Vital rates, limiting factors and monitoring methods for moose in Montana

Federal Aid in Wildlife Restoration Grant W-157-R-7

Annual report, September 1, 2022

Nick DeCesare
Research biologist, FWP
ndecesare@mt.gov
406-542-5558

Collin Peterson
Research technician, FWP
collin.peterson@mt.gov
406-751-4588

Rich Harris
Wildlife Biologist, FWP
richard.harris@mt.gov
406-210-5008

State: Montana
Agency: Fish, Wildlife & Parks
Grant: Montana Shiras Moose Study
Grant number: W-157-R-7
Time period: 1 July 2021 – 30 June 2022

FUNDING PARTNERS:
Safari Club International Foundation:
Conservation Grants, 2016, 2018

Note: All results should be considered preliminary and subject to change; please contact the authors before citing or referencing these data.

Background and summary

In 2013, Montana Fish, Wildlife, & Parks (MFWP) began a 10-year study designed to improve our understanding of: 1) cost-effective means to monitor statewide moose (*Alces alces*) populations, and 2) the current status and trends of moose populations and the relative importance of factors influencing moose vital rates and limiting population growth (including predators, disease, habitat, and weather). We are using a mechanistic approach to hierarchically assess which factors are drivers of moose vital rates (e.g., adult survival, pregnancy, calf survival), and ultimately influence annual growth of moose populations.

This document is the 10th annual report produced as part of this work. This report contains preliminary results from a subset of our work, including results from the first 9 biological years of moose research and monitoring. All results should be considered preliminary as both data collection and analyses are works in progress.

In this report, we provide updates on:

- Estimating moose abundance using statewide hunter sightings data
- Capture and vital rate monitoring of moose in 3 study areas
- Effects of the parasite *Elaeophora schnederi* on moose survival
- Forage quality and diet sampling during both summer and winter

Web site: We refer readers to our the FWP website for additional information, reports, publications, photos and videos. More information on this study specifically can be found under the "Research" heading at this page:

https://fwp.mt.gov/conservation/wildlife-management/moose

Location

Moose vital rate research is focused primarily within Beaverhead, Lincoln, Lewis and Clark, Pondera, and Teton counties, Montana. Other portions of monitoring (e.g., genetic and parasite sampling) involve sampling moose from across their statewide distribution.

Study Objectives (2021-2022)

For the 2021-2022 field season of this moose study, the primary objectives were;

1) Continue to evaluate moose monitoring data and techniques.
2) Monitor vital rates and limiting factors of moose in three study areas.

Objective #1: *Moose monitoring methods*

1.1. Estimating moose abundance from hunter sightings

An important goal of this study is to evaluate and apply techniques for monitoring moose at a statewide scale and over the long-term. One such approach that we've reported on previously is the use of hunter phone surveys to collect sightings of moose. This work is currently under review at a scientific journal, and here we present abridged and preliminary results.

During 2012–2016, we queried hunters of deer and elk for observations of moose across their statewide distribution in Montana. We analyzed data in an abundance-detection framework with n-mixture models and evaluated the effects of covariates such as hunter effort, survey response totals, weekly session, and forest cover on detection probability before using models to predict moose abundance. We collected an average of 3,409 moose observations per year and our best n-mixture model included effects of week, year (number of responses), site (proportionate forest cover), and site-year (hunter effort) on detection probability (Figure 1), as well as an effect of site (area of forest and shrub habitat) on abundance. Density estimates averaged 0.099 (range 0.002–0.439) moose/km2 across sites or 0.200 (range 0.017–0.799) moose/km2 when limited to density within shrub and forest cover specifically. Statewide abundance totals across the five-year study period averaged 10,755 (range 9,925–11,620; Figure 2). Goodness-of-fit tests showed that models were identifiable and overdispersion of the data was low, yet some caution is still warranted when extrapolating these data to abundance estimates. Abundance estimates at this scale are unprecedented for moose in Montana and are encouraging for long-term monitoring over space and time.

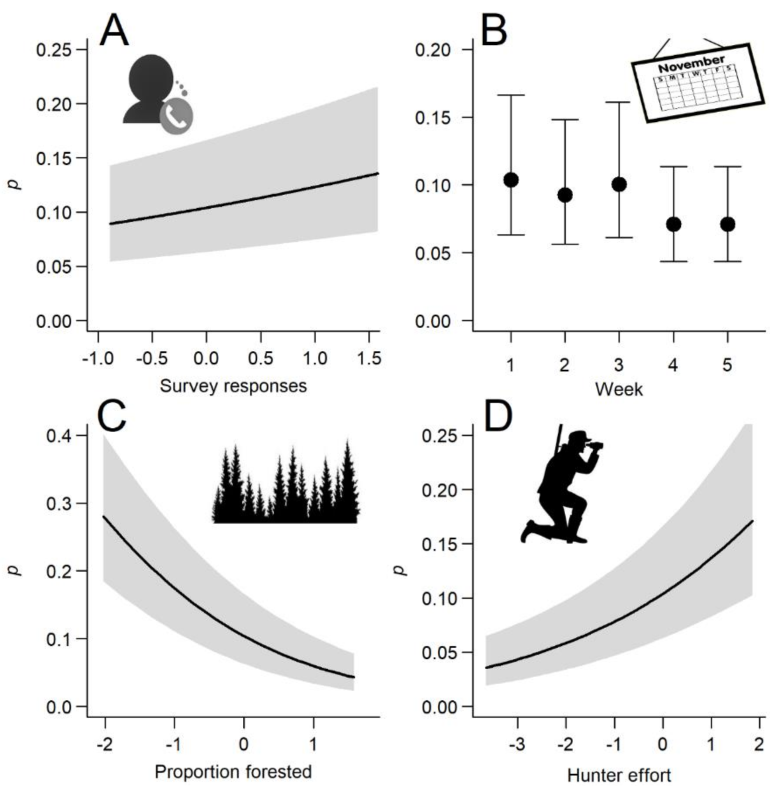

Figure 1. *Preliminary results regarding the predicted effects of A) the number of survey respondents, B) week of hunting season, C) proportion of forested land cover within each site, and D) the amount of hunter effort per hunting district, on the probability of detection when counting moose with observations made by deer-elk hunters, according to centered and standardized covariates Montana, 2012–2016.*

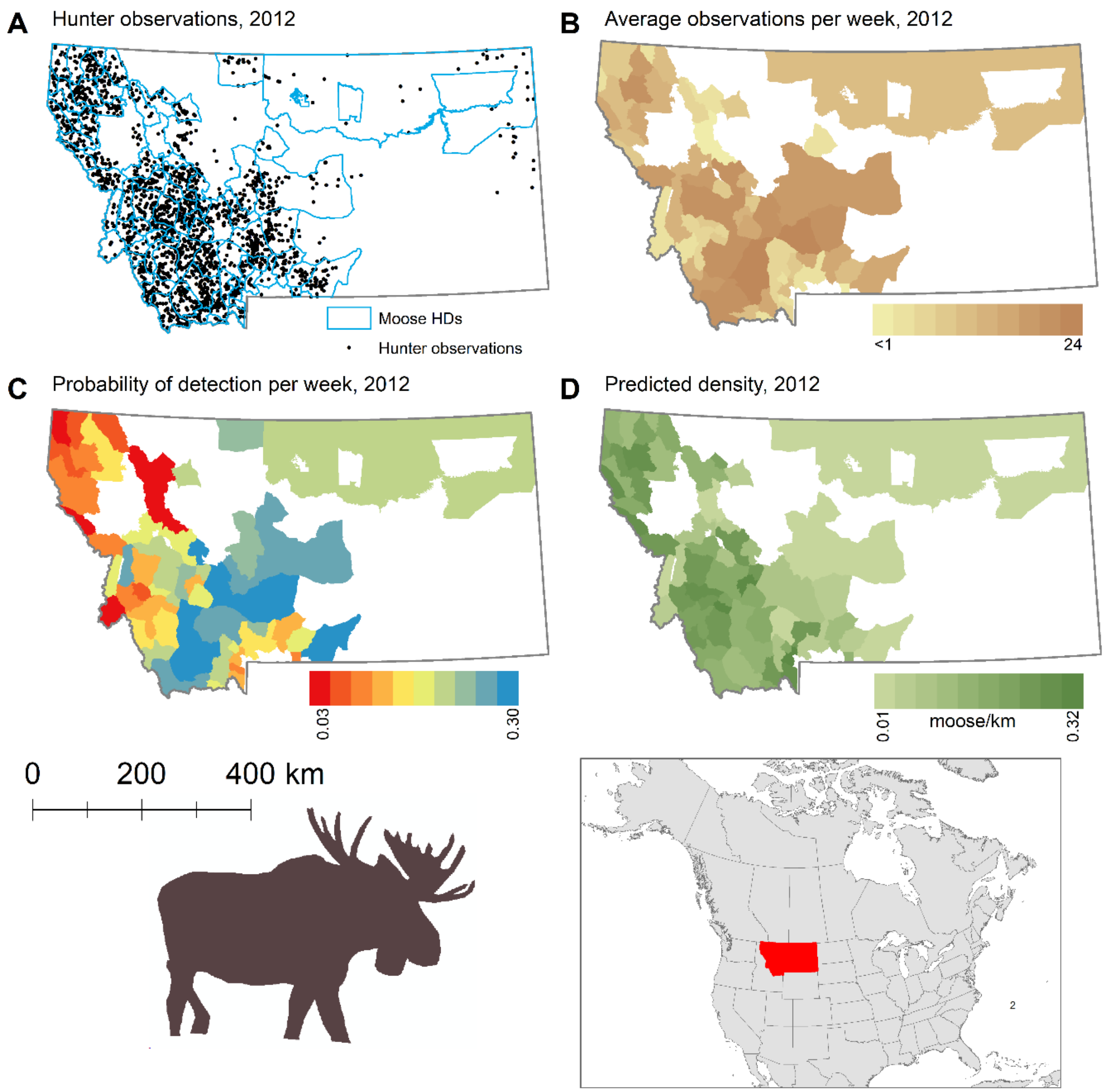

Figure 2. *Statewide maps of A) hunter observations of moose, B) the weekly average of observations summed per moose hunting district (HD), C) n-mixture model predictions of weekly probability of detection by HD, and D) n-mixture model predicted density of moose by HD for an example study year, 2012, Montana.*

Objective #2: *Monitor moose vital rates and potential limiting factors*

2.1. Animal capture and handling

During 2013–21, we conducted a total of 229 captures of 193 individual adult female moose, and as of September 1, 2022, 65 are currently being monitored (Table 1, Figures 3,4). The 2022-2023 biological year is our final year of monitoring, and collars with timed release mechanisms will drop off in July, 2023.

Table 1. *Captures of adult female moose by study area and year, excluding 6 capture-related mortalities, and the number of adult females being monitored as of September 1, 2021.*

	Study Area			
	Cabinet-Salish	*Big Hole Valley*	*Rocky Mtn Front*	*Total*
2013 captures	11	12	11	34
2014 captures	7	20	8	35
2015 captures	13	6	7	26
2016 captures	0	4	6	10
2017 captures	10	7	9	26
2018 captures	7	8	11	26
2019 captures	8	6	10	24
2020 captures	8	6	4	18
2021 captures	6	7	11	24
Total captures	**62**	**70**	**73**	**229**
Moose currently on–air	25	21	19	65

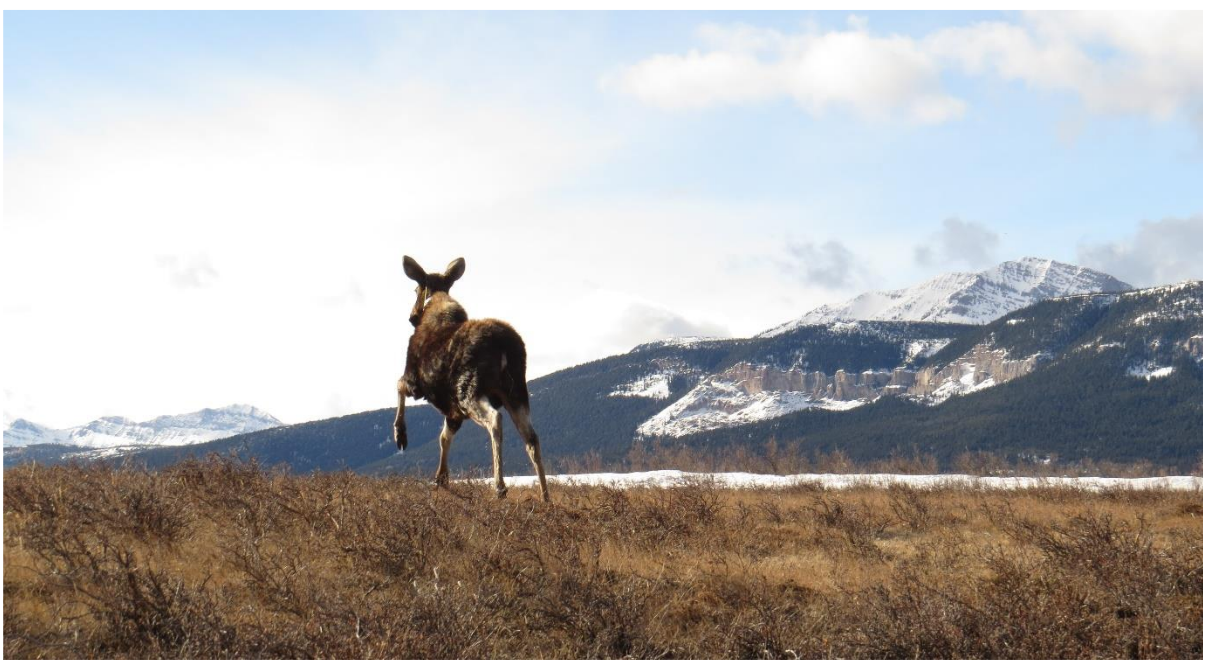

Figure 3. *Moose F437 after being captured and released in the Rocky Mountain Front study area in February, 2017. As of summer 2022, this female is still alive and has given birth to a single calf during five of six total years of monitoring.*

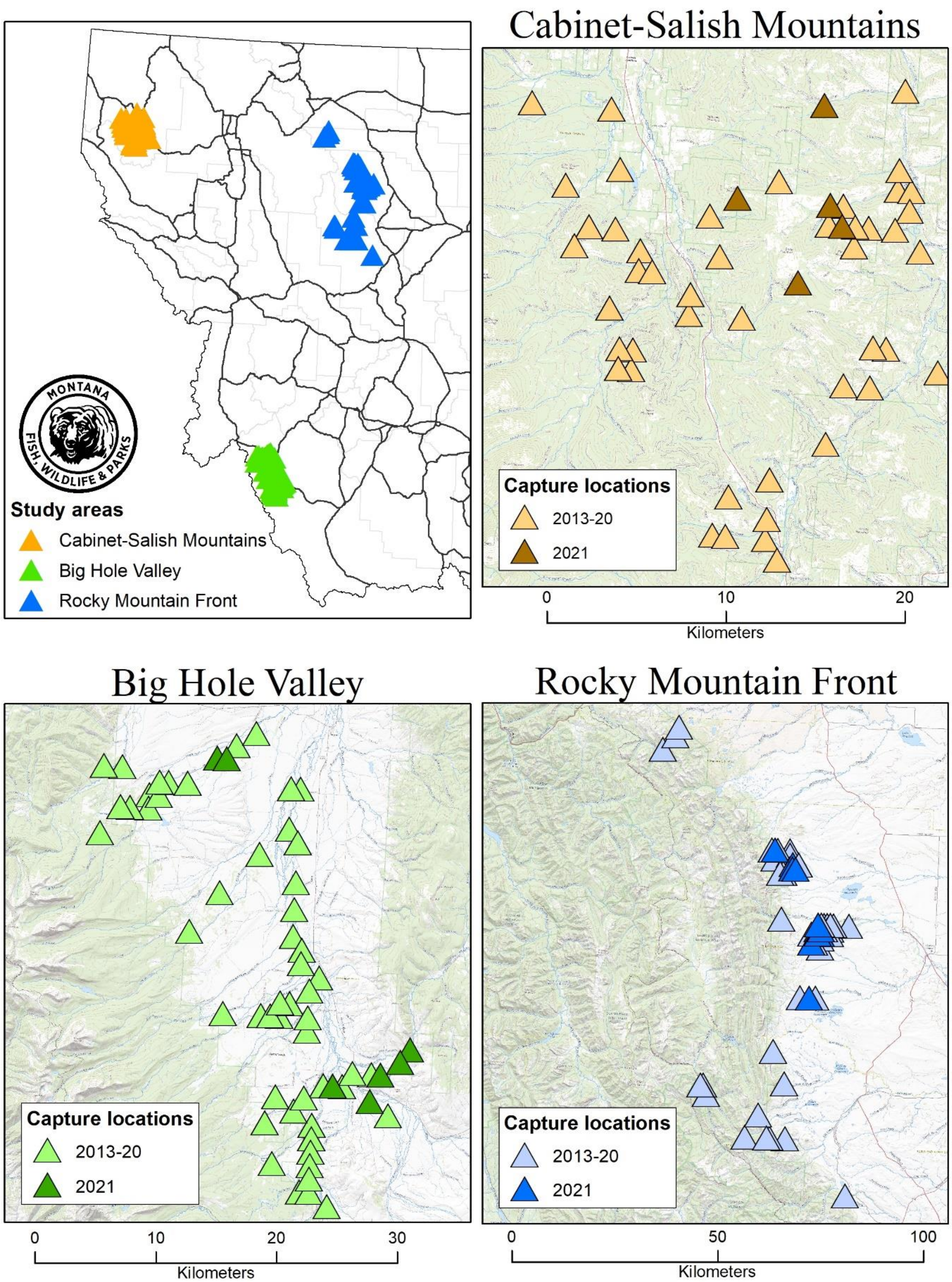

Figure 4. *Moose winter capture locations during 2013–2021 across 3 study areas in Montana.*

2.2. Monitoring vital rates

2.2.1. Adult female survival.— Our study of adult female survival to date includes 186 radio-collared adult female moose and 705 animal-years of monitoring, with a staggered-entry design of individuals entering into the study across 9 winter capture seasons (*see* 2.1 Animal capture and handling). Animals have been deployed with both VHF (*N*=73) and GPS (*N*=150) collars. We estimated Kaplan-Meier annual survival rates for each study area during each biological year as well as across the 9 biological years pooled together in a recurrent-time format.

Pooled annual survival estimates across the entire monitoring period for each study area were 0.892 (SE=0.193, 95% CI=[0.86,0.93]) in the Cabinet-Salish, 0.854 (SE=0.0225, 95% CI=[0.81,0.90]) in the Big Hole Valley, and 0.874 (SE=0.021, 95% CI=[0.84,0.92]) on the Rocky Mountain Front (Figure 5). In comparison to these 7-year averages, survival during the 2019-20 biological year was higher than average in the Cabinet-Salish (0.90), close to average in the Big Hole Valley (0.85) and lower than average in the Rocky Mountain Front (0.85). While differences among study areas were noted during the early years of this study, the mean estimates in each area have gradually grown closer to one another as we continue to accumulate data. These estimates do not account for differences in age distribution of our collared sample, which we will address in more detail upon completion of the study (Prichard et al. 2012).

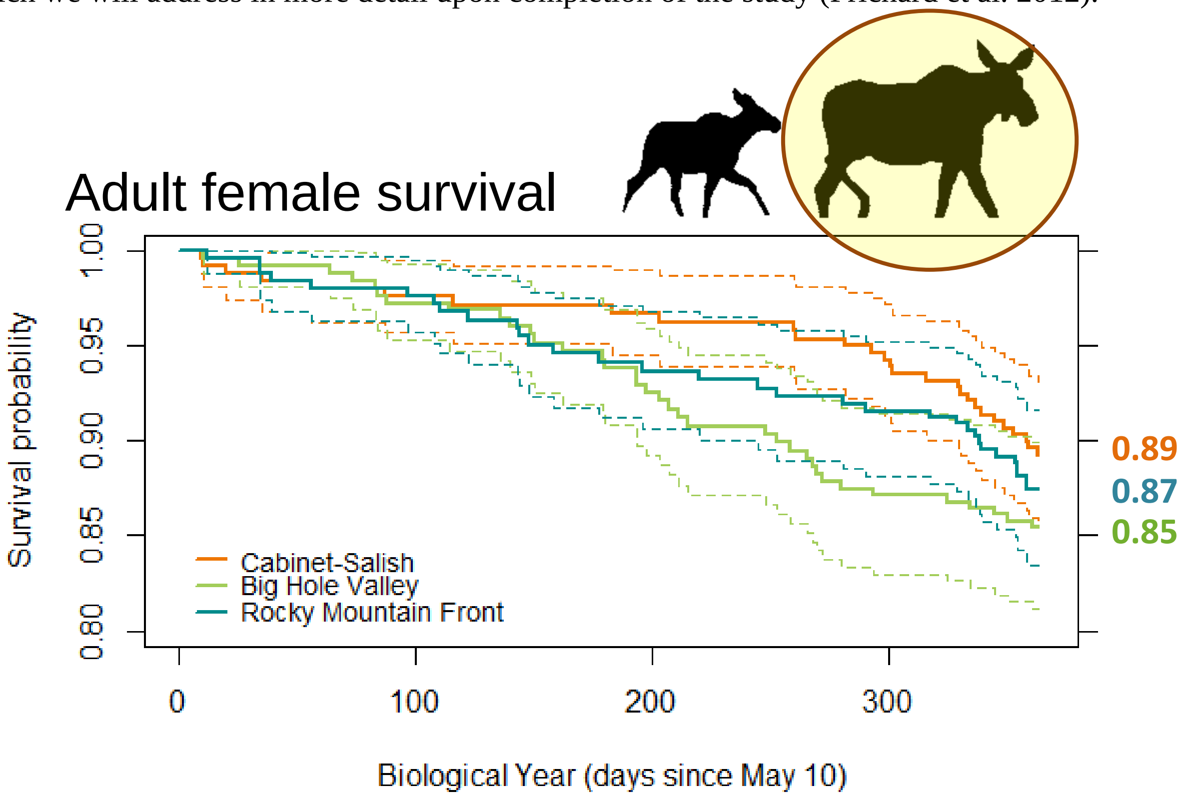

Figure 5. *Kaplan-Meier estimates and 95% confidence limits of annual adult female survival within each study, across 9 biological years for each study area, Montana, 2013–2022.*

During 9 biological years of monitoring, we have documented 96 mortalities of collared adult moose across all study areas: 27 in the Cabinet-Fisher, 36 in the Big Hole Valley and 33 in the Rocky Mountain Front (Figure 6). While determining the causes of adult female moose mortality was not initially a key objective of this study, the relatively high proportion of health-related (non-predation) mortalities has prompted greater emphasis on prioritizing collar technology and staff time to document cause of death when logistics permit.

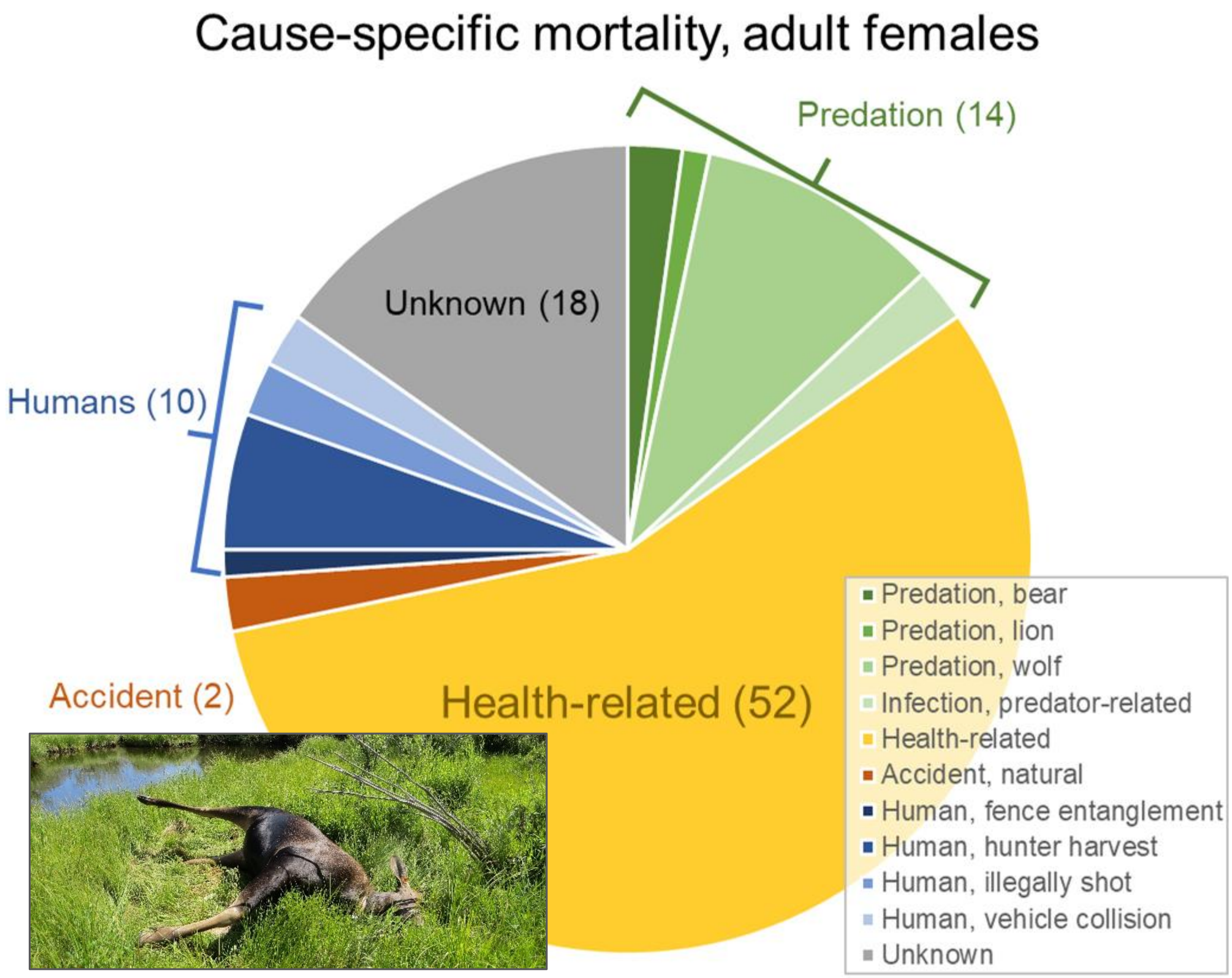

Figure 6. *Counts of radio-collared adult female moose by cause-of-mortality across all 3 focal study areas. Note, this summary does not account for variations in sample size, age, and timing that can affect the perceived relative risk to each cause. Such concerns will be accounted for using formal cumulative incidence analyses upon completion of this study.*

Preliminary results concerning the parasite, *Elaeophora schneideri*

Health-related mortalities have been relatively common during our study, and roughly 66% of moose in those cases have been infected with the arterial worm *Elaeophora schnederi*. *Elaeophora schneideri* is a filarial nematode of North America that occasionally infects aberrant ruminant hosts such as moose. The role *E. schneideri* plays in clinical morbidity or mortality of moose remains uncertain. We compared infection prevalence and infection loads, when present, of worms in carotid arteries hunter-killed moose (n = 127) to a separate sample of moose that died of health-related causes (n = 34).

We found both higher prevalence of E. schneideri and higher worm loads, when present, to be associated with increased probability of health-related mortality for moose (Figures 7,8). Our results suggest presence and load of E. schneideri infection play a role in the mortality of adult moose, though the acute and/or chronic mechanisms of mortality remain uncertain. *These results are currently in review at a scientific journal and should be considered preliminary.*

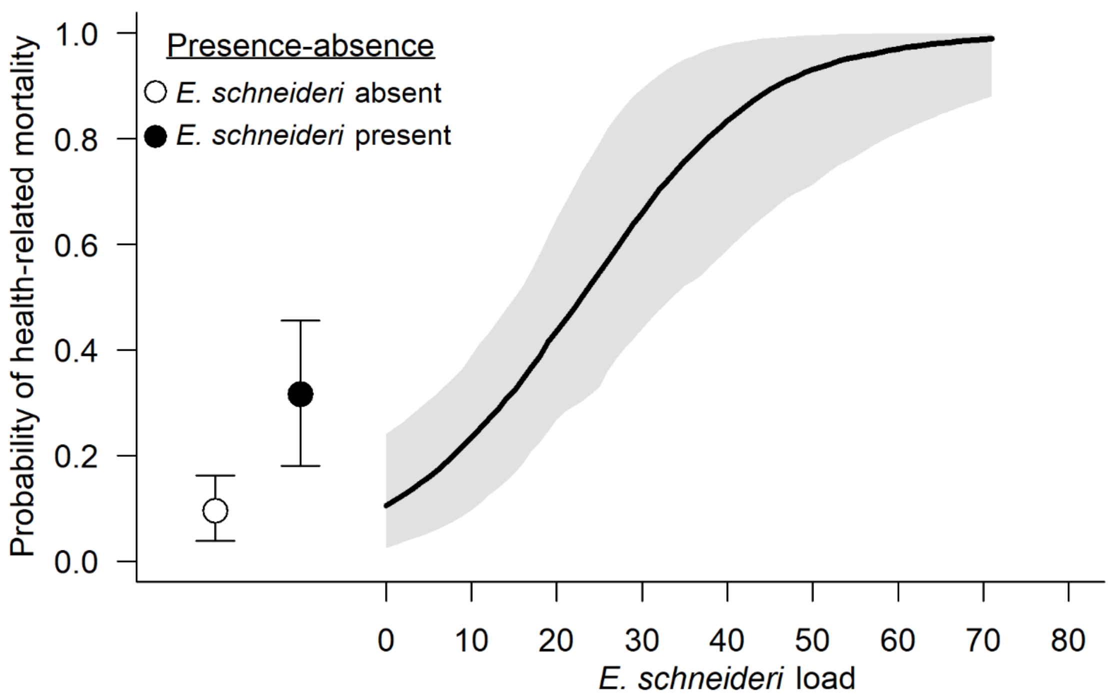

Figure 7. *Predicted probability of a sampled moose mortality event being health-related as a function of E. schneideri presence-absence and load, western Montana, 2009–2021.*

Figure 8. *Adult E. schneideri worms revealed within the carotid artery of moose as observed during necropsy.*

2.2.2 Calf survival.— We decompose calf survival into 2 components: 1) observed parturition rate – the proportion of pregnancies resulting in a calf-at-heel during spring; and 2) calf survival – the proportion of documented calves that survive through their first year of life (Figure 9).

Observed parturition rates: Following winter pregnancy testing, we use aerial telemetry during 15 May – 15 July to estimate an "observed parturition" rate, representing the proportion of pregnant cows with neonate calves each spring. A limitation of this approach is the unknown proportion of calves born that die before we visually confirm them. Thus, our sample for subsequent study of calf survival is left truncated (Gilbert et al. 2014), and calf survival estimates are optimistic in that they don't account for mortality of calves prior to initial detection. These data have yet to be updated with 2020–2021 litters, pending final pregnancy analyses. Through 2021, observed parturition rates have been lower in the Cabinet-Fisher (69%) compared to the Rocky Mountain Front (79%) and Big Hole Valley (85%); Figure 10). These results are similar to those of other studies (e.g,, Becker 2008) where parturition rates are lower than pregnancy rates due to presumed fetal losses and/or death of neonatal calves prior to detection.

Figure 9. *Adult female moose F127 and twin calves observed while monitoring calf survival during a winter telemetry flight in the Cabinet Mountains study area, 2022.*

Calf survival: As a result of spring monitoring of neonate calves, we have documented 496 calves from 453 litters born during 2013–2021. We then monitored the fates of these calves by visually locating them with their dams throughout their first year of life. Over the first 9 biological years (May 2013 – May 2022), pooled Kaplan-Meier survival estimates of calves-at-heel were 0.437 (SE=0.042, 95% CI=[0.36,0.53]) in the Cabinet-Fisher, 0.438 (SE=0.040, 95% CI=[0.37,0.52]) in the Big Hole Valley, and 0.464 (SE=0.038, 95% CI=[0.40, 0.55]) on the Rocky Mountain Front (Figures 9, 10). Calf survival results mirror those of observed parturition, suggesting observed parturition rates are likely influenced by mortality of neonates prior to detection, more so than fetal losses.

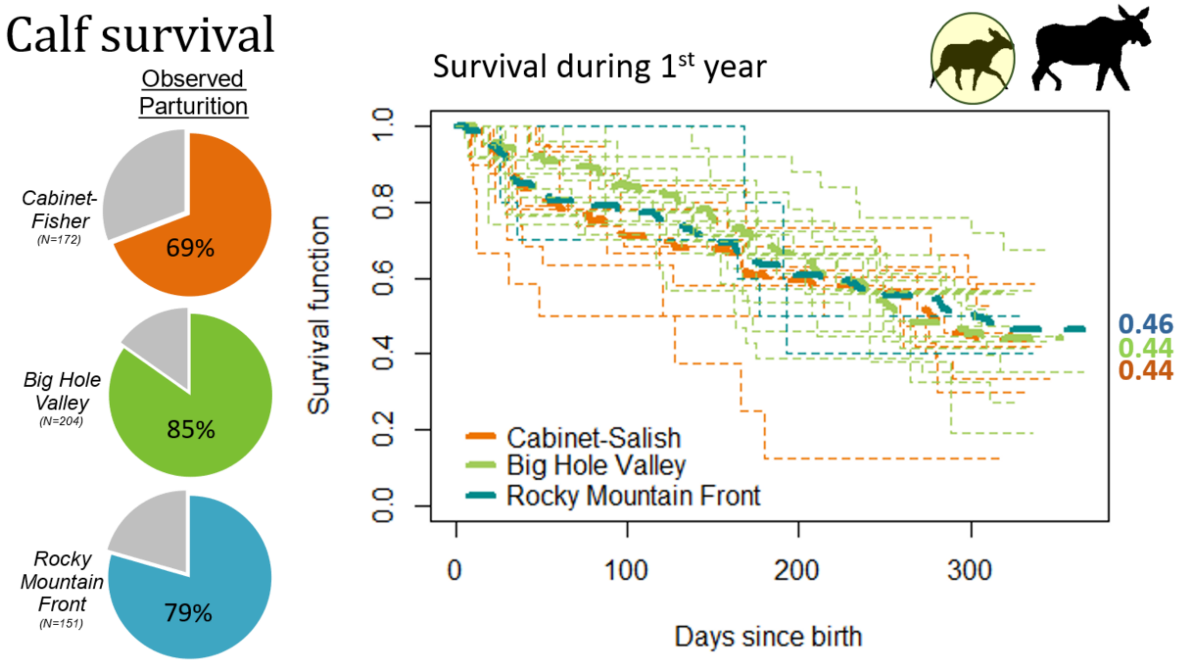

Figure 10. *Observed parturition (proportion of pregnant cows with calves-at-heel during spring) and Kaplan-Meier estimates of annual calf survival for the first year of life within each study area, where bold lines are pooled estimates across 8 biological years and thin lines are annual estimates per year, Montana, 2013–2021.*

<u>*2.2.3 Adult female fecundity.*</u>—Fecundity for moose is the product of age-specific pregnancy rates and litter size. We monitor pregnancy of animals during winter with laboratory analyses of both blood (serum PSPB levels; Huang et al. 2000) and scat (fecal progestagens; Berger et al. 1999, Murray et al. 2012). To estimate pregnancy in absence of handling animals each winter, we use fecal progestagens from samples collected via telemetry guided snow-tracking.

Pregnancy rates: Pooled across study areas, years, and 703 animal-years of monitoring, the average adult (ages ≥2.5) pregnancy rate was 81% and range 80–88% across areas (Figure 11). Yearling (age 1.5) pregnancy rates appear to vary by region, with 0% pregnancy in both the Cabinet-Fisher and Big Hole Valley study areas compared to 40% yearling pregnancy on the Rocky Mountain Front; however, sample sizes for yearling pregnancy are small (*N* = 4, 8, and 15 in the 3 areas, respectively). Final summary of pregnancy rates will necessarily also account for the effect of old-aged females in each sample, as rates decline with age after a certain point.

Observed twinning rates: Moose are capable of giving birth to 1–3 calves, though litters are most commonly composed of either 1 or 2 calves (Van Ballenberghe and Ballard 2007). Twinning rates in North American populations can vary from 0 to 90% of births (Gasaway et al. 1992), with variation linked to nutritional condition (Franzmann and Schwartz 1985) and animal age (Ericsson et al. 2001). Twinning rates for Shiras moose are typically low (e.g., <15%; Peek 1962, Schladweiler and Stevens 1973, Becker 2008). Thus far our observed twinning rates are 7% in the Cabinet-Fisher (*N*=132 litters), 1% in the Big Hole Valley (*N*=161 litters), and 21% in the Rocky Mountain Front study areas (*N*=156 litters; Figure 11).

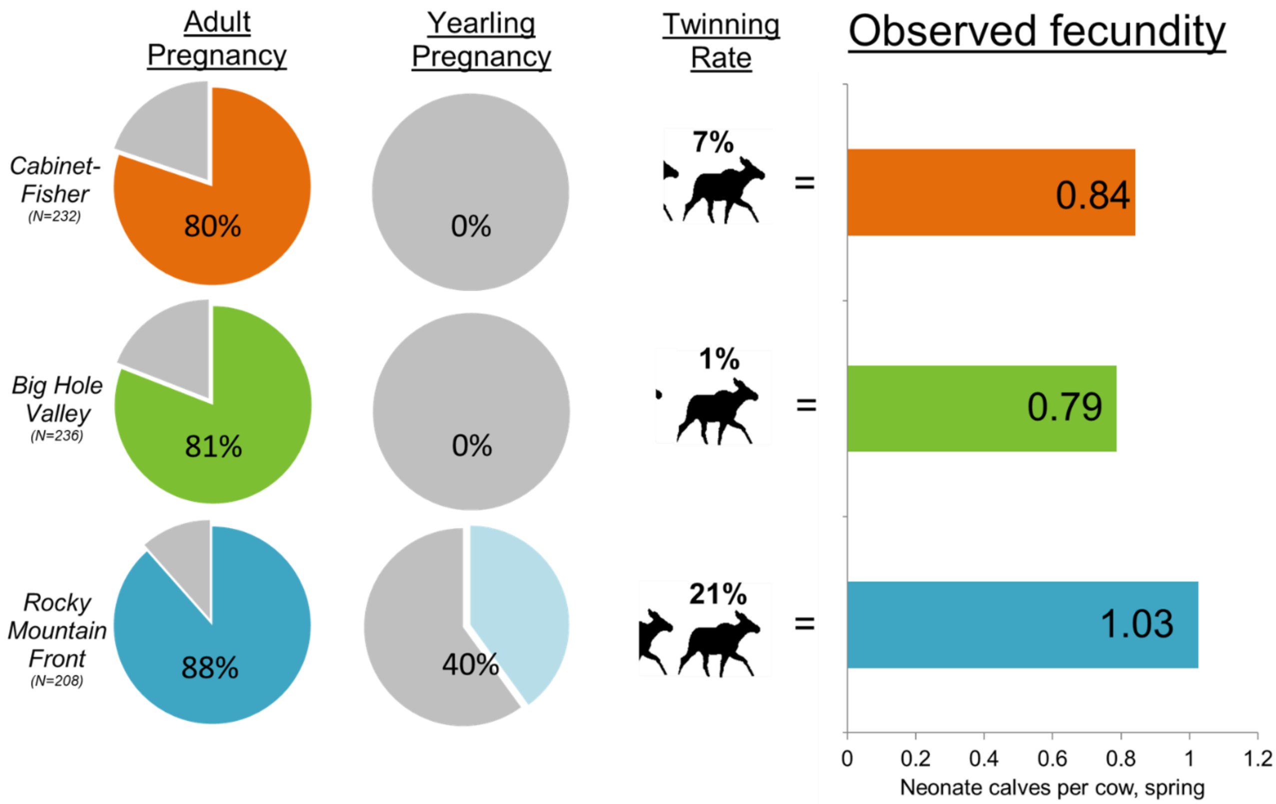

Figure 11. *Estimated adult (age≥2.5) pregnancy rates, yearling (aged 1.5) pregnancy rates, observed twinning rates, and net observed fecundity of calves per adult female in 3 study areas of Montana to date, 2013–2021.*

2.3 Composition and nutritional quality of moose diets

The composition and nutritional quality of the diets of moose is an important influence on adult survival, pregnancy, and parturition rates (Franzmann and Schwartz 2007, McArt et al. 2009, Milner et al. 2013). To better understand the effects of forage nutrition on vital rates of moose, we are assessing the composition and quality of the diets of moose during 2 important life-history stages: post-parturition during summer and late winter. We will be determining the digestible energy content (kilocalories/gram), digestible protein content, and concentration of tannins (which influences forage digestibility) of plants in moose diets during these time periods.

Summer forage surveys. —

The quality of forage during summer is important for moose because lactation poses high energetic demands for maintenance of females with calves during summer, and summer foraging allows moose to accumulate fat stores prior to winter, influencing over-winter survival, pregnancy, and calf recruitment (Franzmann and Schwartz 2007, McArt et al. 2009). During the months of June-August, 2021-2022, we surveyed the locations of GPS-collared moose for evidence of recent browsing activity by moose on trees, shrubs, and forbs within the vicinity of each location. For each species with evidence of browse, we located 3-5 individual plants with browse evidence and clipped the new growth of 5-10 stems and their leaves from each individual plant. We stored samples within paper bags in a freezer. We compiled these samples by browse species, study area, and year, and have submitted them for quality analyses from which we are awaiting results. For our summer sampling effort, we surveyed 158 locations from 50 GPS-collared moose (41 locations among 14 moose in the Big Hole, 64 locations among 20 moose in Cabinet-Salish, and 53 locations among 16 moose on the Rocky Mountain Front). We collected 82 plant samples among 10 species browsed in the Big Hole, 211 samples among 29 species in Cabinet-Salish, and 107 samples among 24 species on the Rocky Mountain Front (Table 2).

While surveying these locations, we also collected fresh fecal samples from moose, which we will use to determine the composition of individual diets during summer through DNA metabarcoding techniques. By combining data on the proportion of different forage species in diets and the quality of those forage species, we will be able to estimate the average quality of both the diets of individuals, and of the collective diets of moose in each of our 3 study areas. In total, we collected 131 fecal samples: 45 in Cabinet-Salish, 38 in Big Hole, and 48 in Rocky Mountain Front.

Table 2. *Plant species with evidence of browse by moose sampled at locations of GPS-collared moose between June-August, 2021-2022 and January-March 2022 in the Big Hole (BH), Cabinet-Salish (CAB) and Rocky Mountain Front (RMF) study areas.*

Study area	Season	Common name	Genus	Species	Family	Lifeform
BH	Summer	Cow parsnip	Heracleum	maximum	Apiaceae	forb
BH	Summer	Bog birch	Betula	pumila	Betulaceae	shrub
BH	Summer	Twinberry honeysuckle	Lonicera	involucrata	Caprifoliaceae	shrub
BH	Summer	False azalea	Menziesia	feruginea	Ericaceae	shrub
BH	Summer	Black swamp gooseberry	Ribes	lacustre	Grossulariaceae	shrub
BH	Summer	Barclay's willow	Salix	barclayi	Salicaceae	shrub
BH	Summer	Booth's willow	Salix	boothii	Salicaceae	shrub
BH	Summer	Drummond's willow	Salix	drummondiana	Salicaceae	shrub

Study area	Season	Common name	Genus	Species	Family	Lifeform
BH	Summer	Geyer's willow	Salix	geyeriana	Salicaceae	shrub
BH	Summer	Lemmon's willow	Salix	lemmonii	Salicaceae	shrub
BH	Summer	Plane-leaf willow	Salix	planifolia	Salicaceae	shrub
CAB	Summer	Black cottonwood	Populus	balsamifera	Salicaceae	deciduous tree
CAB	Summer	Quaking aspen	Populus	tremuloides	Salicaceae	deciduous tree
CAB	Summer	Bracken fern	Pteridium	aquilinum	Dennstaedtaceae	fern
CAB	Summer	Aster	Aster	sp	Asteraceae	forb
CAB	Summer	Hooker's fairybells	Prosartes	hookeri	Liliaceae	forb
CAB	Summer	Rocky Mountain maple	Acer	glabrum	Sapindaceae	shrub
CAB	Summer	Grey alder	Alnus	incana	Betulaceae	shrub
CAB	Summer	Serviceberry	Amelanchier	alnifolia	Rosaceae	shrub
CAB	Summer	Snowbrush Ceanothus	Ceanothus	velutinus	Rhamnaceae	shrub
CAB	Summer	Red osier dogwood	Cornus	sericea	Cornaceae	shrub
CAB	Summer	Hawthorne	Cratageus	douglasii	Rosaceae	shrub
CAB	Summer	Oceanspray	Holodiscus	discolor	Rosaceae	shrub
CAB	Summer	Utah honeysuckle	Lonicera	utahensis	Caprifoliaceae	shrub
CAB	Summer	False azalea	Menziesia	feruginea	Ericaceae	shrub
CAB	Summer	Mock orange	Philedelphus	lewisii	Hydrangeaceae	shrub
CAB	Summer	Chokecherry	Prunus	virginiana	Rosaceae	shrub
CAB	Summer	Black swamp gooseberry	Ribes	lacustre	Grossulariaceae	shrub
CAB	Summer	Wild rose	Rosa	sp	Rosaceae	shrub
CAB	Summer	Thimbleberry	Rubus	parviflora	Rosaceae	shrub
CAB	Summer	Pussy willow	Salix	discolor	Salicaceae	shrub
CAB	Summer	Drummond's willow	Salix	drummondiana	Salicaceae	shrub
CAB	Summer	Scouler's willow	Salix	scouleriana	Salicaceae	shrub
CAB	Summer	Buffaloberry	Sheperdia	canadensis	Elaeagnaceae	shrub
CAB	Summer	Mountain ash	Sorbus	scopulina	Rosaceae	shrub
CAB	Summer	Birchlead spirea	Spiraea	betulifolia	Rosaceae	shrub
CAB	Summer	Douglas' spirea	Spiraea	douglasii	Rosaceae	shrub
CAB	Summer	Snowberry	Symphoricarpos	albus	Caprifoliaceae	shrub
CAB	Summer	Mountain huckleberry	Vaccinium	globulare	Ericaceae	shrub
RMF	Summer	Quaking aspen	Populus	tremuloides	Salicaceae	deciduous tree
RMF	Summer	Firweed	Chamerion	angustifolium	Onagraceae	forb
RMF	Summer	Rocky Mountain maple	Acer	glabrum	Sapindaceae	shrub
RMF	Summer	Serviceberry	Amelanchier	alnifolia	Rosaceae	shrub
RMF	Summer	Bog birch	Betula	pumila	Betulaceae	shrub
RMF	Summer	Red osier dogwood	Cornus	sericea	Cornaceae	shrub
RMF	Summer	Chokecherry	Prunus	virginiana	Rosaceae	shrub
RMF	Summer	Black swamp gooseberry	Ribes	lacustre	Grossulariaceae	shrub
RMF	Summer	Barclay's willow	Salix	barclayi	Salicaceae	shrub
RMF	Summer	Bebb's willow	Salix	bebbiana	Salicaceae	shrub

Study area	Season	Common name	Genus	Species	Family	Lifeform
RMF	Summer	Booth's willow	Salix	boothii	Salicaceae	shrub
RMF	Summer	Undergreen willow	Salix	commutata	Salicaceae	shrub
RMF	Summer	Pussy willow	Salix	discolor	Salicaceae	shrub
RMF	Summer	Drummond's willow	Salix	drummondiana	Salicaceae	shrub
RMF	Summer	Missouri river willow	Salix	eriocephala	Salicaceae	shrub
RMF	Summer	Coyote willow	Salix	exigua	Salicaceae	shrub
RMF	Summer	Geyer's willow	Salix	geyeriana	Salicaceae	shrub
RMF	Summer	Lemmon's willow	Salix	lemmonii	Salicaceae	shrub
RMF	Summer	Dusky willow	Salix	melanopsis	Salicaceae	shrub
RMF	Summer	Plane-leaf willow	Salix	planifolia	Salicaceae	shrub
RMF	Summer	False mountain willow	Salix	pseudomonticola	Salicaceae	shrub
RMF	Summer	Scouler's willow	Salix	scouleriana	Salicaceae	shrub
RMF	Summer	Autumn willow	Salix	serissima	Salicaceae	shrub
RMF	Summer	Sitka willow	Salix	sitchensis	Salicaceae	shrub
BH	Winter	Lodgepole pine	Pinus	contorta	Pinaceae	coniferous tree
BH	Winter	Haystacks	Multiple	Multiple	Multiple	graminoid
BH	Winter	Black swamp gooseberry	Ribes	lacustre	Grossulariaceae	shrub
BH	Winter	Booth's willow	Salix	boothii	Salicaceae	shrub
BH	Winter	Drummond's willow	Salix	drummondiana	Salicaceae	shrub
BH	Winter	Geyer's willow	Salix	geyeriana	Salicaceae	shrub
BH	Winter	Plane-leaf willow	Salix	planifolia	Salicaceae	shrub
CAB	Winter	Black cottonwood	Populus	balsamifera	Salicaceae	deciduous tree
CAB	Winter	Rocky Mountain maple	Acer	glabrum	Sapindaceae	shrub
CAB	Winter	Serviceberry	Amelanchier	alnifolia	Rosaceae	shrub
CAB	Winter	Snowbrush Ceanothus	Ceanothus	velutinus	Rhamnaceae	shrub
CAB	Winter	Red osier dogwood	Cornus	sericea	Cornaceae	shrub
CAB	Winter	Hawthorne	Cratageus	douglasii	Rosaceae	shrub
CAB	Winter	Scouler's willow	Salix	scouleriana	Salicaceae	shrub
CAB	Winter	Buffaloberry	Sheperdia	canadensis	Elaeagnaceae	shrub
RMF	Winter	Black cottonwood	Populus	balsamifera	Salicaceae	deciduous tree
RMF	Winter	Quaking aspen	Populus	tremuloides	Salicaceae	deciduous tree
RMF	Winter	Bog birch	Betula	pumila	Betulaceae	shrub
RMF	Winter	Red osier dogwood	Cornus	sericea	Cornaceae	shrub
RMF	Winter	Bebb's willow	Salix	bebbiana	Salicaceae	shrub
RMF	Winter	Booth's willow	Salix	boothii	Salicaceae	shrub
RMF	Winter	Shortfruit willow	Salix	brachycarpa	Salicaceae	shrub
RMF	Winter	Missouri river willow	Salix	eriocephala	Salicaceae	shrub
RMF	Winter	Geyer's willow	Salix	geyeriana	Salicaceae	shrub
RMF	Winter	Dusky willow	Salix	melanopsis	Salicaceae	shrub
RMF	Winter	Autumn willow	Salix	serissima	Salicaceae	shrub

Winter forage surveys and diet composition. —

The quality of forage during winter influences important moose vital rates like calf recruitment and adult survival (Testa 2004, Milner et al. 2013). Between January-March 2022, we replicated our summer forage monitoring methods by visiting the locations of GPS-collared females and sampling plants with browse evidence. We surveyed 77 locations from 37 GPS-collared moose (39 locations among 13 moose in the Big Hole, 14 locations among 14 moose in Cabinet-Salish, and 23 locations among 10 moose on the Rocky Mountain Front). We collected 48 plant samples among 7 species browsed in the Big Hole, 31 samples among 8 species in Cabinet-Salish, and 32 samples among 11 species on the Rocky Mountain Front (Table 2). We will have these plants analyzed for nutritional quality, and then combine winter diet composition data with quality information to estimate the quality of individual moose diets during winter. We will repeat this sampling effort during the winter of 2022-2023.

During the winters of 2013-2020, we collected fecal samples from captured moose. We submitted these samples to Jonah Ventures Laboratory (Boulder, CO) to be analyzed for diet composition, and have summarized the composition of diets of individuals, and the collective diet composition of moose throughout our 3 study areas. In Cabinet-Salish, moose primarily consumed evergreen and deciduous shrubs and coniferous trees. Snowbrush Ceanothus (*Ceanothus velutinus*) was the most heavily consumed species during winter (42% of diet), followed by willow (*Salix* spp., 16%) and Douglas fir (*Pseudotsuga menziesii*, 13%, Figures 12,13). In the Big Hole, moose primarily foraged on willows and grasses during the winter, as well as a higher proportion of rushes and sedges than in other study areas. Most of these grasses were likely consumed at hay piles visited by moose. Willows were the most consumed forage item (71%) followed by grasses (*Poaceae*, 14%), black swamp gooseberry (*Ribes lacustre*, 4%), rushes (*Juncus* spp., 2%) and sedges (*Carex* spp.; 2%). On the Rocky Mountain Front, winter browse primarily occurred on deciduous shrubs and trees. Willows were the most consumed forage item (38%) followed by red osier dogwood (*Cornus sericea,* 24%), birch (*Betula* spp., 15%), members of the rose family (*Rosaceae*, 8%, most likely comprising wild rose [*Rosa* spp.] and serviceberry [*Amelanchier alnifolia*]), and cottonwood and aspen trees (*Populus* spp., 5%).

Figure 12. *Heavily browsed snowbrush Ceanothus (Ceanothus velutinus), an evergreen shrub that is the most consumed diet item of moose in the Cabinet-Salish during winter.*

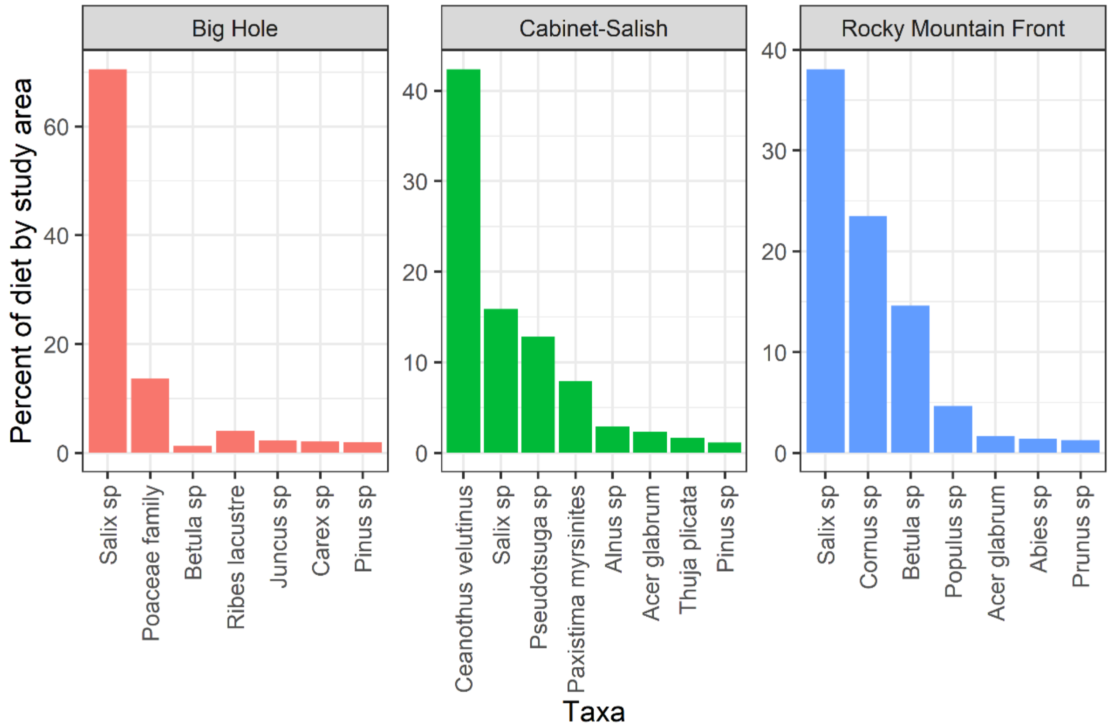

Figure 13. *Percent of plants exceeding 2% of the collective winter diets of collared moose in the Big Hole, Cabinet-Salish, and Rocky Mountain Front study areas. Diet composition was determined through DNA metabarcoding of fecal samples collected from moose captured during winters 2013-2020.*

Figure 14. *Samples of vegetation species consumed by moose ready to be sent off to the lab for forage quality analysis.*

Deliverables

Below we list project deliverables (publications, reports, presentations, media communications, and value-added collaborations) stemming from this moose research project, during FYs 13–19 (July 2012–June 2019). In addition to those communications listed below, are frequent discussions with moose hunters statewide. Copies of reports and publications are available on the moose study's website (note: the web address is case-sensitive): http://fwp.mt.gov/fishAndWildlife/diseasesAndResearch/research/moose/populationsMonitoring

1. **Annual Reports**:

2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021,2022. DeCesare, N. J., and J. R. Newby. *Vital rates, limiting factors and monitoring methods for moose in Montana*. Annual reports, Federal Aid in Wildlife Restoration Grant W-157-R-1 through R-7.

2. Peer-reviewed Publications

Burkholder, B. O., N. J. DeCesare, R. A. Garrott, and S. J. Boccadori. 2017. *Heterogeneity and power to detect trends in moose browsing of willow communities*. Alces 53:23–39.

Burkholder, B. O., R. B. Harris, N. J. DeCesare, S. J. Boccadori, and R. A. Garrott. 2022. Winter habitat selection by female moose in southwestern Montana and effects of snow and temperature. Wildlife Biology 2022:e01040

DeCesare, N. J., T. D. Smucker, R. A. Garrott, and J. A. Gude. 2014. *Moose status and management in Montana*. Alces 50:31–51.

DeCesare, N. J., J. R. Newby, V. Boccadori, T. Chilton-Radandt, T. Thier, D. Waltee, K. Podruzny, and J. A. Gude. 2016. *Calibrating minimum counts and catch per unit effort as indices of moose population trend*. Wildlife Society Bulletin 40:537–547.

DeCesare N. J., B. V. Weckworth, K. L. Pilgrim, A. B. D. Walker, E. J. Bergman, K. E. Colson, R. Corrigan, R. B. Harris, M. Hebblewhite, B. R. Jesmer, J. R. Newby, J. R. Smith, R. B. Tether, T. P. Thomas, M. K. Schwartz. 2020. Phylogeography of moose in western North America. Journal of Mammalogy 101:10–23.

Nadeau, M. S., N. J. DeCesare, D. G. Brimeyer, E. J. Bergman, R. B. Harris, K. R. Hersey, K. K. Huebner, P. E. Matthews, and T. P. Thomas. 2017. *Status and trends of moose populations and hunting opportunity in the western United States*. Alces 53:99–112.

Newby, J. R., and N. J. DeCesare. 2020. Multiple nutritional currencies shape pregnancy in a large herbivore. Canadian Journal of Zoology 98:307–15.

Ruprecht, J. S., K. R. Hersey, K. Hafen, K. L. Monteith, N. J. DeCesare, M. J. Kauffman, and D. R. MacNulty. 2016. *Reproduction in moose at their southern range limit*. Journal of Mammalogy 97:1355–1365.

3. Other Publications

DeCesare, N. J. 2013. *Research: Understanding the factors behind both growing and shrinking Shiras moose populations in the West*. The Pope and Young Ethic 41(2):58–59.

DeCesare, N. J. 2014. *Conservation Project Spotlight: What and where are Shiras moose?* The Pope and Young Ethic 42(4):26–27.

DeCesare, N. J. 2020. *Is there such thing as a Shiras moose?* Big Hole Breeze, June 2020 Issue.

4. Professional Conference Presentations

DeCesare, N. J., J. Newby, V. Boccadori, T. Chilton-Radant, T. Their, D. Waltee, K. Podruzny, and J. Gude. 2015. *Calibrating indices of moose population trend in Montana*. North American Moose Conference and Workshop, Granby, Colorado.

Nadeau, S., E. Bergman, N. DeCesare, R. Harris, K. Hersey, P. Mathews, J. Smith, T. Thomas, and D. Brimeyer. 2015. *Status of moose in the northwest United States*. North American Moose Conference and Workshop, Granby, Colorado.

DeCesare, N. J., J. R. Newby, and J. M. Ramsey. 2015. *A review of parasites and diseases impacting moose in North America*. Montana Chapter of the Wildlife Society. Annual Meeting, Helena, Montana.

DeCesare, N. J., J. Newby, K. Podruzny, K. Wash, and J. Gude. 2016. *Occupancy modeling of hunter sightings for monitoring moose in Montana*. North American Moose Conference and Workshop, Brandon, Manitoba.

Newby, J. R., N. J. DeCesare, and J. A Gude. 2016. *Assessing age structure, winter ticks, and nutritional condition as potential drivers of fecundity in Montana moose*. Montana Chapter of the Wildlife Society. Annual Meeting, Missoula, Montana.

Newby, J. R., N. J. DeCesare, and J. A Gude. 2016. *Assessing age structure, winter ticks, and nutritional condition as potential drivers of fecundity in Montana moose*. North American Moose Conference and Workshop, Brandon, Manitoba.

DeCesare, N. J., J. Newby, K. Podruzny, K. Wash, and J. Gude. 2017. *Occupancy modeling of hunter sightings for monitoring moose in Montana*. Montana Chapter of the Wildlife Society. Annual Meeting, Helena, Montana.

DeCesare, N. J., and J. R. Newby. 2018. Moose population dynamics in Montana: results from the halfway point of a 10-year study. Montana Chapter of the Wildlife Society. Annual Meeting, Butte, Montana.

Oyster, J. H., N. J. DeCesare, et al. 2018. An update on *Elaeophora schneideri* in western North American moose. North American Moose Conference and Workshop, Spokane, Washington.

DeCesare, N. J., and J. R. Newby. 2018. Moose population dynamics in Montana. North American Moose Conference and Workshop, Spokane, Washington.

DeCesare, N. J., et al. 2019. Phylogeography of a range edge subspecies: is there such thing as Shiras moose? Montana Chapter of the Wildlife Society. Annual Meeting, Helena, Montana.

DeCesare, N. J., et al. 2021. Phylogeography of moose in western North America. North American Moose Conference and Workshop, online.

5. Public and/or Workshop Presentations

FY	Organization (*Speaker*)	Location
2013	Helena Hunters and Anglers Association (*DeCesare*)	Helena, MT
	Marias River Livestock Association (*DeCesare*)	Whitlash, MT
	Plum Creek Timber Company, Staff meeting (*DeCesare*)	Libby, MT
	Sun River Working Group (*DeCesare*)	Augusta, MT
2014	Big Hole Watershed Committee (*DeCesare*)	Divide, MT
	Flathead Wildlife Incorporated (*DeCesare*)	Kalispell, MT
	MFWP R1, Regional Citizens Advisory Council (*Newby*)	Kalispell, MT
	MFWP R1, Biologists' Meeting (*Newby*)	Kalispell, MT
	MFWP R1, Bow Hunter Education Workshop	Kalispell, MT
	MFWP R2, Regional Meeting (*DeCesare*)	Missoula, MT
	MFWP, Wildlife Division Meeting (*DeCesare*)	Fairmont, MT
	Plum Creek Timber Annual Contractors Meeting (*DeCesare*)	Kalispell, MT
	Rocky Mountain Front Land Managers Forum (*DeCesare*)	Choteau, MT
	Swan Ecosystem Center Campfire Program (*Newby*)	Holland Lake, MT
	WCS Community Speaker Series (*Newby*)	Laurin, MT
2015	Big Hole Watershed Committee (*Boccadori*)	Divide, MT
	Flathead Chapter of Society of American Foresters (*Newby*)	Kalispell, MT
	Libby Chapter of Society of American Foresters (*Newby*)	Libby, MT
	MFWP R1, Regional Citizens Advisory Council (*Newby*)	Kalispell, MT
	MFWP R2, Bow Hunter Education Workshop (*DeCesare*)	Lolo, MT
	MFWP R2, Regional Citizens Advisory Council (*DeCesare*)	Missoula, MT
	Rocky Mountain Front Land Managers Forum (*Newby*)	Choteau, MT
	Sanders County Commission Meeting (*DeCesare*)	Thompson Falls, MT
	Sheridan Wildlife Speaker Series (*DeCesare*)	Sheridan, MT
	Univ. Montana Guest Lecture – WILD105 (*DeCesare*)	Missoula, MT
2016	Confederated Salish & Kootenai Tribe, Nat Res Commission (*Newby*)	Marion, MT
	Ducks Unlimited State Convention (*Newby*)	Lewistown, MT
	Helena Hunters and Anglers Association (*DeCesare*)	Helena, MT
	MFWP R1 Law Enforcement Annual Meeting (*Newby*)	Kalispell, MT
	Montana State University, Ecology Seminar Series (*DeCesare*)	Bozeman, MT
	Ravalli County Fish and Wildlife Association (*DeCesare*)	Hamilton, MT
	Univ. Montana Guest Lecture – WILD480 (*DeCesare*)	Missoula, MT
	Upper Sun River Wildlife Team Meeting (*DeCesare*)	August, MT

2017	Big Hole Watershed Committee (*Boccadori*)	Divide, MT
	Mountain Bluebird Trails Conference (*DeCesare*)	Dillon, MT
	Swan Valley Connections Speaker Series (*DeCesare*)	Condon, MT
	University of Montana, STEAMfest (*DeCesare*)	Missoula, MT
	Univ. Montana Guest Lectures – WILD180, WILD480 (*DeCesare*)	Missoula, MT
	WCS Community Speaker Series (*DeCesare*)	Dillon, MT
	Flathead Valley Lions Club (*Newby*)	Kalispell, MT
	Flathead Wildlife Incorporated (*Newby*)	Kalispell, MT
	North Fork Inter-local (*Anderson*)	Polebridge, MT
2018	Bitterroot College (*DeCesare*)	Hamilton, MT
	Clearwater Resource Council (*DeCesare*)	Seeley Lake, MT
	MFWP R1, Regional Citizens Advisory Council (*Newby*)	Kalispell, MT
	Montana Forest Landowner Conference (*DeCesare*)	Helena, MT
	Montana Audubon Chapter (*Newby*)	Polson, MT
	Science on Tap (*Newby*)	Bigfork, MT
2019	MFWP HQ, Brown Bag Seminar (*DeCesare*)	Helena, MT
	MFWP Wildlife Manager Meeting (*DeCesare*)	Helena, MT
	Hellgate Hunters and Anglers (*DeCesare*)	Missoula, MT
	Rocky Mountain Front Land Managers Forum (*Newby*)	Choteau, MT
	Upper Sun Wildlife Team (*DeCesare*)	Fairfield, MT
	Univ. Montana Guest Lectures – WILD240 (*DeCesare*)	Missoula, MT
	Idaho Fish & Game/MFWP Joint Meeting (*Newby*)	De Borgia, MT
2020	Flathead Wildlife Incorporated (*Newby*)	Kalispell, MT
	Devil's Kitchen Working Group (*DeCesare*)	Cascade, MT
	Lake County Conservation District (*DeCesare*)	Polson, MT
2021	Big Hole Watershed Committee (*Newby*)	Divide, MT (remote)
	Swan Valley Connections (*DeCesare*)	Condon, MT (remote)
2022	American Society of Foresters (*Peterson*)	Libby, MT
	Flathead Lake Biological Station (*Peterson)*	Polson, MT
	Upper Sun River Wildlife Team (*Peterson*)	Augusta, MT

6. Media Communications

FY	Organization (Location)	Topic	Media
2013	Bozeman Chronicle (MT)	Moose research	Newspaper
	Liberty County Times (MT)	Moose research	Newspaper
	MFWP Outdoor Report (MT)	Moose research	Television
2014	Carbon County News (MT)	Moose research	Newspaper
	Flathead Beacon (MT)	Moose research	Newspaper
	Helena Independent Record (MT)	Moose research	Newspaper
	High Country News, blog	Moose research	Blog
	KPAX (MT)	Moose-human conflict	Television
	MFWP Outdoor Report	Moose research	Television
	Missoulian (MT)	Urban moose	Newspaper
	The Monocle Daily (London, UK)	Moose research	Radio
	Nature Conservancy Magazine (VA)	Moose research	Magazine
	New York Times (NY)	Moose research	Newspaper
	NWF Teleconference (MT)	Climate change	Newspaper
	Radio New Zealand (New Zealand)	Moose research	Radio

	Summit Daily (CO)	Moose research	Newspaper
	UM Science Source (MT)	Moose research	Newspaper
2015	KOFI (MT)	Moose research	Radio
	MFWP Outdoor Report (MT)	Moose research	Television
	Western News (MT)	Moose research	Newspaper
2016	Missoulian (MT)	Climate & moose	Newspaper
	Bozeman Daily Chronicle (MT)	Climate & moose	Newspaper
	Montana Standard (MT)	Climate & moose	Newspaper
	Billings Gazette (MT)	Climate & moose	Newspaper
	Daily Interlake (MT)	Moose research	Newspaper
	Ravalli Republic (MT)	Moose research	Newspaper
	Montana Public Radio (MT)	Moose research	Radio
	Montana Public Radio – Field Notes (MT)	Moose taxonomy	Radio
	Post Rider (MT)	Moose research	Newsletter
	KAJ18 (MT)	Moose research	Television
2017	Dillon Tribune (MT)	Moose research	Newspaper
	Billings Gazette (MT)	Moose research	Newspaper
	Missoulian (MT)	Moose research	Newspaper
	Great Falls Tribune (MT)	Moose research	Newspaper
	Weather Network (Canada)	Moose sightings	Website
	The Nature Conservancy Magazine (VA)	Wildlife tracking	Magazine
2018	Hungry Horse News (MT)	Moose research	Newspaper
	Missoulian (MT)	Moose research	Newspaper
2019	Missoulian (MT)	Moose hunting	Newspaper
	Montana Outdoors	Moose research	Magazine
2020	Bugle magazine (MT)	Moose conservation	Magazine
	MFWP Facebook (MT)	Moose genetics	Social Media
2021	MFWP Facebook (MT)	Moose research	Social Media
2022	Montana Outdoors (MT)	Moose genetics	Magazine
	MFWP Outdoor Report (MT)	Moose genetics	Television

7. Other Project-related Collaborations

Partners	Title	Status
Rick Gerhold University of Tennessee	Development of a serological assay for *Elaeophora schneideri* detection and surveillance in cervids	*Labwork is ongoing *Providing MT blood samples and worm samples for lab work
Biologists from western states and provinces (AB, BC, CO, ID, MT, OR, SK, UT, WA, WY)	Assessing range-wide genetic differentiation and spatial distribution of a moose subspecies, *Alces alces shirasi*	*Completed, manuscript published, 2020.

Biologists from western states (CO, ID, MT, OR, UT, WA, WY)	Summarize status and management of western states moose.	*Completed, manuscript published, 2017.
Ky Koitzsch, K2 Consulting, LLC	Estimating population demographics of moose in northern Yellowstone National Park using non-invasive methods	*Completed, manuscript published, 2021.
Jason Ferrante & Margaret Hunter, USGS – Gainseville, FL	Genetic approaches to understanding moose health	*Completed, manuscript published, 2021.

Acknowledgements

Private landowners & hunters: We are particularly thankful to The Nature Conservancy, Stoltze Land & Lumber, Weyerhaeuser and the many private landowners and area residents who graciously allowed us to conduct captures and ground monitoring on their properties. They also have provided much logistical support and local knowledge about moose distributions and local flora and fauna. We are very grateful for the privilege to work on these properties and for all the help. We are also grateful to the many moose hunters who have given their time and effort to submit samples and information to us as part of their moose hunting experience.

This project is a large collaboration among many FWP biologists. These begin with Jesse Newby, who was integral to this work for 7 years, and also include but are not limited to Justin Gude, Jennifer Ramsey, Neil Anderson, Colby Anton, Rich Harris, Keri Carson, Kevin Podruzny, Keri Wash, Jim Williams, Howard Burt, Graham Taylor, Tonya Chilton-Radant, Kent Laudon, John Vore, Vanna Boccadori, Brent Lonner, Gary Olson, Jessy Coltrane, and Ryan Rauscher. Undoubtedly this list should be larger to fully incorporate the many biologists and other personnel who have assisted with coordination of hunter sample collection, harvest statistics, opportunistic sampling of other moose throughout the state. We also acknowledge a great deal of help from other cooperating biologists and agency personnel including Nathan Birkeland, Dave Hanna, Dan Carney, Lorin Hicks, Allison Kolbe, Jenna Roose, Michael Munoz, and Eric Eneboe, Alissa Anderson and Kaitlyn Farrar. Thanks also to Caryn Dearing, Adam Brooks, Kari Shinn, Quentin Kujala, and others at FWP-HQ for their help with project administration.

Many thanks go to the pilots who have safely conducted capture and telemetry work, including Mike Campbell, Rob Cherot, Rick Geiger, Ken Justus, Blake Malo, Jim-Bob Pierce, Joe Rahn, Mark Stott, Rick Swisher, Guy Terrill, and Trever Throop.

Funding for this project during FYs 13–19 has been in part derived from FWP moose license auction sales, matched with USFWS Grants-in-Aid funds. We also thank the Safari Club International Foundation for 2 Conservation Grants to support this research during FY16–19.

Thanks to Ducks Unlimited and the Rocky Mountain Elk Foundation for holding license auctions. Many thanks also go to Plum Creek Timber Company and Two Bear Aviation, which have supported the project with helicopter flights during capture and monitoring efforts.

Literature cited

Becker, S. A. 2008. Habitat selection, condition, and survival of Shiras moose in northwest Wyoming. University of Wyoming.

Berger, J., J. W. Testa, T. Roffe, and S. L. Monfort. 1999. Conservation endocrinology: a noninvasive tool to understand relationships between carnivore colonization and ecological carrying capacity. Conservation Biology 13:980–989.

Ericsson, G., K. Wallin, J. P. Ball, and M. Broberg. 2001. Age-related reproductive effort and senescence in free-ranging moose, Alces alces. Ecology 82:1613–1620.

Franzmann, A. W., and C. C. Schwartz. 1985. Moose twinning rates: a possible population condition assessment. The Journal of wildlife management 49:394–396.

Franzmann, A. W., and C. C. Schwartz. 2007. Ecology and management of the North American moose. 2nd edition. University Press of Colorado, Boulder, Colorado.

Gasaway, W. C., R. D. Boertje, D. V. Grangaard, D. G. Kelleyhouse, R. O. Stephenson, and D. G. Larsen. 1992. The role of predation in limiting moose at low densities in Alaska and Yukon and implications for conservation. Wildlife Monographs:3–59.

Gilbert, S.L., Lindberg, M.S., Hundertmark, K.J., Person, D.K., 2014. Dead before detection: addressing the effects of left truncation on survival estimation and ecological inference for neonates. Methods in Ecology and Evolution 5, 992–1001.

Huang, F., D. C. Cockrell, T. R. Stephenson, J. H. Noyes, and R. G. Sasser. 2000. A serum pregnancy test with a specific radioimmunoassay for moose and elk pregnancy-specific protein B. Journal of Wildlife Management 64:492–499.

McArt, S. H., D. E. Spalinger, W. B. Collins, E. R. Schoen, T. Stevenson, M. Bucho, S. H. Mcart, D. E. Spalinger, W. B. Collins, E. R. Schoen, and T. Stevenson. 2009. Summer Dietary Nitrogen Availability as a Potential Bottom-Up Constraint on Moose in South-Central Alaska. Ecology 90:1400–1411.

Milner, J. M., F. M. van Beest, E. J. Solberg, and T. Storaas. 2013. Reproductive success and failure: The role of winter body mass in reproductive allocation in Norwegian moose. Oecologia 172:995–1005.

Murray, D. L., K. F. Hussey, L. A. Finnegan, S. J. Lowe, G. N. Price, J. Benson, K. M. Loveless, K. R. Middel, K. Mills, D. Potter, A. Silver, M.-J. Fortin, B. R. Patterson, and P. J. Wilson. 2012. Assessment of the status and viability of a population of moose (Alces alces) at its southern range limit in Ontario.

Peek, J. M. 1962. Studies of moose in the Gravelly and Snowcrest Mountains, Montana. The Journal of Wildlife Management 26:360–365.

Prichard, A. K., K. Joly, and J. Dau. 2012. Quantifying telemetry collar bias when age is unknown: a simulation study with a long-lived ungulate. Journal of Wildlife Management 76:1441–1449.

Schladweiler, P., and D. R. Stevens. 1973. Reproduction of Shiras moose in Montana. The Journal of Wildlife Management:535–544.

Van Ballenberghe, V., and W. B. Ballard. 2007. Population dynamics. Pages 223–245 Ecology and management of the North American moose. 2nd edition. University Press of Colorado, Boulder, Colorado.