 1,000 individuals in areas less than 2,000 km^2.


-111°20'
-111°
-110°40'
-110°20'
-110°
45°20'
45°
44°40'
44°20'
44°
Yellowstone Bison
Low use corridor
Medium use corridor
High use corridor
MT
ID
WY
191
540
191
64
89
212
287
87
West Yellowstone
YELLOWSTONE NATIONAL PARK
20
14
16
Island Park
Stopovers
Winter range
0 10 20 mi
JOHN D. ROCKEFELLER, JR., MEMORIAL PARKWAY
89
GRAND TETON NATIONAL PARK
0 10 20 mi

Yellowstone | Bison

Plains bison in Yellowstone National Park represent one of the last ecologically relevant populations in North America. Although bison are mainly confined to park boundaries, individuals migrate up to 80 miles from lower elevations just outside the park to higher elevations in the central part of the park. There are three major bison migration routes within Yellowstone National Park: North, Central-West, and Central-North. Bison don't preemptively migrate to avoid deep snow in autumn. Instead they "play the winter," pushing a bit farther down the valleys with each snow storm and sometimes lingering halfway for weeks or even months. Most Yellowstone bison have two migration routes—one they use in light winters, and an extended version they use during heavy winters. If snow remains thin, they stay close to their summer ranges deep inside Yellowstone. When snow piles up, bison head down river, moving to and beyond the park boundaries. While multi-agency efforts are being made to accommodate these migrations, bison are still restricted to Yellowstone National Park and limited to areas just outside the park. Outside the park, bison are permitted on a small region near Gardiner and West Yellowstone, Montana, as well as near east entrance, near Cody, Wyoming.

Animal Capture and Data Collection

Sample size: 92 female bison
Relocation frequency: ~ 1 hour
Project duration: 2004 - 2017

Data Analysis

Corridor, stopover and winter range analysis: Brownian bridge movement models (Sawyer et al. 2009)

Delineation of migration periods: Net Squared Displacement (Bunnefeld et al. 2011)

Models derived from:

- **Migration:** 159 sequences from 92 individuals (55 spring sequences, 104 fall sequences)
- **Winter:** 254 sequences from 95 individuals

Corridor and Stopover Summary

Migration start and end date (median):

- **Spring:** April 12th to June 20th
- **Fall:** February 19th to April 5th

Days migrating (mean):

- **Spring:** 63 days
- **Fall:** 42 days

Migration corridor length:

- **Min**: 21 miles
- **Mean**: 57 miles
- **Max**: 81 miles

Migration corridor area:

- 857,091 acres (low use)
- 177,739 acres (medium use)
- 57,327 acres (high use)

Stopover area: 39,882 acres

Winter Range Summary

Winter start and end date (median):

- March 27th to April 20th

Days of winter use (mean): 28 days
Winter range (50% contour) area: 149,397 acres

Other Information

Project contacts:

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Data analyst:

- Jerod Merkle, Assistant Professor, University of Wyoming

Reports and publications:

- Geremia, C., White, P. J., Wallen, R. L., Watson, F. G., Treanor, J. J., Borkowski, J., and Crabtree, R. L. (2011). Predicting bison migration out of Yellowstone National Park using Bayesian models. PLoS one, 6(2), e16848.
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Appendix 1. Methods

Corridors and Stopovers

Extracting and mapping migration sequences
To identify spring and fall migration start and end dates for a given individual in a given year, we visually inspected the Net Squared Displacement (NSD) curve (Bunnefeld et al. 2011, Bastille-Rousseau et al. 2016) alongside digital maps of the animal's movement trajectory (Merkle et al. 2017). The NSD represents the square of the straight-line distance between any GPS location of an animal's movement trajectory and a point within the animal's winter range. When an animal stays within a defined home range, the NSD varies relatively little over time as the animal travels. However, when an animal migrates away from its winter range, the NSD of each successive location increases until it settles in its summer range (Fig. 1). The days with clear breakpoints in the NSD curves represent the start and end dates for migration and were used to define migration sequences for spring and fall migration. Migration paths were mapped by joining successive GPS locations within each given migration sequence.

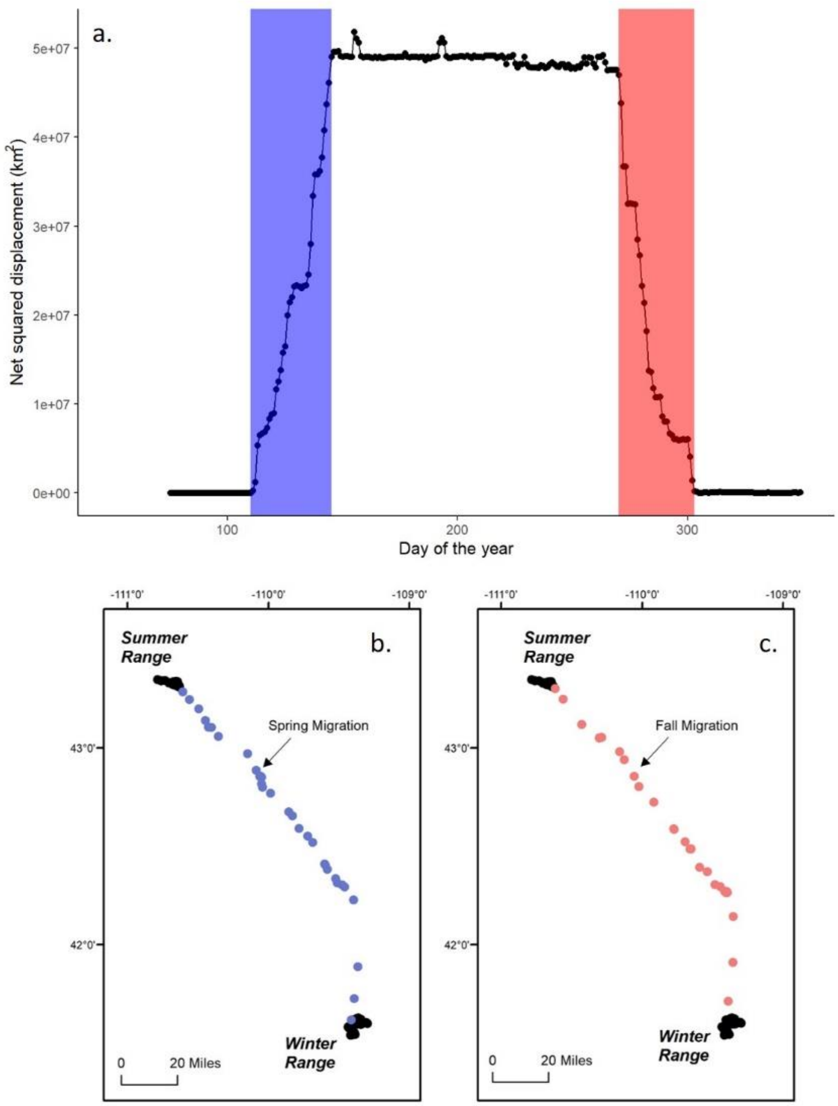

Figure 1. Example of Net Squared Displacement (NSD) analysis to identify migration sequences. Breakpoints in the NSD curve provide the start and end dates for the spring migration (in blue) when an animal migrates away from its winter range to its summer range, and the fall migration (in red) when an animal leaves its summer range and returns to its winter range (a). The corresponding GPS fixes are highlighted on the map insets for the spring migration (b) and the fall migration (c), respectively. For ease of readability, only 1 GPS fix per day is shown.

Calculating probability of use with Brownian Bridge Movement Models

Once migration sequences were extracted for each individual-year, we used a Brownian Bridge Movement Model (BBMM) (Horne et al. 2007) to estimate the probability of where the animal could have traveled during its migration (i.e., utilization distribution, hereafter, UD). The UD provides a heat map (probability) of use for each migration sequence. Thus, the UD estimates width of the movement path around the straight line between two successive locations, and can therefore be used to identify migration corridors (Sawyer et al. 2009) and the stopover sites where animals spent extended time foraging along their movement path (Sawyer and Kauffman 2011).

Using a grid with 50-m resolution, we calculated a BBMM for each migration sequence. When GPS collars mixed fixes, and there were breaks in the sequential data above an 8-hour time lag, we did not build a bridge between them. A key parameter of the BBMM is the Brownian Motion Variance (BMV), which provides an index of the mobility of the particular animal under observation (Horne et al. 2007). An empirical estimate of the BMV was obtained following the methods of Horne et al. (2007) from the location data used to construct each BBMM. Thus a unique BMV was estimated for each migration sequence. We did not include migration sequences with a BMV $\geq$ 8,000, because subsequent visualizations of the heat map generated from BBMMs with large BMV values poorly represented the observed migration trajectory.

Variations of the method: sparse data and fixed motion variance

BBMM performs poorly when location data are sparse – i.e., when GPS fixes are not taken very often. In these cases, there is a higher uncertainty of the animal's movement path between successive GPS fixes (Horne et al. 2007, Benhamou 2011). Fitting a BBMM to sparse empirical data inflates the estimate of the BMV, which leads to overestimates of the corridor width and area. This limits the application of BBMM modeling for corridor delineation to datasets with fix rates of less than every 3 to 5 hours. Yet, many datasets on ungulate movements are collected using 'life cycle' collars that log a GPS fix every 13 hours.

To facilitate corridor analyses of migration sequences collected with life-cycle collars, we developed a modification of the traditional BBMM approach. Instead of estimating the BMV empirically for each migration sequence as discussed above, we provided the BBMM code with a fixed value of motion variance (Fixed Motion Variance, hereafter, FMV) for all migration sequences in a given population. Our method, discussed in detail in the subsequent paragraph, provided estimates of corridor area that were comparable to using typical 2-hour GPS collar fix rates.

To estimate biologically meaningful FMV values for elk and mule deer, we tested a range of values against those generated from the standard 2-hour BBMM approach described above. For our analysis, we identified three mule deer herds, and three elk herds with GPS locations at 2-hour intervals. We subset the datasets to one fix every 12 hours as a proxy for life-cycle collar data. We calculated individual probability of use as well as population-level migration corridors on the original 2-hour data as a baseline 'truth' (see above). We then calculated individual probability of use and population-level migration corridors on the thinned data using different values of the FMV ranging from 200-3,000. We defined the 'baseline corridor' as the corridor calculated with 2-hour data and the 'sparse corridor' as the corridor calculated with 12-hour data for each value of the FMV. We first calculated the proportion (percent overlap) of the baseline corridor overlapped by the sparse corridor. Second, we defined relative area as the ratio of the area of the sparse corridor with the area of the baseline corridor. We selected the

FMV value that maximized the percent overlap while minimizing the relative area for each level of the corridor (low, medium, high, and stopover; Fig. 2).

We found that FMV values of 1,400 for elk, and 1,000 for mule deer, while specifying a maximum time lag of 1 fix interval plus 1 hour, provided corridors that most closely resembled those calculated using 2-hr data. We advise that analysts consider other FMV or maximum time lag values according to their knowledge of the local population (e.g., if the resulting heat map appears too fragmented). A smaller FMV value would generate a tighter corridor, while a larger maximum time lag of 2 fix intervals plus 1 hour allows building Brownian bridges between successive locations farther apart in time, i.e., allowing one for missing GPS fix.

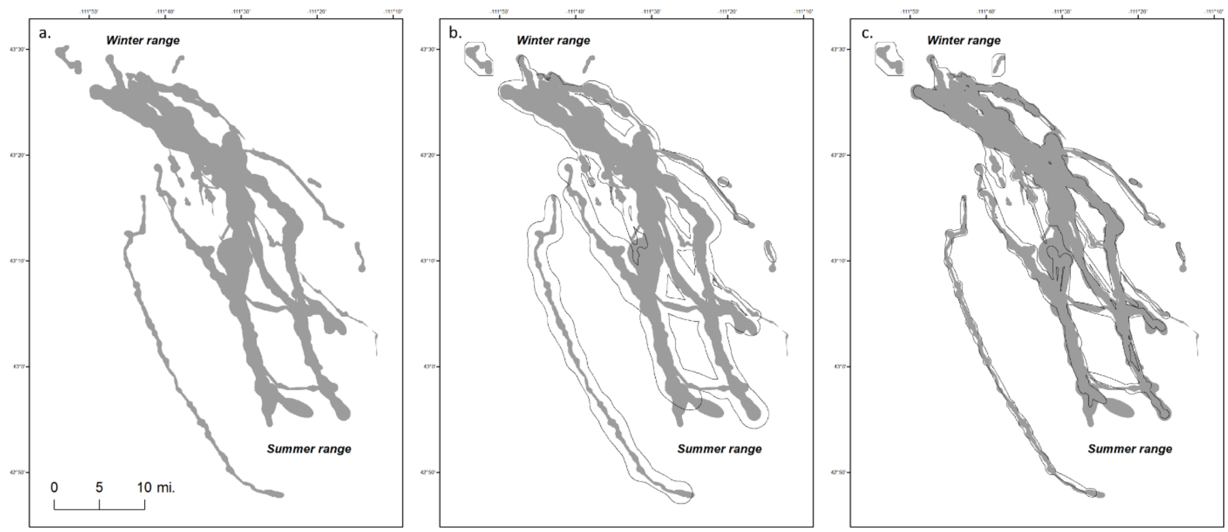

Figure 2. Illustration of the Fixed Motion Variance (FMV) alternative to the Brownian Bridge Movement Model (BBMM) for corridor mapping on sparse data. The baseline corridor footprint delineated using 2-hour data is represented in gray in all panels The black contour in (b) represents the corridor footprint calculated using the original BBMM method fitted to the sparse 12-hour data (b). The black contour in (c) represents the corridor footprint calculated using the FMV method fitted to the sparse 12-hour data (c). The FMV methods provides a tighter corridor that better represents the corridor calculated with the 2-hour data (c).

Calculating population-level corridors and stopovers

We applied a three-step process to calculate population-level corridors and to identify stopovers, which generally followed the approach outlined by Sawyer et al. (2009). First, we averaged the UDs for a given individual's spring and fall migration sequences across all years to produce a single, individual-level migration UD. We rescaled this averaged UD to sum to 1. We then defined a migration footprint for each individual as the 99% isopleth of this UD. We stacked up all the individual footprints for a given population, and defined different levels of corridor use based on the number of individuals using a given pixel. We defined low-use corridors as areas traversed by ≥1 individual during migration, medium-use corridors were used by ≥10% of individuals within the population, and high-use corridors were used by ≥20% individuals within the population. We then converted these corridors from a grid-based format to a polygon format, while removing isolated use polygons of less than 20,000 m^2 (i.e., less than approximately 5 acres). Finally, for stopover calculation, instead of calculating footprints from each individual-level UD, we averaged all the individual-level UDs to produce a single population-level UD, rescaled to sum to one. We defined stopovers as the top 10% of the area of use from the population-averaged UD values. As with the corridors, we then converted stopovers from a grid-based format to a polygon format, and then removed isolated polygons of less than five acres.

Variations of the method to calculate population-level corridors

Across different states, the number of animals represented in different corridor use categories varied. For example, in Idaho, low-use corridors were defined as areas used by ≥2 individuals (i.e., areas used by only a single individual were not included in any corridor category).

Most maps in this report display low-, medium- and high-use corridors. However, there were a few exceptions. For example, in Idaho when sample size was ≤ 30 individuals, only medium- and high-use corridors were shown. Also, in Wyoming, the only corridors that are shown are corridors officially designated by the Wyoming Game and Fish Department. These corridors represent areas where ≥ 2 individuals migrate.

In the vast majority of cases, traditional BBMM methods were used to calculate corridors and stopovers. However, when there were significant amounts of data acquisition failures in the migration sequences due to topography, for example, corridors were calculated using FMV techniques if they improved delineation. In general, by bridging gaps in the probability surface due to missing GPS locations, using FMV provided a modeled corridor that our analyses show more closely matches 2-hour data. In most of these cases, a 14-hour time lag was used. A 27-hour time lag was used only when it provided more complete migration corridors relative to using a 14-hour time lag. If the annual or multi-annual footprints of an individual animal did not include 50% of the individual's seasonal migration route identified by the GPS points, then that individual was dropped from the analysis. When converting final corridors from grid to polygon data, all 50-m pixels were preserved in the final migration corridors and stopovers.

Winter range

To estimate a population's winter range, we generally followed the methods for calculating migration stopover sites with some exceptions. First, instead of migration sequences, we isolated winter sequences, defined as movements between fall and spring migrations. For each year, we calculated a standard date for start and end of winter. States used one of two options to calculate winter range dates: (1) for each year, we calculated the start of winter as the 95% quantile of the end dates of all fall migrations, and the end of winter as the 5% quantile of the start dates of all spring migrations, or (2) we defined a fixed date range based on local expert knowledge for a given herd (e.g., Dec.15 - Mar. 15). We discarded winter sequences that spanned less than 30 days. Following the methods for migration corridors, we calculated a population-level UD of winter use. Using this population UD, we calculated the core winter range using the 50% isopleth.