Ya Ha Tinda Elk Project

Long-term monitoring of the partially migratory Ya Ha Tinda elk population, predators, and foraging resources

Final Report

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Presented to:
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Prepared by:
Mark Hebblewhite (Principal Investigator), Hans Martin, Sara Williams, Gabrielle Coulombe, Mateen Hessami, Birch Gano; University of Montana
&
Evelyn Merrill (Principal Investigator), Madeline Trottier, Jacalyn Normandeau, Mitchell Flowers, Kara MacAuley, Peter Smolko; University of Alberta

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Disclaimer

This report includes preliminary data from ongoing academic research directed by the University of Montana and University of Alberta. These data will form portions of graduate student theses, dissertations, and scientific publications. Some of the results and opinions presented herein are therefore considered preliminary, to be interpreted with caution, and are subject to revision.

Executive Summary

The Ya Ha Tinda (YHT) Elk Project is a long-term research study of a partially migratory elk population with a sympatric winter range in the Ya Ha Tinda Heritage Area and Banff National Park (BNP) in Alberta. The project is a collaboration between the University of Alberta, University of Montana, Parks Canada, and Alberta Environment and Parks – Fish and Wildlife. In this report, we present the results of our research for the 2017–2021 reporting period, along with some long-term (2001–present) summaries and findings. During the reporting period, our research was largely sustained by Federal (National Science Foundation, Natural Sciences and Engineering Research Council) and NGO funding, with key in-kind support from Parks Canada and Alberta Environment and Parks.

Elk numbers from winter ground counts were relatively stable, from 390 elk in winter 2017/18 to 328 elk in winter 2020/21. During aerial surveys conducted in winter 2017/18, 416 elk were counted. We captured a total of 94 adult female elk during the reporting period and maintained 45-75 active GPS and/or VHF collared female elk in the YHT population. Pregnancy rates varied between 70–95% (mean=88%) across years. Wolves and hunting continue to primary causes of mortality of adult female elk. Recruitment rate (cow:calf ratio) averaged 0.18 for 2017–2021. Across our long-term study, adult female survival was lower inside BNP due to wolves and grizzly bear mortality, was highest for residents at YHT. We combined all long-term demographic data from the population in a Bayesian Integrated Population Model (IPM) that estimated population vital rates and trends over time. The differences in demography amongst migratory tactics lead to faster rates of decline of western elk in BNP since 2002. Declines were also driven by individual elk switching away from western migratory tactics to resident or eastern tactics faster than vice-versa. Our research suggests elk are switching in search of the best reproductive outcomes - calf survival - by searching for lower predation risk in our study area during calving and summer.

With wolves remaining a primary cause of adult elk mortality, we continued to work with Parks Canada to capture and monitor 6 adult wolves with GPS collars during the reporting period. We also conducted an analysis of wolf survival from 1985 - 2020 in collaboration with Parks Canada. Our analyses showed that wolf survival was moderate (0.733), similar to unprotected populations. We found that mortality was 6.7 times higher outside BNP than inside, and the leading causes of wolf mortality were trapping, hunting, and highways. The most important hotspot for mortality for BNP wolves was the Panther-Dormer Corners just outside BNP.

Despite the importance of the YHT to bull elk hunting in Alberta, we have not previously studied male elk ecology. In 2018, we captured and radiocollared the first of 80 total male elk in a new 3-year study lead by PhD student Hans Martin. We collected body condition, age, and antler score as a measure of trophy quality, and studied space use, survival, migration and vulnerability to harvest. More male elk migrated west into BNP (64% of all) than females, supporting the hypothesis that males selected the highest quality forage in BNP compared to females because of their lower vulnerability to non-human predation. Cause-specific mortality supported this interpretation as > 90% of all male elk were harvested by humans; only 2 were killed by wolves. Antler size increased with bull elk age, and exposure to higher forage quality on migrant summer ranges. While there were slight differences in survival between migratory and resident bull elk, but the main thing driving survival was age and thus harvest vulnerability. Survival of males 2-3 was 0.86, 4-year-old survival was 0.72, whereas survival of 5+ year old males was 0.42. There were few elk that survived past 6 years of age in our population, and from a trophy quality perspective, few elk in the Ya Ha Tinda exceeded SCI antler scores of 300, indicating high harvest vulnerability likely limited trophy quality in this population.

To monitor the multiple predators important for the ecology of YHT elk, we continued to work cooperatively with Parks Canada to maintain a network of ~ 40 remote camera's in and around the YHT. We monitored elk response to multi-carnivore predation risk using remote cameras during the reporting period. We found that return times of elk to remote camera sites differed following detection of a wolf, grizzly bear, and cougar. Elk took longer to 'return' to camera sites following a wolf or cougar visit, 65% and 59% longer, compared to grizzly bears which increased return times by 26%. Habitat features known to facilitate predation (edge density) also delayed return times. These results show that cameras can be used to study fine-scale predator-prey dynamics for multiple species. We also report on results of a scat-based predation risk modeling framework using scat detection dogs collected earlier from 2013 - 2016. Spatial models of predation risk developed from scats were also predictive of predation risk experienced by adult female elk in our study area. These results help us understand the influence of carnivores in addition to wolves on elk in the YHT.

We also took advantage of remote cameras to test the ability to monitor calf:cow ratios of YHT resident elk during the summer of 2018. We found a strong correlation between ground counts of calf:cow ratio and those derived from remote camera's following the neonate hiding phase especially. These results indicate Parks Canada's remote camera monitoring system could successfully monitor population demography of ungulates and perhaps other species.

We conducted an analysis of elk selection for fires and forage biomass while accounting for predation risk on summer ranges. We focused on 4 main summering areas: residents at the YHT, eastern migrants, western migrants and elk in the Panther, Dormer and Cascade valleys (southern migrants) from 2002 - 2019. Abundance of herbaceous biomass was lower on migratory ranges at high elevations inside Banff National Park (BNP) than on low-elevation ranges outside BNP due to growing season, extent of different vegetation communities, and burn patterns over the past 2 decades. Overall, burning increased herbaceous biomass in areas by 65 % in grasslands, 18 % in shrublands, and 170% in forest compared to unburned sites, with the peak increase occurring 4-6 years after burning in both grasslands and forest/shrublands. Migratory elk on high-elevation summer ranges inside BNP strongly selected for high quality where there were few burns (western elk). Eastern migrants selected for burned areas more strongly than unburned areas but also gave up high quality forage for lower wolf predation risk. Southern migrant elk selected strongly for unburned than burned areas early in study, but later, when new burns were recovering (> 8 years old), southern migrant elk selected for burns regardless of wolf predation risk but avoided them when they were selected by grizzly bears. These results help inform the ecological effects of the extensive prescribed and natural fires in the study area. And results reveal that elk selection for burns generally depends on their exposure to predation risk by wolves and grizzly bears.

Many studies of ungulate populations focus on predation, but parasites can also be as important in affecting mortality especially as an indirect cause. Thus, we also monitored elk exposure to endoparasites such as *Fasciodes magna*, the giant liver fluke, across different migratory tactics. Across all years and seasons eastern migrant elk had an average prevalence of 66% where residents and Banff migrants had an average prevalence of 31% and 42% respectively. Analysis of individual elk use and *F. magna* egg output showed that residents had lower *F. magna* egg output than eastern and Banff migrants. Exposure to wetlands - known transmission foci - also increased *F. magna* egg output significantly. Higher *F. magna* prevalence and intensity in eastern migrant elk could have health implications for elk using the new eastern migration tactic.

Despite the shift to the eastern tactic in the YHT population in the last 2 decades, we do not know if eastern migratory elk segregate socially or respond to predation risk differently on the shared winter range. This could expose eastern elk to different risks of predation from non-human (wolves) and human hunting on the shared winter range. To address these questions, we conducted detailed behavioral observations of adult female elk of known migratory tactics on the shared winter range from 2018 - 2020. There was high overlap between the 3 different migratory tactics on the shared winter range, with > 69% overlap in tactic ranges during winter. At the individual level, overlap was also high and increased over the winter. Despite this overlap, there were potential differences in antipredator behaviors between the 3 migratory tactics that could indeed render them vulnerable to wolf predation and hunting by humans on the shared winter range.

Finally, we started collecting DNA samples (n=73) via biopsy darting for a new branch of our research aiming to build a wild pedigree of the YHT elk population. We will use population genomics to investigate individual reproductive success and fitness of female and male elk, including migrants and residents.

We made significant contributions to science and public outreach during the 2017–2021 reporting period. Together with students and agency collaborators, we published 32 peer-reviewed publications in scientific journals and disseminated scientific results at dozens of national and international conferences in >= 35 scientific conference presentations. The Ya Ha Tinda elk project continues to provide its GPS and other data to several high-profile global collaboratives that resulted in several high-profile scientific papers such as the Tucker et al. (2019) *Science*, and other international collaborations including evaluating effects of COVID restrictions on wildlife. We completed 10 graduate and undergraduate student theses (2 undergrad, 6 MS, 2 PhD) in the reporting period, and our graduates and technicians populate wildlife manager, biologist and research positions throughout western Canada and beyond. We also communicated our science to the public through > 6 formal public presentations at the Ya Ha Tinda, Sundre, Banff and more broadly. Our science was featured in > 40 popular news media articles, and our website continues to be visited by the public. Our research has promoted interagency cooperation and management of the important YHT elk population and provided support to other projects, including bison reintroduction, caribou recovery, prescribed fire programs, and connectivity analyses in BNP and the Canmore area.

Permits & Approvals for Research

- Alberta Fish and Wildlife Research and Collection Permits: 18-001, 18-229, 18-323, 19-002, 19-003, 20-004, 20-003, 57633, 57631
- Parks Canada Research and Collection Permit: YHTR-2017-26977
- University of Alberta Animal Use Protocol (AUP): 000624
- University of Alberta's Canadian Council on Animal Care Protocol (CCAC): AUP00000624_AME7
- University of Montana Institutional Animal Care and Use Protocols (IACUC): 004-16MHECS-020916, 066-18MHWB-123118

Introduction

The Ya Ha Tinda (YHT) Elk Project is now the longest running study of free-ranging elk (*Cervus canadensis*) in the world. The project was initiated in 2000 to answer questions about the changing migratory dynamics of the YHT elk, Alberta's most important elk population, and is the result of a collaboration between the University of Alberta, University of Montana, Parks Canada, and Alberta Environment and Parks – Fish and Wildlife. While early studies in the late 1970s and early 1980s (Morgantini & Hudson 1988) laid the foundation for our latter studies, there was a 20-year gap in active research. Our work focuses on both fundamental and applied research. Our long-term research has shown that parts of the herd migrate to Banff National Park (BNP) and other areas in the summer, while other elk reside year-round at YHT. Some elk have been switching year to year between the different strategies of eastern migration, western migration, and year-round residency. In the population, the proportion of migrants has been decreasing over the years and some migrants have been using new migratory routes and destinations.

Objectives

Our broad research goals are to monitor and understand the plastic migratory behaviors of the Ya Ha Tinda elk and predator-prey dynamics across their range in a transboundary montane system. Fundamental research on elk ecology, foraging, and predator-prey dynamics builds a foundation to answer applied questions including topics related to the effects of prescribed and natural fires, transboundary management policies and implications, salvage logging, and the harvest of both elk and large carnivores. Our objectives in the 2017–2021 period were to:

1) Continue the long-term monitoring of YHT elk population trends and migratory habits;
2) Monitor wolf predation risk, movements, and demography;
3) Study male elk recruitment, survival, and harvest;
4) Monitor the predator community that preys on YHT elk and the effects of predation and predation risk on the elk population;
5) Monitor habitat quality and maintain dynamic models of forage quality and biomass;
6) Monitor endoparasites in YHT elk and compare endoparasite species composition and abundance between elk using different migration strategies;
7) Study behavioural disparity in the partially-migratory YHT elk herd on its sympatric winter range; and
8) Investigate individual reproductive success and fitness by building a wild pedigree of the YHT elk herd using population genomics.

Study area

The Ya Ha Tinda, or *mountain prairie* in Stoney Sioux language, is a pristine montane rough fescue range that provides habitat to Alberta's large and iconic YHT elk population (Morgantini 1995). YHT elk form a transboundary herd, with annual migratory cycles that have spanned two provinces (elk have migrated into Yoho National Park, British Columbia) and different land management regimes including Banff National Park (BNP), Provincial Forest Land Use Zones, and Provincial Multiple Use Zones. Our study area encompasses > 6,000 km^2 in the Ya Ha Tinda Heritage Area and BNP, Alberta, where the partially migratory YHT elk population occurs. The main study area includes portions of the Banff Field Unit and the Lake Louise, Yoho and Kootenay Field Unit in the remote front ranges of BNP through the Panther, Red deer, Cascade, Clearwater, Pipestone, and Upper Bow River drainages. The Ya Ha Tinda is home to recovered populations of grizzly bears (*Ursus arctos horribilis*), wolves (*Canis lupus*), and other large mammal predator and prey species, including – for the first time in over a century, Plains bison (*Bison bison bison*). The YHT region has long been important to First Nation communities for hunting and traditional land use practices and is also managed as a male elk harvest area for both resident and guided licensed recreational hunters.

Objective 1. Long-term Ya Ha Tinda elk population trends and migratory habits

We surveyed the Ya Ha Tinda (YHT) elk population using ground counts, aerial surveys, pellet plot surveys, radiotelemetry, and GPS collars, and analyzed demographic data following methods described by Morgantini and Hudson (1988) and Hebblewhite et al. (2006). We captured adult female elk each year to maintain 43-54 active GPS-collars, tested blood samples to determine pregnancy rates, and monitored movement and survival using telemetry. We also used telemetry mark-resight to monitor calf:cow ratios and determine female reproductive success. We classified the migratory status of individuals and analyzed population vital rates, population growth rates, and relative fitness of western migrants, eastern migrants, and residents. We also studied the effects of predation risk, forage dynamics, habitat characteristics, and group size on adult elk survival in migratory and resident herd segments.

1.1. Ground counts

Ground counts were conducted annually between 1 February–30 April, a period during which the majority of the YHT elk population is aggregated on the YHT Ranch grasslands. Our counts included the majority of the population's females and juveniles, as all collared females were present and no other large elk groups were observed elsewhere when these counts were conducted. The number of elk was relatively stable over the reporting period, from 390 elk in winter 2017/18 to 328 elk in winter 2020/21 (**Table 1.1**).

Table 1.1. Highest counts of the Ya Ha Tinda elk population obtained from the ground in late winter (1 Feb.–30 Apr. 2002–2021) at Ya Ha Tinda, Alberta, Canada.

Year	Number of Surveys	Highest Count
2001/02	83	700
2002/03	178	748
2003/04	69	616
2004/05	38	948
2005/06	62	609
2006/07	32	620
2007/08	29	300
2008/09	28	450
2009/10	14	400
2010/11	20	325
2011/12	6	279
2012/13	22	335
2013/14	16	387

2014/15	14	358
2015/16	21	355
2016/17	21	357
2017/18	36	390
2018/19	56	371
2019/20	63	348
2020/21	80	328

1.2. Aerial surveys

Aerial surveys under-represent male elk numbers because males are more spread out than females and juveniles and tend to be in denser cover, limiting visibility from the aircraft. We addressed this challenge by developing an integrated population model that explicitly estimates the total elk population size, including males (see **Objective 3**). To date (June 2021), no new aerial surveys have been conducted since February 2018. Given the importance of aerial survey data for understanding long-term trends in the YHT elk population (Hebblewhite et al. 2006), we recommend conducting annual winter aerial surveys, to be coordinated by Parks Canada and Alberta Environment.

A summer aerial survey was conducted on 13-14 July 2017 by Parks Canada, Alberta Environment and Parks, and University of Montana staff. We surveyed all alpine and subalpine summer elk ranges and key winter ranges identified by Morgantini and Hudson (1988). Telemetry data from early and late periods confirmed that no major summer ranges were missed during surveys (Morgantini and Hudson 1988, Hebblewhite and Morgantini 2003, Spaedtke 2007). Large herds (>50) were photographed to ensure count accuracy. We recorded group size, general group composition (male, female, mixed), activity, and GPS location. A total of 279 elk were counted during the 2017 summer aerial survey (similar to the 232 elk recorded in 2007): 47 elk within Banff National Park, 58 elk in the eastern portion of the study area, and 174 elk on the winter range on or near the YHT Ranch (**Fig. 1.1**).

Winter aerial surveys were conducted in January–February 2018 by Parks Canada (Blair Fyten), in the morning (8 am–12 pm) on sunny or flat-light days, 1–2 days following heavy snowfalls to maximize sightability of elk (Allen et al. 2008). We counted a total of 416 elk, including 357 individuals in a single large female-juvenile group and 57 males.

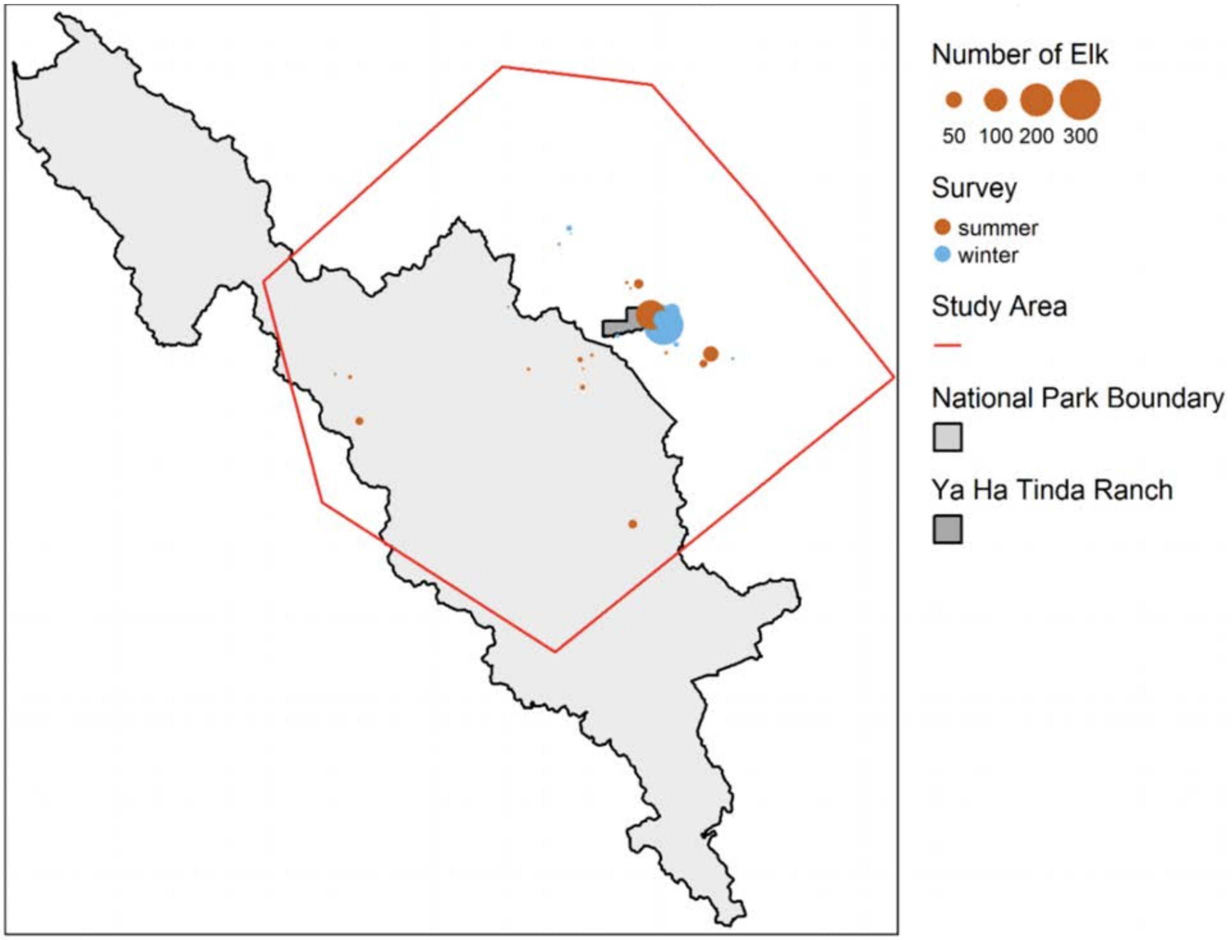

Figure 1.1. Ya Ha Tinda elk population counts from aerial surveys conducted in summer 2017 (total = 279 elk) and winter 2017/18 (total = 416 elk) across the herd's range; Alberta, Canada. Summer counts are lower because some of the elk migrate in summer and are thus more widely dispersed and difficult to detect.

1.3. Pellet plot surveys

We continued our annual long-term pellet plot surveys in the YHT grasslands and adjacent shrubby and forested areas of <60% canopy cover to assess ungulate grazing pressure, relative abundance, and distribution. Pellet plot surveys were conducted annually in spring (May) as an indicator of winter use and in the fall (September) as an indicator of summer use. Plots were 25 m^2 and located on a 250-m grid (**Fig. 1.2**). Pellet groups were defined as containing at least 8 pellets and counted if >50% of the group was within the plot. Pellet shape, color, and weathering helped determine species and time of deposition (current year, previous year, or older). We recorded all ungulate species, including elk, deer (*Odocoileus virginiana, O. hemonius*), horse (*Equus*), and moose (*Alces alces*). We calculated the mean number of elk pellet groups per plot and the mean daily deposition rate (**Table 1.2**).

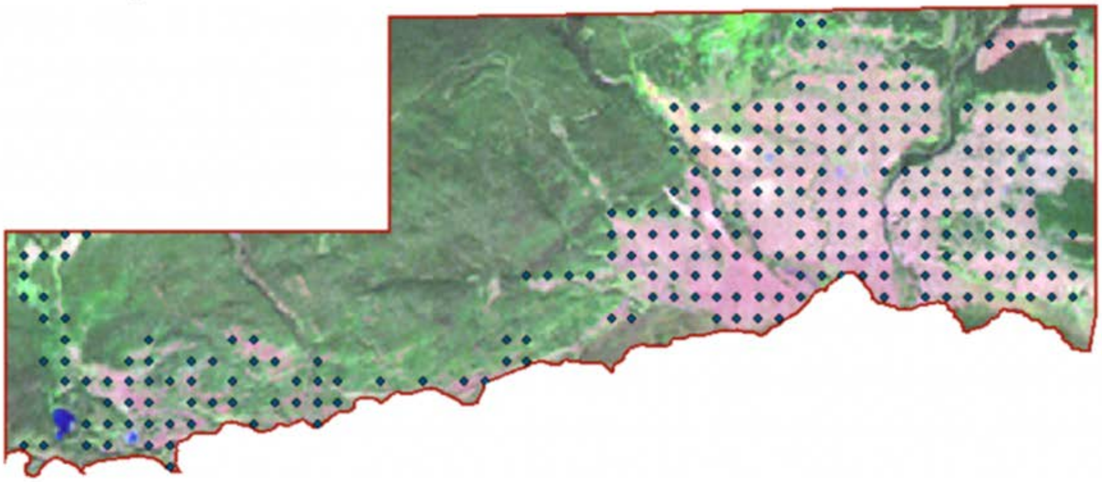

Figure 1.2. Grid from which ungulate pellet plots of 25 m^2 were selected and surveyed annually in spring and fall in the Ya Ha Tinda grasslands in Alberta, Canada; pink indicates grassland areas.

Table 1.2. Mean number of elk pellet groups counted on 25m^2 plots surveyed annually on the Ya Ha Tinda Ranch grasslands, Alberta, Canada, and deposition rate (# elk pellet groups/day). Spring surveys were used as an indicator of winter use while fall surveys were used as an indicator of summer use.

Season	Year	# Plots	Min	Max	Mean	SD	#/Day	SD
Summer	2000	275	0	8	0.57	1.07	n/a	n/a
Summer	2001	277	0	10	0.42	1.03	0.003	0.008
Summer	2005	37	0	3	0.78	1.00	0.008	0.010
Summer	2006	37	0	2	0.38	0.59	0.003	0.005
Summer	2007	45	0	3	0.31	0.67	0.003	0.006
Summer	2008	367	0	10	1.08	1.69	0.011	0.017
Summer	2009	325	0	8	0.84	1.32	0.006	0.009
Summer	2010	379	0	18	1.39	2.28	0.011	0.019
Summer	2011	356	0	6	0.43	0.89	0.004	0.008
Summer	2012	382	0	2	0.08	0.32	0.001	0.002
Summer	2013	366	0	5	0.23	0.63	0.002	0.005
Summer	2014	374	0	8	0.28	0.79	0.002	0.007
Summer	2015	376	0	9	0.52	1.08	0.004	0.009
Summer	2016	377	0	9	0.37	1.02	0.003	0.009
Summer	2017	152	0	7	0.41	0.89	0.003	0.001
Summer	2018	78	0	4	0.52	0.88	0.004	0.006
Winter	2000/01	270	0	24	3.01	3.33	0.013	0.014
Winter	2001/02	272	0	21	3.94	2.60	0.017	0.018

Winter	2004/05	37	0	16	3.76	3.12	n/a	n/a
Winter	2005/06	38	0	14	2.74	3.36	0.011	0.013
Winter	2006/07	46	0	16	2.85	3.48	0.011	0.014
Winter	2007/08	120	0	16	1.47	2.31	0.007	0.011
Winter	2008/09	356	0	25	1.7	2.55	0.008	0.011
Winter	2009/10	359	0	16	1.37	2.09	0.006	0.010
Winter	2010/11	356	0	19	1.15	2.11	0.005	0.008
Winter	2011/12	357	0	16	0.9	1.80	0.004	0.001
Winter	2012/13	378	0	21	0.95	1.67	0.004	0.009
Winter	2013/14	358	0	22	0.63	2.01	0.003	0.009
Winter	2014/15	372	0	12	0.78	1.86	0.003	0.008
Winter	2015/16	375	0	12	0.752	1.52	0.003	0.006
Winter	2016/17	375	0	7	0.54	1.18	0.002	0.005
Winter	2017/18	593	0	19	1.57	2.80	0.007	0.003
Winter	2018/19	393	0	15	1.04	2.04	0.005	0.009

1.4. Adult female elk capture and handling

In February and March 2018–2021, a total of 94 adult female elk were free-range darted and immobilized (**Table 1.3**, **Fig. 1.3**). They were fitted with GPS collars scheduled to record a location every 6-13 hours. We collected hair and blood samples, assessed body condition, and recorded body measurements. The elk were provided oxygen during the immobilization and vital signs were monitored. Blood samples were analyzed for the presence of Pregnancy-Specific Protein B to determine pregnancy (BioPRYN; Biotracking Inc.). Elk that were captured for the first time were ear-tagged in both ears and a vestigial canine tooth was removed for aging after numbing the nerve using Lidocaine, in accordance with our approved animal handling protocol.

Table 1.3. Number of female elk captured, pregnancy rates, and total number of active GPS collars at Ya Ha Tinda, Alberta, Canada, from 2018–2021.

Year	New	Recaptured from previous year	Total Captures	Pregnancy Rate	Total Number of Active GPS Collars
2018	9	29	38	92.1%	50
2019	11	9	20	70.0%	45
2020	13	7	20	94.7%	54
2021	10	6	16	93.3%	43

Figure 1.3. Elk captures from horseback using darts; 2021; Alberta, Canada.

1.5. Telemetry

A total of 110 unique collared adult female elk were monitored in 2017–2020 and we maintained 45-75 collared female elk in the YHT population (**Table 1.4**). Individual elk were collared for 3.1 years on average. Since 2017, we stopped deploying VHF-only collars and continued to deploy GPS collars (which have a VHF beacon as well). GPS capabilities reduced the flight time required for relocating migrant elk and decreased the time needed to locate elk mortalities (**Fig. 1.4**). Our new GPS collars collect ~2 locations per day (1 location every 13 hours), providing sufficient location data for monitoring migration and habitat selection but with a lifespan comparable to that of a VHF-only collar (5-7 years).

Table 1.4. Number of VHF-collared and GPS-collared female elk and number of GSP locations recorded in 2018–2021 in the Ya Ha Tinda elk herd, Alberta, Canada.

Year	Total # Collared Elk	# Active VHF-only Collars	# Active GPS Collars	Total # GPS Locations	Mean # GPS Locations/Elk
2018	75	25	50	37,236	745
2019	60	15	45	In progress	In progress
2020	60	6	54	In progress	In progress
2021	45	2	43	In progress	In progress

Figure 1.4. Hans Martin conducting ground elk telemetry in summer; Upper Dogrib Creek, Alberta, Canada.

1.6. Adult mortality

A major goal of our long-term research has been assessing cause-specific mortality of adult (and collared neonate) elk. Data on cause-specific mortality are critical for understanding predator-prey dynamics, density-dependent predation by specific carnivore species, and drivers of long-term changes in elk migration dynamics. Mortality signals from radio-collars were detected using ground and aerial telemetry and were investigated from the ground or via helicopter as soon as possible. Between 2016–2021, the average wait to investigate kill sites was 6 days (SE=1.7), similar to our long-term time-to-investigation of 5.5 days (Hebblewhite and Merrill 2011, Hebblewhite et al. 2018).

Over the entire duration of the project, we have investigated 223 mortalities of radio-collared adult female elk (**Table 1.5**, **Fig. 1.5**). The leading known cause of mortality in terms of number of mortalities was wolves (18% of all mortalities), followed by hunting (bow harvest, rifle, poaching, and treaty First Nation; 17%), grizzly bears (15%), other causes (8%), and cougars (5%). Overall trends have remained similar in this reporting period (2017–2021, n=65), with wolf (22%), hunting (22%) and 'other' (22%) as the leading known causes of adult female mortality (**Table 1.5**, **Fig. 1.5**).

It is important to note that the number of cause-specific mortalities do not necessarily reflect more advanced estimates of cause-specific mortality rates using time-to-event survival models (e.g., section **1.9** below). In our previous studies examining mortality of adult female elk (Hebblewhite and Merrill 2011, Hebblewhite et al. 2018), minor discrepancies occurred between numbers of cause-specific mortalities and estimates of cause-specific mortality rates, but, overall, the rankings of mortality causes were similar between the two approaches. For this reason, we recommend simply using the reported numbers to rank mortality causes in terms of importance, but not in estimating cause-specific mortality rates. We will estimate cause-specific mortality rates in future analyses.

Table 1.5. Number and proportion of mortalities of radio-collared adult female elk at the Ya Ha Tinda from two time periods; i) the entire study (2002–2021; n=223), and ii) this reporting period (2017–2021; n=65). Note 'Hunting' as a cause includes legal licensed hunting (which was legal during 2002, 2003), but is otherwise treaty First Nation hunting. 'Other' causes include death in a trapline snare, drowning, death during parturition, and disease.

Cause	**2002–2021**	**Proportion**	**2017–2021**	**Proportion**
Cougar	13	0.05	3	0.05
Grizzly	36	0.15	6	0.09
Road/Rail	4	0.02	1	0.02
Hunting	36	0.15	14	0.22
Other	19	0.08	14	0.22
Poaching	4	0.02	3	0.05
Unknown	69	0.29	10	0.15
Wolf	42	0.18	14	0.22
Total	**223**		**65**	

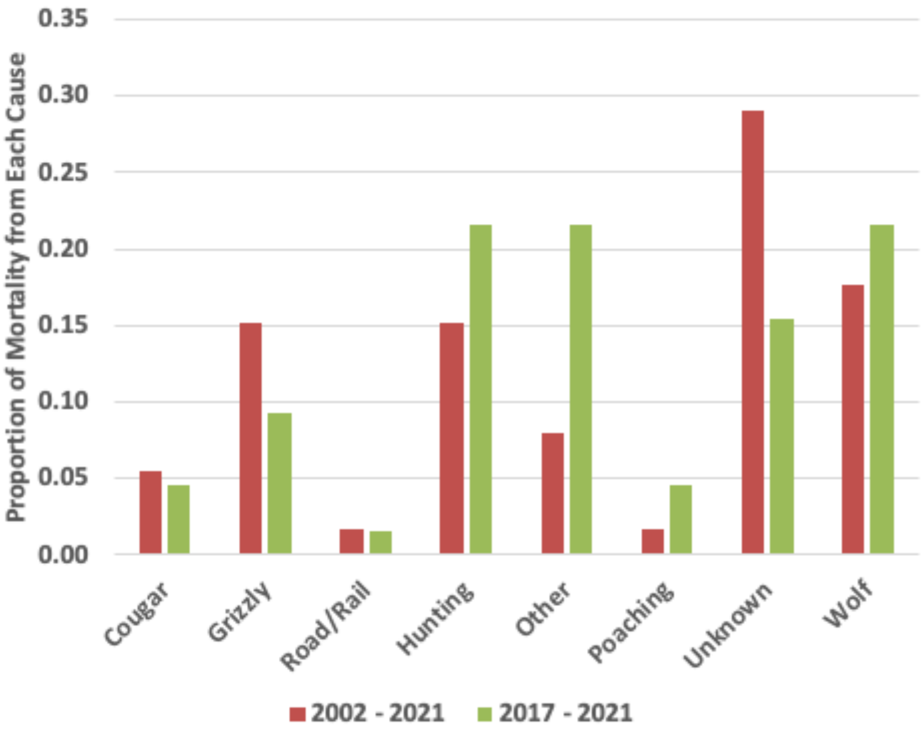

Figure 1.5. Causes of mortality of radio-collared adult female elk (*n* = 223), shown as proportions, from 2002–April 2021 in the Ya Ha Tinda elk population, Alberta, Canada.

1.7. Winter calf:cow ratios

For all observations of groups of collared, tagged, and/or un-collared elk, we recorded time, date, location, and the number of tagged elk in the herd when possible. Observations were made through binoculars or spotting scopes (**Fig. 1.6**) from suitable distances to avoid influencing elk behavior elk (~30-100 m from horseback and ~100-500 m from the ground or truck). We counted the number of individuals several times and classified elk sex and age using criteria from Smith and McDonald (2002). Our most skilled observers attempted to classify yearling females in the field, but only at very close range, as body size of yearling females is variable and there is considerable risk of misclassification (Smith and MacDonald 2002). Therefore, we included any of the classified yearling females in the adult female total. We examined trends in recruitment from 2001–2021 by examining calf:cow ratios in late winter (1 Feb.–30 Apr.; **Fig. 1.7**). We followed statistical methods from Hebblewhite (2006, Appendix 1B).

Figure 1.6. Research technician extraordinaire Birch Gano conducting calf:cow classification surveys in winter 2020/21.

Average recruitment rate from 2002–2021 was 0.182 (95% CI = 0.154–0.210), ranging from a low of 0.090 in 2003 to a high of 0.315 in 2014 (**Fig. 1.7**). Recruitment surveys had inadequate sample sizes in 2008, 2012, and 2013. In this reporting period (2017–2021), spring recruitment rates were very similar to the long-term average: 0.190 in winter 2017/18, 0.238 in 2018/19, and then declined to 0.134 and 0.144 in 2019/20 and 2020/21, respectively (**Fig. 1.7**).

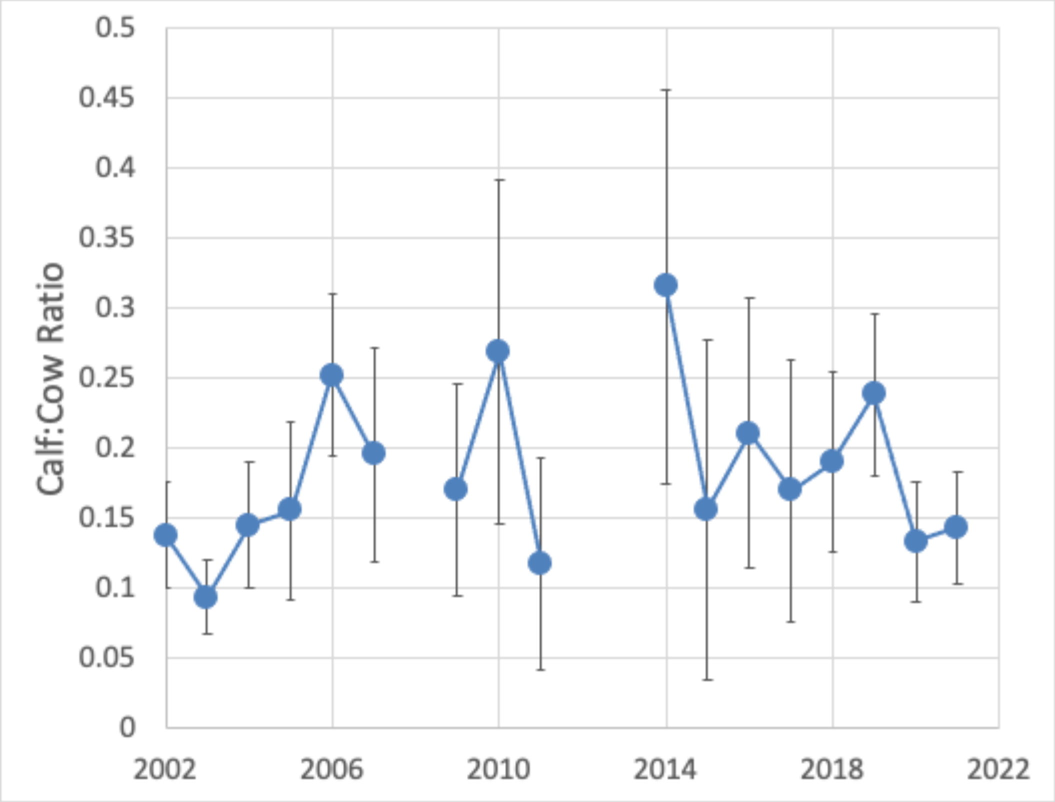

Figure 1.7. Calf:cow ratios in late winter (1 Feb.–30 Apr.) from 2002–2021 (with 95% CI) for the Ya Ha Tinda elk herd, Alberta, Canada. Adult female total includes female yearlings.

1.8. Classifying migrant and resident trends over time

Sara Williams, Joshua Killeen, Evelyn Merrill, Mark Hebblewhite

Analyses of long-term YHT population trends and migratory dynamics were developed for peer-reviewed scientific papers (Williams et al. *In Review*; Martin et al. *In Review*) and Hans Martin's completed PhD dissertation (Martin 2021). We report trends in migration tactics in this section, and then results of IPM modeling in section **1.9** below. We used a nearly 20-year record of individual-based monitoring to test hypotheses for changing patterns of migration. We tested whether bottom-up (forage quality) or top-down (predation risk) factors explained trends in i) the proportion of individuals using different migratory tactics, ii) differences in survival rates of migratory tactics and on summer ranges, and iii) cause-specific mortality by wolves and grizzly bears during the summer migratory period.

We first fit Dynamic Bayesian Brownian bridge movement models to identify migratory routes of individual female elk. We considered up to 5 different migratory tactics, depending on the direction and location of the summer range, and simplified the migratory system at Ya Ha Tinda to: resident non-migratory elk, western migrant elk, and eastern migrant elk. Western migratory elk included elk that migrated west anywhere into Banff National Park (BNP) or northwest into the Clearwater River. Brownian bridge migratory corridors are shown in **Fig. 1.8**.

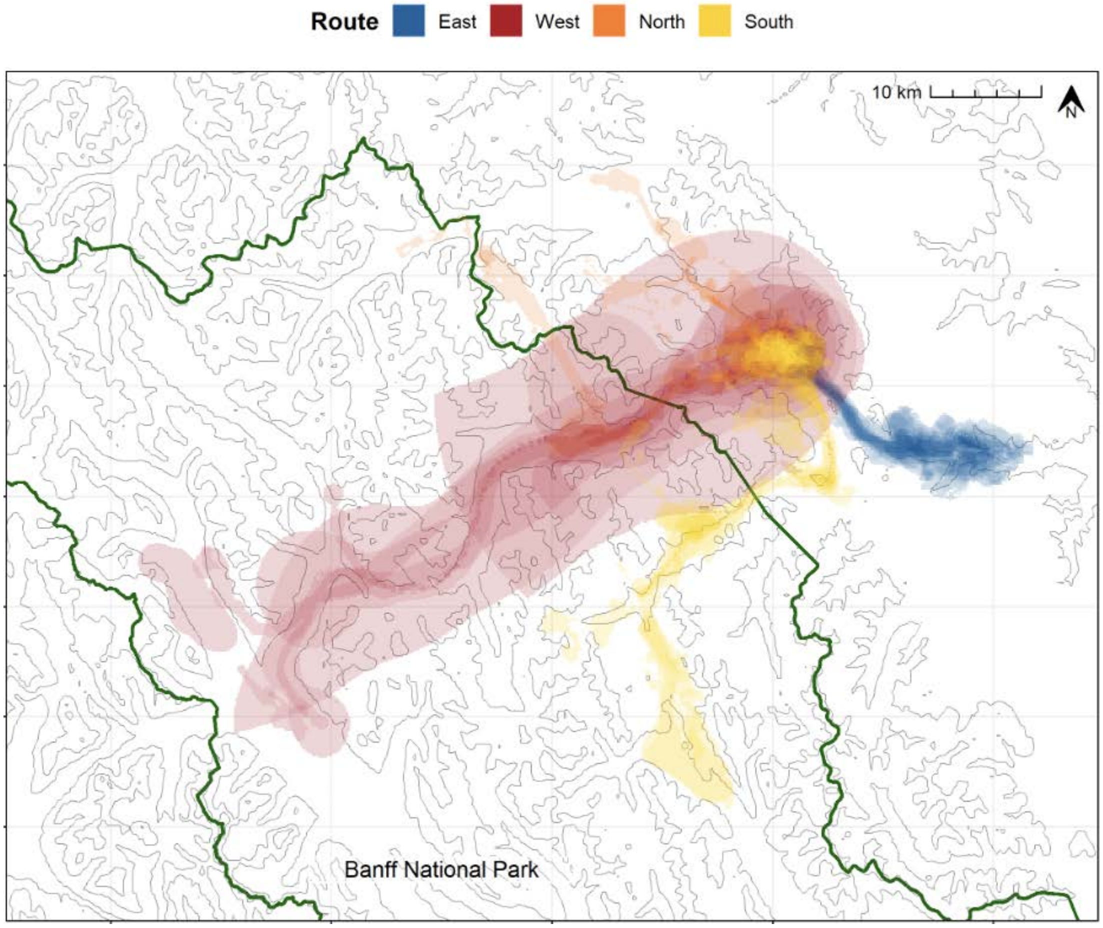

Figure 1.8. High-use boundaries around migration route utilization distributions generated by Brownian Bridge movement models for adult female elk (*Cervus canadensis*) classified as migrants and wearing GPS-collars during migration periods in the Ya Ha Tinda population, Alberta, Canada, 2002–2019. Polygon color indicates classified migration route and transparency shows relative use (more transparent indicates fewer overlapping migration utilization distributions and more opaque indicates more overlapping utilization distributions).

We found dramatic shifts in migratory behavior consistent with established behavioral plasticity in annual choice of migratory routes. Shifts were inconsistent with the demonstrated bottom-up benefits of migration to high-elevation montane summer ranges shown previously in our system by Hebblewhite et al. (2008). Instead, transboundary gradients in predation risk caused by predator protection inside BNP, and exploitation of wolves and grizzly bears outside the park led to low survival rates inside BNP, and the highest survival rate for the resident tactic (**Fig. 1.9**). Cause-specific mortality aligned with exposure to predation risk along migratory routes and summer ranges (**Fig. 1.10**).

Wolf predation risk was higher on migratory routes than summer ranges of mountain-migrant tactics, but wolf predation risk traded-off with heightened risk from grizzly bears on summer ranges. Instead, a new eastern migrant tactic emerged during the study following a large burn and lower predation risk from grizzly bears and exploited wolves. The changes in migratory behavior were reflected in changes in population abundance, where abundance of the mountain tactics declined over time, but the diversity of migratory life-histories maintained a higher population abundance overall than without migratory tactics. Our study demonstrates the complex ways in which migratory populations change over time through behavioral plasticity and demographic consequences as a result of individuals balancing predation risk and forage trade-offs.

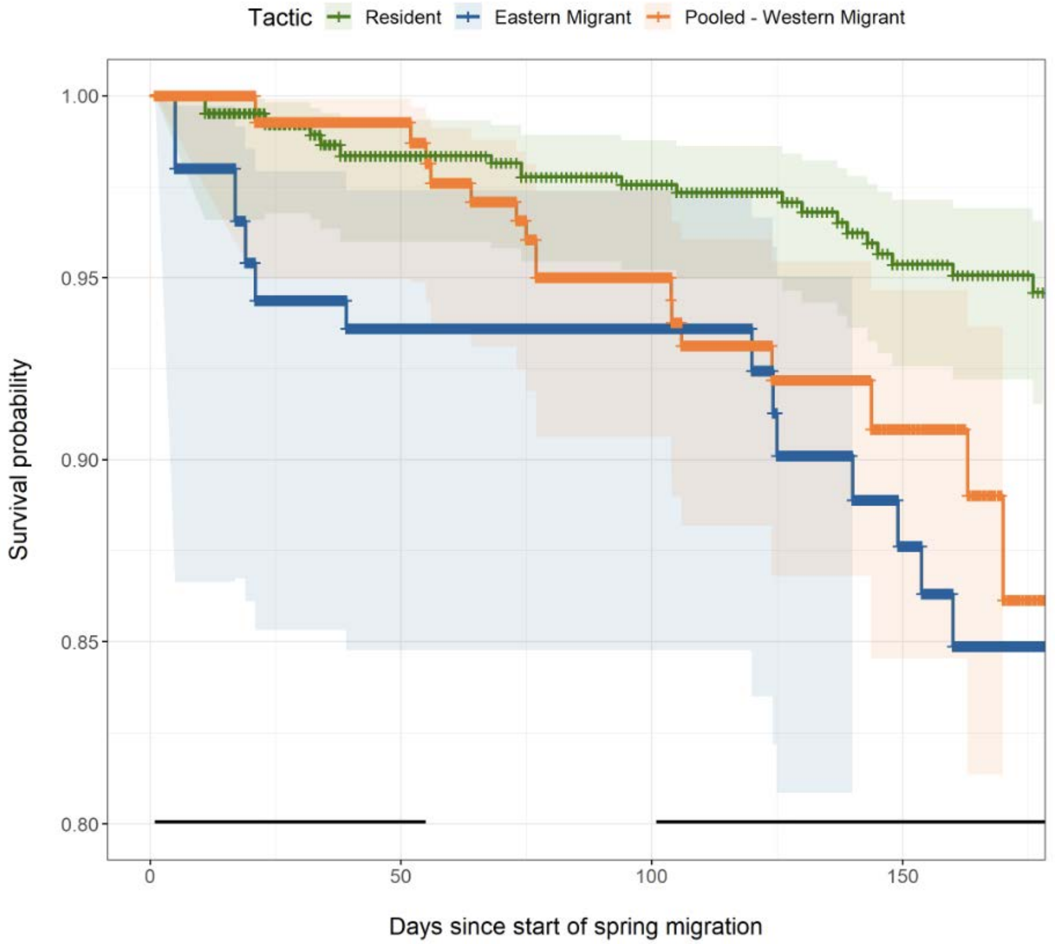

Figure 1.9. Kaplan-Meier analysis plot for the model predicting probability of survival of adult female elk (*Cervus canadensis*) with classified migratory tactic in the Ya Ha Tinda herd, Alberta, Canada from 2002–2019. Survival analysis covers the period from the start of spring migration to the end of fall migration annually. Model shows variation in survival probability between residents and migrants split into two migration routes (eastern and western, which pools northern, southern, and western routes).

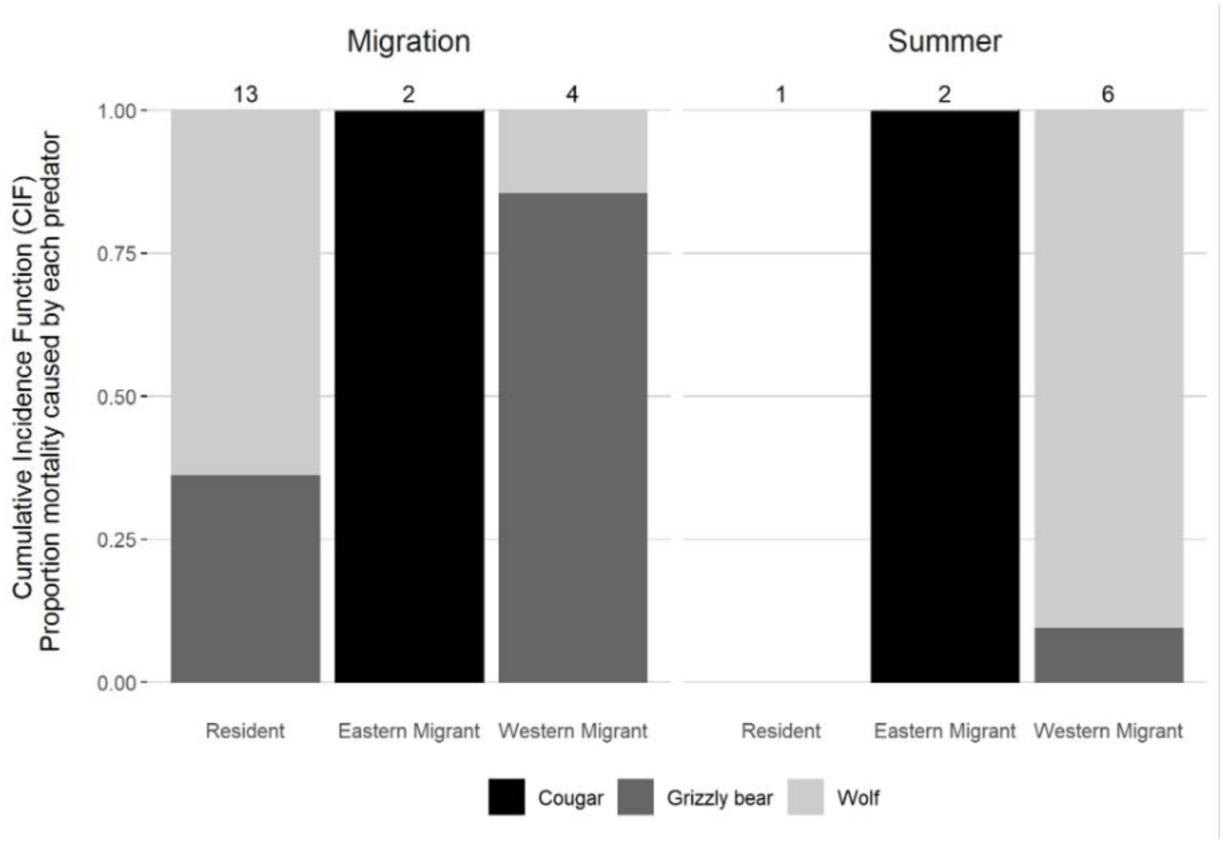

Figure 1.10. Cause-specific mortality of migrant and resident adult female elk (*Cervus canadensis*) over the migration seasons (fall and spring) and summer season in the Ya Ha Tinda population, Alberta, Canada, 2002–2019. The integer above bar is the number of nonhuman predator-caused mortalities.

1.9. Elk population trends using integrated population models

Hans Martin, Evelyn Merrill, Mark Hebblewhite

In many respects, migration is a form of habitat selection and the proportion of migrants and residents may be the result of density-dependent habitat selection. We tested whether the theory of Ideal Free Distribution (IFD) can explain the coexistence of different migratory tactics in a partially migratory population. IFD predicts individuals exhibit density-dependent vital rates and select different migratory tactics to maximize individual fitness resulting in equal fitness between tactics. We continue our tradition of defining tactic-specific fitness as population growth rate (lambda) of each tactic. We then tested these predictions of IFD in a partially migratory elk population that declined by 70% with 19 years of demographic data and migratory tactic switching rates from >300 individuals.

To test these ideas, University of Montana PhD student Hans Martin led the development of a Bayesian Integrated Population Model (IPM). The IPM had the additional advantage of providing a single unifying framework to estimate trends in population dynamics over time for the 19-year period (2002–2020). IPM models use a combination of population-level data with varying levels of certainty and quality to estimate population growth (λ) and demographic rates (Besbeas et al. 2002, Johnson et al. 2010, Kéry and Schaub 2011). IPMs consist of biological process and observation models that are linked, allowing the variances between respective data sources to be integrated into a single consistent population estimate. Model inputs consisted of annual estimates of adult elk survival, migratory switching rates, and pregnancy rates from marked individuals, annual counts of elk and calf:cow ratios on winter ranges based on ground and aerial surveys, and 9 years of calf survival estimates from mark-resight of known-tactic adult females (Hebblewhite and Merrill 2011, Hebblewhite et al. 2018). See Martin (2021) for more details on the development of the IPM model.

We found evidence of density dependence for resident pregnancy and adult female survival, providing a fitness incentive to switch tactics. We found evidence in support of our first prediction of the IFD, that vital rates were density dependent, providing a mechanism for density-dependent habitat selection. We found a negative effect of density on adult survival rates in the resident tactic, but not for other migratory tactics' survival (**Fig. 1.11**). Pregnancy rates also were weakly negatively density-dependent, but also only for residents (**Fig. 1.11**). There was no effect of winter-range population size on the young-of-year survival for any tactic (p >0.1; **Fig. 1.11**).

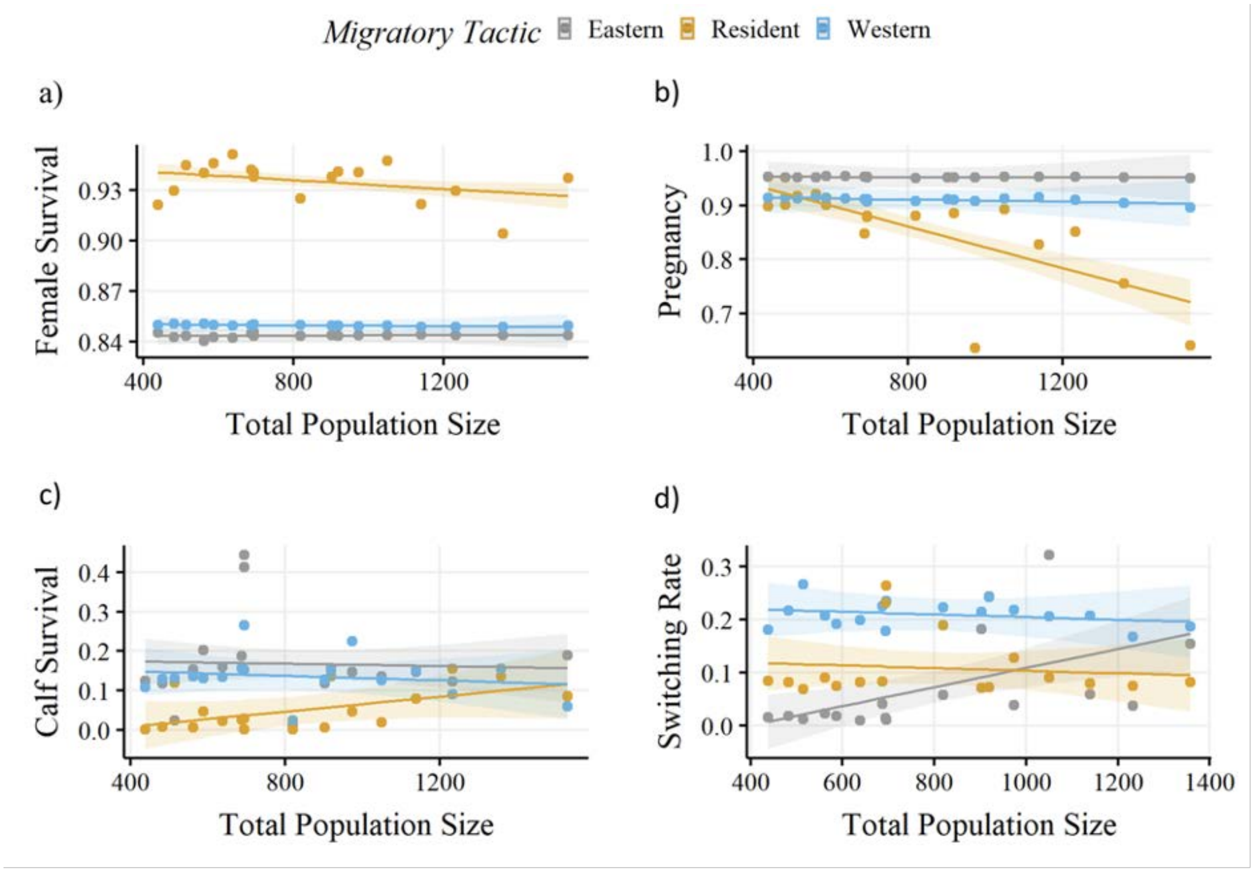

Figure 1.11. Switching and point estimates of vital rates estimated in the IPM of the eastern (gray), resident (yellow), and western (blue) migratory tactics as a function of female winter range density indicates density dependent switching, resident pregnancy rates, and resident calf survival.

Despite differences in vital rates between migratory tactics, mean λ (fitness) was equal. However, as predicted by the IFD, individuals switched tactics toward those of higher fitness.

Specifically, in our study, the mean annual switching rate was highest for elk switching from the western migratory tactic ($\overline{x}$ =0.199, 95% CRI=0.083-0.341) to the resident tactic, whereas switching rates from eastern migrant to the resident tactic ($\overline{x}$=0.084, 95% CRI= 0-0.995) and resident to the eastern migrant tactic ($\overline{x}$ =0.077, 95% CRI= 0.029-0.149) did not differ. In other words, elk were switching at more than double the rate from western migratory behavior to be a resident. And resident and eastern migrant switching rates were similar.

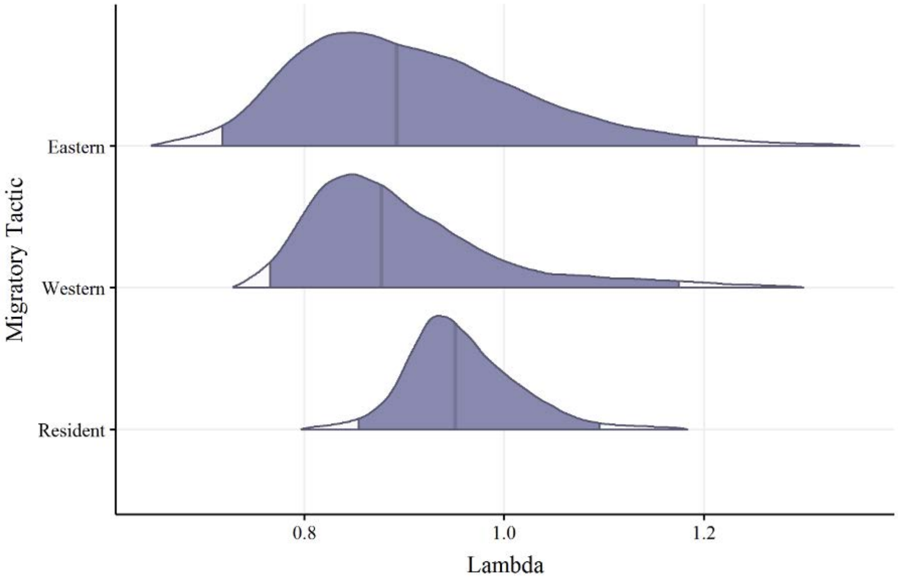

Figure 1.12. Posterior distribution and 95% credible intervals of the geometric mean of population growth rate (lambda, λ) of the eastern, western, and resident migratory tactics.

Our analysis reveals that partial migration may be driven by tactic selection that follows the ideal free distribution. These findings reinforce that migration across taxa may be a polymorphic behavior in large herbivores where migratory tactic selection is determined by differential costs and benefits, mediated by density-dependence.

These switching trends between migratory tactics, combined with the demographic rates in **Fig. 1.12** lead to the population trends estimated from the IPM in **Fig. 1.13**. Note these numbers are total population size including male elk. Starting in 2002 when the study first began, most (~600) elk in the population adopted the western migratory tactic, with a continuous decline to only ~100 elk now migrating westward into Banff National Park. Instead, there was slow but steady growth in the number of resident elk up until ~2009, when they also declined in the population to more stable levels of ~ 250 since 2010. And while there were low numbers of elk predicted to be migrating east in 2002, the numbers of migratory eastern elk increased until about 2013, when it peaked, and has stabilized since. Overall, there has been remarkable population stability since about 2013 in the Ya Ha Tinda elk population but continued declines in the number of elk migrating westwards into Banff National Park (**Fig. 1.13**).

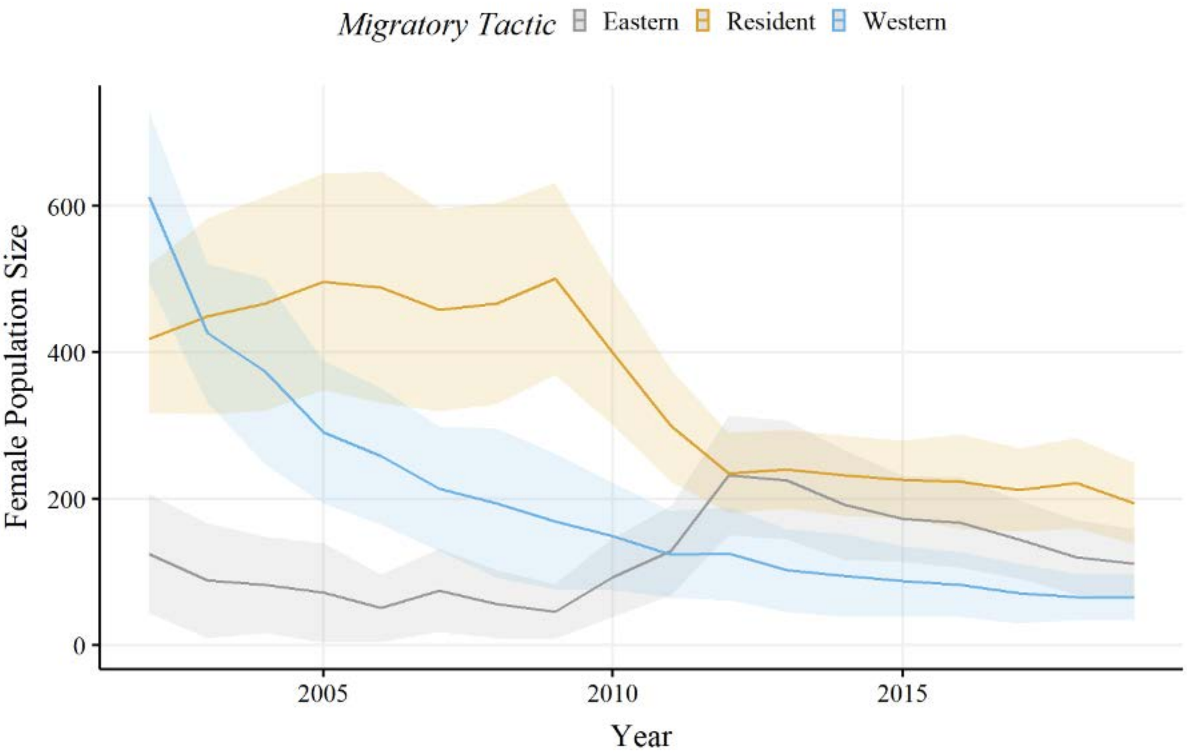

Figure 1.13. Estimated number of adult female elk and 95% credible intervals (shaded area) of the eastern, resident, and western migratory tactics of the Ya Ha Tinda elk (*Cervus canadensis*) population (2002–2019), Alberta, Canada, from Martin et al. (2021).

Objective 2. Wolf Population Monitoring

Mark Hebblewhite

Wolves remain the leading cause of mortality of adult female elk in our Ya Ha Tinda study area (see **Objective 1**) and a driving force of antipredator behavior for male and female elk of all ages. Previous studies in our study area developed spatiotemporal wolf predation risk models to help understand forage risk trade-offs. Therefore, we continued to work cooperatively with Parks Canada and Alberta Fish and Wildlife to attempt to capture and radio-collar wolves almost every winter in the 2-3 wolf packs overlapping our study area.

We captured wolves using helicopter netgunning during winter with Bighorn Helicopters in coordination with Parks Canada wolf captures in the Bow Valley and inside Banff National Park (BNP). Since 2017, wolves were outfitted with Vectronic Global Positioning System (GPS) radio-collars. Wolf GPS collars were programmed to obtain anywhere from 2–24 locations/day.

During 2017–2021, we captured and radio-collared 6 adult wolves, 3 females and 3 males in 2-3 wolf packs in the study area (**Table 2.1, Fig. 2.1**). Two wolves were captured from the Panther wolf pack in 2018, which largely used the traditional Panther, Cascade, Dormer River valleys in BNP and the Ranch area outside the park. In 2019, 2 wolves were captured in the Red Deer river valley, and these 2 wolves used the traditional territory of the Red Deer pack in that same valley both inside and outside BNP, including the Ya Ha Tinda. And in 2019, 2 wolves were captured on two different occasions in the Clearwater and on the east side of the Ranch that seemed to make use of just the Ranch areas outside BNP and eastwards. These wolf movements were very similar to territories during the initial phase of the project from 2001–2005. GPS location data (**Table 2.2**) will be integrated into spatial models of predation risk in future studies. Almost all of these 6 radio-collared wolves were trapped and harvested outside of BNP (**Fig. 2.2**) before their GPS collection ended.

Therefore, we also tested for effects of transboundary movements on survival of 72 radio-collared gray wolves from a much longer time period, spanning from 1987–2018, in and adjacent to Banff National Park. These results are published in Hebblewhite and Whittington (2020). We fit Bayesian survival models to known-fate radiotelemetry data and tested for the influence of intrinsic covariates including sex and age, time, and movements outside of protected area on survival of wolves. We also estimated cause-specific mortality.

Non-parametric wolf survival was 0.733 (95% CI 0.622–0.816), and the top Bayesian survival model indicated that wolves outside BNP had much lower annual survival rates (0.44, 95% BCI = 0.24–0.65) compared to wolves inside BNP (0.84, 95% BCI = 0.73–0.91; **Fig. 2.3**). The cumulative risk of mortality was on average 6.7 times higher (odds ratio 95% BCI = 2.2–21.4) for wolves outside BNP, peaking during the winter hunting and trapping seasons in the fall/winter (**Fig. 2.3**). We found weak evidence for declining survival over time, opposite to patterns predicted by density-dependence. Bayesian cause-specific mortality indicated that the top three sources of mortality were trapping (rate = 0.080, 36% of mortality), followed by hunting (0.053, 18%), and highway (0.046, 18%) mortality. Surprisingly, we found no intraspecific mortality, and low dispersal from BNP. This demographic profile is akin to other exploited populations across North America. While we were unable to combine survival rates with reproduction to estimate population trends, the overall mortality rates within our study area are consistent with a stable wolf population. Nonetheless, the long-term stability and ecological effectiveness of wolves likely differed inside and outside of protected areas, which highlights a challenge with managing transboundary carnivores exposed to different management regimes. This transboundary gradient in wolf harvest mortality could affect benefits and costs of different migratory strategies in the Ya Ha Tinda elk population (see other sections).

Table 2.1. Wolf individuals captured and radio-collared (GPS collars; Vectronic) in Alberta, Canada in 2018–2019. Wolves > 1.5 years old were classified as adults.

Wolf ID	Pack	Capture Date	Capture Location	Age-Sex Class
1503	Panther	2018-01-08	South of Panther River	Adult Female
1801	Panther	2018-01-08	South of Panther River by Dormer Plateau	Adult Female
1802	Red Deer	2018-02-23	Drummond Glacier Upper Red Deer River	Adult Male
1803	Red Deer	2018-02-24	Upper Red Deer below Drummond Glacier	Adult Female
1902	Ya Ha Tinda/All?	2019-03-02	Near 40 Mile Cabin, outside the park	Adult Male
1903	Ya Ha Tinda	2019-03-06	East side of Ya Ha Tinda Ranch	Adult Male

Table 2.2. Number of GPS locations collected for each bio-year and wolf pack in 2017–2020.

Wolf Pack/ID	2017	2018	2019	2020	Total
Panther	**6040**	**3002**			**9042**
1503	4108	447			4555
1702	594				594
1801	1338	2555			3893
Red Deer	**1554**	**4268**			**5822**
1802	774	1301			2075
1803	780	2967			3747
Ya Ha Tinda		**1376**	**6571**	**459**	**8406**
1902		712	3483		4195
1903		664	3088	459	4211
Grand Total	**7594**	**8646**	**6571**	**459**	**23270**

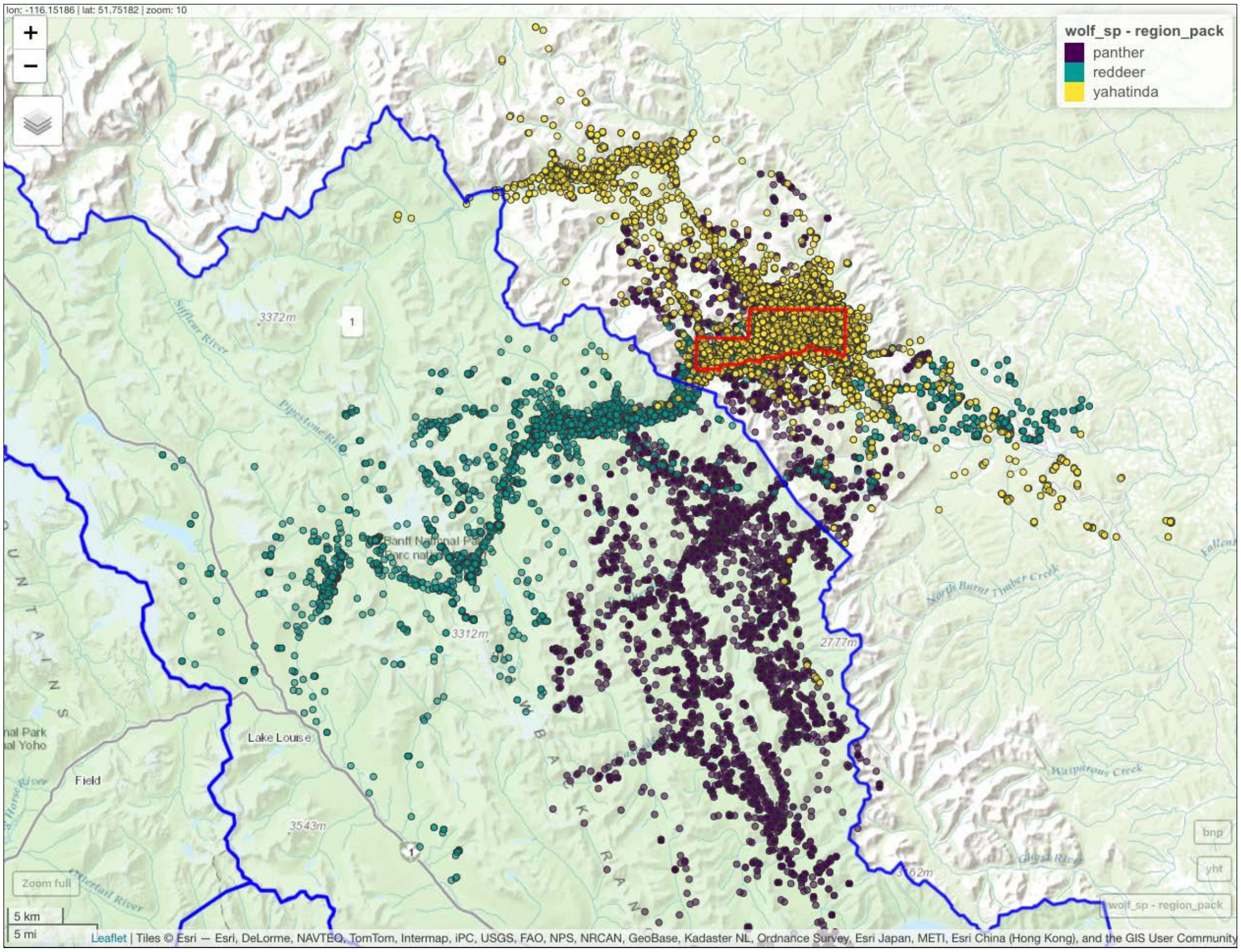

Figure 2.1. Map of wolf GPS locations collected in 2017–2021, colored by individual wolf pack at the Ya Ha Tinda study area from the Panther, Red Deer and Ranch wolf packs. The Ya Ha Tinda Ranch boundary is in Red, and Banff National Park in Blue.

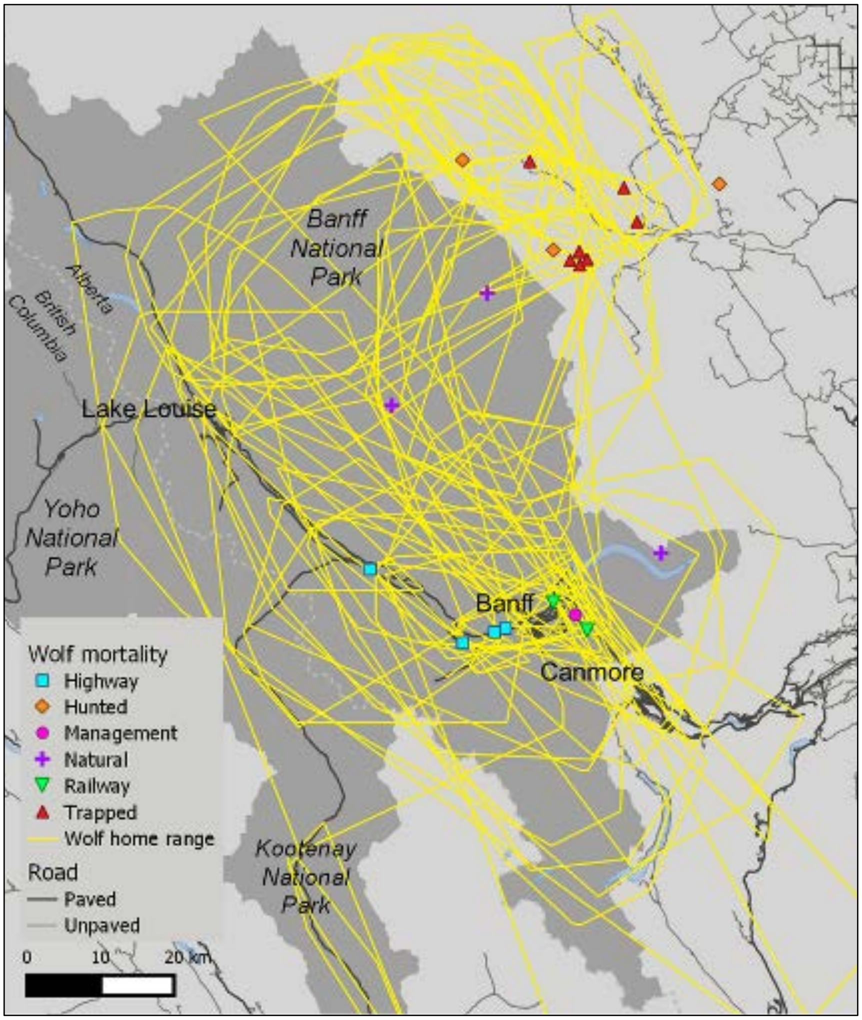

Figure 2.2. Mortality locations and home ranges of radio-collared wolves (95% minimum convex polygon) collected from 1987–2019 in and around Banff National Park, Alberta, Canada.

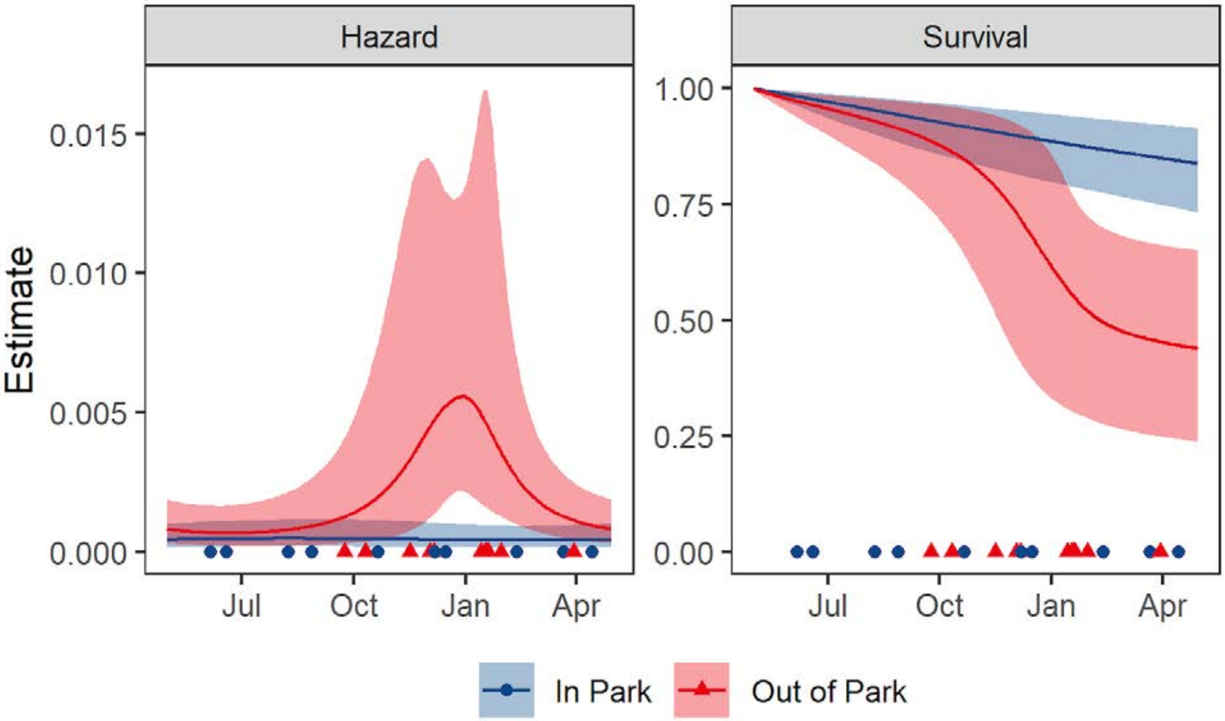

Figure 2.3. Daily mortality hazard (left) and daily cumulative probability of survival (right; median + 95% BCI) for wolves travelling in and outside Banff National Park, 1987–2018. Points along the x-axis show mortality events inside (blue dot) and outside (red triangle) Banff National Park.

Objective 3. Male elk survival, harvest, and trophy quality

Hans Martin, Mark Hebblewhite, Evelyn H. Merrill

Most ungulate studies (ours included) focus on the female component of the population due to their direct link to population growth. However, male ungulates are an important source of food for carnivores and provide viewing opportunities desired by park visitors. Moreover, the Ya Ha Tinda – like many elk populations – provide important elk harvest opportunities for resident, non-resident, and Treaty First Nation hunters alike focusing on the bull elk component of the population. The Ya Ha Tinda is also amongst one of Alberta's premier trophy bull elk regions, producing one of Canada's largest bull elk ever harvested.

Our goal in this research objective was to investigate potential drivers of male elk survival and antler size in the YHT. We first determined how antler size was affected by male age. Second, we tested whether migratory behavior affected antler size through access to forage quality. We predicted that migratory males, like females, would be exposed to higher forage quality, and would have larger antler size than a resident male elk. Next, we assessed whether sources of mortality that could lead to differences in age structure between migrants and residents. Based on previous studies indicating wolf predation is a key cause of winter mortality when male elk are in poor body condition post rut, we tested whether wolf predation would be greater for resident males. We used movements of GPS-collar elk to assign migratory tactic to individual males. To test our hypotheses, we modeled the effects of age, migratory behavior, biological year, and forage quality on antler size of capture and harvested male elk.

Methods

To investigate the potential drivers of male elk survival and antler size, we radio-collared male elk and used data collected on hunter harvested males. We captured a total of 80 male elk in 2018–2020 (**Table 3.1; Fig. 3.1, 3.2**) using helicopter darting (n=78) and ground darting (n=2). Eight of these were subadult males (aged 1.5–2.5; darted from helicopter in 2018) and 72 were adult males. We collected body condition, age, and antler score using the Safari Club International (SCI) scoring system as a measure of trophy quality (e.g., **Fig. 3.1**).

Table 3.1. Male elk captures at Ya Ha Tinda, Alberta, Canada, in 2018–2020 (no male captures in 2021).

Year	New	Recaptured from previous year	Total Captures
2018	31	1	32
2019	24	5	29
2020	15	4	19

Figure 3.1. Hans Martin with a radio-collared bull elk during captures in January 2019 in Alberta, Canada. Bull elk antlers were measured following the SCI antler scoring system to measure trophy quality.

Using the relationship developed between antler size and age, we predicted antler sizes of collared male elk in t+1 to allow us to assess the effect of antler size on survival (in year t+1). This allowed us to compare the effect of survival on collared elk in the years after capture when we did not have known antler measurements. To assess survival of age-classes based on the age class vulnerability to recreational harvest, modeled survival as a function of age and antler size. Less than 25 % of males age 1–3 were legal for harvest, 64% of 4-year-old males were legal for harvest, and >75% of 5+ year old bulls were legal for harvest. Finally, to understand the effect of age and migratory tactic on survival, we derived non-parametric survival estimates using K-M, and then tested for factors affecting male elk survival using Cox-proportional hazards models.

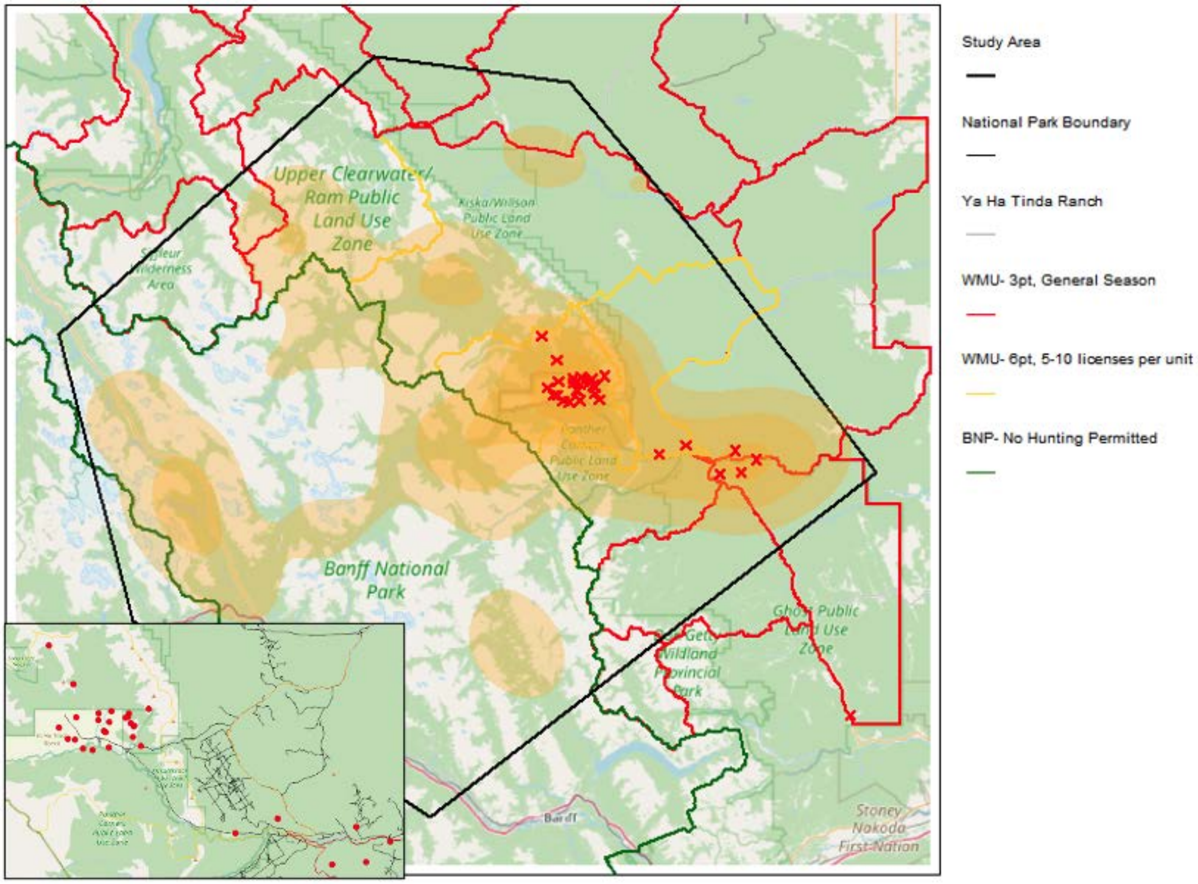

Figure 3.3. The Ya Ha Tinda study area with 95% isopleths of Kernel density for radio-collared male elk during the month of September 2018–2020 with mortality locations delineated by red x's. The inset map on the lower left shows the roads and mortality locations of harvested male elk with known mortality locations. Wildlife management units (WMU) with 6-point antler point restrictions (APR) and special licenses are outlined in yellow, and WMUs with 3-point APR and unlimited licenses in red. Banff National Park is outlined in green and does not allow hunting.

Results

We classified 64% (n=69) of males as western migrants summering in Banff National Park, 17% (n=21) as eastern migrants summering to the east of the Ya Ha Tinda, and 19% (n=20) as residents **(Fig. 3.3)**. We recorded 95 antler measurements from 66 elk captured in January, 18 elk harvested by hunters in September/October, and 3 elk found dead between October to February from 2018–2020. As expected, antler size increased with age as did the number of antler points (**Fig. 3.4**). Less than 16% of 1–3-year-old bulls were legal for harvest under the 6-pt Antler Point Restriction (APR), 64% of 4-year-olds, and over 83% of 5+ year old males (**Fig. 3.4, 3.5**). Using measurements from all known-aged individuals, the top-model describing antler size included a quadratic effect of age with a random effect for individuals (**Fig. 3.4**). Using individuals we had repeat measures on in the fall, we tested for effects of exposure to summer forage on angler size. Males that used higher summer forage biomass (lower forage quality) had smaller antlers (B-forage from regression model = -12.19, SE = 8.06, p = 0.147), indicating a 12" difference in antler SCI score for lower forage quality bulls. These results confirm a potentially important role of migration and access to higher quality forage on trophy quality.

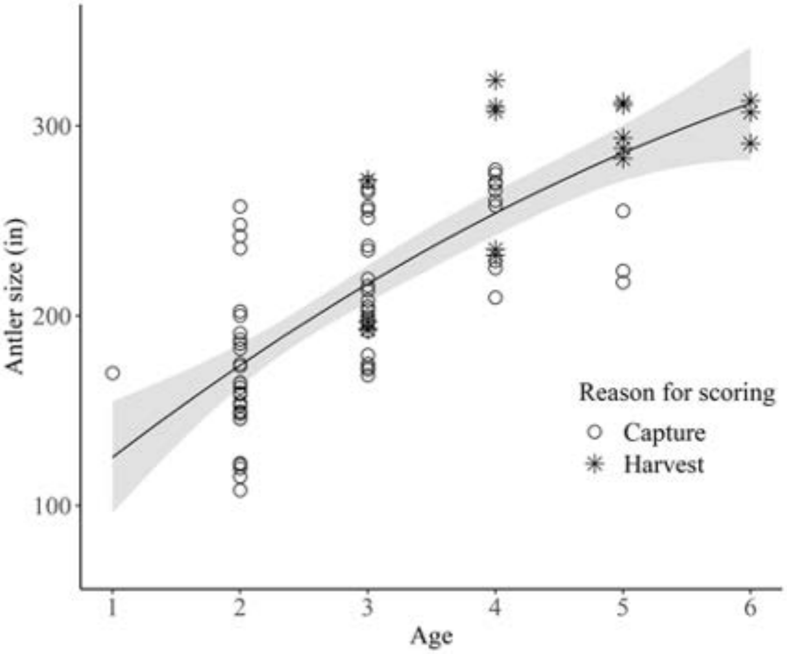

Figure 3.4. Actual antler size (n=90) as measured using guidelines for the Safari Club International gross antler score for elk in inches and modeled antler size using a GLM model of age+age2 of male elk by age measured during captures and harvest in the Ya Ha Tinda herd, in and adjacent to Banff National Park, Alberta, Canada 2017–2020.

Male elk survival was largely a function of age (**Fig. 3.5**) because human harvest was the primary cause of mortality. Antler-point-restrictions resulted in low yearly survival rates for male elk over 4 years of age (Survival rate, S=0.42). We used 105 male elk-years of age-specific survival data from 70 unique individuals with classified migratory tactics. The annual survival rate (1 June–31 May) for residents (S = 0.85, 95% CI = 0.60-0.95) was 40% higher than eastern migrants (S = 0.44, 95% CI = 0.182-0.680) and 18% higher than western migrants (S = 0.66, 95% CI = 0.54-0.77) (**Fig. 3.5**), although these differences were not statistically significant (p = 0.10). Annual survival significantly (p=0.006) differed by age class with 2–3-year-old males having the highest survival (S = 0.86, 95% CI = 0.69–0.94), compared to 4-year-old males (S = 0.72, 95% CI = 0.55–0.83), and 5+ year old males (S = 0.42, 95% CI = 0.24–0.58).

We recorded 36 uncensored mortalities of the 75 male radio-collared male elk over the 105 elk-years. Most mortalities were human caused; 20 recreational harvest, 11 First Nation harvest, 2 wounding losses each associated with harvest, 1 starved, and only 2 were killed by wolves. Overall, the annual mortality due to recreational harvest was greatest (Cause-specific mortality rate estimated with Cumulative Incidence Functions, CIF = 0.203, 95% CI = 0.129-0.303), followed by First Nations harvest (CIF = 0.101, 95% CI = 0.053–0.173), wolf-caused mortality (CIF = 0.015 95% CI=0.002–0.051), and malnutrition (CIF = 0.005, 95% CI = 0–0.030). These findings will help wildlife managers understand how vulnerability to natural and human predation risk affects male elk and how the relationship between forage quality and predation risk shapes male elk antler size and age structure.

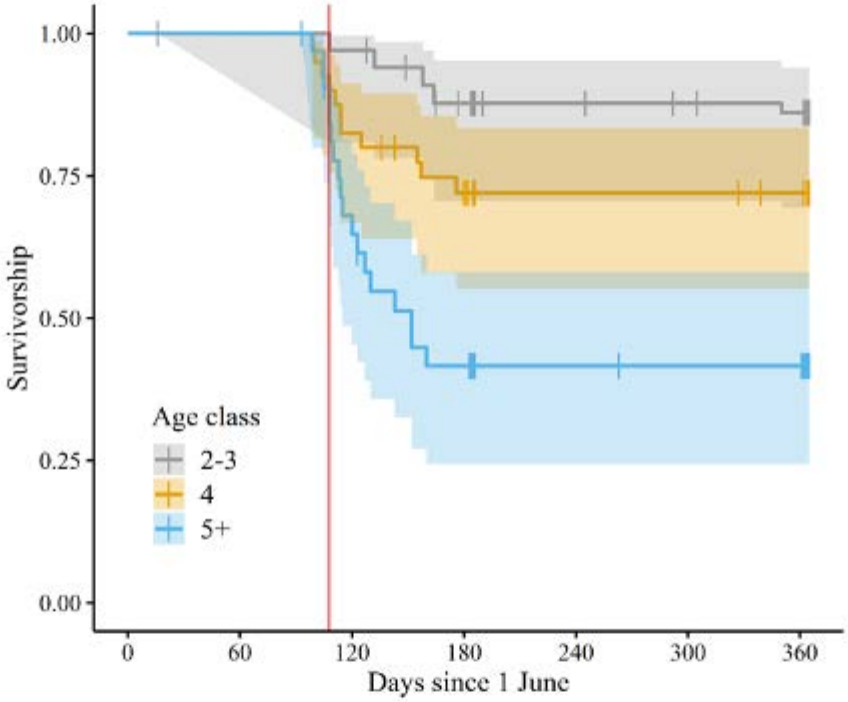

Figure 3.5. Annual (1 June–31 May) Kaplan-Meier survivorship curves for 3 age classes (2-3 years old, 4 years old, and 5+ years old) in the Ya Ha Tinda herd Alberta, Canada, 2018-2020. Rifle hunting season begins on 17 September denoted by the red vertical line and archery season begins on August 25th. Kaplan-Meier yearly survival estimates for age-class 2-3 is highest (0.86 SE=0.059) followed by 4-year-old (0.72, SE=0.072) and 5+ year-old males (0.42, SE=0.089).

Objective 4. Monitoring elk recruitment and predator communities with remote cameras

We monitored predator and prey distribution and abundance using a long-term remote camera monitoring system in collaboration with Banff National Park. Building on previous collaborative studies with Parks Canada (Steenweg et al. 2016, 2018, 2019), remote cameras provide a useful tool to monitor trends in predators and prey, including elk and other ungulates such as white-tailed deer. We refer to these previous studies for general inferences about monitoring these other species. Here, we first test the ability to monitor juvenile elk recruitment at YHT. Second, we also used remote camera data to develop predation risk models to assess the effect of predation risk on elk movement, behavior, and potentially consequences to survival. Third, we use remote cameras and scats to model spatial predation risk for elk from multiple species across a focused region surrounding the YHT winter range.

We maintained ~36 long-term remote camera traps (**Fig. 4.1**) on the YHT Ranch and adjacent provincial lands to collect data on predator community ecology overlapping the elk population, and to monitor elk. This sampling design is consistent with and extends the Parks Canada camera trapping grid with at least 1 camera within each 10x10km grid cell. Cameras were deployed in 2013/14, and again continuously in summer of 2016 to 2019. In addition, Mitchell Flowers (MS student at University of Alberta) deployed an additional ~ 30 cameras for 2 years at the Ya Ha Tinda Ranch (2.5 km^2).

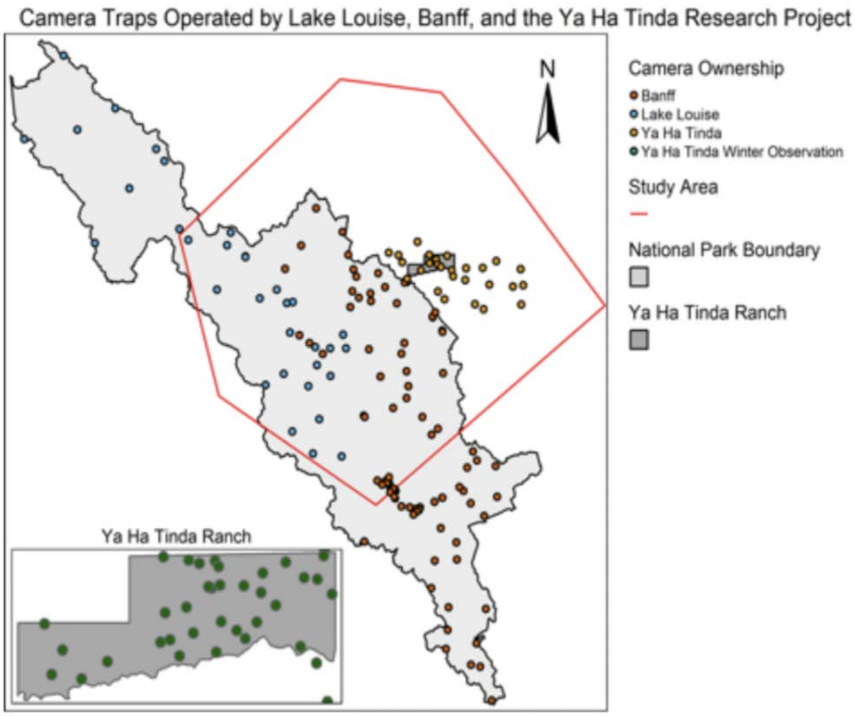

Figure 4.1. Map of camera trap locations maintained collaboratively by the Ya Ha Tinda Elk Project and Parks Canada.

Image Classification

Camera data were analyzed using Timelapse software (Greenberg and Goudin 2012) consistent with Parks Canada protocols, enabling seamless integration of our data into joint databases. Events were defined as any consecutive sequence of images of the same species. For wolves and cougars, sequences separated by at least 5 minutes were considered independent, regardless of whether the same individuals were being photographed. This definition was chosen specifically for the analysis of predator imagery because heightened use (i.e., high number of events) of an area can result from intense use by a single individual or moderate use by several individuals. Image sequences of all other species were assigned a threshold of 10 minutes, in accordance with classification protocols for Parks Canada. Elk events separated by more than 10 minutes were not considered a new event if there were other individuals present beyond the camera's field of detection through consecutive sequences.

4.1. Estimating recruitment of juvenile elk using remote cameras

Mateen Hessami, Mark Hebblewhite, Hans Martin, Evelyn Merrill

Juvenile recruitment is a key parameter in understanding ungulate population dynamics. Traditional methods for surveying population composition, such as estimating calf:cow ratios, are often costly, and pose safety and feasibility challenges. We tested the potential of remote cameras to estimate calf:cow ratios and juvenile survival of elk using the Royle and Nichols (2003) occupancy model. We compared camera-based estimates of calf:cow ratios to ground-based estimates obtained from group classification surveys. We used all remote cameras from our sampling design (**Fig. 4.1**) across the YHT. We fit Royle-Nichols occupancy models for female and young-of-year elk, estimating abundance of respective age classes for a 110-day period between 15 May–1 September 2018. We estimated juvenile recruitment by comparing the abundance estimates of juveniles between sampling periods while accounting for the effect of abiotic, biotic and anthropogenic covariates on detection probability and abundance.

The first juvenile to be detected by a camera was 15 May 2018 (e.g., **Fig. 4.2**). The 110 days of camera-data was further partitioned into five, three-week sample intervals to best account for detection probability (i.e., hiding period) and juvenile phenology. Early-spring was defined between (15 May–5 June), spring (6 June–27 June), early summer (28 June–19 July), summer (20 July–10 August), and fall (11 August–1 September). Ground observation data were divided into the same time periods. We converted adult female and young of year data to detection/ non-detection for each sample interval to model abundance.

We used package *unmarked* (Fiske and Chandler 2011) in program R (R Development Core 3.3 Team 2011) to first determine covariates that effect detection probability, next we estimated adult female and juvenile abundance using the occuRN function in unmarked and the Poisson distribution to characterize site abundance (Royle and Nichols 2003). The occuRN function fits the latent abundance mixture model described in Royle and Nichols (2003), which uses detection/non-detection data of un-marked individuals by linking heterogeneity in detection probability to differences in site abundances (Royle Nichols 2003).

Figure 4.2. Radio-collared adult female elk with a neonatal elk calf in June of 2014.

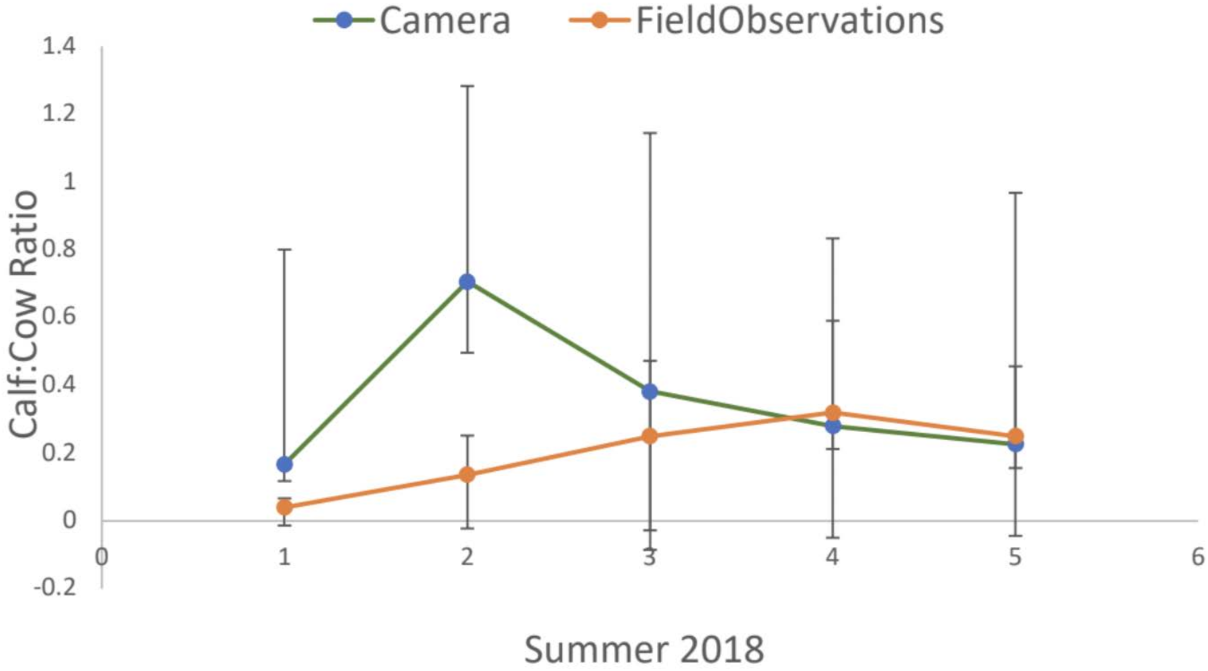

Figure 4.3. Calf:cow ratios sampled at 3-week intervals in summer 2018 using camera traps and field observations at Ya Ha Tinda, Alberta, Canada.

The calf:cow ratios obtained differed between the camera trap method and field observations (Pearson correlation test, r = 0.46). Calf:cow ratios and detection variability using camera traps were as expected, including peak juvenile abundance during the parturition period, followed by a decline over time due to predation (**Fig. 4.2**). However, field observations indicated an increasing ratio, possibly due to sightability issues. Remote cameras may be a useful tool for monitoring calf:cow ratios and understanding ungulate population dynamics.

4.2. The waiting game: elk avoid predators at fine spatial scales

Mitchell Flowers, Evelyn H. Merrill

Predators and prey have several ways of sensing each other's presence and will alter their behavior in response to predation risk across a variety of spatial and temporal scales. They likely also respond differently to different predator species. Because wolves range widely, elk may not be able to reduce encounter rates by altering their space-use, whereas they may avoid ambush predators like cougars or bears that may instead only search a narrow area. We tested for changes in elk movement rates during summer and account for movement rates and habitat preferences to determine if elk avoid areas where predators have occurred. We expected that elk would increase their return times to a site if a predator had recently used the site, and the response would be greater for cougars and bears than wolves.

Methods

We used a time-to-event framework to test how return time of any elk to a camera site was related to elk movement rates, elk group size and composition, site characteristics, and whether predators had visited the site. We focused on summer 2017 and 2018. An "event" was defined as an image of an elk or group of elk detected by the camera. The time to an event was determined as the time between two consecutive elk events >12 hrs apart at a camera site. We used a mixed effects Cox-proportional hazards model to determine the influence of covariates on elk return times. Random effects were included to control for repeated observations at the same camera. We tested whether movement rates of GPS-collared elk (n =21) changed over the summer, and accounted for seasonally changing movement rates in time-to-event models. Models were developed with the 'coxme' function in the R survival package and tested with model selection using AIC. Prior to their use in candidate models, we tested for collinearity among covariates and did not include any with a Pearson correlation (r) ≥ 0.50.

Elk movement rates

We tested for a change in mean daily 2-hr step length across of GPS-collared elk (n = 21) in 2017 by comparing the fit of the data to a null model (average), linear regression, quadratic, and cubic function model using a model selection approach because number of parameters varied. Because we found a nonlinear (cubic) model best fit the 2017 data, we used the model to predict the mean movement rate across the specific days between each pair of elk events and included movement rate in all models. We used the same model in 2018 because GPS-collared elk were monitored on 12-hr time steps in 2018, which was considered too coarse a temporal resolution to determine movement rates.

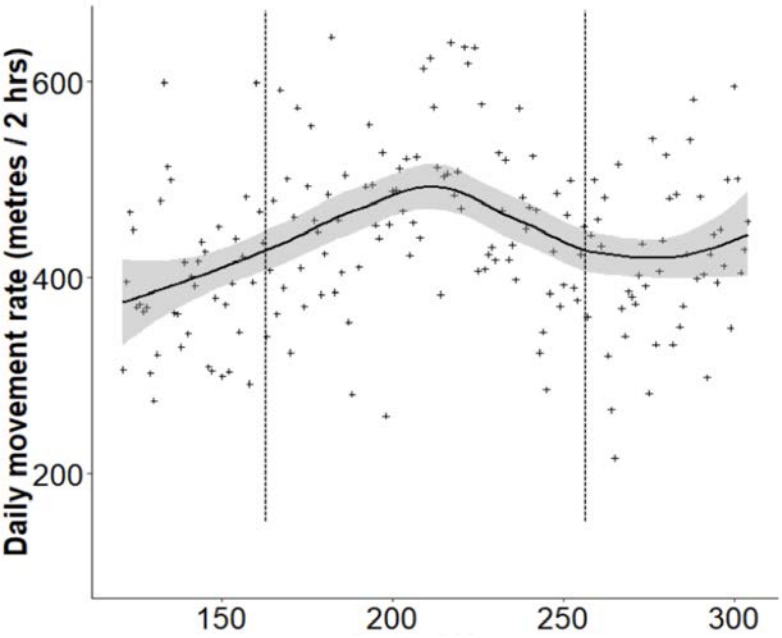

Figure 4.3. Daily movement rates of GPS-collared elk (n = 21) during summer of 2017. Summer was defined as 1 June to 15 Sept (dotted lines), when only resident elk were occupying the YHT.

Results and Discussion

Elk were detected at 42 of 44 remote camera locations and distributions of return times did not significantly differ between years (P = 0.114). Return times in summer had a median of 5.11 days and a mean [± SE] of 9.66 ± 0.48 days (n = 665). There were 85 wolf events, 54 grizzly events and 9 cougar events that occurred between elk events across both summers. Variation in summer elk movements was best predicted by a cubic function (ΔAIC > 2; **Fig. 4.3**).

Model selection indicated that return times of elk were related to the amount of edge habitat surrounding the site as well as the occurrence of wolves, grizzlies, and cougars (ΔAIC > 2). Higher edge densities around sites delayed return times. The presence of a cougar and wolves increased return times by 65% and 59%, respectively, whereas the occurrence of grizzlies increased return times by 26% (**Figure 4.4**). There was little support for interactions between predator occurrences and habitat characteristics. Return times to camera sites with high edge densities were longer. Cougars are known to hunt prey along forested edges and wolf predation of large ungulates can be facilitated by both natural edges and linear features, where prey might be most easily detected and vulnerable. Elk return times were further increased after a predator occurrence, regardless of habitat characteristics, suggesting elk actively avoided areas with recent predator signs.

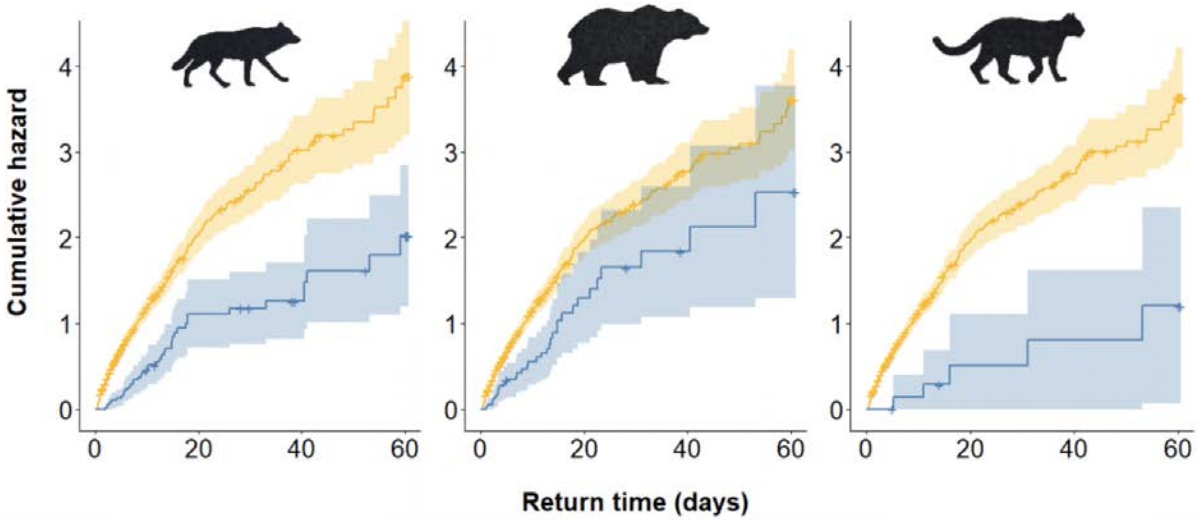

Figure 4.4. Cumulative hazard curves stratified by predator presence (blue) and absence (orange) throughout the summers of 2017 and 2018 (n = 665, CI = 0.95). Each set of curves represents the cumulative probability of an elk returning to a site in the presence of a different predator; Wolves (left), grizzlies (centre), and cougars (right). The hazard (or likelihood) of an elk returning to a site is consistently lower when predators have been detected between elk events.

4.4. Predicting multi-predator risk to elk using scats: are migrant elk exposed to different predation risk?

Kara MacAuley, Jodi Berg, Eric Spilker, Evelyn Merrill.

We combined spatial predictions of scat-based resource selection functions (RSFs) for bears), cougars, coyotes, and wolves based on surveys with scat-detection dogs with predictions for the probability that a predator-specific scat in a location contained elk. We evaluated our approach by comparing predictions to a model of predation risk developed from elk kill sites and applied it to describing spatial patterns in predation risk that were consistent with changes in the distribution of elk over the past decade.

We found a strong correlation between risk predicted by kill sites and risk predicted by our approach ($r = 0.98$, $P < 0.001$, **Fig. 4.5**). There was a spatial pattern to predation risk, where elk that migrated east of their winter range were exposed to highest risk from cougars, non-migratory elk were exposed to high risk from wolves and bears, and risk to elk that migrated west of their winter range into protected areas was high only from bears (**Fig. 4.6**). The patterns in predator risk were consistent with changes in the migratory tactics in this population. The scat-based approach we present permits broad-scale inferences on predation risk for prey species that has advantages especially in multiple predator species.

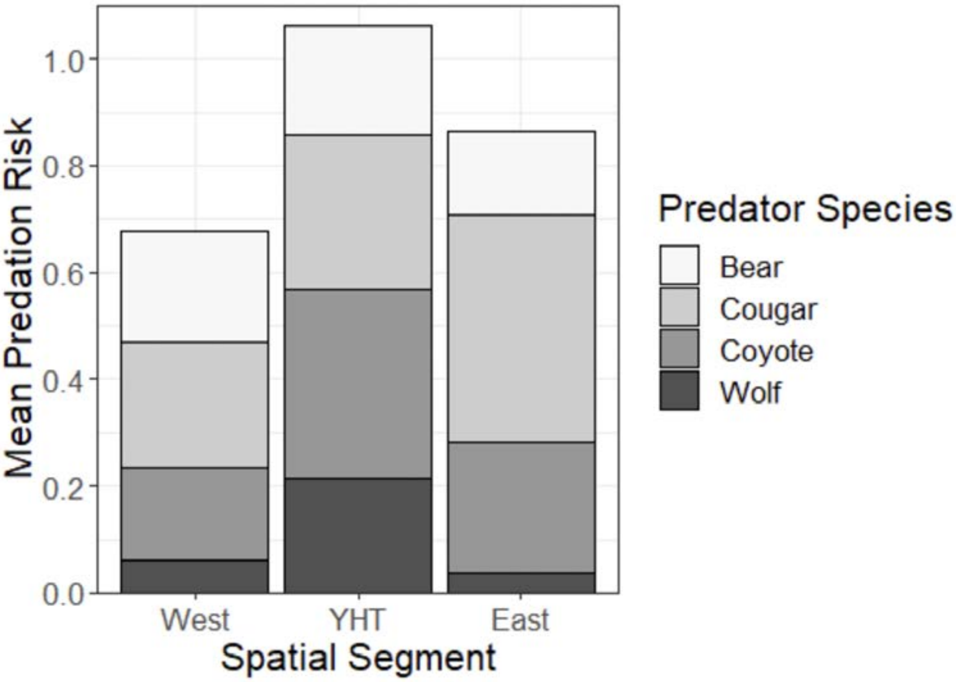

Figure 4.5. Mean predation risk (based on scat contents, equation 2) for elk in each migratory segment of the Ya Ha Tinda (YHT) herd, Alberta, Canada, 2013–2016.

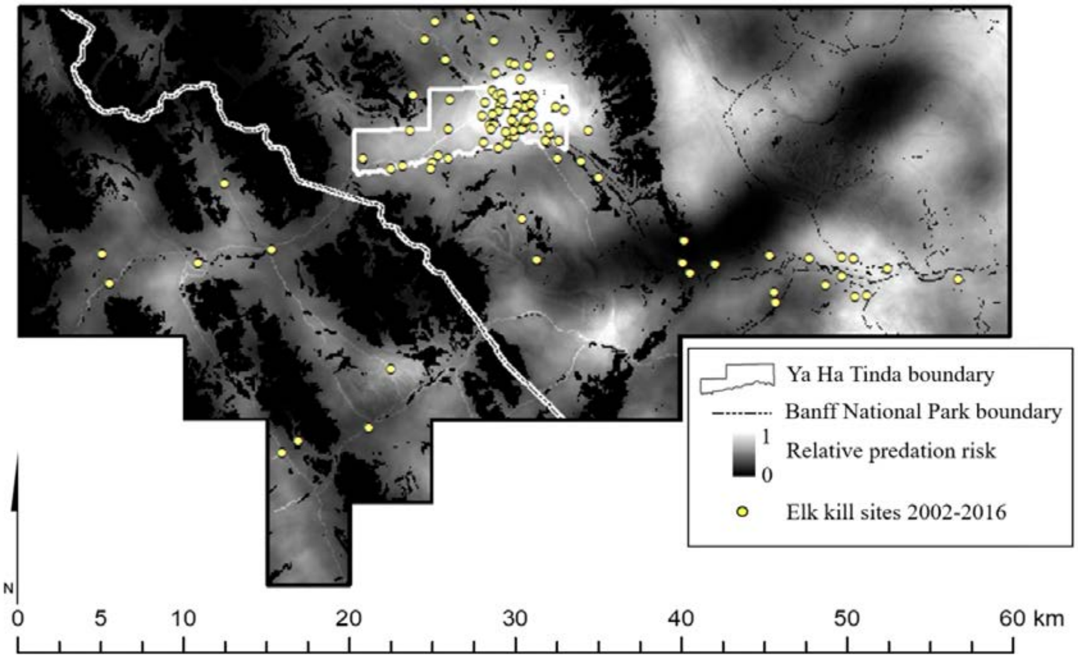

Figure 4.6. Predicted predation risk for elk based on combined metric of predator resource selection and elk presence in scats from four predators (wolves, bears, cougars and coyotes) combined along the eastern slopes of the Rocky Mountains in Alberta. Yellow circles indicate locations of elk killed by bears, cougars, or wolves.

Objective 5. Modeling forage quality and biomass

Peter Smolko, Evelyn H. Merrill, Mark Hebblewhite, Jodi E. Berg, Holger Bohm, Scott Eggeman, Jane Parks, Rudolf Kropil

Fire is a key disturbance that can alter the relative nutritional benefits on summer ranges and may influence migratory dynamics. We studied habitat selection of adult female elk for burns on their summer ranges over a 14-year period when the extent of burned areas (<15 years) varied due to prescribed and human-caused fires and plant succession. Elk on different summer ranges also were exposed to varied levels of predation risk from grizzly bears and wolves. We compared trade-offs in selection by elk for forage and predation risk on three migratory ranges (eastern, western, and southern) and one resident range in an early (2003–2006) and late (2013–2016) period. We assessed whether elk selection followed the 'green magnet' hypothesis, where they are attracted to the expected improved forage resources after burning or whether they traded-off selection for burns under high predation risk from bears and wolves.

We developed resource selection probability functions (RSPFs) for elk in each migratory tactic in summer (1 July–15 September) in early and late periods to assess elk response to variation in predation risk and burn extents. We focused on selection of burns < 15 years because forage quality is considered most improved during these years. We focused on selection for herbaceous biomass because it made up the highest proportion of the diet in summer. Spatial predictions of herbaceous biomass were based on a field sampling and a previously derived landscape model (Hebblewhite et al. 2008). Date of burn and burn polygons were obtained from Parks Canada and Alberta Environment and Parks. Predation risk was based on previously developed predation risk models for wolves (Hebblewhite and Merrill 2008) or grizzly bears (Berg et al. 2019).

Herbaceous biomass was lower on migratory ranges at high elevations in western regions of BNP than low-elevation ranges outside BNP due to growing season, extent of different vegetation communities, and burn patterns over the past 2 decades. Overall, burning increased herbaceous biomass in areas by 65 % in grasslands, 18 % in shrublands, and 170% in forest compared to unburned sites, with the peak increase occurring 4-6 years after burning in both grasslands and forest/shrublands. Forage availability on the high-elevation summer ranges of the western migrant elk in BNP changed little over time because < 1% of the area was burned during the study (**Fig. 5.1**). In contrast, a 20% drop in the extent of burns (<15 years) on the high-elevation summer ranges in the southern migratory ranges reduced herbaceous forage abundance between the early and later periods because of plant succession (**Fig. 5.1**). On the low-elevation summer ranges, forage availability increased in the late period at the YHT due to a 400% increase in extent of burns. East of YHT, burn extent remained constant because of the single, large human-caused wildfire that occurred at the beginning of the study (the Dogrib fire). Nevertheless, herbaceous forage declined within burns over time, but overall herbaceous biomass remained high due to forest clearcutting. Elk migrating to high elevations in BNP had lower wolf predation risk but greater grizzly bear predation risk, consistent with Williams et al. 2021) and section **1.8**. Because both carnivores also selected for burns, predation risk was higher in burned areas, except for on ranges of western migrants where burning was minor.

Migratory elk on high-elevation summer ranges showed strong selection for intermediate forage biomass during both time periods (**Fig. 5.2**), consistent with selecting the highest quality forage.

On the ranges of western migrants where there was little burning, elk consistently avoided higher forage quality when risk of predation from wolves and bears was high. In the early period, elk migrating to the high-elevation southern ranges selected more strongly for unburned than burned areas, but also reduced selection for high quality foraging areas under high wolf risk. In contrast, in the late period when burns were less extensive and proportionally more of the burned area recovered (> 8 years), elk selected for burns regardless of wolf predation risk. Instead, elk reduced selection for burns under high bear risk. Eastern migrants also responded more to wolf than bear predation risk and selected for intermediate herbaceous biomass (**Fig. 5.2**). Like high-elevation migrants, eastern migrants selected for burned areas more strongly than unburned areas but also traded off high quality forage for lower wolf predation risk. Unlike migrant elk, in both time periods resident elk increased selection for areas as herbaceous biomass increased, and response to burns were more complex. In the early period, when most burns were young (<6 years), elk did not select for burns except where herbaceous biomass was high (>100g/m^2), and wolf predation risk was low (**Fig. 5.2**). In the late period when a greater portion of elk ranges were > 6 years post-burn, elk showed stronger selection for burns than unburned areas only when forage biomass was low, even under high predation.

Our study indicates that the responses of elk to burning programs are more diverse than predicted by the "green magnet" hypothesis based solely on bottom-up forage improvements. First, burning may not have had the same benefit to elk at high and low-elevation summer ranges. Selection by migrant elk on high-elevation ranges was generally stronger for unburned than burned areas, which may reflect lower relative increase in forage quality from burning on high elevation ranges in BNP. Second, elk consistently reduced their selection for burned areas under high predation risk across migratory tactics. Thus, top-down effects may diminish the bottom-up benefits of any forage improvements from burning. In summer, elk regularly reduced their selection of unburned areas under high wolf predation risk more than when faced by bear risk, which is consistent with wolves being the primary, year-round predator on adult elk in this system. In contrast, elk exhibited stronger responses to bear predation risk than wolves in high bear areas where vegetation recovered more after burning, likely providing hiding cover for elk to evade wolves but also directly attracted bears. We conclude that outcomes of prescribed burning for large herbivore may be more variable than expected based solely on bottom-up vegetation changes because of responses of multi-predator communities after burning.

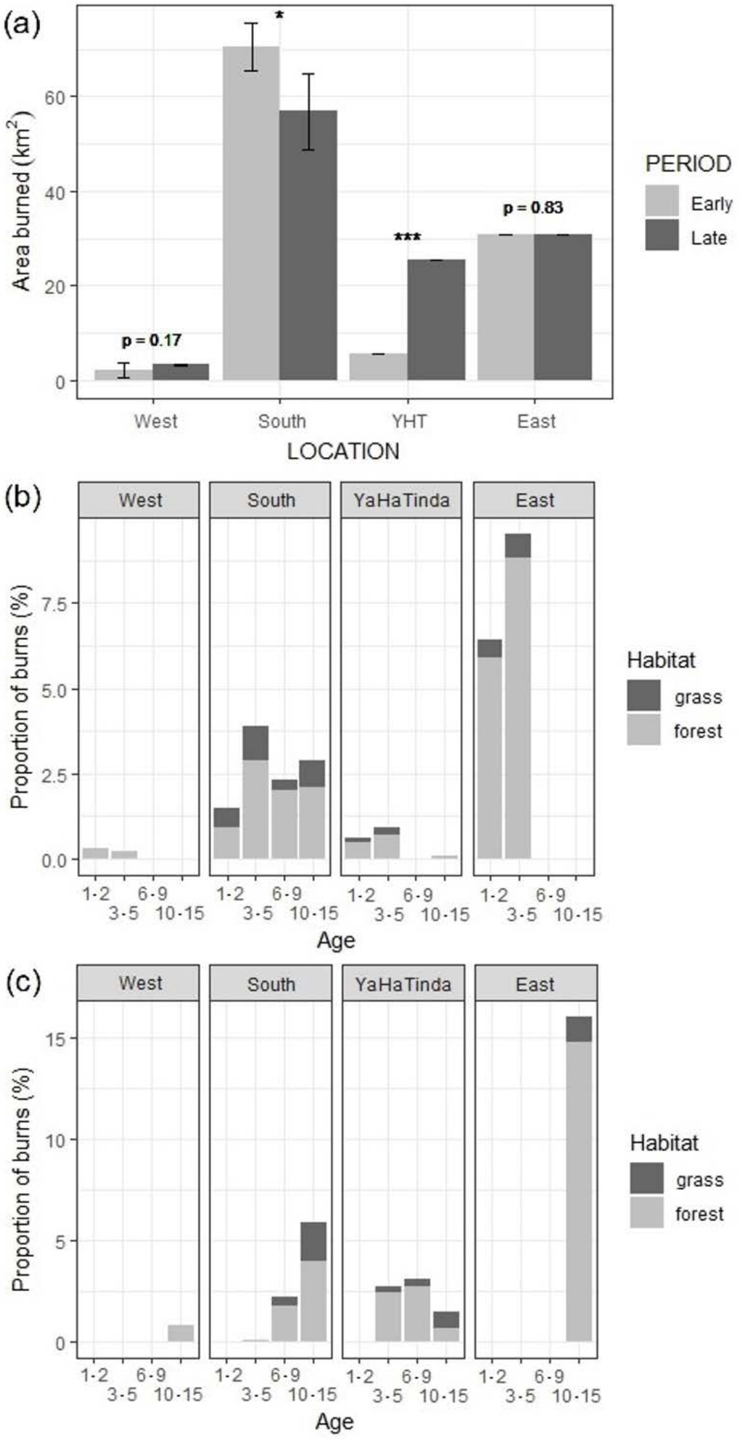

Figure 5.1. Mean and 95% confidence limits of the extent of area (km^2) of burns (<15 years) (a) and proportions of area burned in 4 age classes since fire (i.e., 1-2, 3-5, 6-9, 10-15 years) within grassland and forested areas (b and c) on the individual summer ranges of elk following 3 migratory elk tactics and of resident elk of the Ya Ha Tinda elk herd in and adjacent to Banff National Park in the Rocky Mountains of Alberta, Canada during the early (b) and (c) late periods of the study. P valves in (a) denote significant levels testing for differences in extent of burned areas during the early and late periods based on a t-test.

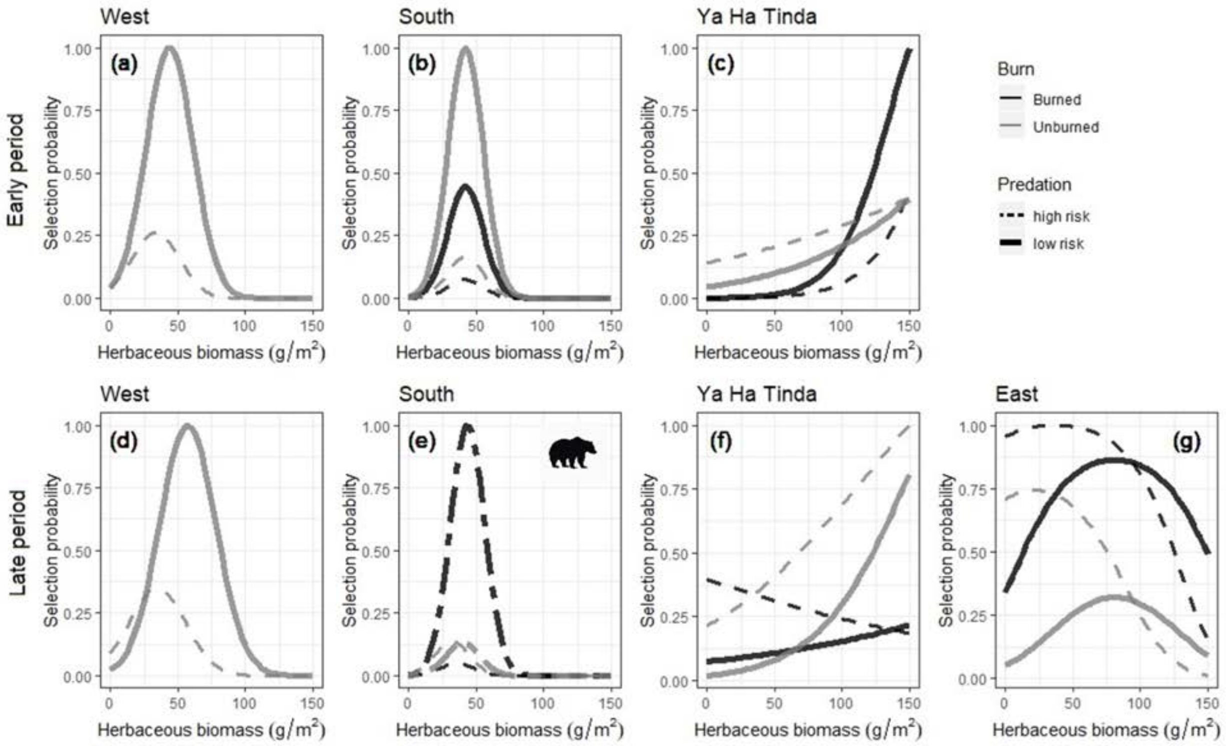

Figure 5.2. Predicted probability of selection based on resource probability selection functions at different herbaceous forage biomass (g/m^2) levels on the summer ranges of the 3 migratory tactics and resident elk in the Ya Ha Tinda elk population in burned (black lines) and unburned (gray lines) areas in and adjacent to Banff National Park in the Rocky Mountains of Alberta, Canada during the early (2002–2006, a–c) and late periods (2013–2016, d–g).

Objective 6. Endoparasite diversity and abundance in migrant and resident Ya Ha Tinda elk

Jacalyn Normandeau (MS Student, University of Alberta), Dr. Susan Kutz (Collaborator, University of Calgary)

Many studies of ungulate populations focus on predation, but parasites can be as important in indirectly affecting mortality and health. Parasites affect host body condition, reproduction and survival in ungulates, but the interaction between migration and parasite infection is not well understood (Pybus et al. 2015). Here, we compared the prevalence and intensity of *Fascioloides magna*, and important endoparasite of elk in Alberta, among migration strategies in 2017-2018. We predicted that (1) elk migrating into Banff National Park would have lower *F. magna* infection than resident elk because they have high quality forage and are not concentrated in summer, whereas (2) elk that migrated east of YHT would have higher fluke infection than both Banff migrants and residents because they are concentrated in human-mediated refuges and may have lower forage quality making them more susceptible to parasite infections. We also collected samples from collared elk in spring of 2018 to relate to habitat use in the summer of 2017 to determine factors potentially increasing *F. magna* exposure.

During spring and summer 2017 and 2018, we radio-tracked collared elk in each of the 3 migration strategies at 6-week intervals (n=3 times) from May-August with the goal of collecting ~30 fresh samples/segment/interval. We collected fresh samples from unknown elk after observed elk groups had moved away or from game trails following telemetry of collared elk. We also collected pellet samples from individual elk on the winter range during March and April of 2018 to compare their *F. magna* egg excretion to summer habitat use. We collected 3 pellet groups from known, radio-collared individuals for a total of 39 individuals. We created Brownian Bridge utilization distributions for each elk using GPS data from May to October 2017 to weight covariates including total elk use of the landscape, elevation, and wetland presence/absence by individual elk use. We used a negative binomial model with a nested random effect of pellet group and individual to determine which factors influenced *F. magna* egg output.

Samples showed that eastern migrants had significantly higher fluke prevalence than Banff migrants and residents using a logistic regression ($p = 0.001$). Across all years and seasons eastern migrant elk had an average prevalence of 66% where residents and Banff migrants had an average prevalence of 31% and 42% respectively (**Fig. 6.1**). *F. magna* intensity was significantly higher in 2018 ($p = 0.008$) and in eastern migrant elk ($p < 0.001$) according to a negative binomial model. Analysis of individual elk use from May 2017–October 2017 and *F. magna* egg output in spring of 2018 showed that residents had lower *F. magna* egg output than eastern and Banff migrants and wetlands increased *F. magna* egg output significantly.

Wetland exposure is critical to *F. magna* transmission because of the need for snail secondary hosts. Despite some support for wetlands as foci, high elk use of the landscape is not needed for high exposure to *F. magna*. This suggests that other species besides elk may be contributing to *F. magna* presence on the landscape including deer and that suitability of wetland habitats for *F. magna* snail secondary hosts may be higher in eastern areas. Higher *F. magna* prevalence and intensity in eastern migrant elk could have health implications if these elk have higher *F. magna* infection consistently.

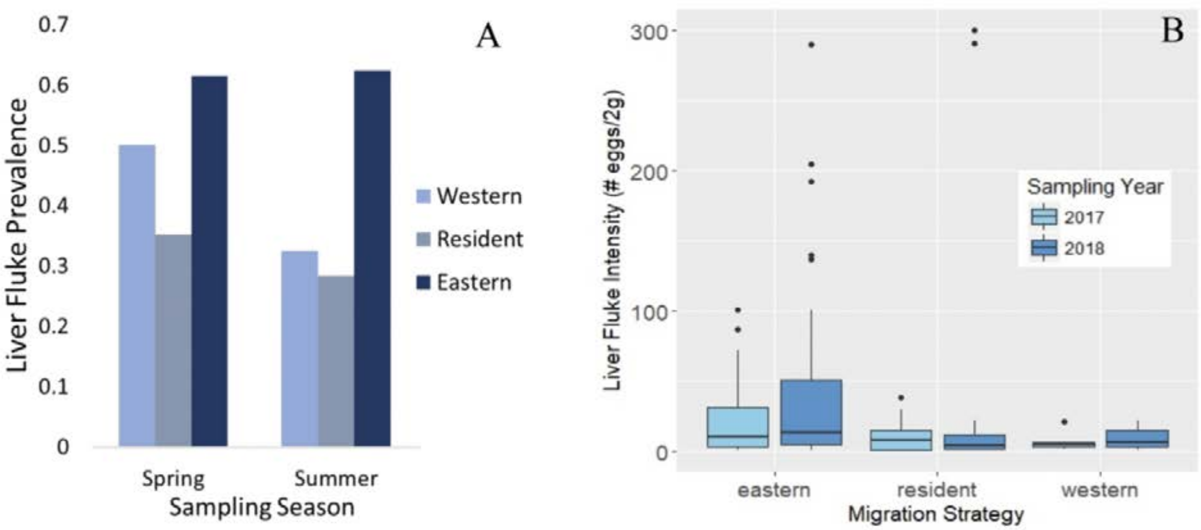

Figure 6.1. (A) Fluke prevalence (infected animals/all animals sampled) and (B) fluke intensity (number of eggs/2g of feces) detected in each elk migrant strategy separated by sampling period.

Objective 7. Behavioural disparity in the partially migratory Ya Ha Tinda elk herd on its sympatric winter range

Madeline Trottier, Mark Hebblewhite, Evelyn Merrill

In the past two decades, there has been a shift in the summer distribution of elk that winter on the YHT, with a decrease in elk migrating into BNP, an increase in elk migrating east, and an increase in residents. Differential exposure to forage quality and predation risk in summer has been attributed to these shifts. However, interactions among elk of different tactics on winter ranges may contribute to these shifts. In previous studies, resident elk did not exclude western migrants from areas of the winter range as hypothesized. Instead, resident elk showed less vigilance in response to humans and predators and were better at coordinating vigilance with forage intake than western migrants (Robinson et al. 2013). Differences in behavior were attributed to differential familiarity with patterns of predation risk, exposure to humans during the summer, and higher social cohesion in residents because they remained together during summer. Behavioral responses of eastern migrants to these factors are unknown. We compared distribution, foraging and vigilance behaviors, and direct interactions among the three migratory herd segments on the Ya Ha Tinda range in winter. We expected resident elk to be the most cohesive, and eastern migrants to respond most similarly to western migrants relative to predation risk but more similarly to residents in response to human infrastructure due to higher human activity on their summer range.

7.1. Methods

Home range overlap

We estimated weekly elk utilization distributions (UDs) using location data collected from 2-hour fixes from GPS collared elk during the winters (1 November–31 March) of 2015-2018. Weekly 95% UDs were estimated using the R package ‘adehabitatHR’ for each elk using fixed kernel analysis using the reference bandwidth as the smoothing parameter. We estimated overlap between elk UDs using a Volume of Intersection index (VI) between all pairwise combinations (resident-resident, RR; eastern-eastern, EE; and western-western, WW; resident-eastern, RE; resident-western, RW; eastern-western, EW). We modelled VI values (0-1) as a function of pair type (RR, RE, RW, EE, WW, EW), week, and their interaction using a beta regression model. We included elk pair ID as a random effect to account for pairs with multiple occurrences.

Behavioural observations

During the winters (January-April) of 2018-2020, we observed foraging behaviour of GPS-collared female elk (n = 34) within each migratory tactic. Focal elk were observed 6-8 times for 2-15 minutes, where we recorded time spent foraging, time spent vigilant, location of elk in the group (centre or periphery), and density of neighbouring elk around the focal. During winter 2019-2020, interactions of focal animals were also recorded opportunistically during foraging observations. We characterized interaction events when a focal animal came in contact with a conspecific physically, by directing attention and movement towards another elk, or by moving in response to directed movement and attention from another elk. We recorded time spent interacting and the type of interaction (e.g., aggressive, displacement, etc.).

Interaction rates and vigilance
To assess the factors influencing the rate of interactions among migrant tactics, we used a negative binomial mixed-effects model to relate counts of interactions to elk age (years), migrant tactic, local density, position in the herd (periphery or centre), forage biomass and day of winter from 1 January. We included a random effect of elk ID. To account for different observation lengths (range: 2-15 minutes), we included an offset for logged observation length, then used an AICc selection method to choose the best fitting model. To assess factors influencing vigilance during foraging, we used a negative binomial mixed-effects model to relate time spent vigilant to distance to humans, position, group size, density, biomass, wolf presence, and migration tactic. We included a random effect of elk ID to account for multiple observations across years.

7.2. Results

Between the winters of 2015-2018, 99,306 GPS fixes were collected from 69 individual collared elk, totaling 175 elk-winters. Average overlap (VI) between all pairwise comparisons (RR, RE, RW, EE, WW, EW) was high (0.83 ± 0.04 SD; **Fig. 7.1**), though eastern-eastern overlap was highest ($\beta = 0.612$, SE = 0.04, $p < 0.001$). As winter progressed, overlap increased for all pair types, although resident-western and western-western pairs increased more than other pairwise comparisons (**Fig. 7.2** pair x week interaction). Overlap among all migrant tactics was high across the winter (VI > 0.69, **Fig. 7.1**).

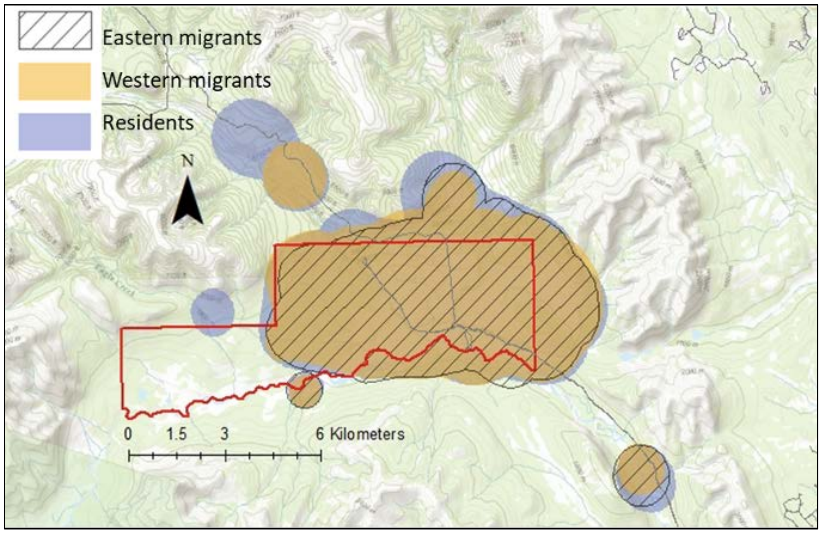

Figure 7.1. Average elk 95% UDs over the winters (Nov 1–Mar 31) of 2015–2018 for resident (blue), eastern (hatch), and western (yellow) tactics on the YHT winter range.

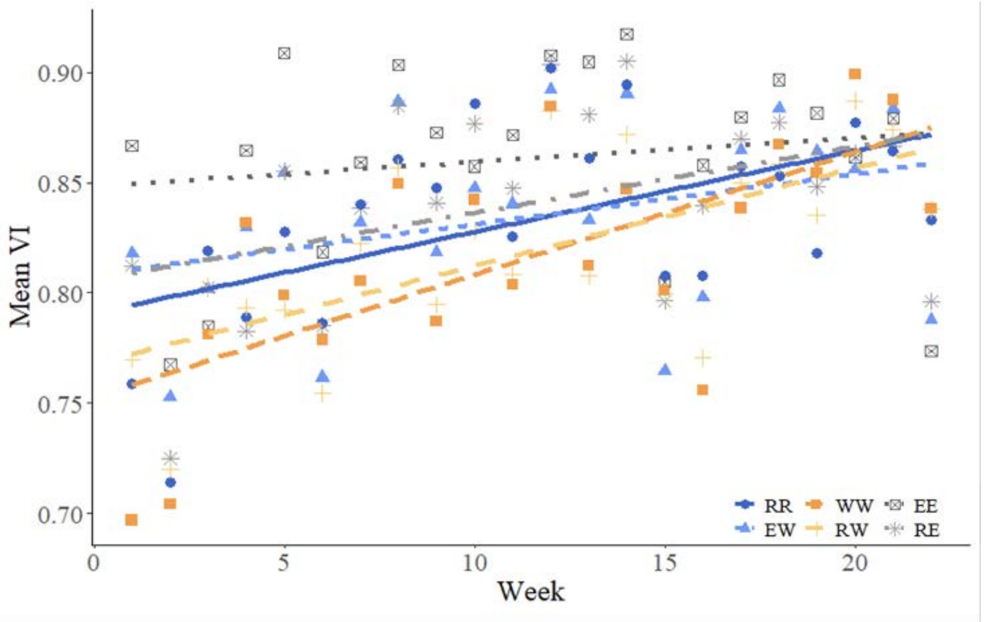

Figure 7.2. Average weekly Volume of Intersection (VI) values between all pair types (resident-resident, resident-eastern, resident-western, eastern-eastern, western-western, and eastern-western) across the 2015-2018 winter period (n weeks = 22), with lines representing a linear model fit.

Interaction rates across all migrant tactics were generally low ($\bar{x}$ = 0.06 ± 0.14 SD interactions/min; **Fig. 7.3**). Preliminary modelling suggests that interaction rate increases with an increase in density ($\beta = 0.612$, SE = 0.04, $p < 0.001$), and that interaction rates did not differ between tactics (**Fig. 7.3**). Across all three years, migrant elk spent a higher proportion of observed time vigilant (**Fig. 7.4**). Position within a group was a stronger predictor of vigilance than forage biomass, wolf presence and distance to edge and infrastructure. When on the periphery, all migration strategies had higher levels of vigilance than in the centre (seconds vigilant; = 121.58 ± 47.72 SE and = 48.06 ± 7.80 SE, respectively), but residents showed lower vigilance in the periphery and centre (73.47 ± 120.01 SE and = 39.32 ± 45.98 SE, respectively).

These results suggest that there are few differences in the spatial distribution or overlap of population-level tactics (e.g., **Fig. 7.1**) or at the individual-level on the shared winter range between western, eastern and resident females. But there was evidence for slight differences in behavioral interactions between tactics on the winter range, both in terms of the interaction rates, the types of interactions, and antipredator behaviors such as vigilance. These fine-scale differences in social behavior and organization on the winter range have implications for social dynamics, vulnerability to mortality from both wolves, and winter hunting on females (under Treaty rights) and even potential disease transmission.

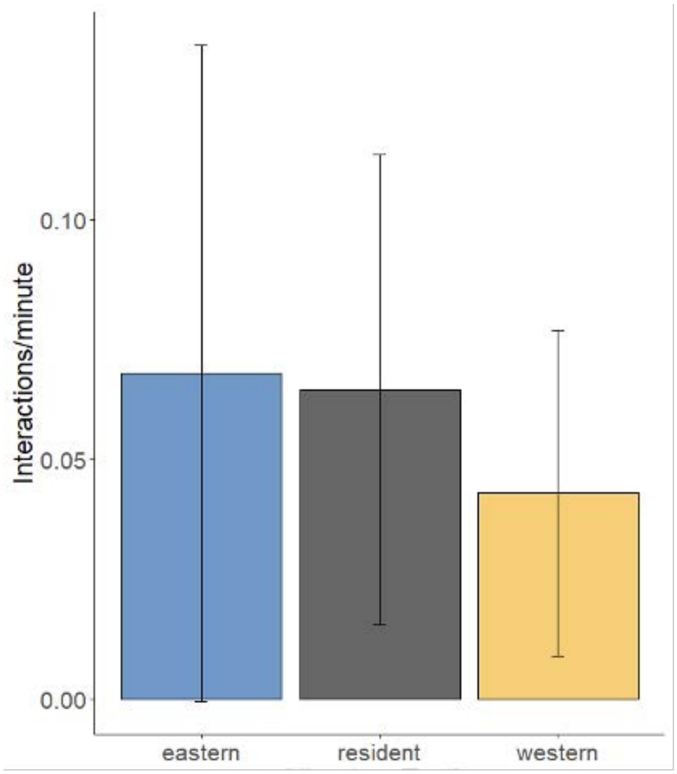

Figure 7.3. Mean interaction rate (interactions/minute) during behavioural observations for eastern (blue), resident (grey), and western (yellow) elk during winters 2019-2020. Error bars indicate ± 1 SE.

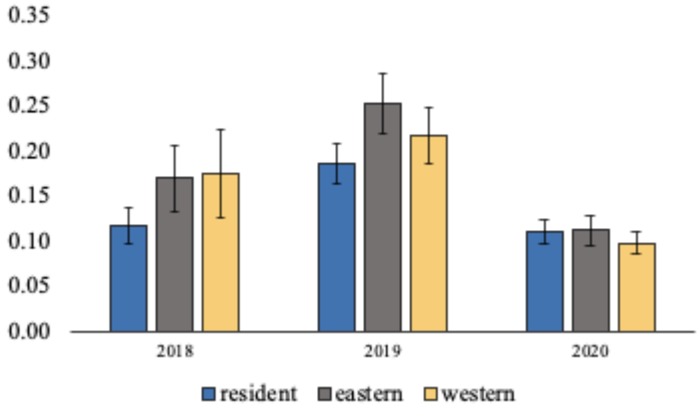

Figure 7.4. Average proportion of vigilance during foraging observations in winters of 2018-2020 in resident (blue), eastern migrant (grey), and western migrant (yellow) elk. Error bars represent ± 1 SE.

Objective 8. Developing a wild pedigree of the Ya Ha Tinda elk population

In a new branch of our research, we will use population genomic to investigate reproductive success and fitness of male and female elk in different migratory and non-migratory tactics. Working toward this goal, we collected a total of 72 DNA samples from juvenile elk through biopsy darting from horseback, following protocols in our animal care permits. Samples were collected in February-March 2020 using Pneu-Dart biopsy darts (n=35), and February-March 2021 using Dan-Inject biopsy darts (n=37).

We are currently genotyping individuals from these samples, working in collaboration with population genomicists and evolutionary biologists at the University of Montana. Our first step will be to estimate recapture rates of unique individuals and then pair males, females, and unique individual genotypes from 2017–2021 to develop a wild pedigree (Charmantier et al. 2014; Kruuk et al. 2014).

Figure 8.1. Juvenile elk with a biopsy dart temporarily inserted in the rump; March 2020; Alberta, Canada.

Conclusion and Broader Impacts

As the world's longest-running study of a wild elk population, our Ya Ha Tinda elk project is increasingly valued as scientific research that informs management and science in shorter-term studies. This highlights the key role of Parks Canada, Alberta Environment and Parks, and our other long-term funders in supporting our work. Within this reporting period (2017–2021), we have published 32 peer-reviewed papers in scientific journals. These and previous papers stemming from our work at the Ya Ha Tinda site have been cited thousands of times and continue to be cited by other researchers, indicating that our work is having a lasting impact in the field of ecology and conservation. Ya Ha Tinda research was also the focus of 12 student theses and dissertations at the University of Alberta and University of Montana. Our research has also helped train over 20 graduate students who now work across western Canada and the United States managing wildlife in positions with State, Provincial, and Federal natural resource agencies, universities, and private industry, contributing to training the next generation of natural resource managers and researchers. We continued to deliver broad scientific outreach through 42 presentations and conferences in 4 different countries and 7 different states and provinces, as well as online, within the reporting period. Finally, we have a strong track record of delivering public presentations and getting our science covered in local, national, and global media, with >40 news stories in 2017–2021.

Our long-term research has also provided supporting science for Parks Canada's Plains bison reintroduction program, long-term caribou recovery planning by Parks Canada, and environmental assessments and evaluation of prescribed fire programs in Parks and Alberta lands. In this transboundary setting, our long-term research has contributed directly to enhancing interagency cooperation and management of this important elk population.

Project Outputs

Peer-reviewed Publications

1. Aikens EO, Mysterud A, Merkle JA, Cagnacci F, Rivrud IM, Hebblewhite M, Hurley MA, Peters W, Bergen S, De Groeve J, Dwinnell SPH, Gehr B, Heurich M, Hewison AJM, Jarnemo A, Kjellander P, Kröschel M, Licoppe A, Linnell JDC, Merrill EH, Middleton AD, Morellet N, Neufeld L, Ortega AC, Parker KL, Pedrotti L, Proffitt KM, Saïd S, Sawyer H, Scurlock BM, Signer J, Stent P, Šustr P, Szkorupa T, Monteith KL, Kauffman MJ (2020) Wave-like Patterns of Plant Phenology Determine Ungulate Movement Tactics. Current Biology 30(17):3444-3449.
2. Berg JE, Hebblewhite M, St. Clair CC, Merrill EH (2019) Prevalence and mechanisms of partial migration in ungulates. Frontiers in Ecology and Evolution 7:325.
3. Berg JE, Reimer J, Smolko P, Bohm H, Hebblewhite M, Merrill EH (2021) Mothers' movements: shifts in calving area selection by partially migratory elk. Journal of Wildlife Management [In Press].
4. Boelman NT, Liston GE, Gurarie E, Meddens A, Mahoney PJ, Kirchner P, Bohrer G, Brinkman TJ, Cosgrove C, Eitel J, Hebblewhite M, Kimball J, Lapoint SD, Nolin A, Hojlund PS, Prugh

LR, Reinking A, Vierling L (2019) Integrating snow science and wildlife ecology in Arctic-Boreal North America. *Environmental Research Letters* 14:010401.

5. Geremia C, Merkle JA, Eacker DR, Wallen RL, White PJ, Hebblewhite M, Kauffman MJ (2019) Migrating bison engineer the green wave. *Proceedings of the National Academy of Sciences* 14:10401.
6. Geremia C, Merkle JA, Eacker DR, Wallen RL, White PJ, Hebblewhite M, Kauffman MJ (2020) Reply to Joseph M. Craine: Bison redefine what it means to move to find food. *Proceedings of the National Academy of Sciences* 117.
7. Hebblewhite M, Eacker DR, Eggeman S, Bohm H, Merrill EH (2018) Density-Independent Predation Affects Migrants and Residents Equally in a Declining Partially Migratory Elk Population. Oikos 127:1304-1318.
8. Hebblewhite M, Whittington J (2020) Wolves without borders: Transboundary survival of wolves in Banff National Park over three decades. Global Ecology and Conservation 24:e01293
9. Hessami M, Martin H, Whittington J, Hebblewhite M, Steenweg R, Flowers M, Merrill EH (2020) Estimating neonatal elk calf survival with remote cameras using Royle-Nichol's abundance models. *Wildlife Society Bulletin* [In Revision].
10. Joly K, Gurarie E, Sorum MS, Kaczensky P, Cameron MD, Jakes AF, Borg BL, Nandintsetseg D, Hopcraft GC, Buuveibaatar B, Jones PF, Mueller T, Walzer C, Olson KA, Payne JC, Yadamsuren A, Hebblewhite M (2019) Who goes the farthest of them all? World's longest terrestrial migrations and movements. *Scientific Reports* 9:15333.
11. Kauffman MJ, Cagnacci F, Chamaillé-Jammes S, Hebblewhite M, Hopcraft JGC, Merkle JA, Mueller T, Mysterud A, Peters W, Roettger C, Steingisser A, Meacham JE, Abera K, Adamczewski J, Aikens EO, Bartlam-Brooks H, Bennitt E, Berger J, Boyd C, Côté SD, Debeffe L, Dekrout AS, Dejid N, Donadio E, Dziba L, Fagan WF, Fischer C, Focardi S, Fryxell JM, Fynn RWS, Geremia C, González BA, Gunn A, Gurarie E, Heurich M, Hilty J, Hurley M, Johnson A, Joly K, Kaczensky P, Kendall CJ, Kochkarev P, Kolpaschikov L, Kowalczyk R, van Langevelde F, Li BV, Lobora AL, Loison A, Madiri TH, Mallon D, Marchand P, Medellin RA, Meisingset E, Merrill E, Middleton AD, Monteith KL, Morjan M, Morrison TA, Mumme S, Naidoo R, Novaro A, Ogutu JO, Olson KA, Oteng-Yeboah A, Ovejero RJA, Owen-Smith N, Paasivaara A, Packer C, Panchenko D, Pedrotti L, Plumptre AJ, Rolandsen CM, Said S, Salemgareyev A, Savchenko A, Savchenko P, Sawyer H, Selebatso M, Skroch M, Solberg E, Stabach JA, Strand O, Suitor MJ, Tachiki Y, Trainor A, Tshipa A, Virani MZ, Vynne C, Ward S, Wittemyer G, Xu W, Zuther S (2021) Mapping out a future for ungulate migrations: Limited mapping of migrations hampers conservation. Science **372**:566-569.
12. MacAulay KM, Spilker E, Berg J, Hebblewhite M, Merrill EH (2021) Predicting multi-predator risk to elk (*Cervus canadensis*) using scats: Are migrant elk exposed to different predation risk? Ecology and Evolution [In Review].
13. Mahoney PJ, Joly K, Borg BL, Sorum MS, Rinaldi TA, Saalfeld D, Golden H, Latham ADM, Kelly AP, Mangipane B, Koizumi CL, Neufeld L, Hebblewhite M, Boelman NT, Prugh LR (2020) Denning phenology and reproductive success of wolves in response to climate signals. Environ. Res. Lett. 15:125001.
14. Martin H, Hebblewhite M, Merrill EH (2021) Large herbivores in a partially migratory population search for the ideal free home. Ecology [In Revision].

15. Merrill EH, Killeen J, Pettit J, Trottier M, Martin H, Berg J, Bohm H, Eggeman S, Hebblewhite M (2020) Density-Dependent Foraging Behaviors on Sympatric Winter Ranges in a Partially Migratory Elk Population, Frontiers in Ecology and Evolution 8:269.
16. Metz MC, Emlen DJ, Stahler DR, MacNulty DR, Smith DW, Hebblewhite M (2018) Predation shapes the evolutionary traits of cervid weapons. *Nature Ecology & Evolution* 2:1619.
17. Normandeau J, St.Clair CC, Kutz S, Hebblewhite M, Merrill EH (2021) What makes elk tick: winter tick grooming behavior in wild elk (*Cervus canadensis*). Journal of Mammalogy [In Press].
18. Normandeau J, Kutz SJ, Hebblewhite M, Merrill EH. Living with liver flukes: Does migration matter? International Journal for Parasitology: Parasites and Wildlife. 2020 May 12;12:76-84.
19. Normandeau J, Macaulay K, Berg J, Merrill EH (2018) Identifying guard hairs of Rocky Mountain carnivores. Wildlife Society Bulletin 42:706-712.
20. Normandeau J, Martin H, Merrill EH, Hebblewhite M (2021) Potential case of pseudo-hermaphroditism in Elk (*Cervus canadensis*) in Alberta, Canada. Canadian Field Naturalist 134: 241-247.
21. Sabal MC, Boyce MS, Charpentier CL, Furey NB, Luhring TM, Martin HW, Melnychuk MC, Srygley RB, Wagner CM, Wirsing AJ, Ydenberg RC, Palkovacs EP. 2021. Predation landscapes influence migratory prey ecology and evolution. Trends Ecol Evol. 13:00124-5.
22. Schlagel UE, Merrill EH, Lewis MA (2017) Territory surveillance and prey management: Wolves keep track of space and time. Ecology and Evolution 7:8388-8405.
23. Sperling J, MacDonald Z, Normandeau J, Merrill E, Sperling F, Magor K (2020) Within-population diversity of bacterial microbiomes in winter ticks (Dermacentor albipictus). Ticks and Tick-borne Diseases. 11(6):101535.
24. Spitz DB, Hebblewhite M, Stephenson TR (2017) 'MigrateR': extending model-driven methods for classifying and quantifying animal movement behavior. Ecography 40:788-799.
25. Steenweg R, Hebblewhite M, McKelvey K, Lukacs P, Whittington J (2019) Species-specific trade-offs in statistical power when monitoring trends in multispecies occupancy. Ecosphere 10:e02639.
26. Steenweg R, Hebblewhite M, Whittington J, Mckelvey K, Lukacs P (2018) Sampling scales define occupancy and the occupancy-abundance relationship in animals. Ecology 99:172-183.
27. Steenweg R, Hebblewhite M, Kays R, Ahumada J, Fisher JT, Burton C, Townsend SE, Carbone C, Rowcliffe JM, Whittington J, Brodie J, Royle JA, Switalski A, Clevenger AP, Heim N, Rich LN (2017) Scaling-up camera traps: monitoring the planet's biodiversity with networks of remote sensors. Frontiers in Ecology and the Environment 15:26–34.
28. Suraci JP, Gaynor KM, Allen ML, Alexander P, Brashares JS, Cendejas-Zarelli S, Crooks K, Elbroch LM, Forrester T, Green AM, Haight J, Harris NC, Hebblewhite M, Isbell F, Johnston B, Kays R, Lendrum PE, Lewis JS, McInturff A, McShea W, Murphy TW, Palmer MS, Parsons A, Parsons MA, Pendergast ME, Pekins C, Prugh LR, Sager-Fradkin KA, Schuttler S, Şekercioğlu ÇH, Shepherd B, Whipple L, Whittington J, Wittemyer G, Wilmers CC (2021) Disturbance type and species life history predict mammal responses to humans. Global Change Biology, Early View.

29. Tucker MA, Bohning-Gaese K, Fagan WF, Fryxell JM, Van Moorter B, Alberts SC, Ali AH, Allen AM, Attias N, Avgar T, Bartlam-Brooks HLA, Bayarbaatar B, Belant JL, Bertassoni A, Beyer DE, Bidner L, van Beest FM, Blake S, Blaum N, Bracis C, Brown D, de Bruyn PN, Cagnacci F, Calabrese JM, Camilo-Alves C, Chamaille-Jammes S, Chiaradia A, Davidson SC, Dennis T, DeStefano S, Deifenbach D, Douglas-Hamilton I, Fennesey J, Fichtel C, Fiedler W, Fischer C, Fischoff I, Fleming CH, Ford AT, Fritz S, Gehr B, Goheen JR, Gurarie E, Hebblewhite M, Heurich M, Hewison AJ, Hof C, Hurme E, Isbell LA, Janssen R, Jeltsch F, Kaczensky P, Kane A, Kappler P, Kauffman M, Kays R, Kimuyu D, Koch F, Kranstauber B, Lapoint SD, Leimgruber P, Linnell JDC, Lopez-Lopez P, Markham AC, Mattison J, Medici EP, Mellone U, Merrill EH, de Miranda-Mourao G, Morato RG, Morellet N, Morrison TA, Diaz-Munoz SL, Mysterud A, Nandintsetseg D, Nathan R, Niamir A, Odden J, O'Hara RB, Olvieria-Santos GR, Olson KA, Patterson BD, de Paula RC, Pedrotti L, Rimmler M, Rogers TL, Rolandsen CM, Rosenberry CS, Rubenstein DI, Safi K, Said S, Sapir N, Sawyer H, Schmidt NM, Selva N, Sergiel A, Shiilegdamba E, Silva JP, Singh NJ, Solberg EJ, Spiegel O, Strand O, Sundaresan S, Ullmann W, Voigt U, Wall J, Wattles D, Wikelski M, Wilmers CC, Wilson JW, Wittemyer G, Zięba F, Zwijacz-Kozica T, Mueller T (2017) Moving in the anthropocene: global reductions in terrestrial mammalian movements. Science 359:466-469.
30. Visscher DR, Merrill EH (2018) Functional connectivity in ruminants: A generalized state-dependent modelling approach. PLoS ONE 13(6):e0199671.
31. Whittington J, Baron R, Hebblewhite M, Ford AT, Paczkowski J (2021) Towns and trails drive carnivore connectivity using a step selection approach. Movement Ecology [In Review].
32. Williams S, Hebblewhite M, Martin H, Killeen J, Berg J, MacAulay KM, Smolko P, Merrill EH (2021) Predation Risk Drives Long-Term Shifts in Migratory Behavior and Demography in a Large Herbivore Population. Journal of Animal Ecology [In Review].

Theses and Dissertations

1. Berg JE (2019) Shifts in strategy: Calving and calf survival in a partially migratory elk population. University of Alberta.
2. Flowers M (2019) Winter behavior of resident and migrant elk at Ya Ha Tinda Ranch. MS Thesis, University of Alberta.
3. Hessami M (2019) Estimating Migratory-Resident Elk Populations and Juvenile Recruitment Using Remote Cameras in the Canadian Rockies. Undergraduate Senior Honors Thesis. University of Montana.
4. Keery L (2019) Effects of bison reintroduction on vegetation and landcover in Banff National Park. Royal Rhodes University, Advisor: Mark Hebblewhite.
5. MacAulay KM (2019) Spatial predation risk for elk (*Cervus elaphus*) in a multi-predator community on the Rocky Mountain East Slopes, Alberta. University of Alberta.
6. Martin HW (2021) Ungulates Search for the Ideal Home: How Predation and Forage Differentially Affect Males and Females in a Partially Migratory Population. PhD Dissertation, University of Montana.
7. Normandeau J (2019) Elk contact networks and parasite dynamics. MSc, University of Alberta.

8. Spilker E (2018) Spatial predation risk and interactions within a predator community on the Rocky Mountains east slopes, Alberta. University of Alberta.
9. Trottier M (2020) The Waiting Game: Elk avoid predators at fine spatial scales MS thesis, University of Alberta.
10. Weeks TC (2020) Bottom-up Herbivore-Plant Feedbacks Trump Trophic Cascades in a Wolf-Elk-Grassland System. Undergraduate Thesis. University of Montana, Missoula, MT, USA.

Popular Media Articles

1. Rott N (2017) Volcanic beginning launches a lifetime of outstanding elk research. Bugle Magazine, September-October Issue.
2. Chaney R (2017) Camera Traps shed new light on wildlife biology. Missoulian, Oct 15, 2017.
3. Robbins J (2018) Animals are losing their vagility, or ability to roam freely. New York Times, February 19, 2018. **Our Tucker et al. paper was also covered in > 25 other major global news outlets including Globe and Mail, Science, Scientific American, Atlantic, National Post, National Observer, and Rocky Mountain Outlook - featuring elk data from Ya Ha Tinda.*
4. Safari Club International (2018) First big bulls collared in North America's longest running elk study. Safari Club International, First for Wildlife. January 16, 2018.
5. Outlet N (2019) Fading migrations: historic elk migrations have dwindled sharply over the last decades. What does it mean for the future of wild elk? Bugle Magazine, July-August 2019.
6. Giamio C (2019) Still the undisputed champs of mammalian migrations. New York Times, November 13, 2019.
7. Landers R (2020) Idaho digs into the predator pit: researchers are peeling back the layers to learn why some elk herds flourish despite predation while others crash and languish. Bugle Magazine, Jan-Feb 2020.
8. Ellis C (2020) Low survival rate for Banff wolves due to hunting and trapping outside park boundaries. Rocky Mountain Outlook, Oct 10, 2020.
9. Ellis C (2021) New study shows wildlife struggle to navigate busy Bow Valley. Rocky Mountain Outlook, March 11, 2021.
10. Frangou C (2021) Canmore at a crossroads: proposal to double Alberta town's population worries residents. Narwhal, April 24, 2021.

Scientific Meetings & Conference Presentations

1. Aikens EO, Mysterud A, Merkle J, Cagnacci F, Rivrud IM, Hebblewhite M, Hurley MA, Peters W, Bergen S, De Groeve J, Dwinnel SPH, Gehr B, Heurich M, Hewison MA, Jarnemo A, Kjellander P, Kroschel M, Licoppe A, Linnell J, Merrill EH, Middleton AD, Morellet N, Neufeld L, Ortega AC, Parker KL, Pedrotti L, Proffitt KM, Said S, Sawyer H, Scurlock BM, Singer J, Stent P, Sustr P, Szkorupa T, Monteith KL, Kauffman MJ (2019) *Wave-like patterns of plant phenology determine ungulate migration tactics across northern temperate ecosystems*. Wildlife Society and American Fisheries Society Joint Annual Conference. Reno, Nevada, USA.
2. Berg J (2019) *Shifts in strategy: Calving and calf survival in a partially migratory elk population*. 2019 University of Alberta Campus Seminar. Edmonton, Alberta, Canada.

3. Flowers M (2019) *Ways to use remote camera data to study predator-prey interactions*. 2019 Alberta Conservation Association Workshop. Edmonton, Alberta, Canada.
4. Flowers M (2019) *The Waiting Game: Using remote cameras to assess seasonal differences in how elk respond to multiple predators*. 2019 University of Alberta Wednesday Night Ecology Seminar Series. Edmonton, Alberta, Canada.
5. Flowers M, Hebblewhite M, Merrill EH (2018) *Using remote cameras to investigate how elk respond to predators in winter*. 2018 International Deer Biology Congress. Estes Park, Colorado, USA.
6. Flowers M, Hessami M, Hebblewhite M, Merrill EH (2019) *The Waiting Game: Using remote cameras to investigate how elk avoid multiple predators at the Ya Ha Tinda*. 2019 RE Peter Conference. Edmonton, Alberta, Canada.
7. Flowers M, Hessami M, Hebblewhite M, Merrill EH (2019) *The Waiting Game: Elk maintain fine-scale spatial avoidance of predators across various temporal scales*. 2019 Joint Alberta Chapter of the Wildlife Society and Canadian Section of the Wildlife Society Conference. Canmore, Alberta, Canada.
8. Flowers M, Melsted J, Hebblewhite M, Merrill EH (2018) Remote cameras for investigating elk responses to wolves. Alberta Chapter of The Wildlife Society conference. Lethbridge, Alberta, Canada.
9. Gurarie E, Alvarez S (2017) WORKSHOP: Animal movement for conservation: New Tools for Data Management, Visualization and Analysis. International Conservation Biology Conference. Cartagena, Columbia.
10. Hebblewhite M (2019) Plenary: Twenty Years of the GPS-Infused Movement Revolution: Linking Movement Responses to Humans to Animal Fitness. In Gordon Research Conference: Animal Movement as a Link Between Ecology, Evolution and Behavior, Lucca, Italy.
11. Hebblewhite M, Merrill EH (2017) Ecology & Management of Partially Migratory Ungulates: Insights from Canada's Longest Running Elk Research Project, the Ya Ha Tinda. Invited plenary speaker at University of British Columbia-Okanagan Department of Biology Speaker Series. Kelowna, BC, Canada.
12. Hebblewhite M, Merrill EH, Eggeman S, Bohm H, Berg J, Killeen J (2017) Unexpected flexibility in migratory behavior, its drivers, and population consequences in a large herbivore. Ecological Society of America. Portland, OR, USA.
13. Hessami M, Hebblewhite M, Nowak J, Whittington J, Flowers M, Merrill EH (2019) *Estimating neonatal survival for elk in an occupancy framework*. Wildlife Society and American Fisheries Society Joint Annual Conference, Reno, Nevada, USA, October 2019. Reno, Nevada, USA.
14. Hessami M, Whittington J, Hebblewhite M (2018) *Parks Canada Remote Camera protocol/data integration workshop*. 2018 WIRE Lab Camera Workshop UBC-O (Dr. Adam Ford). Kelowna, BC, Canada.
15. Lukacs P, Nowak J, Hebblewhite M, Martin H (2018) Integrated population modeling for wildlife management. Webinar presentation to 43 Alberta Fish and Wildlife Biologists. Webinar.
16. MacAulay KM (2018) *Spatial predation risk for elk (Cervus elaphus) in a multi-predator community on the Rocky Mountain East Slopes, Alberta.* 2018 University of Alberta Campus Seminar. Edmonton, Alberta, Canada.

17. MacAuley K, Spilker E, Berg J, Merrill EH (2018) Spatial mortality risk for elk in a multi-predator community. RE Peter Student Symposium. Edmonton, Alberta, Canada.
18. MacAuley K, Spilker E, Berg J, Merrill EH (2018) Spatial mortality risk for elk in a multi-predator community. Alberta Chapter of The Wildlife Society conference. Lethbridge, Alberta, Canada.
19. MacAuley K, Spilker E, Berg J, Merrill EH (2018) *Spatial predation risk for elk (Cervus elaphus) in a multi-predator community*. 2018 International Deer Biology Congress. Estes Park, Colorado, USA.
20. Martin H, Hebblewhite M, Merrill EH (2019) *Ideal free migration? Testing for density-dependent migration in partially migratory elk.* Wildlife Society and American Fisheries Society Joint Annual Conference. Reno, Nevada, USA.
21. Martin H, Killeen J, Merrill EH, Hebblewhite M, Berg J, Eggeman S, Bohm H (2018). Migratory flexibility suggests facultative switching in a partially migratory elk herd. Poster Presentation. Greater Yellowstone Coordinating Committee Wildlife Migration Symposium. Jackson Hole, Wyoming, USA.
22. Martin H, Killeen J, Merrill EH, Hebblewhite M, Berg J, Eggeman S, Bohm H (2018) *Testing for facultative switching between migratory strategies in a partially migratory, long-lived herbivore population*. 2018 Greater Yellowstone Coordinating Committee Wildlife Migration Symposium. Jackson Hole, Wyoming, USA.
23. Martin H, Normandeau J, Merrill EH, Hebblewhite M (2019) Bull Elk Ecology and Vulnerability in a Partially Migratory Population. Poster Presentation. Alberta Chapter of the Wildlife Society Conference. Canmore, AB, Canada.
24. McPhee D (2019) *Vigilance and Cohesion in the Elk of Ya-Ha Tinda*. 2019 University of Alberta Campus Seminar. Edmonton, Alberta, Canada.
25. McPhee D, Trottier M, Normandeau J, Merrill EH (2019) *Elk Behaviour Between Migratory Tactics in Winter*. 2019 RE Peter Conference. Edmonton, Alberta, Canada
26. McPhee D, Trottier M, Normandeau J, Merrill EH (2019) *Elk behaviour between migratory tactics in winter*. 2019 joint Alberta Chapter of the Wildlife Society and Canadian Section of the Wildlife Society Conference. Canmore, Alberta, Canada.
27. Normandeau J, Kutz S, Merrill EH, Hebblewhite M (2018) Are there costs to shifting migration linked to parasitism? RE Peter Student Symposium. Edmonton, Alberta.
28. Normandeau J, Kutz S, Merrill EH, Hebblewhite M (2018) Are there costs to shifting migration linked to parasitism? Alberta Chapter of The Wildlife Society conference. Lethbridge, Alberta, Canada.
29. Normandeau J, Merrill EH, Kutz S, Hebblewhite M (2018) *Are there costs of shifting elk migration linked to parasitism?* International Deer Biology Congress. Estes Park, Colorado, USA.
30. Normandeau J, Merrill EH, Kutz S, Hebblewhite M (2019) *Is there differential parasite exposure in a migratory elk population?* 7th Annual World Mountain Ungulate Conference. Bozeman, Montana, USA.
31. Normandeau J, Merrill EH, Kutz S, Hebblewhite M (2019) *Is there differential parasite exposure in a migratory elk population?*. 2019 joint Alberta Chapter of the Wildlife Society and Canadian Section of the Wildlife Society Conference. Canmore, Alberta, Canada.
32. Trottier M, McPhee D, Normandeau J, Hebblewhite M, Merrill EH (2019) *Disparity in elk (Cervus canadensis) behaviour following different migratory tactics on a sympatric*

winter range.. 7th Annual World Mountain Ungulate Conference. Bozeman, Montana, USA.

33. Trottier M, Merrill E, Hebblewhite M (2020) Elk behaviour on sympatric winter ranges: Does migratory tactic influence interactions? Oral presentation, March 2020. Alberta Chapter of the Wildlife Society Annual Conference [Online].
34. Trottier M, Merrill E, Hebblewhite M (2020) Disparity in elk (*Cervus canadensis*) movement and behaviour following different migratory tactics on a sympatric winter range. Poster presentation, September 2020. The Wildlife Society Annual Conference, [Online].
35. Weeks T, Williams S, Merrill EH, Hebblewhite M (2020) *Top-down and bottom-up interactions in a Montana grassland system driven by rainfall*. University of Montana Conference on Undergraduate Research (UMCUR). Missoula, Montana, USA.

Public Presentations

1. Martin H, Merrill EH, Hebblewhite M (2017) The history of elk research and ecology at the Ya Ha Tinda. Ya Ha Tinda 100th Year Parks Canada Celebration Conference. Ya Ha Tinda Ranch, Alberta, Canada.
2. MacAuley K, Spilker E, Berg J, Merrill EH (2017) Guess who's coming to dinner? Linking predator diets to elk predation risk. A Celebration of ACA Research Funding Reception. Edmonton, Alberta, Canada.
3. Normandeau J, Merrill EH, Hebblewhite M (2018) *Ya Ha Tinda Long-term Elk Project*. 2018 Sundre Forestry Products Public Input Round Table. Caroline, Alberta, Canada.
4. Martin H, Berg J, Normandeau J, Flowers M, MacAulay K, Merrill E, Hebblewhite M (2019) *The Ya Ha Tinda Elk Research Project*. 2019 Public Meeting. Sundre, Alberta, Canada.
5. Normandeau J, Flowers M, Merrill EH, Hebblewhite M (2019) *Ya Ha Tinda Long-term Elk Project*. 2019 Strathcona All-Breed Horse Association monthly meeting. Ardrossan, Alberta, Canada.
6. Hebblewhite, M. 2021. The Ya Ha Tinda Elk Herd: Long-term Insights into Predator-prey Ecology and ConservationBow Valley Natualists, February 24, 2021. ZOOM presentation to 175 attendees.

Websites

- https://terpconnect.umd.edu/~egurarie/teaching/MovementAtICCB2017/index.html Gurarie E, Hebblewhite M (2018) Animal movement for conservation: New Tools for Data Management, Visualization and Analysis. Workshop presented at the International Conservation Biology Congress, Cartagena, Columbia, 2018. This website makes use of long-term Ya Ha Tinda telemetry data hosted on Movebank. The goal of the course was to develop basic skills to process and visualize movement data and environmental variables as a first step to answer questions related to habitat use and animal responses to environmental changes and conservation strategies. Recent tools in R make high-level visualizations, including maps, animations, interactive graphics, and incorporation of environmental layers, easy to create and manipulate. Movebank provides a standardized web-supported database for managing, sharing and annotating movement data with environmental covariates, a vital step in encouraging and supporting conservation decisions.

- http://www.umt.edu/yahatinda/
  Ya Ha Tinda Long-Term Elk Monitoring Project. Our regularly updated project website features information about who we are, our research areas of focus, access to reports and publications, information about datasharing and access to collaborative datasets, and links to webinars and educational resources.

Digital Data Products

- https://www.movebank.org/
  Our GPS location data are partially available (with permission required) on the Movebank data repository.
- Data from camera traps stored in the Parks Canada Camera Trap Database.
- All other data are stored in Microsoft Access databases, as ArcGIS maps and shapefiles, and as digital photographs.

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- Berg JE, Hebblewhite M, St. Clair CC, Merrill EH (2019) Prevalence and mechanisms of partial migration in ungulates. Frontiers in Ecology and Evolution 7:325.
- Berg JE, Reimer J, Smolko P, Bohm H, Hebblewhite M, Merrill EH (2021) Mothers' movements: shifts in calving area selection by partially migratory elk. Journal of Wildlife Management [In Press].
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- Fiske IJ, Chandler RB (2011) Unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software 43:1-23.
- Hebblewhite M (2006) Linking predation risk and forage dynamics to landscape scale ungulate population dynamics. PhD Dissertation, University of Alberta, Edmonton. 298pp.
- Hebblewhite M, Eacker DR, Eggeman S, Bohm H, Merrill EH (2018) Density-Independent Predation Affects Migrants and Residents Equally in a Declining Partially Migratory Elk Population. Oikos 127:1304-1318.
- Hebblewhite M, Merrill EH (2008) Modelling wildlife–human relationships for social species with mixed-effects resource selection models. Journal Applied Ecology 45: 834–844.
- Hebblewhite M, Merrill EH (2011) Demographic balancing of migrant and resident elk in a partially migratory population through forage-predation tradeoffs. Oikos 120:1860-1870.
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