

# **Carnivore Scat Analysis along the Central East Slopes of the Rocky Mountains, Alberta**

**Final Report  
2016-2018**



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*Photo credit: K. MacAulay*

## INTRODUCTION

Large predators play an important role in the trophic structure of an ecosystem, and this awareness has led to a greater emphasis on their conservation and management (Estes et al. 2011). Predation is an ecological process that can shape prey communities, and ecologists have long been interested in predator diets to understand potential community level impacts (Hairston et al. 1960, Schmitz et al. 2000). Not only can prey be negatively impacted by direct predation, but there is evidence they can perceive the risk of predation, as they navigate a “landscape of fear” and alter their behaviour in response (Laundré et al. 2001). For example, effects of predation risk have been shown to affect habitat selection, migratory behaviour and reproductive fitness of female ungulates (Hebblewhite et al. 2006; Creel et al. 2007).

Lima and Dill (1990) decomposed the components of predation risk leading to a predation event into the probability of an encounter, the probability of death given an encounter, and attack success once encountered. This framework can be used to predict predation risk to prey in space if landscape attributes determine how predators distribute themselves and whether an encounter will lead to a successful attack. Previous studies of large ungulates have mapped variation in predation risk based on either predator resource selection functions (Hebblewhite et al. 2005) or density (Theuerkauf and Rouys 2008) assuming the main driver of predation is predator distribution. However, these approaches do not account for prey distribution, or other factors that may influence the attack success given a predator-prey encounter.

Spatial predation risk also has been quantified based on locations of prey kill sites by comparing the characteristics locations to either random points on a landscape or prey locations. For a kill site to occur, both the predator and prey must be present, and the attack must be successful. For example, Kauffman et al. (2007) found that kill sites of elk (*Cervus elaphus*) by wolves were related to wolf density, topography, and vegetation type in Yellowstone National Park, whereas kills made by cougars were found to be best predicted by topography and vegetation cover (Holmes and Laundré 2006). However, using kill sites as the basis of predation risk can be cost intensive if based on capturing and collaring predators. This may require multiple years to accumulate adequate sample sizes of kill sites even with new statistical approaches that identify kill sites based on clusters of GPS locations of predators (Webb et al. 2008, Knopff et al. 2009) An alternative is to use the location of predator scats and their contents to identify areas where prey are killed. Although the scat may not reflect the precise location of the kill, it provides a broad-scale indication of the patterns of where different prey species may be at risk. Further, the advantage of this approach is that a large number of scats for multiple predators can be obtained in a relatively short period of time.

Wolves and cougars are predators of bighorn sheep in Alberta, although the impact of these predators on sheep varies regionally. Through an extensive analysis of wolf kill sites and scats in the foothills region of west central Alberta, there were very few occurrences of wolf killed sheep (Webb et al. 2008, Knamiller 2011), while sheep made up 1.5% of ungulate biomass in wolf diets (estimated from scats) 100-km south in the montane region of Banff National Park (Huggard 1993).



**Fig 1.** A remote camera image of a cougar crossing a fence line at the Ya Ha Tinda ranch, Alberta. Photo supplied by Mitch Flowers, MSc. Student, Ya Ha Tinda elk project.

although these observations are not common throughout the literature (Shank 1977; Festa-Bianchet 1988).

Knopff et al. (2010) found sheep comprised 1.67% of cougar diets over a ten-year period in the Clearwater County and Bow Valley regions of west central Alberta. Cougars tend to be generalist predators, but could potentially reduce populations in small, isolated sheep populations, due to individual specialists (Knopff and Boyce 2007). In southwestern Alberta, Ross et al. (1997) found evidence of sheep specialists, where one female killed 9% of a sheep population in a single season. Coyotes and bears have been observed killing bighorn sheep in Alberta,

The goal of this project was to provide a spatial model of mortality risk for bighorn sheep in the Upper Red Deer River drainage encompassing Ya Ha Tinda, through measuring spatial distribution of prey contents in scats. We hypothesize that prey distribution will have a considerable impact on what prey contents are found in scats. We predict that scats found closer to sheep ranges will be more likely to contain sheep in scat relative to scats located farther from sheep ranges.

## **OBJECTIVES**

The overall objective was to determine whether spatial differences in predator diets reflect predation risk for bighorn sheep relative to sheep ranges. Using scats from four large carnivores, specifically we will:

- (1) Compare the summer diets of cougars, bears, wolves and coyotes at a broad landscape scale, with particular emphasis on distinguishing contents of ungulates
- (2) Spatially model the mortality risk to bighorn sheep based on scat contents across the Ya Ha Tinda region.

## **STUDY AREA**

The 1425-km<sup>2</sup> study area is located adjacent to Banff National Park (BNP) along the eastern slopes of the Rocky Mountains in central Alberta (Fig. 1). Majority of the study area is situated on provincial crown land (62%) and a third is located within Banff National Park (BNP; 34%). The Ya Ha Tinda ranch (YHT), federally managed but falls under provincial jurisdiction, makes up the final 3% of the study area. The climate is cold and continental with long winters interspersed with short warming Chinook periods (October-April), which cause a low snowpack (~25-cm) over winter on the Ya Ha Tinda grassland (Morgantini 1995). The area has brief summers, with precipitation falling in spring and early fall (May-September). Growing season length is reduced at higher elevations within the study area due to cold temperatures and delayed snowmelt (Morgantini 1995).



**Fig. 2.** The Ya Ha Tinda grassland, centering the study area.

Vegetation cover is dominated by conifer forests (43%) comprised of Englemann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*) and lodgepole pine (*Pinus contorta*). Grassland, interspersed with herbaceous plants and shrubs comprised of *Salix* and *Betula* spp. cover 13% of the study area and aspen (*Populus tremuloides*) covers 2%. Burns cover 15% with the Dogrib burn (occurred in 2001) being the most dominant burn. The area has a strong east-west elevation gradient, ranging from 1,300-3,000-m with rock (>2,100-m) covering 26% of the

study area. The remaining 1% of cover is water.

The carnivore community is comprised of grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), coyotes (*Canis latrans*), wolves (*Canis lupus*), lynx (*Lynx canadensis*), and cougars (*Puma concolor*). Bear and wolf probability of resource selection is highest in the western portion of the study area, away from roads (Spilker 2018). Coyotes select highest around the YHT ranch, as well as areas further away from roads. Cougars selected area of high edge density, found primarily in the eastern portion of the study area (Spilker 2018). The ungulate community consists of white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), bighorn sheep (*Ovis canadensis*), mountain goats (*Oreamnos americanus*) and feral horses (*Equus caballus*). Deer numbers have appeared to increase the last decade where the elk numbers have declined from a high of 2000 individuals in the 1980s to a current estimate of ~400 individuals (Berg et al. 2016). Feral horses are present year round, primarily in the eastern portion of the study area, where cattle (*Bos taurus*) are found in provincial grazing leases in the summer and fall in similar areas.

Land use follows an east-west gradient with high resource extraction including timber harvest, oil and gas extraction, cattle grazing, and human recreational activity with OHVs on trails and cut lines in the east, to low human recreational use by hikers and on horse back in BNP. The Ya Ha Tinda ranch, home of the Parks Canada working horse ranch, has restricted OHV use, but has a dense network of trails used by hikers and horseback riders.

## **METHODS**

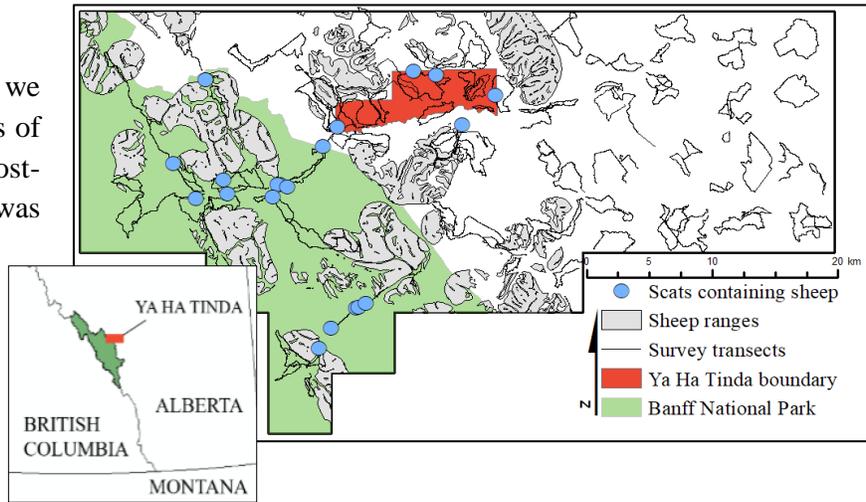
**Scat collection.** We collected scats using trained scat-detection dogs from 1 May to 30 September in 2013, 1 July to 30 September in 2014-2015 and 31 July to 30 August 2016 along 1,500-km of transects (Fig. 2). Transect routes were selected to cover the relative proportion of vegetation communities in each cell. Two-thirds of the transects were placed on human and animal trails and one-third off trails to avoid biases based on travel behaviour of predators. Transect lengths ranged from 2-km to 26-km per cell with a median of 11.5-km. Sampling ceased during heavy rain, strong winds (>30 km/hr), or when fresh snow cover was greater than 3-cm, as these conditions affected the

detection power of the dogs. Scats were also collected opportunistically (without dogs) during this period.

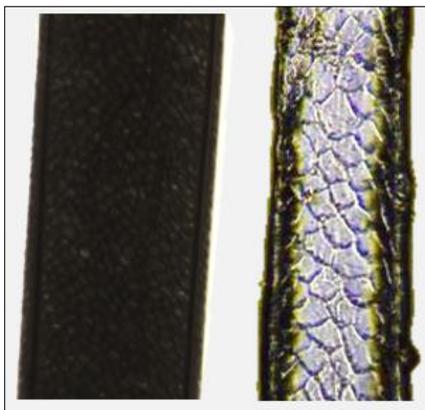
When a scat was located, we recorded the suspected species of the scat, GPS location, age post-defecation, and the scat was swabbed for a DNA sample. Species identification was based on scat diameter measurements and physical descriptions of Elbroch (2003), Weaver and Fritts (1979) and Rezendes

(1992). If possible, other signs to determine species such as tracks were considered when identifying the scat. The age of the scat was

ranked following Wasser et al. (2004) based on moisture, colour and presence of mold. To verify species identification, we collected DNA using non-finished toothpicks to swab approximately 20% of the collected scats in 2014-2015, and 50% of the collected scats in 2016. Based on DNA results from 2014-2015, we swabbed all bear scats in 2016, as we were unable to accurately discriminate between species in the field (51.7% accuracy). The mucous layer was scraped from fresh scats, dry mucous from semi-old scats (3-14 days old), and the outside of the old scats (14+ days old) while avoiding fecal material. DNA analysis was performed by Wildlife Genetics International (WGI; Nelson, BC, Canada). WGI used the Qiagen QIAamp Mini Stool Kit (Qiagen Inc., Valencia, CA) to extract DNA. The 16S ribosomal ribonucleic acid (rRNA) mitochondrial gene was analyzed and compared to reference samples for species (Johnson and O'Brien 1997).



**Fig 2.** Location of study area, encompassing the Ya Ha Tinda ranch and the northeastern corner of Banff National Park. Survey transects (denoted with black lines) were distributed among the study area on and off bighorn sheep ranges.



**Fig 3.** The medulla (left) and cuticle scale pattern (right) of an adult elk hair. These features are used to identify hairs to species and age class.

**Scat Analysis.** Scats were stored at  $-20^{\circ}\text{C}$  until ready for analysis, then autoclaved at  $121^{\circ}\text{C}$  for 60 minutes to kill biohazardous material. Scats were washed through a 0.8mm sieve with room temperature water to remove any debris. Scats were analyzed through two methods: (1) macroscopic hair analysis and (2) fecal hair DNA analysis. We combined the results from both methods for this report due to a low sample size of bighorn sheep occurrences. For scats that were analyzed through both methods (n=99), only the DNA result was reported.

A subset of scats (n=226) were analyzed macroscopically where hair, bones and vegetation were identified to family or species level, and ungulate hair was further identified to one of

two age-classes (neonate or adult). To select hairs, scat matter was divided equally into 10 sections and 2 hairs per section were chosen, for a total of 20 hairs. Hairs were wet mounted with ethanol on a glass slide and a compound light microscope was used to view medulla patterns. Cuticle scale pattern imprints were made by pressing the hair into clear nail polish (Fig. 3). The medulla pattern, width, cuticle scale pattern, scale margin distance, length and colour of hair were recorded and compared to dichotomous keys (Moore et al. 1974, Kennedy and Carbyn 1981, Jones et al. 2009), and reference images (Adjornan and Kolenosky 1969). We also compared hairs from scats to known reference hairs collected from zoos, museums, pelages and from live captures. When possible, bones recovered in scat (teeth, dewclaws, hooves, and other bone fragments) were identified to species and age-class.

We used PCR to amplify DNA of the prey species in a larger set of collected scats (n=378). Scat samples were prepped at the University of Alberta, under protocols recommended by WGI. Hairs randomly selected from scats (n~40) were soaked in a 3uL:100mL Sunlight soap solution for 24 hours. Hairs were then rinsed with hot water to remove remaining dirt and placed in a coin envelope and left overnight to dry. DNA analysis was performed by WGI. Hair samples were digested using a mixture of QIAGEN ATL lysis buffer, proteinase K, and dithiothreitol (DTT) and used QIAGEN's DNeasy Tissue kits (QIAGEN Inc., Valencia, CA) to extract DNA from hair shafts. Species ID was confirmed via a partial sequence analysis of a hypervariable region of the mitochondrial 16S rRNA gene. Due to competition during the PCR phase, this analysis can confidently report the most dominant prey species in the scat. The most dominant species refers to the proportion of DNA. For e.g. if there were 30 bighorn sheep hairs and 10 squirrel hairs in a sample, it is most likely the bighorn sheep will "win" during the PCR competition phase and amplify.

**Statistical Analysis.** Each prey item was summarized as the frequency of occurrence across all scats by noting a prey item being present (1) or absent (0) in the scat. We report frequency of occurrence for all prey items in the scats but tested for difference in frequency of occurrence for bighorn sheep among predators using a  $\chi^2$  analysis.

We modeled the probability of a scat containing sheep using rare event logistic regression, as sheep were not common in most scats collected (<5%). This approach uses a penalized likelihood method to account for biases that may result from small sample sizes (i.e., where a dataset has few presences relative to absences). Input variables in the model include elevation (to the nearest 30-m), slope ( $^{\circ}$ ), UTM easting and northing (m), the taxonomic family the scat belongs to (ursid, canid or felid) and distance to sheep range (m) as defined by Spilker and Merrill (2016). Spilker and Merrill (2016) derived bighorn sheep resource selection values for the Ya Ha Tinda region (Fig. 2) using a resource selection function (RSF) developed for bighorn sheep in Montana (DeCesare and Pletscher 2006). Data used to build the RSF came from aerial surveys conducted by Parks Canada from 1988 to 2012. The RSF values showed selection for areas at higher elevations, steeper slopes ( $>27^{\circ}$ ), and further away from streams/rivers. To define sheep ranges, RSF values not falling within the top 40% were excluded. Each input variable in the model was extracted at the scat location. We tested for collinearity between variables through a Pearson correlation test and did not include variables where  $|r| > 0.6$  in the same model (Table A2). We ranked models using Akaike's Information Criterion,

corrected for small sample size, with a cutoff of  $\Delta AIC_c=4$  to estimate the top model (Burnham et al. 2011). Analyses were performed in RStudio 1.1.442 using R package *brglm*.

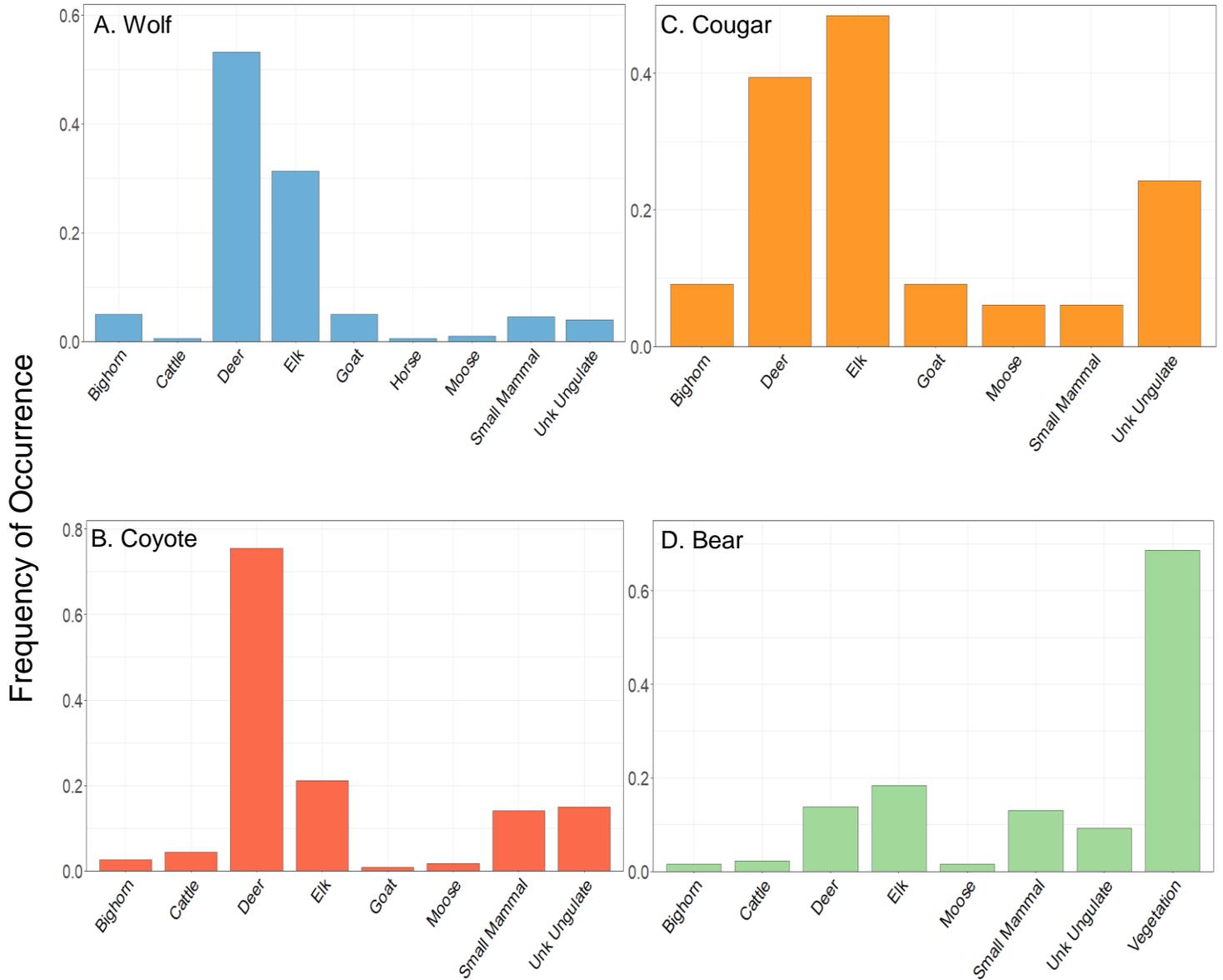
## RESULTS

**Frequency of Occurrence in Scat.** Ungulates comprised the highest frequency of occurrence in wolf (95%, n=201), coyote (93%, n=114) and cougar (100%, n=33) scats, whereas ungulates occurred in only 41% of bear scats (n=131) as they were dominated by vegetation. (Fig. 4). Rodents most frequently occurred in coyote scats (14%), followed by bear (13%), cougar (6%) and wolf (4%). In scats where all ungulate hairs could be identified, elk (28%) and deer (47%) were more frequently found in scats across predators compared to bighorn sheep (Fig. 4). Of the 19 occurrences of bighorn sheep in 505 predator scats examined, 52% (n=10) were juvenile bighorn (young of year), 5% (n=1) were adult bighorn, and 43% (n=8) of occurrences were of unknown age. Frequency of occurrence of sheep in scats was highest in cougars (9.1%) followed by wolf (4.9%), coyote (2.6%) and bear (1.5%), but there was no significant difference among predator species ( $\chi^2 = 5.62$ ,  $df=3$ ,  $P > 0.10$ ) likely due to low number of scats with sheep present.

**Spatial model of sheep in scats.** Four candidate models predicting the presence of sheep in scats from environmental features had equal support ( $\Delta AIC_c < 4$ ; Table 1). Distance to sheep range was the factor most frequently included in these models, but there was also some support for UTM northing and slope. Support for including scat type (i.e., felid) reflects that sheep was found more frequently in cougar scats. However, the confidence limit of the coefficients for slope, UTM northing, and felid overlapped zero indicating that with this small sample there is strong evidence only for distance to sheep range influencing the presence of sheep in scats.

**Table 1.** Summary of model selection results based on  $AIC_c$  for predicting presence of sheep in scats of any of 4 predators based on spatial location. Top models ( $\Delta AIC_c < 4$ ) are bolded.

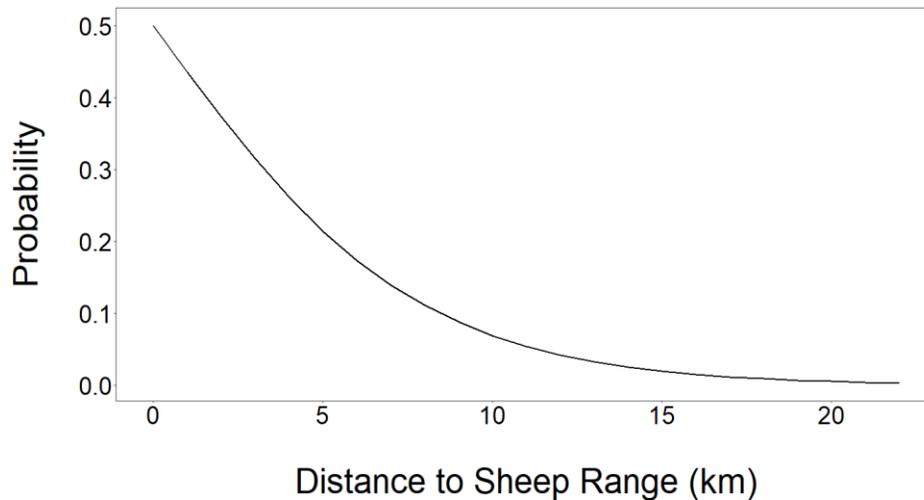
Model variables	$AIC_c$	$\Delta AIC_c$	weight
<b>distance to sheep range + UTM Northing + slope + felid</b>	<b>162.04</b>	<b>0</b>	<b>0.28</b>
<b>distance to sheep range + UTM Northing + slope</b>	<b>162.36</b>	<b>0.32</b>	<b>0.24</b>
<b>distance to sheep range + UTM Northing</b>	<b>163.06</b>	<b>1.02</b>	<b>0.17</b>
<b>distance to sheep range + slope</b>	<b>165.26</b>	<b>3.22</b>	<b>0.06</b>
distance to sheep range + felid	166.16	4.12	0.04
distance to sheep range	166.22	4.18	0.05
distance to sheep range + canid	167.74	5.70	0.02
distance to sheep range + ursid	168.02	5.98	0.02
UTM Northing	169.20	7.16	0.01
UTM Northing + slope	170.10	8.05	0.005
Null model	173.18	11.14	0.002



**Fig 4.** Frequency of occurrence of prey items in scats from predator species from the Ya Ha Tinda region of central Alberta: (A) wolf (n=201), (B) coyote (n=114), (C) cougar (n=33) and (D) bear (n=131). Grizzly bear and black bear scats were combined due to a small sample size. “UnkUngulate” refers to hairs that could not be identified further to a species due to poor hair quality. Note scale of Y axis varies among species.

**Table 2.** Beta coefficients ( $\beta$ ), upper and lower 95% confidence intervals (CI) for top spatial mortality risk models for bighorn sheep as determined through AIC<sub>c</sub> model selection.

Model	Variable	$\beta$	95% CI	
			Lower	Upper
1	distance to sheep range	-0.00037	-0.00005	-0.00111
	UTM Northing	-0.00007	-0.00004	0.00129
	slope	-0.07259	-0.19505	0.01359
	felid	0.98708	-0.26099	2.01607
2	distance to sheep range	-0.00037	-0.00004	-0.00110
	UTM Northing	-0.00007	-0.00009	0.00013
	slope	-0.07259	-0.17300	0.01730
3	distance to sheep range	-0.00025	-0.00003	-0.00083
	UTM Northing	0.00007	-0.00001	0.00013
4	distance to sheep range	-0.00004	-0.00005	-0.00116
	slope	-0.06281	-0.18609	0.02320



**Fig 5.** Logistic regression model depicting the probability that a predator scat will contain sheep as a function of distance from sheep range. The model was based on data from 505 predator scats from the Ya Ha Tinda region of central Alberta. Model predictions were based on the model  $y = \exp(-0.00026 \cdot \text{distance}) / (1 + \exp(-0.00026 \cdot \text{distance}))$

## DISCUSSION

Given our sampling design was directed at surveying the broad landscape rather than sheep ranges, bighorn sheep was not as commonly found in the scats of the four large predators in our study area as other prey species like deer and elk. Bighorn sheep occurrences were also rare in wolf scats collected on broad surveys from the same region and season in 2004 (0%) and 2011 (5%) (unpublished data, Hebblewhite and Merrill). Nevertheless, we found evidence that scats found

closer to sheep range had higher probability of sheep being in the scat, but modeling predicted that even very close to the ranges there still was likely to be only ~50% of scats with sheep present. Although larger sample sizes of scats are needed to validate our results, they suggest that if a study were designed to focus on comparing contents of predator scats among sheep ranges, the most efficient design would be to sample in areas < 5km from the range. At the same time, some species like cougars may show specialization, where individual predators prey disproportionately on prey relative to their availability (Ross et al. 1997, Festa-Bianchet et al. 2006) which would increase the variability of sheep in their scats across ranges. Scats containing bighorn sheep were not localized to single sheep ranges—they were distributed across ranges indicating no evidence of cougar specialization in this study (Fig. 2).

In contrast, the frequency of occurrence of deer as prey in wolf scats increased from 15.6% (2004) to 37% (2011), which is consistent with the current finding of 53%. Elk frequency of occurrence decreased from 54% (2004) to 37% (2011) to our current finding of 31%. The increase in deer in scats we found compared to the past is likely due a nearly 70% decline in the Ya Ha Tinda elk herd and the increase deer in this area (Berg et al. 2016).

In areas along the east slopes of the Rocky Mountains just north of our study area, deer and elk were the most common prey species identified at wolf and cougar kill sites in the summer (Knopff et al. 2010, Knamiller 2011), although deer was more prevalent than elk for both predators. Coyote summer diets are more diverse than wolves and cougars, where they tend to rely on small mammals (Thurber et al. 1992, Gese et al. 1996). Although ungulate remains are often found in coyote scats, it is thought to be a result of scavenging especially in areas where coyote ranges overlap with larger carnivores (Arjo et al. 2002). Unlike the other predators, vegetation dominated bear diets. Bears rely on nutrient rich food that is heavily abundant in order to meet their nutritional requirements for the entire year in 7 months (McLellan and Hovey 1995), however they are well-known predators on neonate ungulates (Mattson et al. 1991, Barber-Meyer et al. 2008, Griffin et al. 2011). Bears accounted for 59% of predator caused elk calf mortalities (n=54) from 2013-2016 at Ya Ha Tinda (Berg et al. 2016). These patterns are also evident in Yellowstone National Park, where bears are the major predator on neonate ungulates with mortality rates peaking in first 2 weeks of life (Mattson et al. 1991, Griffin et al. 2011). There is evidence of bears preying on adult ungulates, although it is less common. Once thought to be a result of scavenging (Murphy et al. 1998), there are several studies that link bears to killing adult ungulates in Yukon and Alaska (reviewed in Zager and Beecham 2006), however it is uncommon at Ya Ha Tinda where only 11% of adult female elk mortality is attributed to bears (Berg et al. 2016).

Based on our study, bighorn sheep in the summer range of the Ya Ha Tinda elk herd are not a major prey species for wolves, bears, coyotes and cougars, although we found weak evidence that cougars may predate on sheep more than other predators. There are spatial patterns in predator scats containing sheep, where sheep were more likely to be present in scats near sheep ranges than further away from ranges. Sheep select habitats near escape terrain and steep slopes (DeCesare and Pletscher 2006), and they have been observed to increase vigilance the farther they are from escape terrain

(Risenhoover and Bailey 1985), suggesting habitat selection is a major anti-predator behaviour for sheep. In Banff National Park, cougars shifted to eating bighorn sheep and deer only when elk numbers decreased due to wolf recolonization (Kortello et al. 2007). With the exception of possible specialists, which we could not identify because we did not identify individual predators, we suggest that spatio-temporal changes in prey availability may be driving the predator diets in this area.

## ACKNOWLEDGMENTS

We would like to thank the project collaborators and funding partners: Alberta Conservation Association – Grants in Biodiversity program, Colleges and Institutes Canada, NSERC Discovery Grant # RGPIN-2016-04733, Parks Canada, Safari Club International: Northern Alberta Chapter, TD-Friends of the Environment Foundation, University of Alberta, University of Montana and the Wild Sheep Foundation of Alberta.

We would also like to thank Rick and Jean Smith and other Parks Canada staff for their continued support of our research and for logistical help with use of the ranch facilities and backcountry cabins.

Funding provided by the Wild Sheep Foundation of Alberta allowed us to hire a technician to assist in scat analysis and contract the services for DNA analysis of scat contents. We thank you for your past and continued support of our research.

## OUTREACH

The Wild Sheep Foundation of Alberta was acknowledged in the following outreach items:

- A popular article co-authored by Kara MacAulay published in the January 2016 issue of *Alberta Outdoorsman*
- A video titled “Using scat as a tool for biological monitoring” featuring Eric Spilker (former MSc student funded by WSFA) and Kara MacAulay prepared by the Alberta Distance Learning Centre for use in their Grade 9 Science curriculum
- Oral presentations presented at the R.E Peter Biology Conference at the University of Alberta and at the Alberta Chapter of The Wildlife Society conference in Lethbridge, AB in March 2018



**Fig 6.** Sheep on Hat Mountain, overlooking the Ya Ha Tinda ranch.  
*Photo credit: Jacky Normandeau*

## UPDATED BUDGET EXPENDITURES

Category	Amount Originally Requested	Actual Spent
Lab Supplies		406.90
Salary & Wages	2,325.00	1,738.72
Contract Services	4,550.00	4,534.04
Travel		195.34
<b>TOTAL</b>	<b>\$6,875.00</b>	<b>\$6,875.00</b>

## APPENDIX A

Table A1. Full summary of model selection results based on AIC<sub>c</sub> for bighorn sheep mortality risk.

Model variables	AIC <sub>c</sub>	ΔAIC <sub>c</sub>	weights
<b>distance to range + UTM Northing + slope + felid</b>	<b>162.04</b>	<b>0.00</b>	<b>0.28</b>
<b>distance to range + UTM Northing + slope</b>	<b>162.36</b>	<b>0.32</b>	<b>0.24</b>
<b>distance to range + UTM Northing</b>	<b>163.06</b>	<b>1.02</b>	<b>0.17</b>
<b>distance to range + slope</b>	<b>165.26</b>	<b>3.22</b>	<b>0.06</b>
distance to range + felid	166.16	4.12	0.04
distance to range	166.22	4.18	0.03
UTM Easting	166.56	4.51	0.03
UTM Easting + slope	167.17	5.13	0.02
distance to range + elevation	167.56	5.52	0.02
distance to range + canid	167.74	5.70	0.02
distance to range + ursid	168.02	5.98	0.01
UTM Northing	169.20	7.16	0.01
UTM Northing + slope	170.10	8.06	0.01
UTM Northing + elevation	170.75	8.71	0.009
felid	173.18	11.14	0.004
felid + slope	173.41	11.37	0.006
slope	173.58	11.54	0.005
elevation	173.95	11.91	0.004
canid	174.83	12.79	0.004
ursid	174.87	12.83	0.003

Table A2. Pearson's correlation matrix for variables include in spatial mortality risk model for bighorn sheep in the Ya Ha Tinda region of central Alberta. Variables with  $|r| > 0.6$  (bolded) were not included in the same model.

	UTM Easting	UTM Northing	elevation	slope	distance to sheep range	canid	felid	ursid
UTM Easting	-	0.16	-0.64	-0.01	<b>0.73</b>	-0.14	0.10	0.08
UTM Northing	0.16	-	0.02	0.04	0.03	0.03	-0.06	0.02
elevation	<b>-0.64</b>	0.02	-	0.29	-0.46	-0.03	-0.01	0.06
slope	-0.01	0.04	0.29	-	-0.01	-0.17	0.13	0.09
distance to sheep range	<b>0.73</b>	0.03	-0.46	-0.01	-	-0.10	0.11	0.03
canid	-0.14	0.03	-0.03	-0.17	-0.10	-	<b>-0.63</b>	<b>-0.66</b>
felid	0.10	-0.06	-0.01	0.13	0.11	-0.63	-	-0.17
ursid	0.08	0.02	0.06	0.09	0.03	-0.66	-0.17	-

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