FACTORS AFFECTING SPATIAL AND TEMPORAL VARIATION IN HUMAN-BEAR INTERACTIONS

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Emily Judith Sunter

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The following individuals certify that they have read, and recommend to the College of Graduate Studies for acceptance, a thesis/dissertation entitled:

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submitted by Emily Judith Sunter in partial fulfillment of the requirements of

the degree of Master of Science .

Dr. Adam T. Ford, Biology Department, Irving K. Barber Faculty of Science

Supervisor

Dr. Lael Parrott, Biology/Earth and Environmental Sciences Department, Irving K. Barber Faculty of Science

Supervisory Committee Member

Dr. Jason Pither, Biology Department, Irving K. Barber Faculty of Science

Supervisory Committee Member

Dr. Sumeet Gulati, Institute for Resources, Environment and Sustainability, Faculty of Land and Food Systems

University Examiner

Abstract

Past research in human-carnivore coexistence has largely focused on conflict interactions, leaving a significant knowledge gap in our understanding of coexistence beyond conflict. I addressed this gap by analyzing the spatial and temporal distribution of both incidents (i.e., conflict; physical attacks, property damage, bear consumption of human food) and sightings (i.e., animal, property, and person remain unharmed). I examined 2 years of human-bear interaction records from Alberta's Bow Valley, a landscape where black bears (*Ursus americanus*) and grizzly bears (*Ursus arctos*) co-occur with people within vital large carnivore habitat. I used generalized linear models to examine patterns of interaction distribution across bear seasons and for each species. The majority of interactions were sightings of black bears reported during summer. Bear activity, primary productivity, and distance to roads and trails were the strongest predictors of interactions overall. Incident interactions were best explained by human presence while sightings models were more complex. In general, I found greater differences between species than between sightings and incidents, but sightings increased the power of predictive models over incidents alone. These results indicate the potential use of incorporating sightings reports with incidents for a broader understanding human-bear coexistence and can aid wildlife managers in further developing regulations to mitigate conflict and ensure viable bear populations. Key recommendations to improve human-bear coexistence in the Bow Valley include increasing the use of sightings reports in research and management decisions, quantifying the effect of management removals on black bear population dynamics, evaluating the human dimensions of human-bear interactions, and limiting human use where it overlaps with high-quality or high-activity bear habitat.

Lay Summary

Large carnivores, such as bears, face survival challenges due to their large territory sizes, slow reproduction, and persecution by people. Improving our ability to predict where human-carnivore interactions occur could help identify effective approaches to prevent the loss of large carnivores from human-occupied landscapes and prevent conflicts with people. To help move towards peaceful co-existence with large carnivores, I investigated the factors that contribute to both incidents (i.e., conflict) and sightings (i.e., animal, property, and person remain unharmed). I used records of human-bear interactions from Alberta's Bow Valley, Canada where grizzly bears and black bears co-occur with people within important large carnivore habitat. Results of this research indicate the potential use of sightings reports along with incidents in research and management decisions. This would contribute to a broader understanding human-carnivore coexistence and to help ensure the Bow Valley can support healthy carnivore populations while improving human safety.

Preface

This thesis used camera trap and human-bear interaction data from 2016-2017 in Alberta's Bow Valley collected and curated by Alberta Environment and Parks (AEP). Early conversations with John Paczkowski and Jay Honeyman helped with formation of research questions and understanding of local context. Camera trap data and human-bear interaction report summaries were provided by AEP. GIS data was provided by AEP, Parks Canada, and the Town of Canmore. Drs. Adam Ford, Lael Parrott, and Jason Pither provided advice and feedback on hypotheses, methodology, analysis, and thesis drafts. WiRE Lab students provided technical support, comments on drafts, and feedback on tables and figures.

Spatially explicit bear activity models were based on camera trap data, with image classification completed by AEP staff and volunteers without involvement from myself or UBC. I created all spatial layers for input into models (except for fetch and human structures layers, which were provided by Dr. Adam Ford), and ran all analyses with extensive feedback from my supervisor and periodic feedback from the supervisory committee.

Human-bear interaction models were based on unsolicited HBI records curated and entered by AEP and Kananaskis Improvement District. An undergraduate research assistant, Eamon Riordan-Short, assisted with extraction of quantitative data from HBI datasets in preparation for analysis. I designed data entry sheets and made final decisions on HBI categorization, partially based on an existing data dictionary used by AEP within the human-wildlife interactions database. I created all spatial layers for input into models (except for fetch and human structures layers, which were provided by Dr. Adam Ford) and ran all analyses with extensive feedback from my supervisor and periodic feedback from the supervisory committee.

I have ensured that all scripts from my analyses are accessible on the OSF platform (https://osf.io/nkhg9/), and where applicable, have prepared ReadMe files for instructions. Data is available from AEP but will not be shared on the OSF platform due to stipulations in data sharing agreements.

This manuscript was improved based on feedback from supervisory committee and will be adapted and submitted as a paper co-authored by Adam Ford, Lael Parrott, Jason Pither, and John Paczkowski.

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Acknowledgements

First, I wish to acknowledge that I wrote this thesis while living in the ancestral and unceded territory of the Syilx Okanagan Nation. As well, the study area in the Bow Valley where my data comes from has a long history of removal and exclusion of Siksikaitsitapi (Blackfoot), Tsuut’ina, and Îyãħé Nakoda (Stoney Nakoda) peoples from Banff National Park and beyond. The negative and lasting impacts of colonialism on local communities, both human and animal, is immeasurable and these rights violations continue to resonate in the lives of Indigenous peoples across Canada. I also acknowledge that the themes of my work, including broadening our understanding of human-wildlife relationships and fostering respectful human-carnivore interactions, have been recognized and practiced by Indigenous peoples throughout North America since time immemorial.

Next, I want to acknowledge the contributions of my collaborators in the Bow Valley. This thesis would not be possible without the support, guidance, and ideas of John Paczkowski and Jay Honeyman with Alberta Environment and Parks (AEP). Thank you for your wisdom and hospitality! I also want to thank all those staff and volunteers who contributed to the collection and curation of the AEP camera trap and HBI data – I had the privilege of having access to rich, long-term datasets that were a product of many peoples previous efforts. Special shoutout to Sandra Code with AEP for patiently and promptly answering all kinds of questions about the aforementioned data – thank you! I also want to thank the other organizations in the Bow Valley who work on human-wildlife coexistence who offered me support and guidance in crafting this research, including the Town of Canmore, Yellowstone to Yukon Conservation Initiative, and Parks Canada.

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Lastly, I want to thank my friends and family for being the reason I want to come home every day, and for making me keep working when I thought I didn't want to anymore. Thank you to my mom and dad – I would not be where I am today without their support, knowing I can call anytime and find a sympathetic and loving ear, and for teaching me that I can only do my best, and my best is enough. Thank you to the rest of my family for showing so much enthusiasm for what I’m doing and for being there along the way. I also need to thank my friends, both the new and the old. The beers, texts, snapchats, and bike rides make the work part not so bad! Finally, I need to thank my wonderful partner, Gavin. You make me laugh every day, you stay by me when I fall down and help me back up when I’m ready. I could not have done this without you.

Dedication

This work is dedicated to my family and friends. And of course, my GGG.

Chapter 1: Introduction

1.1 Large Carnivores and People

Large carnivores play an essential role in ecosystem functioning (Terborgh et al. 2001, Ford et al. 2014) and hold a special cultural and emotional significance for the public (Kellert et al. 1996, Sergio et al. 2008). However, coexistence with large carnivores is problematic when their ecological requirements intersect with the physical and social structures of people. As human development intensifies across the globe, interactions between people and large carnivores are increasing (Kellert et al. 1996, Quigley and Herrero 2005, Treves et al. 2006, Goswami and Vasudev 2017, Bombieri et al. 2019) and human-caused mortality remains the major mortality factor for most terrestrial carnivore species (Woodroffe et al. 1998, Woodroffe 2000, Wolf and Ripple 2017). Improving our ability to predict the occurrence of interactions could aid in identifying effective approaches to prevent the loss of large carnivores from human-occupied landscapes and improving human safety (Marker et al. 2003, Treves et al. 2006, Dorresteijn et al. 2014).

Research on human-wildlife conflict and coexistence has increased dramatically over the past 30 years (Nyhus 2016, Knox et al. 2020). The majority of this work focuses on understanding conflict interactions (e.g. attacks) with limited work on non-conflict interactions where animal, property, and person remain unharmed (Bath and Enck 2003, Redpath et al. 2013, Nyhus 2016, Pooley et al. 2017, Soulsbury and White 2019). This trend remains the same for human-large carnivore coexistence research (i.e., bears, hyenas, large felines, large canids), particularly in biological studies, where the literature on conflict is extensive (Treves and Karanth 2003, Inskip and Zimmermann 2009, Smith and Herrero 2018). As per Frank (2016), in this thesis I define human-carnivore coexistence as taking place ‘when the interests of humans and [carnivores] are both satisfied, or when a compromise is negotiated to allow the existence of both humans and [carnivores] together'.

1.1.1 Contributing Factors for Human-Large Carnivore Interactions

The occurrence of human-wildlife interactions and their outcomes has both biological and social drivers. For conflict, these include the juxtaposition of human and carnivore habitat, the historical social context, the level of social tolerance, and wildlife habitat connectivity. I will describe each of these factors in turn below and how they apply to conflict specifically.

Expectedly, increased human presence increases the likelihood of conflicts (Quigley & Herrero, 2005), particularly where humans overlap with high-quality carnivore habitat. For example, conflict between humans and tigers (*Panthera tigris*) occurs most frequently within reserve edges in India where people and livestock access high quality tiger habitat (Karanth and Gopal 2005, Miller et al. 2016b). Likewise, hotspots of human-grizzly bear (*Ursus arctos horribilis*) conflict in North America occur on ranches containing high-quality riparian habitat (Northrup et al. 2012). The risk of conflict is especially high where carnivores are attracted to resources within otherwise low-quality habitat. For example, American black bears (*Ursus americanus*) forage on orchard crops even when wildland food are available (Merkle et al. 2013) and African wild dogs (*Lycaon pictus*) preferentially choose home ranges outside of protected areas, even where human-caused mortality increases significantly (van der Meer et al. 2014).

Important social predictors of conflict include perception of wildlife by people, historical context, and cultural norms (Kellert et al. 1996, Bath and Enck 2003, Slagle et al. 2013). For example, nineteenth century North American settlers viewed wolves (*Canis lupus*) as livestock-killing vermin, leading to a highly successful government eradication campaign (Jones 2010). In contrast, in some regions, high levels of human-carnivore interactions are tolerated because of longstanding religious beliefs, such as with spotted hyenas (*Crocuta crocuta*) in the Hararge region, Ethiopia (Baynes-Rock 2013).

Finally, landscape connectivity is necessary for long-term persistence of carnivore populations (Hanski 1998, Crooks 2002, Vasudev et al. 2015), and human-carnivore conflict increases as landscape connectivity decreases (Treves et al. 2006, Evans et al. 2014, McFadden-Hiller et al. 2016). For example, pumas (*Puma concolor*) in a highly fragmented region in southern California, USA, experience very low survival resulting from human-puma conflict (Vickers et al. 2015). Conflict can also decrease when landscape connectivity is high, such as for grizzly bears (*Ursus arctos*) in Transylvania, Romania, where bear habitat connected to source populations was found to be an important contributing factor to coexistence (Dorresteijn et al. 2014).

The historic research focus on conflict outlined above means that non-conflict interactions are not well understood (Soulsbury and White 2015). Research on non-conflict interactions is particularly important in multiuse landscapes, where interactions with large carnivores may not always be preventable (Breitenmoser et al. 2005, Carter and Linnell 2016). Despite policies emphasizing ecological integrity, agencies operating in these multiuse landscapes face significant challenges when tasked with both large carnivore conservation and protecting human safety (Weaver et al. 1996, Treves and Karanth 2003, Treves et al. 2006). A better understanding of the physical landscape of interactions, including both conflict and non-conflict types, may increase the ability of wildlife management agencies to work towards coexistence.

1.1.2 Potential Lessons from Non-Conflict Interactions

The majority of human-carnivore interactions in many landscapes are benign (Bounds and Shaw 1994, Quigley and Herrero 2005, Morehouse and Boyce 2017, Soulsbury and White 2019), yet these non-conflict interactions are understudied. This knowledge gap presents an exciting avenue of exploration in human-carnivore coexistence research. The study of the distribution of both conflict and non-conflict interactions could represent a quantifiable measure of the landscape of coexistence. For instance, studying the ratio of conflict to non-conflict reports at varying scales, may provide spatial and temporal measures of successful coexistence across neighbourhoods, cities, and entire landscapes. A ratio of conflict to non-conflict reports may represent spaces where coexistence is working, and determining which landscape factors lead to these patterns could provide wildlife managers with tools to decrease conflict to non-conflict ratios in other areas.

Measuring coexistence via a ratio of conflict to non-conflict interactions cannot operate in isolation, as there are biases in the types of reports the public make about wildlife (Kretser et al. 2008, Wilbur et al. 2018). There are also regions in the world where long-term or recent human-large carnivore interaction data do not exist due to lack of resources, expertise, or political instability (Rotshuizen and Smith 2013, Acharya et al. 2016). For example, in India, comprehensive data collection on tiger attacks ended in 1927 because data were believed to be unreliable (Löe and Röskaft 2004), while in Mozambique, the federal government only began collecting human-wildlife conflict data in 2006 following concern over fatal attacks on people (Dunham et al. 2010). Despite these data gaps, some research has already shown the value of including the spatial and temporal distribution of multiple types of interactions (e.g. Merkle et al. 2011b), but conflict and non-conflict reports are not differentiated in these analyses (but see Lukasik and Alexander 2011 as an exception).

1.1.3 Focal Conflict Species

In North America, black bears and grizzly bears are carnivores that come into frequent contact with people due to their opportunistic foraging behaviours and overlapping habitat with expanding human development, such as riparian areas and valley bottoms (Raine and Kansas 1990, Mowat and Heard 2006, Evans et al. 2014, Lamb et al. 2017). Bears are non-obligate carnivores and can become dependant on human food, such as garbage, crops, or beehives (Herrero 1976, Beckmann and Berger 2003). This unique behaviour along with the cross-continental range that bears inhabit has led black bears and grizzly bears to be the most commonly reported large carnivore involved in interactions with people in many jurisdictions in North America (e.g. Alberta: Morehouse and Boyce 2017; British Columbia: Government of British Columbia 2020; Parks Canada: Parks Canada 2018; Massachusetts: Huguenin Jr 2015; New York: Kretser et al. 2008). As a result, human-bear coexistence has become one of the most complex management issues for wildlife managers today (Spencer et al. 2007). As with other large carnivores, research on human-bear interactions (hereafter, HBI) is generally limited to conflict or in some recent analyses, conflict and non-conflict interactions grouped together (e.g. Kretser et al. 2008, Merkle et al. 2011b). This means there is a knowledge gap in our understanding of non-conflict HBI, even though the majority of HBIs that occur are benign (Siemer and Decker 2003, Quigley and Herrero 2005).

This thesis will address the knowledge gaps in HBI research from an ecological perspective and will add to our understanding human-large carnivore coexistence beyond conflict. In the following sections, I will review the ecological and cultural role of bears, what is known about HBIs and how they are managed, and lastly, how HBI management could be improved with the results of this study.

1.2 Grizzly Bears and Black Bears in North America

1.2.1 Ecological Roles of Bears

The specific ecological roles that bears play is complex, as they are non-obligate carnivores and have direct impacts on both plant and animal communities. Bears play a major role as seed dispersers (Willson and Gende 2004, Naoe et al. 2016, Harrer and Levi 2018), in limiting cervid densities (Berger et al. 2001, Zager and Beecham 2006, Barber-Meyer et al. 2008), in the distribution of marine nutrients (Hilderbrand et al. 1999), and potentially, as ecosystem engineers (Naiman and Rogers 1997, Takahashi et al. 2015, Zyśk-Gorczyńska et al.

2015). Bears and other carnivores also have additive effects when grouped into guilds, such as co-occurring bears and wolves limiting ungulate populations in North America (Ripple and Beschta 2012).

In North America, grizzly bears and black bears influence ungulate prey behavior, contributing to the ‘landscape of fear’ (Brown et al. 1999, Berger 2007). Grizzly bears and black bears also interact with each other, and cases of grizzly predation on black bears have been documented, leading to patterns of avoidance of grizzly bears by black bears (MacHutchon et al. 1998, Holm et al. 1999, Belant et al. 2010). In some cases, this avoidance leads to unique ecological impacts, such as devil’s club (*Oplopanax horridus*) in Alaska which was shown to be primarily dispersed by grizzly bears prior to the arrival of seasonal salmon runs, and by black bears once competition with grizzly bears is alleviated (Harrer and Levi 2018). Grizzly bear kills also provide scavenging opportunities for co-occurring large carnivores, such as the black bears, and in Alberta, 50% of investigated grizzly kills showed scavenging evidence by other carnivores (Cristescu et al. 2014). In contrast, black bears are highly efficient scavengers, and can decrease scavenger species richness in areas where they frequently access carrion (Allen et al. 2014).

1.2.2 Cultural Roles of Bears

In North America, bears are sometimes viewed as trouble-making pests, even when the majority of reported conflicts are related to unsecured and unnatural attractants, such as bee hives or free-ranging cattle (e.g. Morehouse and Boyce 2017). Conversely, grizzly bears have been used with a positive connotation in North American conservation campaigns to champion the need for large protected areas and functional wildlife corridors (e.g. Yellowstone to Yukon Conservation Initiative, The Nature Conservancy, Raincoast Conservation Foundation). Perceptions of bears by the public ranges from generally positive (e.g. Siemer and Decker 2003, Beichler 2017) to indifferent (e.g. Gore et al. 2006) to strongly negative (Kellert et al.

1996). Perception may depend on previous experiences with bears, level of education, and vocation. For example, in an agricultural community in Montana, USA, 52% of surveyed residents believed that the area would be a better place to live without grizzlies on private land, citing fear for personal safety and risk to livelihoods as the driving factors (Wilson et al. 2014).The wide range of perceptions of grizzly and black bears contributes to the difficulty of managing HBI, and this same variation in public perceptions is found with regard to bear management decisions as well (Hristienko and McDonald 2007, Merkle et al. 2011a, Slagle et al. 2013).

In many Indigenous cultures across North America, respectful human-bear relationships were celebrated both pre- and post- colonization with sacred religious practices, healing, hunting, and pervasive narratives, such as ‘the woman who marries a bear’ (Loucks 1985, Rockwell 1991, Kailo 1998). Like North American settler perceptions, acknowledgement of the risk bears pose to people is not absent from Indigenous views of bears, but this most often manifests as respect which is bolstered by specific traditions (Rockwell 1991). Currently, some Indigenous Nations have taken leading roles in bear conservation and habitat management, citing a responsibility to protect bears (Coastal First Nations 2017, Laforest 2019, Metcalfe 2019).

1.2.3 What We Know About Human-Bear Interactions

The literature on HBIs and how to predict their outcomes identifies many landscape factors which contribute to the occurrence of HBIs and these covariates often overlap with those found in bear habitat models. HBIs are most common where human access or development overlaps with high quality forest or riparian habitat (Nielsen et al. 2004b, Wilson et al. 2006, Merkle et al. 2011b, Northrup et al. 2012). Other features commonly associated with increased risk or occurrence of HBIs are: 1) decreased distance to roads and increased road densities (Benn and Herrero 2002, Suring and Frate 2002, Schwartz et al. 2010b, Cristescu et al. 2016b, McFadden-Hiller et al. 2016), 2) rural or intermediate housing densities (Suring and Frate 2002, Schwartz et al. 2010b, Merkle et al. 2011b), 3) anthropogenic attractants such as livestock or garbage (Wilson et al. 2006, Baruch-Mordo et al. 2008, McFadden-Hiller et al. 2016, Miller et al. 2016a), 4) natural attractants such as berries (Benn and Herrero 2002, Lamb et al. 2017), and 5) loss of habitat connectivity (Evans et al. 2014, McFadden-Hiller et al. 2016). Unfortunately, highly selected habitat does not always correlate with high quality habitat. In these cases, bears are attracted to resources in areas where human development or access is high, and increased HBIs result (Northrup et al. 2012, Merkle et al. 2013, Lamb et al. 2017). While the impact of some variables differs between studies, the convergence of high-quality habitat or a valuable attractant and human development or access generally cause an increase in the likelihood of an HBI occurring.

Other notable trends in across HBI studies include temporal and age specific effects. Many studies find that bears avoid people and development features temporally by shifting foraging and activity to dusk, night, and dawn hours (Mattson et al. 1987, Gibeau et al. 2002, Kite et al. 2016). This translates to increased probability of HBIs at night in some ecosystems (Miller et al. 2016a). Another trend is the disproportionate number of female bears involved in HBIs (Mattson et al. 1987, Gibeau et al. 2002). This potentially results from security-driven females avoiding dominant males and selecting for habitat closer to human settlement or human use.

Predicting the outcome of HBIs is also dependent on the human dimensions of an ecosystem (Merkle et al. 2011a, Frank and Glikman 2019, Skogen et al. 2019). Siemer et al. (2009) found that non-negative personal experiences with black bears decreased the public’s concern about bears and helped them to understand the realistic risks involved in HBI. They suggested that increased neutral or positive experiences in controlled situations, such as nature walks identifying bear signs, may increase the ability of people to accurately assess true threats from bears (Siemer et al. 2009). There is also interplay between management decisions and

HBIs. For instance, residents in Durango, Colorado were less likely to secure garbage when they trusted local management agencies, i.e. increasing the potential for further fine-scale conflict because managers were perceived to be doing a good job overall (Lischka et al. 2018).

1.2.4 Current Human-Bear Coexistence Management

Managing human-bear conflict is costly and historically most management agencies relied on reactionary measures such as relocation, hazing, or lethal control (Treves and Karanth 2003, Hopkins III et al. 2010). Proactive management has been identified as a longer term, resource efficient, and more socially acceptable technique for preventing HBI (Ciarniello 1997, Baruch-Mordo et al. 2011, Lackey et al. 2018), leading to a diversity of educational campaigns (e.g. 'Bear Smart': Government of British Columbia n.d.) and preventative measures, such as signage and road closures (Hristienko and McDonald 2007, Baruch-Mordo et al. 2011, Coleman et al. 2013, Whittington et al. 2019). Conversely, controlled HBIs have been promoted in some regions (e.g. Yellowstone/Grand Teton National Parks, USA: Gunther et al. 2018; Alaska, USA: Smith et al. 2005; Whistler, Canada: Needham et al. 2004), and bear viewing tourism now represents a significant tourist draw in these areas. In other areas, 'no go' zones have been designated, where a human-carnivore interaction of any kind is seen as unacceptable (Lute et al. 2018, Frank and Glikman 2019, J. Honeyman, *personal communication*).

As HBI have increased and research on human-carnivore coexistence has advanced, there has been a push for improved conflict mitigation across North America (e.g. Wilson et al. 2014, Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018, Firth et al. 2019, Young et al. 2019). As well, grizzly bears are listed as threatened in the lower 48 United States (U.S. Fish and Wildlife Service 2018) and under the Government of Alberta's Wildlife Act in 2010, meaning managers in these areas have additional mandates for conflict mitigation. For these reasons, HBI that lead to death or removal of a bear are highly problematic for management agencies. Conflict prevention is therefore crucial to effectively address these problems.

A challenging area of addressing HBI arises in multiuse landscapes where people and bears co-occur. Individual bear home ranges cover vast areas, up to 1400 km^2 for grizzly bears and 220 km^2 for black bears (Stevens and Gibeau 2005, Karelus et al. 2016). Bears are also not territorial (Horner and Powell 1990, McLellan and Hovey 2001) meaning that attempting to communicate non-structural borders to bears, such as unfenced recreational areas or municipal boundaries, will not work consistently without continuous and costly intervention (Hopkins III et al. 2010, Mazur 2010). There is also a shift in understanding that protected areas alone are not sufficient for large carnivore conservation (Scudder 2000, Carter and Linnell 2016, Santini et al. 2016). Instead, some level of co-occurrence of humans and bears and some level of tolerance for HBIs by people and wildlife management agencies will be necessary for coexistence in multiuse landscapes (Lute et al. 2018).

The complexity of managing HBIs within and among wildlife management agencies is addressed by Hopkins III et al. (2010). Specifically, they address communication, proposing a lexicon of HBI management terms and explicitly define conflict and non-conflict HBI. A common framework, such as Hopkins III et al. (2010), allows for the study of non-conflict HBI across studies and jurisdictions to proactively prevent incidents (Cristescu et al. 2016a). This lexicon has been applied in HBI research, including work where non-conflict HBI were included but not analysed independently of conflict HBI (Merkle et al. 2011a, 2011b, Cristescu et al. 2016a, Morehouse and Boyce 2017).

1.2.5 Improving Human-Bear Coexistence Management

A promising area of exploration to advance the understanding of human-carnivore coexistence focuses on a preventative approach in which the factors that contribute to the timing and location of interactions are identified. The most common outcomes of HBI are benign for both people and bears (Siemer and Decker 2003, Quigley and Herrero 2005), but it is not known whether we can differentiate between the factors that contribute to the occurrence of a conflict HBI versus a non-conflict HBI. In landscapes where both bear persistence and human safety are important objectives, quantifying the factors leading to benign HBI could help reduce the occurrence of conflict interactions (Hopkins III et al. 2010, Cristescu et al. 2016a).

Additionally, there is a dearth of research examining the link between empirically measured bear activity and the occurrence of HBI. Predictive models of human-bear interactions can help to prevent conflict (Treves et al. 2006, Dorresteijn et al. 2014, Cristescu et al. 2016a). Most studies of this type incorporate landscape and anthropogenic variables, such as distance to water or recreational trail density, but empirical measures of bear activity are often excluded (e.g. Wilson et al. 2005, 2006, Baruch-Mordo et al. 2008, Merkle et al. 2011b). Northrup et al. (2012) acknowledged this gap and used grizzly bear habitat use measured via global positioning system radio telemetry data to help explain the distribution of human-grizzly bear incidents in an agricultural area of Alberta, Canada. They identified high overlap of conflict hotspots and grizzly bear habitat selection, suggesting the existence of ecological traps which will require management intervention to prevent future conflict (Northrup et al. 2012).

1.3 Research Objectives and Hypotheses

The objective of my research was to determine factors that contribute to HBI and to develop a predictive model of these interactions and their outcomes. I sought to address the above described knowledge gaps regarding non-conflict interactions and incorporating empirical bear activity data into predictive HBI models by analyzing the distribution of both incidents and sightings for a case study area surrounding the town of Canmore, Alberta. This work will help improve future conflict mitigation tactics and contribute to our understanding of coexistence with large carnivores beyond conflict.

For this thesis, I rely on strict definitions of key terms. Firstly, I define the types of HBI as per Hopkins III et al. (2010) as follows: An **incident** (i.e., conflict) occurs when a bear a) exhibits stress-related or curious behavior, causing a person to take extreme evasive action, b) attacks a person, c) is intentionally harmed or killed (not including legal harvests), or d) causes property damage, obtains anthropogenic food, kills or attempts to kill livestock or pets, or is involved in a vehicle collision. A **sighting** (i.e., non-conflict) occurs when a) a person observes a bear that is seemingly unaware of the person observing it, b) a bear had no observable stress-related response to the person during an interaction, or c) a bear responded to the person (who did not take extreme evasive action) by taking evasive action. Secondly, I define corridors as potential bear habitat without significant barriers to movement, i.e., no steep slopes, no major highways, and no human structures, such as buildings or industrial development. Here, corridors have both width and length, which is the maximum distance a bear can travel without encountering a barrier.

I investigated two key questions: 1) can we predict the distribution of HBIs across space and time using bear activity, human presence, and environment; and 2) if the factors that predict the distribution of sightings differ from those that predict incidents?

To answer these questions, I evaluated potential explanatory factors that may affect human-bear interactions based on reports in the literature, expert opinion, and the availability of candidate data. This exploratory approach means that I was not testing explicit hypotheses per se, rather that I searched for potential sources of causality that could inform future, more mechanistic or experimental approaches to understanding human-bear interactions. As such, the analyses within this thesis are exploratory in nature and it is important to acknowledge the potential increase in false positive rates.

I tested the relative importance of the following groups of competing hypotheses:

1.3.1 Question 1) Can we predict the distribution of HBIs across space and time using bear activity, human presence, and environment?

Hypothesis 1: Spatial and temporal variation in bear activity, human presence, and environment affects the distribution of HBI.

> **Hypothesis 1A**: People drive HBI. Therefore, I predict HBI are positively associated with human presence.
>
> **Hypothesis 1B**: Bears drive HBI. Therefore, I predict HBI are positively associated with bear activity.
>
> **Hypothesis 1C**: Environmental factors, such as attractants/habitat quality and corridor size, drive HBI. Therefore, I predict HBI are positively associated with habitat quality and negatively associated with corridor size
>
> **Hypothesis 1D**: An optimal mixture of people, bears and environment drive HBI. Therefore, I predict peak HBI at moderate levels of human presence and increasing bear activity/habitat quality.

Hypothesis 2: Spatial and temporal variation in bear activity, human presence, and environment does not affect the distribution of HBI; HBI are explained by covariates not measured in this study, such as social factors, bear movement, individual bear behaviour, or interactions between bear species and age groups.

1.3.2 Question 2) Do the factors that predict the distribution of sightings differ from those that predict incidents?

Hypothesis 1: The factors that predict the distribution of sightings differ from those that predict incidents.

> **Hypothesis 1A***:* Anywhere bears occur in high use human areas there is the potential for adverse interactions to occur as bear and humans compete for space, particularly if

they overlap with other factors such as high-quality bear habitat. Therefore, I predict that incidents will increase relative to sightings with increasing human presence.

Hypothesis 1B: Where there are more people interacting with bears, bears become habituated as stimulus from human presence is more consistent. Therefore, I predict that moderate to low human presence increases incidents relative to sightings because human activity is less predictable.

Hypothesis 1C: Decreased space restrictions for bears and people on the landscape, such as roads and steep slopes, allow bears and people to segregate, or for bears to safely escape. Therefore, I predict that sightings relative to incidents increase as corridor size increases.

Hypothesis 1E: Bears moving between foraging patches are less likely to defend food and may be more visible during movement (as opposed to foraging) while traversing or crossing trails and roads. Therefore, I predict that lower habitat quality and food availability increases sightings relative to incidents.

Hypothesis 2: Spatial variation in bear activity, human presence, and environment does not differ between interaction types; sightings and incidents co-occur. Therefore, I predict that models explaining sightings and incidents will be the same.

I also tested for interactions between these hypotheses; for example, recreational trails (i.e., human presence) in narrower corridors could have a greater impact on HBI than trails in a wider corridor. These interactions are described in detail in the Methods (section 2.1.4.2).

Chapter 2: Spatial and Temporal Distribution of Human-Bear Interactions

2.1 Methods

In this methods section, I will first describe the biophysical characteristics of the study area, as well as relevant traits and management information about the focal study species: black bears and grizzly bears. Next, I will outline how I created empirical measurements for bear activity across the study area using camera trap images. Next, I will describe how I modelled human-bear interactions (HBI) using bear activity, environmental, and anthropogenic covariates. I modelled the occurrence of incidents, sightings, as well as all HBI combined. I also modelled HBI outcomes, i.e., I directly compared the distribution of incidents and sightings within latent-selection difference models. Finally, I will describe how I compared the HBI occurrence model raster outputs for incidents against the equivalent sightings output to test whether sightings and incidents co-occurred.

2.1.1 Study Area

The study system is within the Bow Valley of southwest Alberta and is defined by the limits of the human-wildlife interaction data provided by Alberta Environment and Parks (hereafter, AEP) except to the south, where I used the same boundary as previous work on carnivore movement in the region (A. Ford, unpublished data; Figure 1). Human-wildlife interaction records are maintained by AEP throughout the study area, from the east gate of Banff National Park to the eastern boundary of Bow Valley Provincial Park, an area covering approximately 35,000 hectares including Bow Valley Wildland Provincial Park, the Town of Canmore with a population of more than 13,000 people (Town of Canmore 2015), and part of the traditional territories of the Siksikaitsitapi (Blackfoot), Tsuut'ina, and Ĩyãħé Nakoda (Stoney Nakoda) peoples.

The Bow Valley is bisected by the Bow River, the Canada Pacific Railway, and the 4-lane Trans-Canada Highway that has an average traffic volume of 23,000 vehicles per day (Alberta Government 2019; Figure 1). A thriving recreation and tourism industry, along with extensive development of recreational trails and many protected areas, brings more than 4 million visitors and 6.8 million vehicle trips to this region per year (Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018, Parks Canada 2019).

This region is composed of alpine, subalpine, and montane subregions (Alberta Parks 2015). Elevations range from 1280 to 2920 metres, including high mountain peaks, wide flood plains, and lush montane forest. Summers are short and cool while winters are long and snowy.

Figure 1: Study area boundaries and important regional features of Alberta's Bow Valley, Canada.

Dominant tree species are Englemann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Picea contorta*), and aspen (*Populus termuloides*). Understorey shrubs at lower elevation include buffalo berry (*Shepherdia canadensis*), thimbleberry (*Rubus parviflorus*), snowberry (*Symphoricarpos albus*), saskatoon (*Amelanchier alnifolia*), and white meadowsweet (*Spiraea alba*). Grass complexes occur on dry open sites. At higher elevations, false azalea (*Menziesia ferruginea*), grouseberry (*Vaccinium scoparium*), white-flowered rhododendron (*Rhododendron albiflorum*), and tall bilberry (*Vaccinium membranaceum*) dominate, eventually giving way to heath (*Erica* spp.) as tree cover decreases towards the alpine.

The Bow Valley has a long history of human-carnivore coexistence. Grizzly bears, American black bears, pumas (*Puma concolor*), and gray wolves (*Canis lupis*) persist on this landscape and have been heavily managed for decades. More than 30 years of human-wildlife interactions records exist and the local governments have made prevention of HBIs a priority, evident through their resource allocation and the recent formation of a technical working group to address human-wildlife interactions (Alberta Environment and Parks, 2016b, 2016a; Bow Valley Technical Working Group, 2017). In some areas, intensive monitoring of individual bears takes place to prevent HBIs and there are full-time staff dedicated solely to managing human-wildlife conflict in addition to numerous other conservation officers and wildlife biologists. This area has been identified as a crucial corridor for large mammals connecting populations all the way from the northwestern United States to the Yukon (Soulé and Noss 1998, Weber and Rabinowitz 2010). These factors make the Bow Valley ideal to study HBIs and aid wildlife managers in achieving their conservation and public safety goals.

2.1.2 Focal Carnivores

Of the large carnivores present in the Bow Valley, grizzly bears and black bears are the most frequent participants in interactions with people (Morehouse and Boyce 2017). Like elsewhere in Alberta, HBIs in this area have been increasing over the past 20 years (Morehouse and Boyce 2017) and are likely to continue increasing as development and recreation also increase (Kellert et al. 1996, Quigley and Herrero 2005) along with the recovering grizzly bear population.

Grizzly bears are listed as Least Concern by the IUCN (Garshelis et al. 2016), but not all North American populations are stable. The Government of Alberta listed the grizzly bear as threatened under Alberta's Wildlife Act in 2010 following reccomendations from Alberta's Endangered Species Conservation Committee (Alberta Fish and Wildlife Division 2002). According to the draft Grizzly Bear Recovery Plan (Alberta Environment and Parks 2016a), there are approximately 691 bears in the province and the main causes of population decline are human-caused mortality, habitat deterioration, and loss of habitat connectivity. Human-grizzly bear conflict increased in Alberta from 2011-2016 (Alberta Environment and Parks 2016a), indicating a pressing need to address the underlying causes of HBI and how to mitigate negative outcomes for both people and grizzly bears.

Black bears are the most populous bear species on the planet (Garshelis et al. 2016), but like the grizzly bear, black bears have experienced considerable range retractions across southern North America (Laliberte and Ripple 2004, Scheick and McCown 2014). In Canada, the black bear remains listed as 'Secure' (Canadian Endangered Species Conservation Council 2016). In Alberta, the most recent provincial black bear population estimate dates back to 1993 but current reports suggests the population is most likely stable (Alberta Environment and Parks 2016b). Since human-caused mortality is the major source of mortality for Alberta black bears and HBI have increased since 1960 (Larivière 2001, Alberta Environment and Parks 2016b), increased research on HBI is an important aspect of improving public safety and ensuring black bear populations remain stable in Alberta.

2.1.3 Bear Activity Models

2.1.3.1 Camera Trap Data

To create an empirical measurement of bear activity levels in the study area, I used camera trap images collected by AEP from 2012 to 2017. The availability of camera trap data in the Bow Valley was an advantage for this study because while collar data exists for grizzly bears in the region, no recent GPS collar data is available for black bears. Since black bears are more numerous in the area and involved in more HBI than grizzly bears (Alberta Environment and Parks 2016b, Morehouse and Boyce 2017), I wanted a measure of bear activity that was comparable and equivalent between the two species.

Camera traps have been increasingly used in wildlife studies to address the need to non-invasive and cost-effective approaches to wildlife monitoring (O'Connell et al. 2011). They are commonly used to study low density or elusive species, such as large carnivores (Karanth 1995, O'Connell et al. 2011), and one of the earliest published studies using camera traps was on bears in North America (Mace et al. 1994). Camera trap use has increased rapidly in recent years, and up to 1/3 of recent camera trap studies were used to answer behavioural questions, such as activity patterns (Burton et al. 2015).

Camera traps have been used by AEP since 2005 in the Bow Valley and are managed by staff and volunteers. Earlier surveys focused on wildlife crossings or were set-up for specific small-scale monitoring but by 2012, camera traps were placed more broadly across the landscape. Multiple programs have been deployed to study wildlife use of corridors, human recreational activity, as well as to track the presence or activity of various species of wildlife.

AEP camera trap locations are biased towards lower elevations and areas close to roads and trails, likely due to accessibility constraints and AEP's focus on covering human use areas. I addressed this aspect of trap distribution by limiting my analysis of the data to a relative measure of activity only (i.e. spatially-explicit bear activity models; hereafter, SEAM), and since this analysis was completed to inform HBI models, I am most concerned with bear activity only were it overlaps with potential human use.

Camera traps were fixed to trees and maintained by AEP staff and volunteers. Traps were placed on recreational trails, wildlife trails, and at rub trees, and were programmed to run 24 hours/day. At each camera trap location, site information was collected by attending staff, including region, habitat type, topography, canopy cover, trail type (where applicable), and whether a rub tree or bait lure was present (Alberta Environment and Parks n.d.). During maintenance, memory cards were collected, and batteries replaced where necessary. Camera trap operationality was recorded during maintenance and corroborated with picture records during classification. Image classification was completed by AEP staff and volunteers.

I only used camera trap sites with similar operational protocols, such as absence of lures. I eliminated all camera sites outside of the study area boundary (see Figure 1), as well as those sites that included rub trees, licks, lures, or those placed at wildlife crossings. I also eliminated any cameras that were within 60 m of each other and operating at the same time to address spatial collinearity. For pairs of cameras that were within this distance, I combined images between the pair and accounted for the increased trapping effort. I also eliminated images from any cameras that were operating for less than 10 days per trapping session. This resulted in a total of 142 remaining camera trap stations non-randomly distributed across the Bow Valley (Figure 2).

For this study, I used data from camera traps that were collected between April 15 and October 31 of each year. This period encompasses three bear seasons: pre-berry (April 15 – June 15), berry (June 16-July 31), and post-berry (August 1 – Oct 31). These season boundaries were based on local management practices and previous work on bear forage

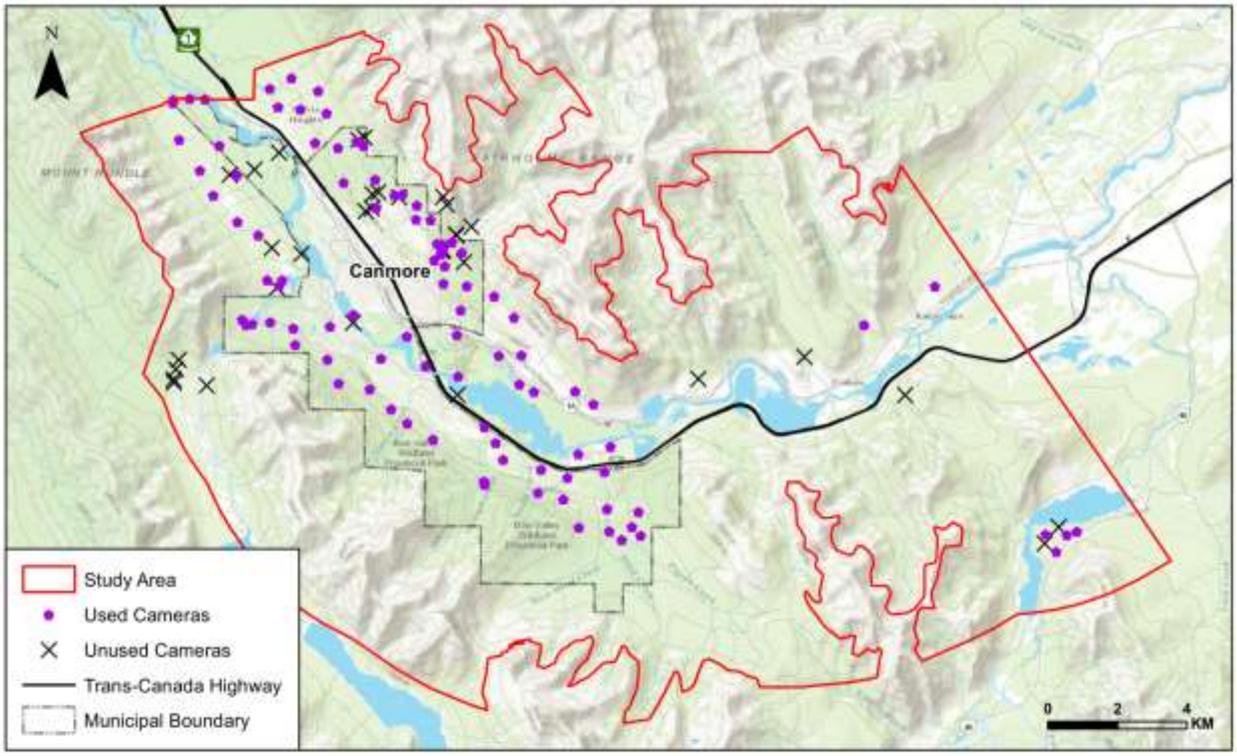

Figure 2: Camera trap locations (n = 142) where I assessed relative bear activity of black bears and grizzly bears in the Bow Valley of Alberta, Canada, 2012-2017. Note that overlap in camera station location represents overlap in space but not time, i.e. some cameras in the Bow Valley were replaced by new cameras in similar locations. I combined images, accounting for the doubled trapping effort, for any cameras within 60 metres of each other that were operational at the same time.

availability in the region (Gaines 2003, Nielsen et al. 2003, 2004b). The final classified image data were then grouped by year and bear season. Camera trapping effort was calculated as the number of days per season each camera was operational. A bear event was defined as an image of bear separated by more than 2 minutes (J. Paczkowski, *personal communication*) or a female bear with cubs. Where a bear occurred in multiple photographs within a short time period and was identifiable as the same individual (e.g. ear tag, collar, or other identifiable feature), this was also classified as a single event. While not quantified explicitly, I assumed equal detectability between sites (i.e. how often a bear was present at the camera trap site and actually captured by the camera). Black bear event counts were standardized within each bear season to calculate relative activity (bear event counts ÷ trapping effort × 100 = relative number of bears per station per 100 trap days; O'Brien et al. 2003, Burton et al. 2011). Grizzly bear event counts were standardized across the whole bear year (i.e., April 15-Oct 31) as sample sizes were too small to analyze images by season. This gave the response variable: bear activity per station, season, and year.

2.1.3.2 Variable Selection for Spatially-Explicit Activity Models

For the SEAMs, I selected a suite of variables that I hypothesized would affect bear activity levels within two categories: landscape and anthropogenic covariates (Table 1). All data were analyzed using R software (R Core Team 2018). All final spatial covariates within the GIS were continuous, in raster format, and snapped to a 30 × 30 metre template raster to ensure accurate calculations when applying model outputs.

Landscape covariates:

I derived topographic variables relevant to bear habitat use from a digital elevation model (AltaLIS Ltd. 2018a), including elevation, slope, terrain ruggedness and aspect (Raine and Kansas 1990, Apps et al. 2004, Nielsen et al. 2004, Costello et al. 2013, Henderson et al. 2015) using the 'raster' (Hijmans 2019) and 'sp' (Pebesma and Bivand 2019) packages. To calculate terrain ruggedness, I used the 'spatialEco' package (Sappington et al. 2005) to produce a terrain ruggedness measure which quantifies variation in terrain roughness more independently of slope than similar methods.

I included layers representing mean and standard deviation of Normalized Difference Vegetation Index (NDVI), a measure of primary productivity and availability of plant food, which bears select for (Mace and Waller 1996, Lamb et al. 2017, Lara-Díaz et al. 2018). NDVI layers were extracted from measurements taken during July and August of 2000-2009 from MODIS data (A. Ford, unpublished data). Areas with high mean NDVI represent areas that are growing throughout the summer, with high productivity overall. Areas with high variation in NDVI

Table 1: Independent covariates considered for analysis of grizzly and black bear activity in the Bow Valley of Alberta, Canada, 2012-2017.

Covariate Name	**Description**
Landscape	
Elevation	Distance above sea level
Slope	Degree of landscape incline
VRM	Vector ruggedness measure, a measure of elevational heterogeneity
Aspect	Compass direction that a slope faces; partitioned into ‘southerliness’ and ‘westerliness’
NDVI	Normalized Difference Vegetation Index, an index of primary productivity; partitioned into mean and standard deviation
Distance to water	Distance to major streams, lakes, and reservoirs
Forest density	Density of coniferous, broadleaf, and mixed forest cover
Shrub/grass density	Density of open habitat, i.e. shrub/grass cover
Corridor width	Maximum width of bear navigable habitat at each pixel; corridor edge = any slope > 30°, Trans-Canada Highway, and human structures
Corridor length	Maximum length of bear navigable habitat at each pixel; corridor edge = any slope > 30°, Trans-Canada Highway, and human structures
Grizzly bear RSF	Scale of resource selection function for grizzly bears in southwest Alberta as per Nielsen (2007) that was partitioned into pre-berry, berry, and post-berry season habitat selection by the authors
Anthropogenic	
Distance to modified greenspace	Distance to human greenspace polygons (i.e., campgrounds, dog parks, urban parks, golf courses)
Distance to human structures	Distance to pixels containing human structures as visible from satellite imagery (excluding roads and modified greenspace)
Population density	Human population density per 2016 census polygon
Distance to TCH	Distance to Trans-Canada Highway (TCH)
Distance to secondary roads	Distance to all secondary roads (i.e. excluding TCH)
Distance to trail	Distance to recreational trails; partitioned into 3 potential categories: official trails, unofficial trails, and all trails combined
Trail density	Density of all recreational trails
Human use	Relative measure of levels of non-motorized human use on roads and trails

represent areas with green-up, or where a flush of palatable new growth occurs where little existed before.

I also calculated distance to water (Natural Resources Canada 2016, AltaLIS Ltd. 2018), forest cover density (Alberta Biodiversity Monitoring Institute 2013), and shrub/grass (open habitat) cover density (Alberta Biodiversity Monitoring Institute 2013) as these landscape characteristics are important for predicting bear habitat use and activity patterns (Mace and Waller 1996, Nielsen et al. 2004b, Carter et al. 2010, Hiller et al. 2015). Distance to water was calculated using the ‘raster’ package and ‘distance’ function based on streams and waterbodies. To create forest cover density, coniferous, deciduous, and mixed forest types were combined as deciduous and mixed forest represented a very small proportion of total forest cover in the study area. For both forest cover and shrub/grass cover density, a range of scales was calculated (100, 500, 1000, 2000, 4000, 8000 metre radii) to address a potential distance effect and the impact of features perceived by bears at varying scales across species and seasons (Suring and Frate 2002, Boyce 2006, Takahata et al. 2014). Forest and shrub/grass cover density at each radius was calculated with the ‘raster’ package and ‘focal’ function using a circular moving window.

As a representation of corridor availability in the models, I used minimum and maximum fetch, or corridor width and length, respectively (A. Ford, unpublished data). In this study, fetch is analogous to the calculation of wind exposure over waterbodies but in this case, the ‘shoreline’ or edge of potential bear corridor is all slopes steeper than 30°, the Trans Canada Highway, and human structures or industrial development.

Finally, I included resource selection layers from a previous broad-scale habitat selection analysis for grizzly bears in southwest Alberta (Nielsen 2007). Data for these layers was combined from two population unit analyses, Clearwater and Livingstone, as the spatial extent of these resource selection functions both covered a part of the study area. I included these layers as they are a recent analysis of bear habitat in this region and predicted they would inform habitat selection with the study area. I did not use these models as a replacement for the bear activity analysis as the Nielsen (2007) data is specific to female grizzlies; to the best of my knowledge there are no recent equivalent estimates of black bear habitat use in this area.

Anthropogenic covariates

I derived several spatial anthropogenic covariates from landcover vector data, satellite imagery, and census data. Linear human disturbance covariates that I included were distance to secondary roads (Kasworm and Manley 1990, Northrup et al. 2012, Cristescu et al. 2016a), distance to the Trans-Canada Highway (Gibeau et al. 2002, Cristescu et al. 2016a), distance to recreational trails, and trail density (Mace and Waller 1996, Gibeau et al. 2002, Hodder et al. 2014). Road data (Natural Resources Canada 2012) was split into two categories (secondary and highway) due to differences in traffic type, volume, and based on previous work (Gibeau et al. 2002). In the study area, there is limited range of secondary road types, such as low-traffic resource roads. Forestry, mining, and oil and gas development are limited due to topography and density of protected areas in the region and existing resource roads tend to be highly used for recreation and tourism; for this reason, I grouped all secondary roads together. Recreational trail distribution was represented with distance to recreational trail and trail density layers. Trail locations were provided by AEP and Parks Canada and were corroborated with crowdsourced trail map applications (AllTrails LLC 2018, Pinkbike 2018). All distance to linear feature layers were created using the ‘raster’ package and ‘distance’ function, and the trail density layers were created using the ‘raster’ package and ‘focal’ function and a circular moving window.

Non-linear human disturbance features included distance to modified greenspace and distance to human structures. To represent the abundance of recreation sites in the Bow Valley with features that may be attractive to bears, such as high NDVI or garbage, I created a distance to modified greenspace layer. These spaces are modified and maintained in a semi-natural state designed for people, but they also end up containing features very attractive to wildlife. Data were amended with additional sites seen in high resolution satellite imagery (ESRI 2018a) or known via local knowledge, such as campgrounds and dog parks, that were missing from the provincial coverage open data (Alberta Biodiversity Monitoring Institute 2018), and the final layer was created using the ‘raster’ package and ‘distance’ function. Permanent human structures (excluding roads and modified greenspaces) were digitized using high resolution satellite imagery (ESRI 2018a; A. Ford, unpublished data) to create a distance to human structure layer using the 'raster' package and 'distance' function. Finally, I created human recreational use and human population density layers, as these covariates impact bear habitat use and activity (Mace and Waller 1996, Woodroffe 2000, Mueller et al. 2004, Muhly et al. 2011) and are highly relevant in landscapes with high human use and settlements, such as the Bow Valley. Human population density was calculated from 2016 dissemination area census data (Statistics Canada 2018) using the 'sp', 'dplyr' (Wickham et al. 2019), and 'raster' packages. Density of human recreational use data was sourced from Strava, a social fitness network that collects cycling and running global positioning system data points from its users, which is then anonymized, packaged, and sold to interested governments for land use, transportation, and recreational planning (Strava LLC 2019). Strava data for 2014-2015 was provided to us by AEP, and I used the spatially-explicit estimates of human trail use from individual users to develop a layer of relative human use for pedestrians and cyclists (Strava LLC 2015). These data provided the widest coverage of actual human use data available for this study and included human use on trails and roads. As with the other density covariates, I calculated a range of scales (100, 500, 1000, 2000, 4000, 8000 metre radii) to address the varying scales at which large carnivores can perceive human features.

In addition to the landscape and anthropogenic predictors, I included year that the bear event occurred a potential explanatory covariate because of the impact that variation in food availability can have on bear distribution among years (Herrero (editor) 2005, Mitchell and Powell 2007, Bastille-Rousseau et al. 2011). I also included four potential interaction terms based on my understanding of bear ecology in the Bow Valley (Table 2).

Spatial covariate values at each camera trap station were extracted using the 'raster' and 'velox' (Hunzinker 2017) packages. Next, all extracted landscape and anthropogenic spatial predictors depicting raw data over varying ranges (e.g. elevation or distance to a feature) were transformed to improve model convergence. ‘Distance to’ variables were transformed with an exponential scale from 0 – 1 based on previous work on grizzly bear habitat selection (Nielsen 2007) using this general formula: Distance to feature = 1 – (exp(-1 × (distance in metres to edge of feature / 500))). All other variables were scaled to be centred on their mean value to improve interpretability of model outputs (Schielzeth 2010).

Table 2: Interaction terms considered for analysis of grizzly and black bear activity in the Bow Valley of Alberta, Canada, 2012-2017.

Candidate Interaction Terms	**Description**
Mean NDVI x Variation in NDVI	Bears may be more active in areas that have highly variable NDVI but highly productive, such as meadows or deciduous forests that experience spring ‘green-up’. Coniferous forests have high NDVI, but low variance. Rocks and bare ground have low NDVI and low variance.
Corridor width x Corridor length	Corridor dimensions may have a positive effect on bear activity. Corridor width/length captures the approximate dimensions of the habitat patch.
Corridor width x Distance to secondary road	Corridor width is defined by both natural and human barriers. This tests if proximity to a human barrier (roads) affects the impact of corridor width.
Corridor width x Distance to trails	Trails in narrower corridors could have a greater impact on bear activity than trails in a wider corridor.
Distance to secondary road x Distance to all trails	Trails closer to roads are more likely to have higher human traffic and could have a greater impact on bear activity than more remote trails.

2.1.3.3 Spatially-Explicit Activity Model Selection

To account for the biased camera trap sampling design, I built activity models as a type of resource selection function that provided a relative measure of bear activity within the study area rather than habitat selection or bear density. Since I was interested in bear activity and how that relates to the likelihood of bears interacting with people, I did not need to know bear abundance, but rather where any bears were active. I modelled bear activity using a zero-inflated negative binomial regression due to our dataset consisting of overdispersed count data (Zuur et al. 2010, Hilbe 2011). I used dispersion factors (Zuur et al. 2009) to test that zero-inflated count models were necessary. I used the 'pscl' package (Jackman 2017) and 'zeroinfl' function to fit each model for each bear SEAM.

To determine which spatial scale of each density covariate (i.e. forest cover density, open habitat density, trail density, and human use density at 100, 500, 1000, 2000, 4000, and 8000 metre radii) was the best predictor for each bear species and season, I compared univariate single predictor models in which bear activity was modeled as a function of each density covariate across radii. I then ranked the models using an information theoretic approach based on Akaike's information criterion (hereafter AIC) to identify the most parsimonious model that best fit the data (Burnham and Anderson 2002). I included the density radius with the lowest AIC for each species and season in the full model (Lewis et al. 2011, 2015b).

To address the problem of collinearity between continuous predictor variables, I calculated a correlation matrix using Pearson's correlation coefficient, 'r' (Zuur et al. 2010). For pairs with $r \geq 0.7$, I either used logic or AIC to determine which member of the pair was dropped. For example, human structures and secondary roads were highly collinear across all models ($r > 0.9$), so I removed human structures from the full model as roads were a better representation of human disturbance in the Bow Valley upon visual inspection. Alternatively, trail density and human use density were highly correlated in the grizzly SEAM, so I ran single predictor regressions with each covariate and ranked them using AIC, dropping the covariate with ΔAIC > 2. If both models were within ΔAIC < 2, I kept both covariates as candidates but ensured neither were included in the same model moving forward (Sheskin 2011, Hiller et al. 2015).

Next, I ran single predictor regressions of all remaining covariates following the prior steps to identify final candidate variables with $P < 0.25$ (Hosmer and Lemeshow 2000, Merkle et al. 2011b). This same method was applied to each interaction term in turn (i.e., 'single' interactions run within a univariate multiple regression consisting of 3 terms: both terms individually as well as multiplied together) using the same cut-off of $P < 0.25$. Final candidate variables ($P < 0.25$) were combined into multiple regressions, and the final model for each bear/season was developed by examining changes to beta coefficients and standard error overlap (Hosmer and Lemeshow 2000, Arnold 2010). This procedure resulted in four SEAMs: black bear pre-berry, black bear berry, black bear post-berry, and grizzly bear 3-season.

2.1.3.4 Projecting the Spatially-Explicit Activity Models Over Space

To create raster layer outputs from final SEAMs for each season/bear, I first scaled the raw input rasters for each final model to account for the extent of data covered by the camera traps, rather than the entire raster layer coverage. ‘Distance to’ rasters were decayed using the same equation as outlined in section 2.1.3.2 and density rasters were scaled using the same mean and standard deviation as the model covariates dataspace, i.e. the same measure of centre and spread as extracted camera trap locations. In addition to the first order term, a quadratic term for elevation was included as a candidate variable in the mapping stage (Ciarniello et al. 2005, Güthlin et al. 2011). Where AIC was improved (ΔAIC > 2) or unchanged, the quadratic term for elevation was included in the final SEAM projection; otherwise it was dropped. This quadratic term addressed the lack of cameras in high elevation areas of the Bow Valley and helped to account for higher activity levels at mid-elevation, i.e. between dense urban and road disturbance in the valley bottom and rugged high-elevation peaks.

The SEAMs were represented as raster layers using the ‘base’ (R Core Team 2019), ‘raster’, and ‘mapview’ (Appelhans et al. 2019) packages by projecting the modified RSF according to relevant coefficients and variables in each top model. I included a high human population density mask after applying the model coefficients to the landscape. High human population density was defined as where human population density was greater than median dissemination area density within the study region. This mask accounted for the lack of cameras in the highest population density polygons and I believe it increased model projection accuracy where the beta coefficient for human population density in the final SEAM was positive. I cropped the projected SEAMs to the study area boundaries, removed the 99th and 1st quantiles to account for any extreme activity estimates, and rescaled the resulting output between 0 and 1. Values of the scaled SEAM indicate the relative probability of activity, which may not be the same as the actual probability of activity.

I created maps of the SEAM layers using ArcGIS software and mapping functions (ESRI 2018b) to visualize the data and identify features of interest.

2.1.4 Human-Bear Interaction Models

2.1.4.1 Human-Bear Interaction Data

To create the predictive model of HBI in the Bow Valley, I used HBI records collected by AEP and Kananaskis Emergency Services from 2016 to 2017. More than 30 years of human-wildlife interactions records exist but these data have been collected by range of personnel under many different management scenarios (Alberta Environment and Parks, 2016b; J. Honeyman, *personal communication*). For this reason, the standardization and classification of the interaction dataset took considerable effort to create 2 years of data, or roughly 1250 records.

I classified HBI records in the Bow Valley study area from two main sources:

1) Kananaskis Emergency Services, a phone-in reporting service operated by the Kananaskis Improvement District where members of the public are encouraged to report large carnivore sightings or any problem wildlife (Kananaskis Improvement District 2020). Reports are entered in the database regardless of the species, type of interaction, or caller. Report information in the database includes a qualitative HBI location, species, human reaction, a summary in the caller’s words, and a summary in the dispatcher’s words.

2) The AEP enforcement database. HBI reports in this database include calls from public, local management agencies, or businesses, and are most often restricted to HBI where an officer needed to respond either in person or on the phone. Report information in the database includes HBI location, dispatcher notes, and type of interaction. Other optional fields filled out by the dispatcher or by the attending fish and wildlife officer can include attractant, human activity during HBI, human reaction to HBI, bear reaction to HBI, or officer actions and notes.

Anonymized HBI records from both the enforcement database and Kananaskis Emergency Services (Alberta Environment and Parks n.d.) were combined into a single database. I filtered out all records that were solely management actions or occurred outside of the study area boundary. Information from duplicate records was combined into a new single entry. I recorded the UTM location for each HBI using report details, high resolution satellite imagery (ESRI 2018a), and local knowledge. Locations were classified as 'exact', 'within 500 m', 'greater than 500 m', or 'unknown' to account for the varying detail provided in the HBI records. I searched to exact location details for a maximum of 5 minutes per record to manage time and address bias in effort spent classifying different record types. I recorded whether I hit the maximum search time for each record to make note of the reports whose details were particularly difficult to discern. In addition to location and HBI type, I also recorded the exact time and date of the HBI, bear season HBI occurred in, species involved, primary attractant, human activity during HBI, human reaction to HBI, bear reaction to HBI, whether cubs were present, if the bear was injured or killed as a result of the HBI, and whether a domestic dog was present. See Appendix A for the data dictionary and definitions of all included fields.

Finally, I classified all records as either sighting or incident based on the framework set out by Hopkins III et al. (2010). Specifically, HBI were classified as incidents anytime when: 1) a human attractant was present (such as railway grain, ornamental fruit trees, or garbage but excluding grass or dandelions), 2) a person took extreme evasive action (such as yelling, running away, or discharging bear spray), 3) a bear charged, whether contact was made with the person or not, or 4) a bear damaged property or entered a human structure (including a deck, porch, or window). I also used comments in the reports to include difficult to categorize records as incidents, such as a person trapped in a tent with a bear outside or a senior unable to enter her residence due to a bear in the driveway. All remaining records were classified as sightings, including records where the bear was recorded as unaware. By distinguishing between HBI types, it allowed me to analyze situations where bears were present (and this is always possible in a landscape shared with large carnivores), but no incident occurred.

2.1.4.2 Variable Selection for Human-Bear Interaction Models

The literature on HBI and how to predict their outcomes suggest that there are many factors which contribute to the occurrence of HBI on the landscape. HBIs in North America are most common where human access or development overlaps with high quality forest or riparian habitat (Nielsen et al. 2004b, Wilson et al. 2006, Merkle et al. 2011b, Northrup et al. 2012). Other features commonly associated with increased risk or occurrence of HBIs are: decreased distance to roads and increased road densities (Benn and Herrero 2002, Suring and Frate 2002, Schwartz et al. 2010b, McFadden-Hiller et al. 2016), rural or intermediate housing densities (Suring and Frate 2002, Schwartz et al. 2010b, Merkle et al. 2011b), both anthropogenic and natural attractants, such as livestock and garbage or native berry crops (Benn and Herrero 2002, Wilson et al. 2006, Baruch-Mordo et al. 2008, McFadden-Hiller et al. 2016, Miller et al. 2016a, Lamb et al. 2017), and loss of habitat connectivity (Evans et al. 2014, McFadden-Hiller et al. 2016). While the impact of some variables varies between studies, the convergence of high-quality habitat or a valuable attractant and human development or access generally cause an increase in the likelihood of an HBI occurring.

Based on this literature and my hypotheses, I selected a suite of variables that may predict HBI and are directly related to bear activity or habitat, human development, and corridors (Table 3). All data were analyzed using R software (R Core Team 2018). All final spatial covariates within the GIS were continuous, in raster format, and snapped to a 30 × 30 metre template raster to ensure accurate calculations when applying model outputs. Creation of all layers in Table 3 was identical to those in section 2.1.3.2.

Table 3: Independent covariates considered for analysis of human-bear interaction occurrence in the Bow Valley of Alberta, Canada, 2016-2017.

Covariate Name	**Description**
Bear activity/habitat	
Spatially-explicit bear activity models	A relative measure of bear activity based on camera trap data in the Bow Valley from 2012-2017; partitioned into black bear pre-berry, berry, and post-berry seasons, as well as grizzly 3-season
NDVI	Normalized Difference Vegetation Index, an index of primary productivity; partitioned into mean and standard deviation
Corridors	
Corridor width	Maximum width of bear navigable habitat at each pixel; corridor edge = any slope > 30°, Trans-Canada Highway, and human structures
Corridor length	Maximum length of bear navigable habitat at each pixel; corridor edge = any slope > 30°, Trans-Canada Highway, and human structures
Human disturbance	
Distance to modified greenspace	Distance to modified greenspace polygons (i.e., campgrounds, dog parks, urban parks, golf courses)
Distance to human structures	Distance to pixels containing human structures as visible from satellite imagery (excluding roads and modified greenspace)
Population density	Human population density per 2016 census polygon
Distance to TCH	Distance to Trans-Canada Highway (TCH)
Distance to secondary roads	Distance to all secondary roads (i.e. excluding TCH)
Distance to trail	Distance to recreational trails; partitioned into three potential categories: official trails, unofficial trails, and all trails combined
Trail density	Density of all recreational trails
Human use	Relative measure of levels of non-motorized human use on roads and trails

I also included four potential interaction terms based on my understanding of bear ecology in the Bow Valley (Table 4); these interactions were the same as those included in the SEAMs.

Covariate values at each HBI location were extracted using the ‘raster’ and ‘velox’ packages. Next, all extracted spatial predictor values depicting raw data over varying ranges (e.g. NDVI or distance to a feature) were transformed to improve model convergence. ‘Distance to’ variables were transformed with an exponential scale from 0 – 1 based on previous work on grizzly bear habitat selection (Nielsen 2007) using this general formula: distance to feature = 1 – (exp(-1 × (distance in metres to edge of feature / 500))). All other variables were scaled to be centred on their mean value to improve interpretability of model outputs (Schielzeth 2010).

Table 4: Interaction terms considered for analysis of human-bear interaction occurrence in the Bow Valley of Alberta, Canada, 2016-2017.

Candidate Interaction Terms	**Description**
Mean NDVI x Variation in NDVI	The probability of human-bear interactions (HBI) may be higher in areas that have highly variable NDVI but highly productive, such as meadows or deciduous forests that experience spring ‘green-up’. Coniferous forests have high NDVI, but low variance. Rocks and bare ground have low NDVI and low variance.
Corridor width x Corridor length	Corridor dimensions may influence the occurrence of HBIs. Corridor width/length captures the approximate dimensions of the habitat patch.
Corridor width x Distance to secondary road	Corridor width is defined by both natural and human barriers. This tests if proximity to a human barrier (roads) affects the impact of corridor width on the occurrence of HBIs.
Corridor width x Distance to trails	Trails in narrower corridors could have a greater impact on the occurrence of HBIs than trails in a wider corridor.
Distance to secondary road x Distance to all trails	Trails closer to roads are more likely to have higher human traffic and could have a greater impact on the occurrence of HBI than more remote trails.

2.1.4.3 Human-Bear Interaction Occurrence and Human-Bear Interaction Outcome Models

I ran two sets of models to determine which covariates contribute to HBI and their outcomes: 1) HBI Occurrence; 2) HBI Outcome. Each of these model types were partitioned into black bear (pre-berry, berry, and post-berry seasons) and grizzly bear (3-season, i.e., April 15-Oct 31) models. I excluded all HBI records where uncertainty of the location (Appendix A) was greater than 500 metres. As before, grizzly bear HBI were analyzed across the whole bear year as the incident sample sizes were too small to analyze HBI by season. I also excluded from the models instances where bears were hit by cars because these represent a different type of HBI to those where a person is on foot or sighting a bear from a vehicle at lower speeds (Evans et al. 2014, Miller et al. 2016a, Morehouse and Boyce 2017).

I used the same process as outlined in the SEAM methods to determine which spatial scale of each density covariate was the best predictor for each model (section 2.1.3.2). I also addressed collinearity between continuous predictor variables as outlined in the SEAM methods (section 2.1.3.2) using a cut-off of $r \geq 0.7$. I either used logic or AIC to determine which member of any correlated pair of variables would move forward as a candidate variable.

Human-Bear Interaction Occurrence

The HBI Occurrence analysis assessed the spatial and temporal distribution of sightings and incidents separately, by bear species and season. Following a use-availability design (Manly et al. 2002), where an interaction location was ‘use’ and random points were ‘available’, HBI Occurrence was modelled using generalized linear models (hereafter GLM). To estimate availability for the HBI Occurrence models, I selected a set of random locations within the study area (Figure 1) with a 1:5 ratio to the number of HBI locations for each bear species and season (Merkle et al. 2011b). I determined the values of candidate variables at available locations using the same methods as those for use locations. I assigned a response value of 1 for HBI locations and 0 for each available location. I used the ‘stats’ package (R Core Team 2019) and ‘glm’ function to run these models.

Human-Bear Interaction Outcomes

The HBI Outcome models used latent selection difference functions within a GLM to contrast covariates associated with sites where incidents occurred to sites where sightings occurred (Erickson et al. 2014). Latent selection difference allowed for direct comparison of the distribution of incidents and sightings (Latham et al. 2011), potentially highlighting variables that significantly affected the likelihood of an HBI outcome as either sighting or incident given an HBI occurs. A response value of 1 was assigned for each incident record and 0 for each sighting record. Models were partitioned into season and species, and I used the ‘stats’ package and ‘glm’ function to run the models. Within these model outputs, a positive beta coefficient for a covariate denotes that given an HBI occurs, there is an increased probability of an incident outcome relative to a sighting as the covariate values increase.

2.1.4.4 Human-Bear Interaction Model Selection and Validation

For both HBI Occurrence and Outcome analyses, I compared all combinations of final candidate variables and interactions based on AIC using the ‘MuMIn’ package and ‘dredge’ function (Bartoń 2019). I limited the number of predictor variables in final HBI Occurrence models and HBI Outcome models according to the limited number of conflicts in the sample to prevent overfitting (Vittinghoff and McCulloch 2007). I chose the top ranked model (lowest AIC score) to move forward for validation and prediction and reported all models within ΔAIC < 2 (Appendix B).

I estimated final HBI Occurrence models and HBI Outcome models using the top ranked models from the previous step. I evaluated each model’s predictive ability using *k*-fold cross validation, partitioning HBI data into model training (80%) and model testing (20%) datasets, based on 5 random divisions (k = 5) (Boyce et al. 2002). I then calculated mean and standard deviation spearman rank coefficients for both observed and available locations. I expected standard deviation of spearman rank coefficients for available locations to overlap with 0, indicating the available points have no predictive power, and I expected standard deviation of spearman rank coefficients for observed locations to not overlap with 0. R code for the above validation calculations was provided by J. Merkle (*personal communication).*

To plot marginal effects of significant statistical interaction terms for final HBI Occurrence models, I used the 'sjPlot' package and 'plot_model' function (Lüdecke 2019). I used predicted values and quartiles of the moderator value to plot the terms. Reported R^2 values are McFadden's pseudo-R^2 (McFadden 1974).

2.1.4.5 Projecting the Human-Bear Interaction Occurrence Models Over Space

I created raster layer outputs from final HBI Occurrence models only. This was due to the low *k*-fold cross validation values of HBI Outcome models in general (see Results).

For HBI Occurrence models, I first scaled the raw input rasters for each final model to account for the extent of data covered by the HBI, rather than the entire raster layer coverage. 'Distance to' rasters were decayed using the same equation as outlined in section 2.1.3.2 and density rasters were scaled using the same mean and standard deviation as the model covariates dataspace, i.e. the same measure of centre and spread as extracted HBI locations. The final SEAMs were represented as raster layers using the 'base', 'raster', and 'mapview' packages by projecting the modified RSF according to relevant coefficients and variables in the top-ranked models. I cropped the projected models to the study area boundaries, removed the 99th and 1st quantiles to account for any extreme HBI Occurrence estimates, and rescaled the entire resulting output between 0 and 1. This rescaling of predicted occurrence of interactions is important to note as a rating close to zero denotes only a relative low probability of a sighting or incident occurring within the constraints of this study but does not necessarily represent a true low probability of an HBI.

I created maps of the HBI Occurrence layers using ArcGIS software and mapping functions (ESRI 2018b) to visualize the data and identify features of interest.

2.1.4.6 Spatial Correlation of Incident and Sighting Model Outputs

To test Question 2, Hypothesis 2 (i.e., that sightings and incidents co-occur), I compared the projected HBI Occurrence layers for sightings and incidents. I extracted predicted sighting and incident values for each species and season at random points distributed across the study area (≥ 200 metres apart). I then performed a non-parametric Spearman rank correlation test between each set of sighting and incident values for black bears in the pre-berry, berry, and post-berry seasons, as well as grizzly bears 3-season model. Spearman rank correlation values closer to 1 indicate that sightings and incidents are highly correlated in space and do co-occur, whereas values closer to 0 indicate that sightings and incidents are not spatially correlated in the study area and do not co-occur.

2.2 Results

In this results section, I will first describe the camera trap data and the output from spatially-explicit bear activity models. Next, I will describe trends evident from the HBI data including differences between black bears and grizzly bears, presence of attractants, and human and bear reactions during HBIs. Next, I will describe the results of the HBI occurrence and outcome models, including where I found did or did not find support for my hypotheses. Finally, I will review the predictive success of HBI occurrence models and how HBI occurrence varied between the focal species.

2.2.1 Bear Activity Models

2.2.1.1 Camera Trap Data

Total sampling effort for the study period was 43123 trap days at 130 camera trap locations. I documented 310 black bear events and 45 grizzly bear events at 97 of the 130 camera trap sites.

2.2.1.2 Spatially-Explicit Activity Models

Across seasons, black bears were most active in low elevations and in long, narrow corridors (Table 5). During berry season, increasing distance from the Trans-Canada Highway was the strongest predictor of increasing black bear activity (Table 5). The berry season model also showed significant increases in bear activity near modified greenspaces, steeper slopes, and low human population density (Table 5). During post-berry season, black bear activity increased significantly with decreasing terrain ruggedness and increasing values of the grizzly bear resource selection function (Table 5).

Grizzly bears were most active far from modified greenspace and where variation in NDVI values was high (Table 5). Year was also a significant predictor of activity levels for grizzly bears (Table 5), indicating the influence that annual differences in food availability or human presence may have on grizzly bear activity.

When the SEAMs were projected across the landscape (Figure 3) areas of high grizzly bear activity appeared farther from high human population densities than black bear activity. Black bear activity in the pre-berry season was positively associated with water and long narrow corridors, resulting in increased relative activity projections near towns at the valley bottom (Figure 3A). During berry season, black bear activity was higher farther away from highways and near low elevation modified greenspaces and trails (Figure 3B). In the post-berry season, bears were more concentrated in their activity near town in the valley bottom (Figure 3C). Grizzly bear activity was predicted to occur away from areas of high human population density and away from areas with the predicted highest black bear activity (Figure 3D).

Table 5: Parameter estimates for top zero-inflated negative binomial regression models based on camera trap images of black bears and grizzly bears collected between 2012 and 2017 in Alberta's Bow Valley, Canada. Relative activity was estimated as function of anthropogenic and environmental covariates. *Note:* NDVI, Normalized Difference Vegetation Index.

	Predictor	Estimate	Std. Error	p-value	
Black bear					
Pre-berry	Elevation	-0.45	0.14	<0.01	**
	Forest density	0.14	0.14	0.31	
	Distance to water	0.51	0.44	0.25	
	Terrain ruggedness	-0.21	0.15	0.16	
	Aspect (west)	0.1	0.1	0.35	
	Corridor width	-0.39	0.16	0.02	*
	Corridor length	0.54	0.26	0.04	*
	Mean NDVI	0.15	0.15	0.32	
	Variation in NDVI	-0.23	0.18	0.21	
	Elevation squared	-0.07	0.1	0.45	
	Corridor width x Corridor length	0.24	0.15	0.11	
	Variation in NDVI x Mean NDVI	-0.11	0.09	0.23	
Berry	Distance to modified greenspace	-0.78	0.28	<0.01	**
	Forest density	0.16	0.1	0.1	
	Slope	0.53	0.13	<0.001	***
	Distance to all trails	-0.75	0.52	0.15	
	Human population density	-0.21	0.09	0.02	*
	Distance to Trans-Canada Highway	1.9	0.9	0.03	*
	Mean NDVI	0.18	0.12	0.11	
	Elevation	-0.59	0.18	<0.01	**
	Elevation squared	-0.03	0.12	0.77	
Post-berry	Elevation	-0.05	0.14	0.71	
	Distance to modified greenspace	-0.63	0.37	0.09	
	Terrain ruggedness	-0.59	0.18	<0.01	**
	Nielsen RSF	0.14	0.05	<0.01	**
	Corridor width	-0.26	0.14	0.07	
	Corridor length	0.6	0.22	<0.01	**
	Elevation squared	-0.27	0.12	0.03	*
	Corridor width x Corridor length	0.34	0.14	0.01	*
Grizzly bear					
3-season	Variation in NDVI	-0.95	0.31	<0.01	**
	Distance to modified greenspace	2.06	0.78	<0.01	**
	Shrub/grass cover	-1.27	0.39	<0.01	**
	Year (2016)	0.27	0.56	0.62	
	Year (2017)	1.27	0.47	<0.01	**
	Elevation	-0.06	0.27	0.82	
	Elevation squared	-0.52	0.31	0.1	

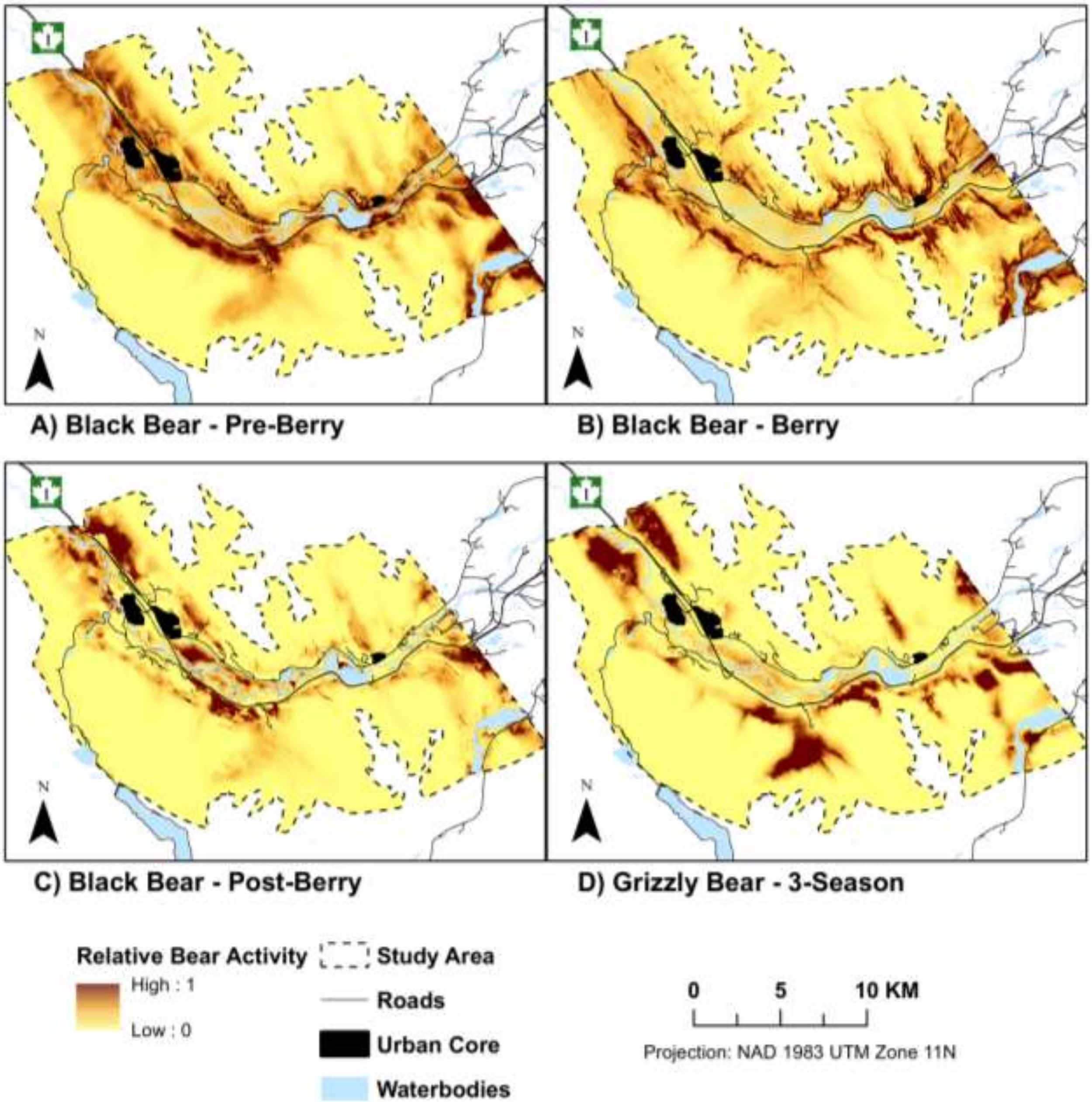

Figure 3: Projection of spatially-explicit activity models for black bears and grizzly bears based on camera trap images of black bears and grizzly bears collected between 2012 and 2017 in Alberta's Bow Valley, Canada.

2.2.2 Human-Bear Interaction Models

2.2.2.1 Interaction Data

There were a total of 1241 HBIs reported in 2016 and 2017 within the study area (April 15 – October 31), including 145 incidents and 1096 sightings. Most interactions occurred with black bears (75%), followed by grizzly (20%), and 5% occurred with an unknown bear species. For both bear species, interactions were reported most often during the berry season, followed by the pre-berry season, and the post-berry season (36, 20, and 17 reports per week, respectively), and this pattern held for both sightings and incidents. The ratio of incidents to sightings was highest in the post-berry season, and lowest in the pre-berry season. There was an average of 1 incident for every 8 sightings.

Factors associated with the incidents and sightings varied and many times were unreported. There was no attractant for 69% of sightings and for 57% of incidents. Natural vegetation or berries were noted as the attractant in 25% of sightings and 14% of incidents, and anthropogenic attractants were reported for 19% of incidents (Figure 4). The human activity during all HBIs was largely unreported (80%), but the top known activities were driving (6%), biking (5%), and walking (4%); this pattern was similar for both incidents and sightings. The actions that people took in response to HBIs was also mostly unknown (86%), but this pattern is notably different between sightings and incident reports, with only 35% of human actions unknown for incidents but 92% unknown for sightings. The most common reported human action during a sighting was to slowly increase distance from the bear (6%), whereas during an incident, it was to discharge noise (50%) or run away (7%). Bear reactions during HBIs were well known for both sightings and incidents (79% and 85%, respectively). The most common bear reaction during interactions was to remain indifferent or retreat walk (37% and 16%, respectively). Bears closed distance during 1% of incidents, 8% included a bluff charge, and there were 3 instances (2%) of a charge where contact with the person was made (Table 6).

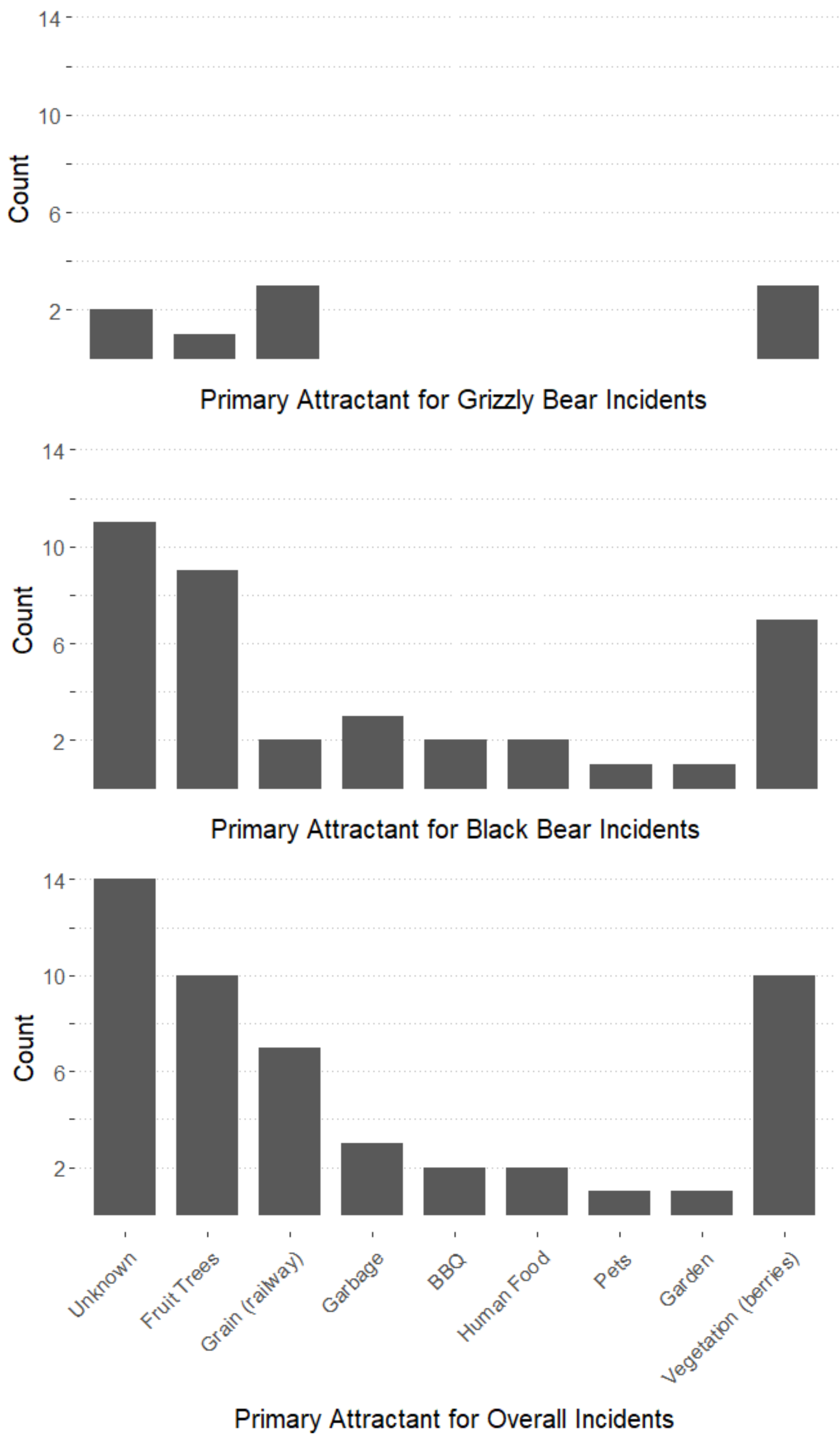

Figure 4: Human-bear incident summaries by attractant category for grizzly bears (n = 9), black bears (n = 38), and all bears (n = 50) in the Bow Valley of Alberta, Canada from 2016-2017.

Table 6: Summary table of reasons that human-bear interactions (HBI) with grizzly bears (n = 29) and black bears (n = 105) were classified as 'incidents' versus 'sightings'. The percentage column represents where a category triggered incident classification; this column does not add to 100% as there was often more than one reason an HBI was classified as an incident (e.g. bear charges AND person deploys bear spray). An HBI data entry was classified as an incident if: a) there was an anthropogenic attractant consumed/investigated by the bear, b) a human took extreme evasive action; c) a bear charged or made contact with the person; d) a bear was injured or killed as a result of the HBI; or e) comments indicated an incident occurred (e.g. person was trapped in tent, terrified, and called for assistance) (as per Hopkins III et al. 2010).

	n	%	Incident Classification Category	Notes
Black bear	20	19	Anthropogenic attractant	Where ornamental fruit trees were the attractant (n=9), no other column (see Appendix A) indicated an incident occurred.
	77	73	Human extreme evasive action	Mostly discharge noise (55% of all black bear incidents).
	5	5	Aggressive bear action	No bear spray was deployed for any charges; there were no charge-contacts in data.
	9	9	Bear injury/mortality	Where an injury/mortality occurred, no other column indicated an incident occurred.
	11	10	Other	
Grizzly bear	4	14	Anthropogenic attractant	Where ornamental fruit trees were the attractant (n=1), other columns did not indicate an incident occurred.
	17	59	Human extreme evasive action	Mostly discharge noise (34% of all grizzly bear incidents).
	9	31	Aggressive bear action	Out of 9 charges during HBI, only 1 person deployed bear spray.
	3	10	Bear injury/mortality	Where an injury/mortality occurred, no other column indicated an incident occurred.
	2	7	Other	

The proportion of extreme evasive action taken by people and the reaction by bears during HBI's differed between species. While the proportion of people who took any kind of extreme evasive action (such as running away or deploying bear spray) did not differ between black bears and grizzly bears (χ^2 = 2.3; df = 1; P = 0.062), people reacted by yelling or making noise during a greater proportion of HBIs with black bears than with grizzly bears (χ^2 = 3.1; df = 1; P = 0.038). As well, grizzly bears reacted aggressively in a significantly greater proportion of HBIs than black bears (χ^2 = 14.1; df = 1; P < 0.001; Table 6). The proportion of incidents with attractants present and the proportion of bear injuries or mortalities were not significantly different between the two species (Table 6).

2.2.2.2 Distribution of Human-Bear Interactions

My hypothesis that people drive the distribution of HBIs was supported. In general, HBIs increased with increasing presence of infrastructure (trail density, secondary roads/Trans-Canada Highway, trails, and modified greenspace; Figure 5, Figure 6; see Appendix C for full summary tables). Distance to secondary roads was consistently one of the strongest significant predictors of HBI across seasons and species (Figure 5, Figure 6) with HBIs more likely to occur near roads. Distance to the Trans-Canada Highway was weakly and negatively associated with HBIs (Figure 5, Figure 6), indicating that like secondary roads, HBI are more likely near the highway, but an exception was found for the black bear pre-berry all HBI top model, where interactions were more likely far from the highway ($\beta = 0.97$, $SE = \pm 0.46$, $p = 0.04$). In contrast to human structures, human population density was a weak negative predictor of HBIs across seasons and species (Figure 5, Figure 6), and human use density was not a significant predictor of overall HBIs in any top model. Where human use density was included in top incident and sighting models, it was a weak positive predictor of interactions (Figure 5 [post-berry incidents]; Figure 6 [sightings]), but in the top model for grizzly bear sightings, this marginal effect was swamped by a significant statistical interaction with distance to secondary roads (Figure 7).

I found strong support for the hypothesis that bear activity drives HBI. Bear activity was a significant positive predictor of overall HBI in the black bear pre-berry and berry season top models (Figure 5). Bear activity was also a significant positive predictor of grizzly bear incidents (Figure 6), and black bear sightings in the pre-berry and berry seasons (Figure 5). Bear activity was not included in black-bear post-berry season top models (Figure 5).

I found partial support for my hypothesis that environment drives HBI. As predicted, increasing habitat quality (represented by mean and standard variation in NDVI values) was associated with increasing HBI (Figure 5, Figure 6; Appendix C; Appendix D). The effect of corridor dimensions on HBI was more difficult to discern. Corridor length was not a significant predictor of HBIs in any top model. Conversely, corridor width was generally a weak positive predictor of HBIs across seasons and bear species (Figure 5, Figure 6). For black bears, the marginal effect of corridor width was swamped by a statistical interaction with distance to secondary roads (Figure 5). The interaction between corridor width and distance to roads indicated that for black bears, HBIs were significantly more likely in narrow corridors when near roads, regardless of season, whereas far from roads, corridor width had no effect on the probability of an HBI occurring (Figure 5, see Appendix D for plots of all significant interaction term marginal effects). A statistical interaction between corridor width and trail density indicated differing effects on black and grizzly bears. At low to moderate trail densities, interactions with grizzly bears increased with increasing corridor width, but at high trail densities, corridor width had no effect on the likelihood of an HBI occurring (Appendix D, Figure D.12). For black bears, a significant statistical interaction between corridor width and trail density only occurred in the pre-berry sighting model. During this season, the probability of a sighting occurring was low in narrow corridors, regardless of trail density, but in wide corridors, sightings were significantly more likely at high trail densities (Appendix D, Figure D.2).

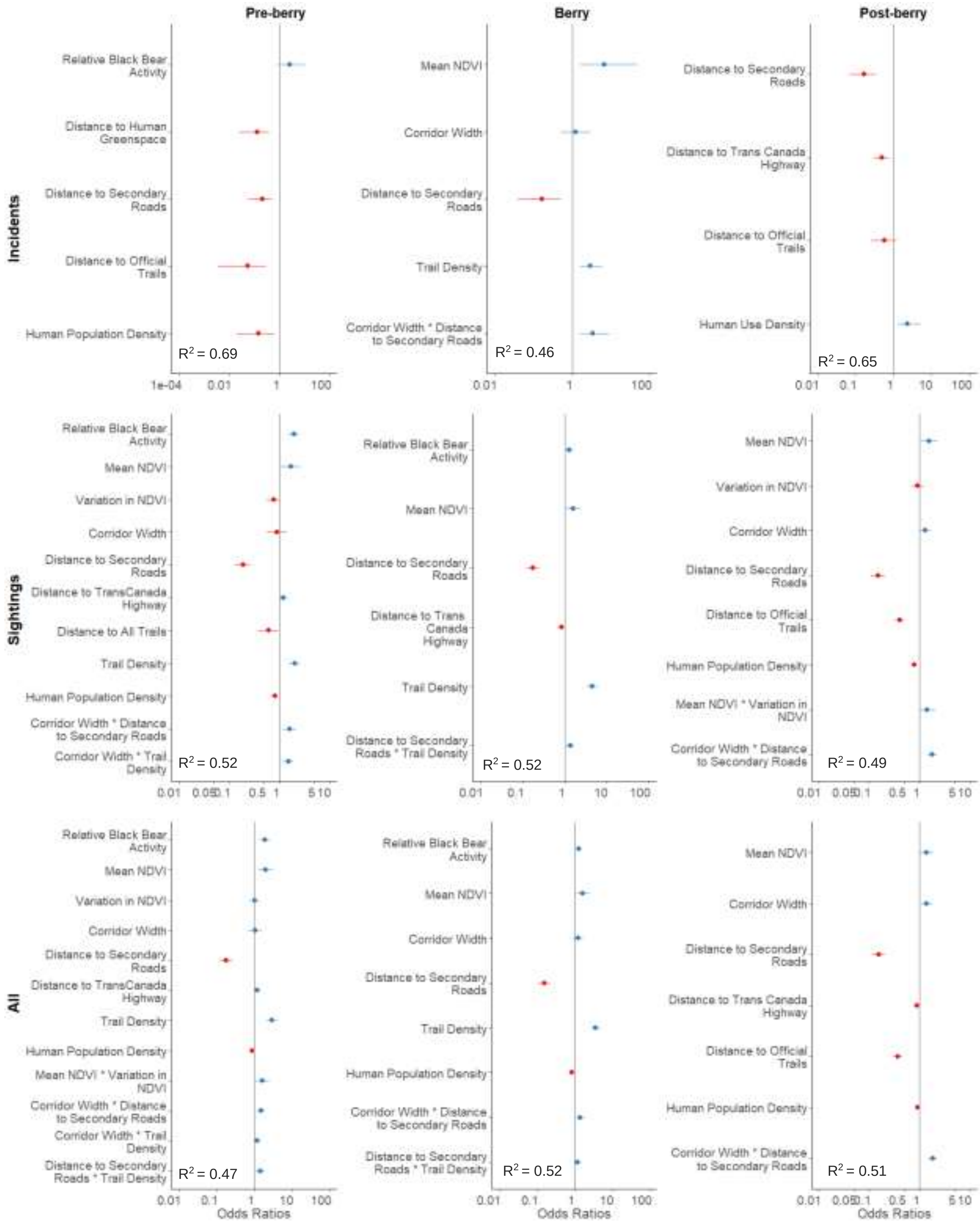

Figure 5: Forest plots for top-ranked generalized linear models explaining the spatial distribution of incident, sighting, and all HBI occurrence for black bears in Alberta's Bow Valley from 2016-2017. Odds ratios and 95% confidence intervals are shown for the top models (lowest AIC).

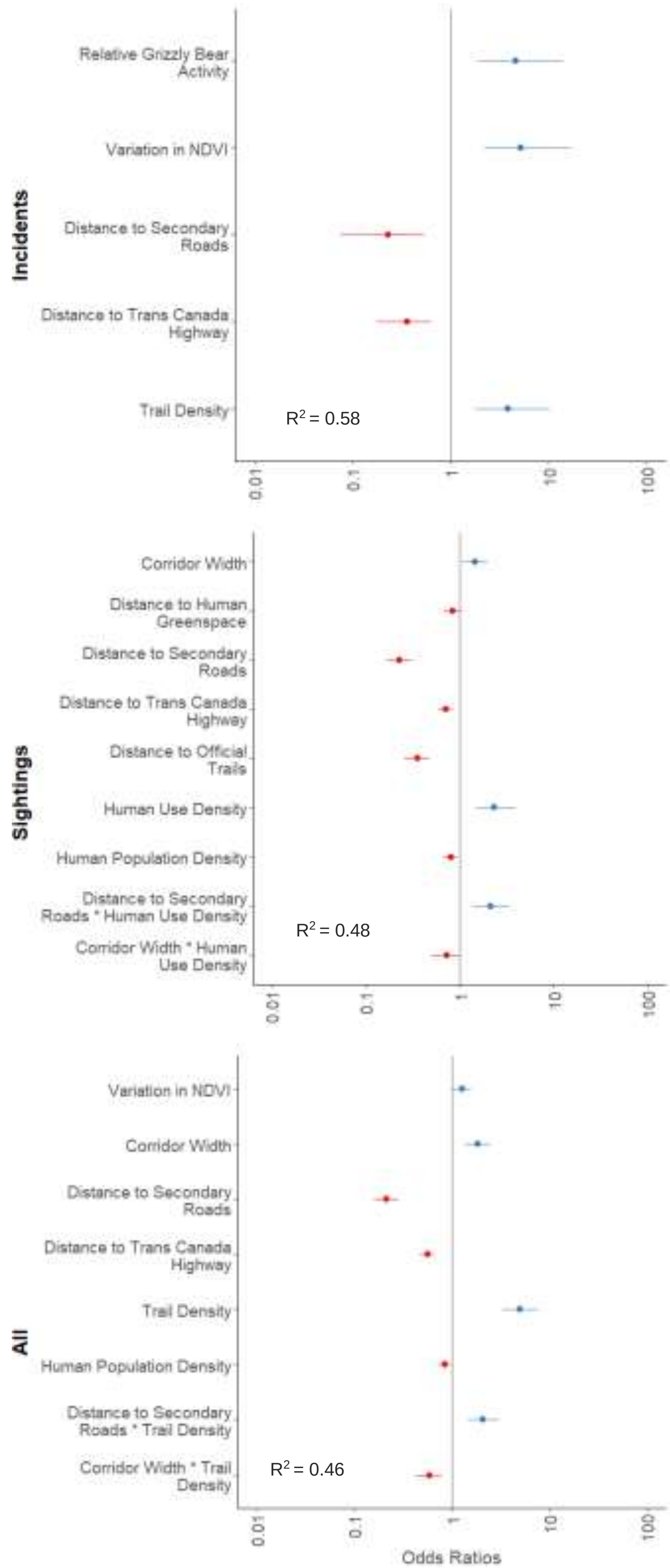

Figure 6: Forest plots for top-ranked generalized linear models explaining the spatial distribution of incident, sighting, and all HBI occurrence for grizzly bears in Alberta's Bow Valley from 2016-2017. Odds ratios and 95% confidence intervals are shown for the top models (lowest AIC).

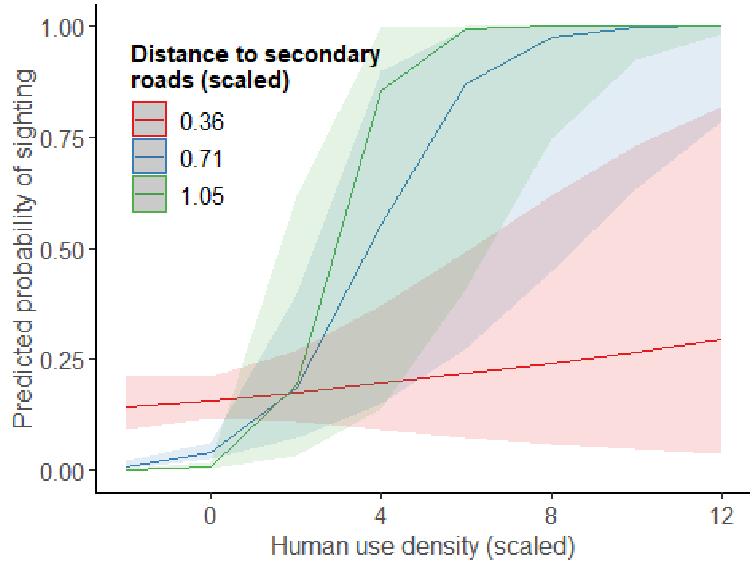

Figure 7: Marginal effects plot of the statistical interaction between human use density (100 m radius) and distance to secondary roads for top grizzly sighting occurrence model. Human-bear interaction data comes from Alberta's Bow Valley, 2016-2017. Shaded regions indicate 95% confidence intervals.

I did not find clear support for my hypothesis that an optimal mixture of people, bear activity, and environment drive the occurrence of HBIs. My prediction that HBIs would be most likely where human presence was moderate and bear activity/habitat quality was high was only partially supported. Rather than a peak in HBIs at moderate levels of human presence, the marginal effect of human use in top models and statistical interaction terms tended to asymptote (Figure 8), showing that above moderate levels of human use or trail density, the probability of HBIs became very high. I also found that decreasing human population density was associated with increasing HBIs (Figure 5, Figure 6). Rather than indicating peak HBIs at moderate levels of human use, these results indicate the type of human presence (i.e. recreational versus population density) is a better predictor of HBIs than moderate levels of human presence overall. I did find support for my prediction that increasing habitat quality (i.e., increasing NDVI values) and increasing bear activity was associated with increased HBIs for both black bears and grizzly bears (Figure 5, Figure 6).

Top models for all HBIs in both grizzly bears and black bears included a combination of anthropogenic and environmental predictors as well as significant statistical interactions between them (Figure 5, Figure 6), indicating that no one factor (e.g. people) drives overall HBIs. Top HBI Occurrence models had moderate to strong predictive capacities (Table 7). Incident models had the lowest *k*-fold cross-validation values for both black bears and grizzly bears (Table 7), potentially due to the limited sample sizes of incident HBIs.

2.2.2.3 Distribution of Sightings Versus Incidents

I found only partial support for the overarching hypothesis that the factors that predict incidents and sightings differ. Where covariates were included in the top models for both sightings and incident models, they were generally associated with the same trends in HBI distribution. Conversely, when models were projected across the landscape, I did find there were differences in model distributions across the study area, likely due to differences in the combination of covariates and their beta coefficients (Figure 5, Figure 6, Figures 9 - 12). The difference in distribution of projected models was particularly evident for grizzly bear incident occurrence versus sighting occurrence (Figure 13).

Incidents were best predicted by anthropogenic covariates, whereas sightings were more complex and consistently included a wider range of covariates than incident models (i.e. bear habitat and activity, corridor width, anthropogenic factors, and significant statistical interactions). When comparing incidents to sightings directly within the LSD analyses, I found few significant differences (Table 8). Top LSD models had low-moderate predictive ability (Table 9) and were particularly poor for black bear pre-berry and grizzly bear models. Finally, spatial correlation analysis between predictive models of incidents and sightings suggested that the distribution of incidents versus sightings were highly correlated in the Bow Valley for black bears (r_s: 0.85 [pre-berry], 0.71 [berry], 0.81 [post-berry]), but less so for grizzly bears (r_s: 0.55 [full year]). I will address my sub-hypotheses below.

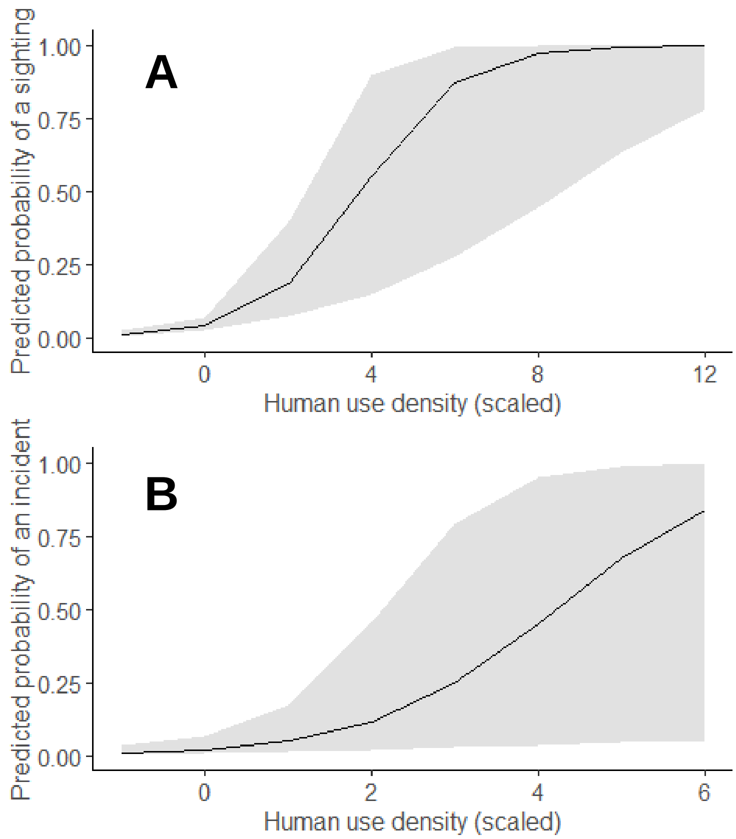

Figure 8: Marginal effects plot of A) human use density (100 metre radius) for top grizzly sighting occurrence model, and B) recreational trail density (1 km radius) for top black bear berry season sighting occurrence model. Human-bear interaction data comes from Alberta's Bow Valley, 2016-2017. Shaded region indicates 95% confidence interval.

I found partial support for Question 2, Hypothesis B (i.e., that moderate to low human presence increases incidents relative to sightings, or that sightings are more likely with increased human presence). The top LSD model for the black bear berry season indicated that a sighting was more likely than an incident close to secondary roads and trails. Statistical interactions between trail density and distance to secondary roads in the black bear berry HBI occurrence top model also indicated that sightings were more likely at high trail densities and high human use, particularly when nearer roads for black bears and further from roads for grizzly bears (Figure 7, Figure 13). The effect of increasing trail density on sightings intensified for black bears in the pre-berry season as corridors became wider (Appendix 4). Contrary to my

Table 7: k-fold cross validated Spearman rank correlations (r_s) between human-bear interaction (HBI) occurrence bin ranks and observed data for top black and grizzly bear HBI occurrence models. Average (*M*) and standard deviation (*SD*) of r_s values come from 100 repetitions of the correlation calculation. HBI data comes from the Bow Valley in Alberta, Canada, 2016-2017.

		Incident type	**Observed**		**Available**	
			M	*SD*	*M*	*SD*
Black bear						
	Pre-berry	Incident	0.55	0.069	0.00	0.323
		Sighting	0.79	0.066	-0.08	0.329
		All	0.84	0.054	-0.03	0.336
	Berry	Incident	0.59	0.137	0.02	0.349
		Sighting	0.83	0.058	-0.08	0.360
		All	0.82	0.082	0.06	0.309
	Post-berry	Incident	0.60	0.090	-0.01	0.338
		Sighting	0.80	0.074	0.02	0.363
		All	0.79	0.077	0.03	0.379
Grizzly bear						
	Full year	Incident	0.58	0.086	0.07	0.339
		Sighting	0.80	0.074	-0.03	0.314
		All	0.81	0.069	-0.04	0.324

predictions, increasing human presence, such as modified greenspace, secondary roads, and recreational trails, were associated with high probability of an incident occurring (Figure 5, Figure 6). Anthropogenic covariates were the most influential predictors of incidents in the HBI occurrence models, but these same covariates were also included in top sighting models with similar coefficients. One exception is in the black bear post-berry season, where human use density was a significant positive predictor of the occurrence of incidents (Figure 5, Appendix C).

Table 8: Parameter estimates for top latent-selection difference (LSD) models based on human-bear interaction (HBI) records from 2016 to 2017 in Alberta's Bow Valley, Canada. The LSD function is the relative probability of an incident outcome versus a sighting outcome given an HBI occurred. HBI outcomes were estimated as function of bear activity, human presence, and environmental covariates.

	Predictor	Estimate	Std. Error	p-value	
Black bear					
Pre-Berry	Human use density	-0.66	0.51	0.19	
Berry	Distance to secondary roads	1.91	0.73	<0.01	**
	Distance to official trails	2.43	0.84	<0.01	**
Post-Berry	Variation in NDVI	0.40	0.16	0.01	*
	Corridor length	-0.50	0.24	0.04	*
	Human population density	0.17	0.11	0.11	
Grizzly bear					
3-Season	Variation in NDVI	0.34	0.15	0.02	*

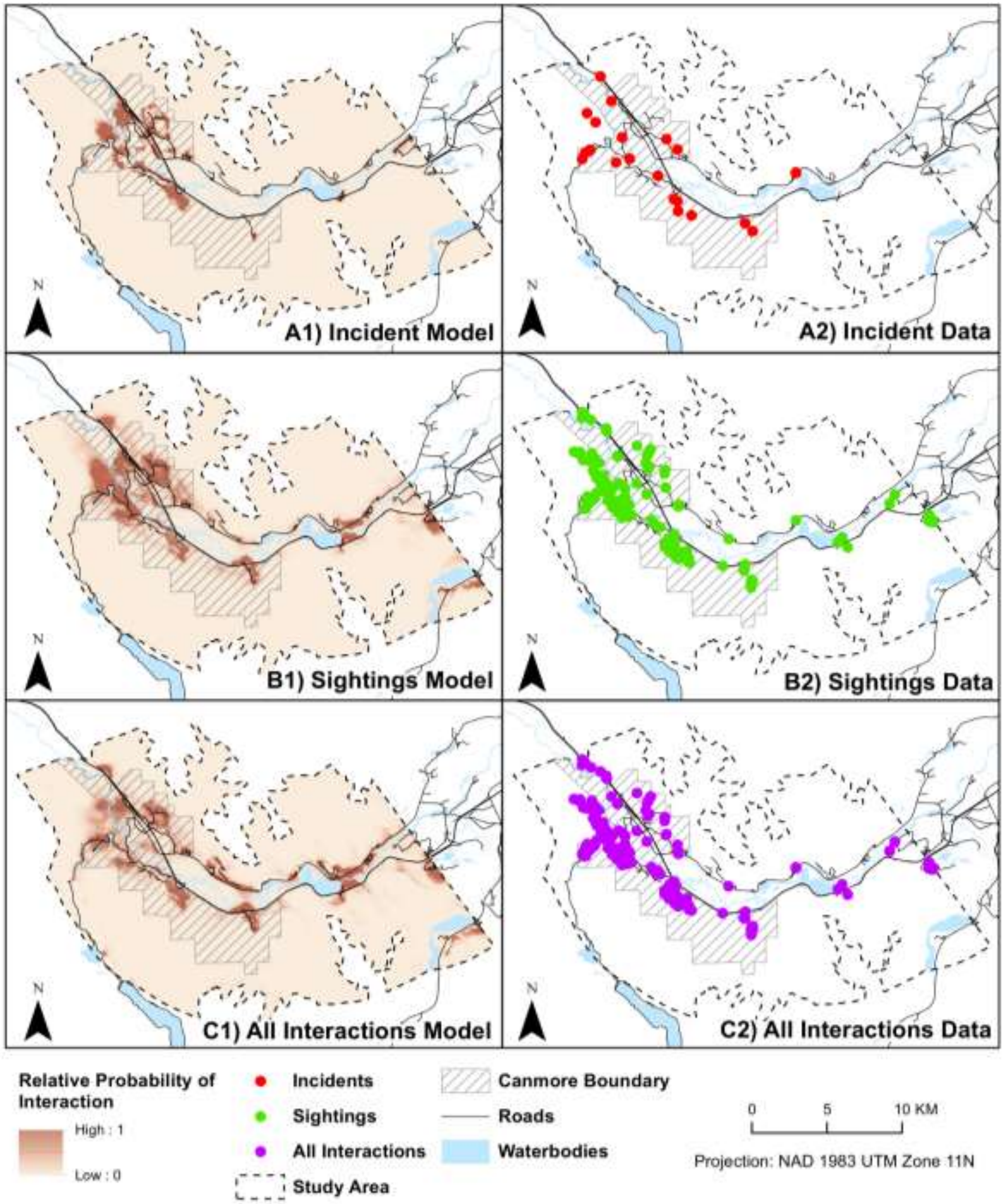

Figure 9: Distribution of predicted pre-berry season human-black bear interaction probabilities for A1) incident interactions only, B1) sighting interactions only, and C1) sightings and incidents combined, along with the distribution of actual HBI locations for A2) incidents, B2) sightings, and C2) sightings and incidents combined. Projected probabilities were based on top logistic regression models of human-black bear interaction occurrence from 2016-2017 pre-berry seasons in the Bow Valley of Alberta, Canada.

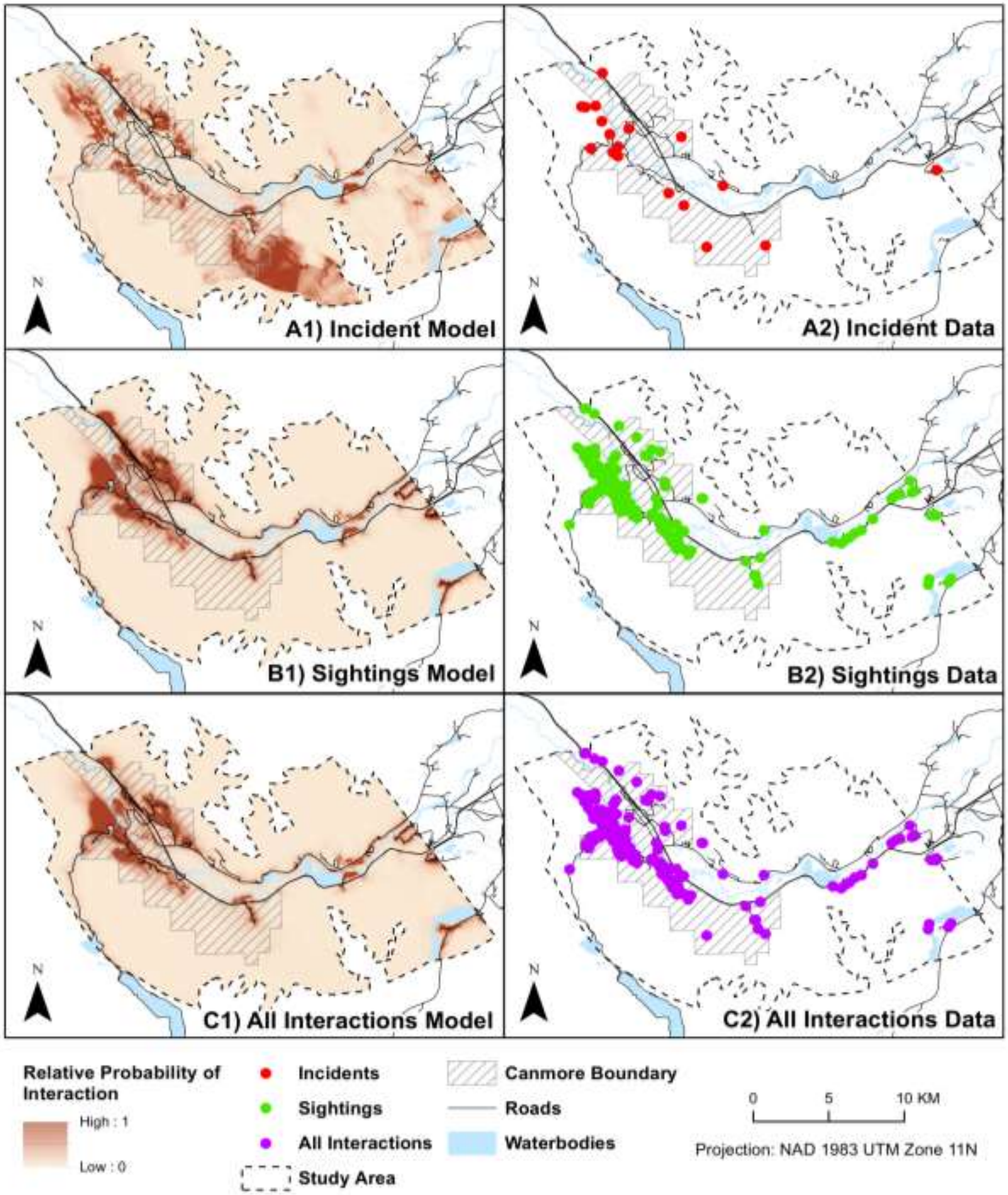

Figure 10: Distribution of predicted berry season human-black bear interaction probabilities for A1) incident interactions only, B1) sighting interactions only, and C1) sightings and incidents combined, along with the distribution of actual HBI locations A2) incidents, B2) sightings, and C2) sightings and incidents combined. Projected probabilities were based on top logistic regression models of human-black bear interaction occurrence from 2016-2017 berry seasons in the Bow Valley of Alberta, Canada.

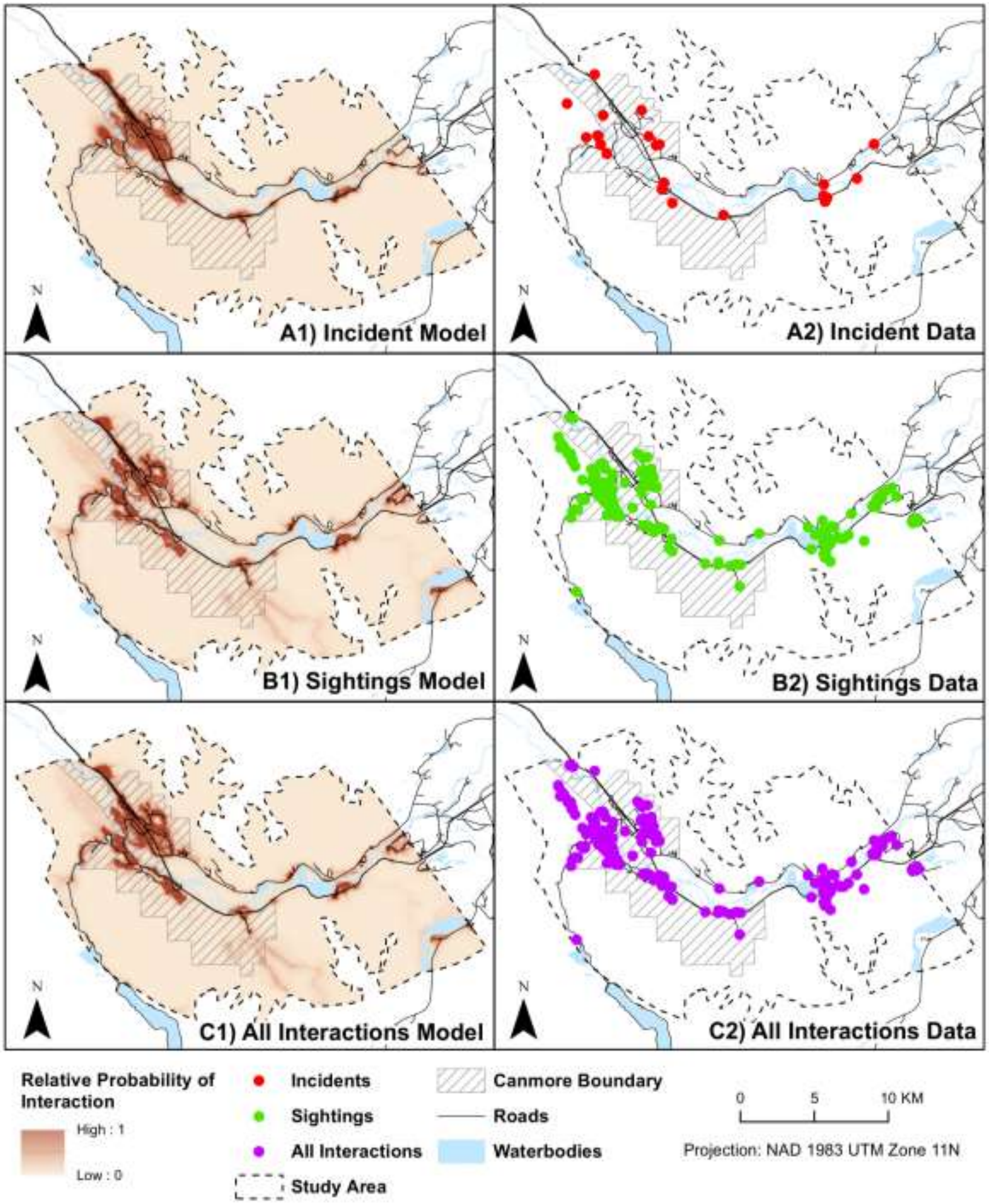

Figure 11: Distribution of predicted post-berry season human-black bear interaction probabilities for A1) incident interactions only, B1) sighting interactions only, and C1) sightings and incidents combined, along with the distribution of actual HBI locations A2) incidents, B2) sightings, and C2) sightings and incidents combined. Projected probabilities were based on top logistic regression models of human-black bear interaction occurrence from 2016-2017 post-berry seasons in the Bow Valley of Alberta, Canada.

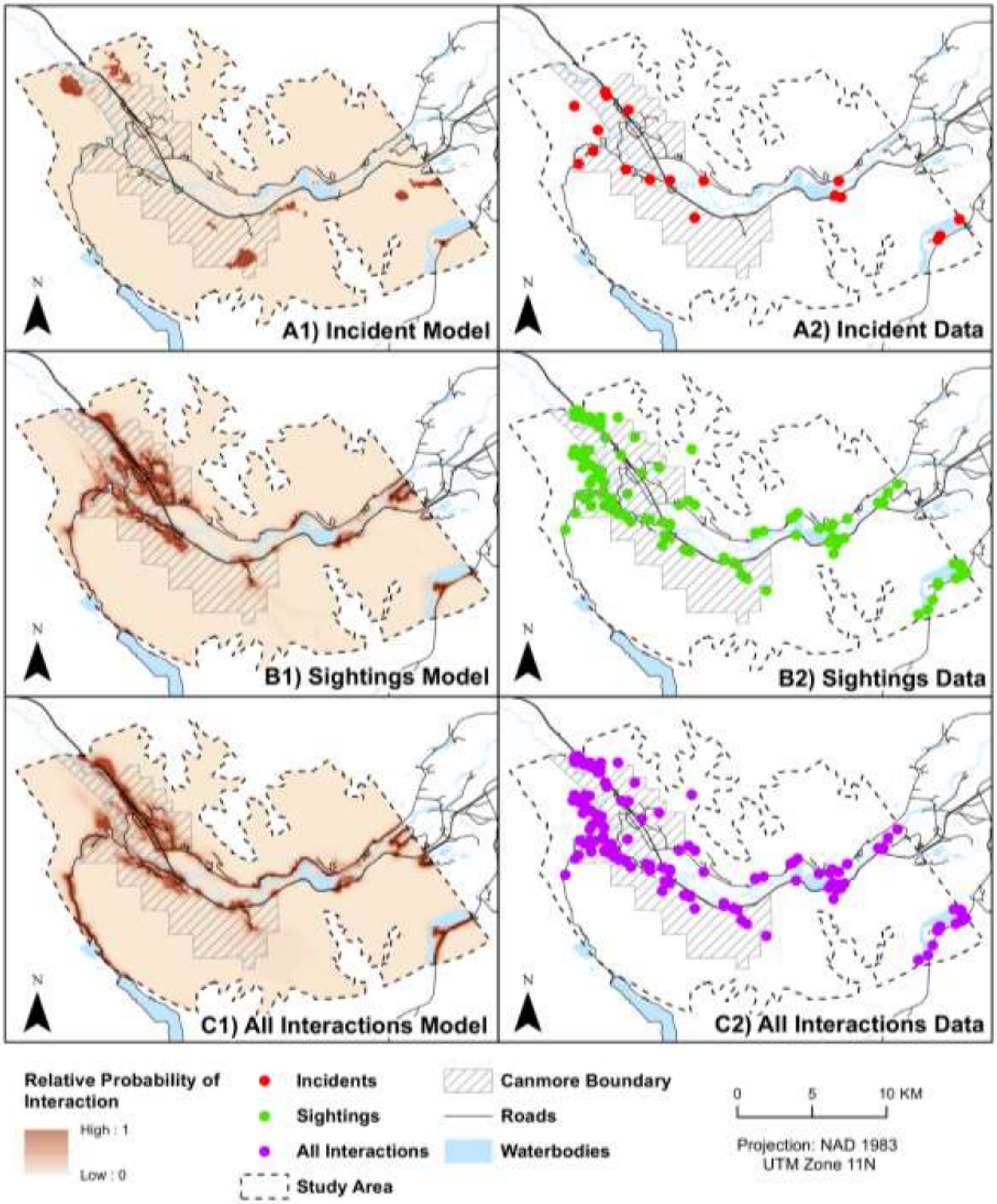

Figure 12: Distribution of predicted human-grizzly bear interaction probabilities for A1) incident interactions only, B1) sighting interactions only, and C1) sightings and incidents combined, along with the distribution of actual HBI locations for A2) incidents, B2) sightings, and C2) sightings and incidents combined. Projected probabilities were based on top logistic regression models of human-grizzly bear interaction occurrence from 2016-2017 in the Bow Valley of Alberta, Canada.

Table 9: k-fold cross validated Spearman rank correlations (r_s) between human-bear interaction (HBI) occurrence bin ranks and observed data for top latent selection difference models where the response variable was incidents (1) and sightings (0). Average (M) and standard deviation (SD) of r_s values come from 100 repetitions of the correlation calculation. HBI data comes from the Bow Valley in Alberta, Canada, 2016-2017.

	Observed		**Available**	
	M	*SD*	*M*	*SD*
Black bear				
Pre-berry	0.08	0.272	0.01	0.292
Berry	0.40	0.263	0.05	0.349
Post-berry	0.53	0.241	0.05	0.333
Grizzly bear				
Full year	0.19	0.310	0.02	0.318

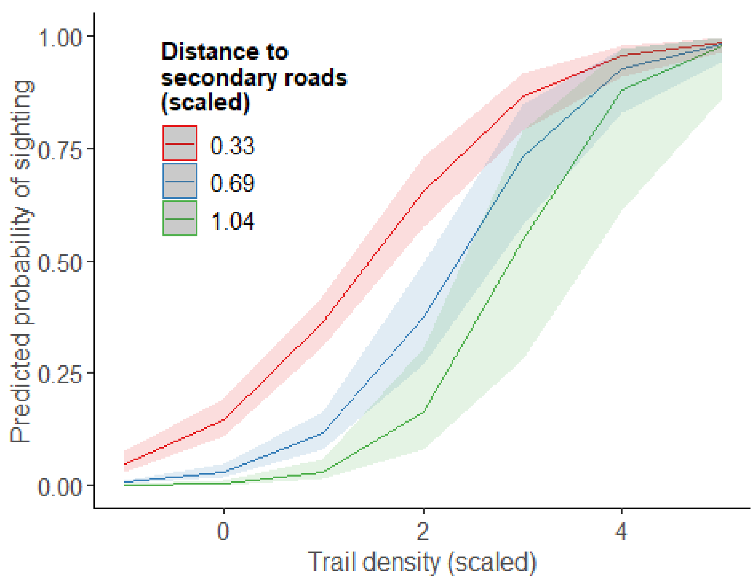

Figure 13: Marginal effects plot of the statistical interaction between recreational trail density (1 km radius) and distance to secondary roads for top black bear berry season sighting occurrence model. Human-bear interaction data comes from Alberta's Bow Valley, 2016-2017. Shaded regions indicate 95% confidence intervals.

I found partial support for my hypothesis that incidents would be more likely than sightings as corridor size decreased. The black bear post-berry LSD model indicates that incidents were more likely in short corridors (Table 8) but this model had only moderate predictive ability (observed r_s = 0.53, σ = 0.241; Table 9). As well, the grizzly bear sightings were more likely in wide corridors (Table 8). Contrary to my hypothesis that incidents increased relative to sightings with decreasing corridor size, corridor width was included in 3 of 4 top sightings models but was less important for incidents (i.e., it was only included in black bear berry season), but the effect was swamped by the statistical interaction between corridor width and distance to secondary roads (Figure 5, Figure 6). Additionally, black bear sightings were significantly more likely as corridor width decreased (Figure 5), particularly when close to secondary roads (Appendix 3, 4).

I found weak support for the hypothesis that lower habitat quality increases sightings versus incidents. While variation in NDVI and mean NDVI were significant positive predictors in LSD models (Table 8) and sighting occurrence models (Figure 5, Figure 6), NDVI was also a positive predictor of incidents in the grizzly bear and black bear berry season models (Figure 5, Figure 6).

2.3 Discussion

HBIs in the Bow Valley vary with season, species of bear, and the types of individual responses of people and bears during HBIs. HBI occurred most often in the summer, when bears are actively foraging and human recreation is high. Black bears were found to be relatively more active than grizzly bears (i.e., on camera traps), and were more likely to be involved in an HBI. Most HBIs had benign outcomes (88%) where people did not have to take extreme evasive action or bears retreated. Taken together, the most common type of HBI in the Bow Valley occurred during summer, with black bears, and as sightings.

Here, I address my initial research questions: can we predict the distribution of HBI's across space and time and do the factors that predict the distribution of sightings differ from those that predict incidents? First, I review the mechanisms underlying HBIs, including a) bear activity; b) human presence and activity; and c) environment. I then evaluate whether the distribution of sightings and incidents in the Bow Valley differed. Finally, I discuss limitations of this research and examine challenges associated with the collection and analysis of HBI data.

2.3.1 Predicting HBI distribution

2.3.1.1 Patterns of Bear Activity

Spatially explicit-activity models

Black bear activity (i.e., the spatially explicit activity models based on camera trap images) was predicted to be highest at low elevations and in long narrow corridors. This pattern of activity may represent the pattern of available habitat and navigable terrain in the valley, i.e., the Bow Valley is bordered to the north and south by steep, rugged mountain peaks and the valley bottoms contain dense human development that constrains bear movements (Figure 1; Herrero (editor) 2005). As well, many habitat patches and designated wildlife corridors are immediately adjacent to the urban development at the valley bottom (Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018). While high predicted black bear activity in low elevations and long narrow corridors may represent the underlying structure of the valley, it is important evidence for where black bears are currently most active, especially because these spaces overlap with recreational areas in the Bow Valley. Black bear activity also increased near modified human greenspaces during the berry season, which is concerning when considering both human and bear safety in these highly-used recreational areas during busy summer months (Schwartz et al. 2010a).

Black bear activity decreased near the Trans-Canada Highway in the berry season. Bears generally avoid high-traffic roads (Fecske et al. 2002, Gibeau et al. 2002, Chruszcz et al. 2003, Proctor et al. 2012, Whittington et al. 2019) and mortality and incidents increase near roads as well (Benn and Herrero 2002, Schwartz et al. 2010b, Wilton et al. 2014, McFadden-Hiller et al. 2016). Lower activity near the highway along with a strong increase in activity at low elevations and gentle slopes, indicates a push-pull for black bears in this space - bears avoid areas close to the highway but stay near the valley bottom (Gibeau et al. 2002).

Grizzly bears tend to avoid high human use areas at broader scales (Laliberte and Ripple 2004, Theberge et al. 2005, Proctor et al. 2012) and this was reflected in the bear activity maps (Figure 3). Unlike black bears, grizzly bears avoided modified greenspaces, despite the potential for valuable food resources. Areas of high predicted grizzly bear activity were far from town centres and Canmore in particular, while black bear activity was predicted to be higher near town centres, particularly in the pre-berry season. The difference between species in areas of highest activity could also be an indication of black bears avoiding areas of high grizzly bear use and being pushed into spaces within municipal boundaries and closer to human recreational areas in order to avoid grizzly bears (MacHutchon et al. 1998, Belant et al. 2010, Elfstrom et al. 2014).

Bear Activity and the Occurrence of HBIs

My hypothesis that bears drive HBI was supported in incident models for both black bears and grizzly bears: HBIs were more likely where bear activity was high. The inclusion of a measure of bear presence is not often included in HBI research (e.g. Merkle et al. 2011b, McFadden-Hiller et al. 2016), but where empirical estimates are included, high levels of bear activity or habitat selection overlapping with human presence increases the likelihood of HBIs (Northrup et al. 2012, Takahata et al. 2014, Bombieri et al. 2019). The type of HBI that occurs may vary with species, attractants, or study location. For instance, Dorresteijn et al. (2014)

found that brown bear activity in Romania was only associated with specific types of incidents, such as agricultural crop damage, but the study area contained much lower levels of development, tourism, and vehicle traffic than the Bow Valley.

Bear activity was a significant predictor of grizzly bear incidents whereas for black bears, it was a better predictor of sightings and all HBIs combined. Grizzly bears may be more likely than black bears to use offensive tactics when encountering threats, such as people, due their evolution in open habitats where retreating was not option (Herrero 1972). This increased aggression in grizzly bears is a potential explanation for the significance of grizzly bear activity in predicting incidents – where grizzlies are most active and when they encounter people, they could be more likely to charge. Bombieri et al (2019) also found that globally, bear attacks were more likely where bear density was high and overlapped with human recreation. The significant impact that grizzly bear activity has on the likelihood of an incident occurrence is important evidence in support of trail and area closures when grizzly bear sightings increase or when seasonal foods are at peak availability. Unlike grizzly bears, sightings and overall HBI were more likely with black bears when black bear activity was high. Again, this may relate to bear behavior, since black bears tend to be less aggressive than grizzly bears and will retreat most often when threatened (Herrero and Higgins 2003, Smith and Herrero 2018).

2.3.1.2 The Effect of Infrastructure and Human Activity on HBIs

Roads and trails were positive predictors of HBIs and this supports the hypothesis that people drive HBIs. The measure of distance to roads in this study was also a measure of human structures since roads and development are closely linked in the Bow Valley and were highly correlated in my analyses. The correlation between suburban and low density development and increased likelihood of HBIs is well established (Kretser et al. 2008, Schwartz et al. 2010b, Merkle et al. 2011b, McFadden-Hiller et al. 2016, Bombieri et al. 2019) and is particularly evident in systems where attractive bear habitats are available as well (Wilson et al. 2006, Baruch-Mordo et al. 2008). Roads impact bear habitat selection, mortality, and behaviour (Gibeau et al. 2002, Chruszcz et al. 2003, Carter et al. 2010, Güthlin et al. 2011, Simek et al. 2015, Whittington et al. 2019) depending on traffic volume, road density, adjacent habitat type, and characteristics of individual bears. In the Bow Valley, the strong association between HBIs and secondary roads indicates that bears are accessing resources near roadways and the perceived tradeoff between mortality risk and a food or security resource is low enough to encourage some bear habitat use near roads (Bourbonnais et al. 2014, Johnson et al. 2015, Kite et al. 2016).

When pooled across seasons and species, HBIs were far more likely near roads (and therefore structures, as well) when in narrow corridors. Note that the HBI occurrence analysis excluded road mortalities and so this is not a representation of vehicle collisions. Potentially, HBIs were more likely in narrow corridors near roads due to the movement constraints, lack of cover, or increased forage availability in narrow habitat patches (Munro et al. 2006, Takahata et al. 2014, Kite et al. 2016). Where fencing and crossings are absent at roadways, maintaining wider habitat patches or utilizing temporary or seasonal road closures will allow bears to forage and move more easily out of sight of humans, decreasing both sightings and incidents (Takahata et al. 2014, Kite et al. 2016, Whittington et al. 2019).

In the Bow Valley, HBIs were also more likely to occur near trails, at high trail densities, and above moderate levels of human use. Bears use spaces where human presence is also high for two potential reasons: 1) the bears are habituated (i.e., show little response to people as a result of no negative consequences during previous interactions; Hopkins III et al. 2010) or are tolerant of humans and will not avoid people (Mattson et al. 1992, Chruszcz et al. 2003, Mueller et al. 2004), or 2) bears may be food conditioned (i.e., associate people with food, Hopkins III et al. 2010), so they seek out human use areas in search of high-calorie or easily accessible anthropogenic food. Habituation and food conditioning can occur separately or together and their combination affects what type of HBI occurs. For instance, non-habituated but food-conditioned bears who have become skilled at accessing resources in high human use areas but are non-habituated to human activity could be more likely to be involved in incidents relating to accessing or guarding anthropogenic foods or charging humans in surprise and predatory encounters (Gunther et al. 1994, Herrero and Higgins 2003, Mazur 2010). Conversely, habituated bears who do not associate humans with food may be involved in higher numbers of sightings as people can approach more closely and bears do not seek cover from humans. Tracking individual bears and linking them to the type the type of HBI they are involved in is a tactic employed by some wildlife management agencies when dealing with problem bears (e.g. Honeyman 2007, Spencer et al. 2007, Mazur 2010) but knowledge of bear behaviour and the type of HBIs that occur when a bear isn't a 'problem', i.e. co-occurring with people but not involved in incidents, is not well understood (Herrero et al. 2005). In addition, monitoring the behaviour and location of non-problem bears could provide a better understanding of landscape characteristics that increase the likelihood of sightings rather than incidents.

The most common human action during an incident was to discharge noise (e.g., yell or scream at a bear) and bear spray was deployed infrequently. Out of 14 reported charges by black bears and grizzly bears during the study period, only one person used bear spray. While bear spray has been acknowledged as one of the most effective non-lethal safety tools in preventing serious incidents (Smith et al. 2008, Smith and Herrero 2018), this dataset indicates that it is still not frequently carried or is inaccessible by recreationalists. Additionally, 10 people involved in HBIs 'ran away', which is strongly advised against during any encounter with a predator. The frequency of this reaction in the data supports the need for continuing education promoting safe and appropriate reactions when encountering a bear, even in a community with a long history of coexisting with bears and multiple organizations promoting safety in bear country (e.g. Biosphere Institute of the Bow Valley n.d., Alberta Environment and Parks 2019).

2.3.1.3 Environment

Habitat quality

Primary productivity, or ‘green-up’, was associated with increased probability of HBIs. This supports my hypothesis that high-quality bear habitat, such as spaces with flushes of primary productivity, increases the likelihood of an HBI occurring. Since areas with seasonal green-up, such as large parks and open spaces next to trails, are used by people and provide high quality habitat for bears, it is not surprising that HBIs occur in these places (Schwartz et al. 2010a). The Bow Valley is surrounded by high quality bear habitat in regional, provincial, and federal parks, and development is interspersed with vegetated river corridors and forest, which are also attractive to bears (Wilson et al. 2006, Nielsen et al. 2009, Latham et al. 2011, Merkle et al. 2011b). These circumstances provide prime opportunities for bears and people to interact.

Where high levels of NDVI overlap with human use or settlements, increased occurrence of HBIs may lead to wider scale impacts on bear populations. Lamb et al. (2017) found that a valley high in berries (i.e., seasonal vegetation) and human use was disproportionately attractive to grizzly bears, and became a population sink. Similarly, Baruch-Mordo et al. (2014) suggest that removal of problem black bears who enter urban areas during poor food years may cause a decline in black bear populations. Since the Bow Valley is a continentally significant movement corridor for large predators (Kellert et al. 1996, Soulé and Noss 1998, Weber and Rabinowitz 2010), black bears and grizzly bears may face disproportionate risk in this landscape where high-quality habitat overlaps with human settlement and recreation.

Corridors

HBIs were more likely in narrow corridors for black bears and in wider corridors for grizzly bears. The effect of corridor width per se on HBIs was difficult to discern as most models included statistical interaction terms that precluded interpretation of corridor width alone. For example, for most black bear models there was an interaction between corridor width and roads, indicating that HBIs were more likely in narrow corridors when near roads. This supports my prediction that HBIs are negatively associated with corridor size for black bears but grizzly bear models go against this prediction. Increased likelihood of HBIs in narrow corridors for black bears could represent their ability and willingness to exist close to higher human activity (MacHutchon et al. 1998, Merkle et al. 2013, Johnson et al. 2015). Additionally, there could be some reporting bias whereby people associate black bears with a lower level of risk when encountering them away from developed areas, and so are less likely to report a sighting (Siemer et al. 2009, Wilbur et al. 2018). Regardless of whether that reporting bias exists, the trend near roads is clear: wide corridors adjacent to roads decreased the likelihood of both sightings and incidents for black bears. Wide corridors represent tracts of land without roads, human structures or steep slopes, providing bears with opportunities for less hindered movement and undisturbed foraging (Noss et al. 1996, Takahata et al. 2014, Peters et al. 2015), and these habitat conditions could allow black bears in the Bow Valley sufficient space to segregate from any human use that is present.

Grizzly bear HBIs were more likely in wide corridors, which contradicts my predictions. Grizzly bears will avoid human use at both broad and fine scales, where possible (Kasworm and Manley 1990, Mattson and Merrill 2002, Schwartz et al. 2010a, Hojnowski 2017). This may mean that they are absent from narrow corridors, i.e., close to development, much of the time, and this was supported in the grizzly bear activity model. Therefore, in wide corridors where off-trail use occurs or where large recreational trail systems exist, grizzly bears are more likely to interact with people. The availability of wide corridors in the study area is limited (see Appendix E for fine scale map of corridor width in Canmore and surrounding environs), particularly when it is compared to the average home range of an adult grizzly (e.g. 1400 km^2; Stevens and Gibeau 2005) or the biological scale at which grizzly bears select habitat (Kasworm and Manley 1990, Gibeau et al. 2002, Apps et al. 2004, Wilson et al. 2014). This means that grizzly bears are limited to using the few wide corridors and habitat patches that remain, which in many cases overlap with popular recreational trail networks in the Bow Valley.

There is a crossover between conservation and HBI prevention where wildlife corridors are used to funnel wildlife around urban centres. Since grizzly bears are threatened in Alberta, corridor design often focuses on grizzly bear biology and habitat selection but may exclude black bear specific reccomendations (e.g. Bow Corridor Ecosystem Advisory Group 2012). Black bears are known to avoid grizzly bears spatially and/or temporally (MacHutchon et al. 1998, Holm et al. 1999, Schwartz et al. 2010a), so there is a potential that black bears are not able to use high quality wildlife corridors to their full potential and enter developed areas as a result. For example, Belant et al. (2010) suggest that black bears are displaced by grizzly bears when alternate resources are available to the subordinate black bear. Elfstrom et al. (2014) suggest this can push black bears into human use areas for use as refuges from dominant grizzly bears. In the Bow Valley, constrained topography and limited habitat mean that refuge for black bears from grizzly bears may be limited to human use areas and modified greenspace, fruit trees, and garbage could represent alternate food resources. GPS collar data and black bear habitat use models would be highly useful in testing these hypotheses and assessing whether black bears choose developed areas over corridors even if grizzly bears are absent, and how black bear habitat selection affects the occurrence of HBIs.

Attractants

Human-bear incidents can occur when high value foraging items are present (such as a carcass or garbage; Wilton et al. 2014, Miller et al. 2016a) or when bears are habituated to people (Herrero and Fleck 1990). Of the reported attractants, both fruit trees and native berry plants were the most common attractant in all incidents, but berries and natural vegetation were actually more commonly recorded in sightings than incidents. Merkle et al. (2013) also found that fruit trees were more influential for attracting bears into residential areas than native vegetation.This is important to note given the focus of many jurisdictions, including Canmore, on removing native berry bushes from municipal areas and recreational trails (e.g. Biosphere Institute of the Bow Valley n.d.). This effort may decrease overall HBIs, but when removal becomes financially or technically unachievable, continued focus on securing anthropogenic attractants, such as fruit trees, may do more for preventing incidents than removing native vegetation does. Additional research assessing the distribution of sightings and incidents pre- and post- native vegetation removal will provide insight on whether this mitigation technique decreases HBI overall in an area, or instead decreases the ratio of incidents to sightings.

Attractant management is working relatively well for grizzly bears in the Bow Valley, but not for black bears. Attractants noted in black bear incidents were numerous and varied, including natural attractants and many types of human attractants, such as garbage, BBQs, human food, pets, and gardens. For grizzly bears, the only human attractants noted were railway grain, fruit trees, as well as limited unknown attractants where bears were investigating houses and patios. This discrepancy in attractants associated with HBIs between species may relate to black bears being more likely to enter areas with human development or activity (Kasworm and Manley 1990, MacHutchon et al. 1998, Merkle et al. 2013, Johnson et al. 2015), which the activity models supported. The HBI data indicate that black bears are still successfully accessing many kinds of human-associated foods in the study area, even though attractant-related incidents have decreased over time (Honeyman 2007, Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018).

When ornamental fruit trees were the attractant in incidents for both grizzly and black bears, there were no reports of extreme reactions taken by people (e.g. shout, run away). The lack of human actions could be due to reporting persons discovering fruit tree damage after bears have left, but half of reports indicate the caller had viewed the bears consuming fruit, while the other half do not specify if the caller observed the bear. Alternatively, there is a possibility that community members view fruit tree consumption by bears as less concerning and are less likely to take action against bears accessing fruit trees. Evidence for this second explanation includes that ornamental fruit trees are still widespread across the valley (J. Paczkowski, *personal communication*) despite programs to remove fruiting trees and fines where the fruit is left unsecured (Town of Canmore 2019, Bow Valley Technical Working Group 2020). Some HBI reports support this explanation as well, such as in one report of a bear actively eating crab apples where the reporting person stated they were 'not concerned' since the 'bear was acting normal'.

Optimal conditions hypothesis

I did not find clear support for the prediction that HBIs would peak at moderate levels of human presence along with high bear activity and habitat quality. Additionally, I predicted that very high levels of human presence, represented by both human activity and development, would preclude HBI from occurring as bears avoid areas of very high human use (e.g. Mace and Waller 1996, Gibeau et al. 2002, Mueller et al. 2004, Herrero (editor) 2005, Hojnowski 2017). Rather than HBIs peaking at moderate human use, I found that the probability of HBIs became very high both at or above moderate levels of human use or trail density. The plateauing of HBI probability above moderate levels of human presence indicates that some bears in the Bow Valley either choose not to or cannot avoid human activity (Gibeau et al. 2002). There is little habitat for bears left in the Bow Valley that does not have recreational trail development (Appendix E). To decrease HBIs and reduce risk to both people and bears, there must be spaces on the landscape where bears can move, forage, and rest with low risk of encountering people. HBIs did decrease with increasing human population density, potentially due to lower bear activity which was reflected in the bear activity models.

2.3.2 Sightings versus incidents

I did not find clear support for my overarching hypothesis that the distribution of sightings and incidents differ. There is some support for sub-hypotheses evident when comparing groups of top occurrence models, LSD analyses, and spatial correlation of sightings and incidents. Below I will outline each of these lines of evidence in turn.

Comparing incident and sighting occurrence models

Incident models were best explained by human presence covariates and this is supported in other work that finds that incidents are often associated with habituated bears or where high value anthropogenic attractants, like garbage, are present (Herrero and Fleck 1990, Wilson et al. 2006, Wilton et al. 2014, Miller et al. 2016a). Both habituation and attractants are found where human presence covariates are high. For instance, near roads, human structures, and at high trail densities, human presence is likely constant and more predictable. This pattern of human activity may allow bears to become habituated to people if they spend a lot of time near these places without negative consequences. For example, bears foraging near roads often cause ‘bear jams’ when people slow or stop vehicles to view the animal (Hopkins III et al. 2010). Bear jams may contribute to habituation by dissociating negative cues of risk from people (Herrero et al. 2005, Gunther et al. 2018).

Sightings were best predicted by a combination of human, bear activity, and environmental predictors. Research on the distribution of bear sightings is extremely limited. Merkle et al. (2011b) included both sightings and incidents in their predictive models and found that HBIs were most likely near forested riparian areas and at intermediate housing densities (peaked at 6.59 dwellings/ha). Larson (2017) found that bear sightings were associated with recreational trails. The Bow Valley contains many forested riparian areas, often overlapping with recreational trail networks. The sighting occurrence models aligned with the findings of Larson (2017) and predicted that sightings were significantly more likely near trails and at high trail densities. Bow Valley sightings models did not suggest a quadratic relationship between HBI and population density (which varied from 0 to 5112 people per km^2 within the study area), instead indicating that sightings decreased with increasing population density. This potentially differs from Merkle et al. (2011b) but comparison is difficult as they measured dwelling density as opposed to population density. Overall, sightings models indicated that human recreational use and features were more influential for predicting HBIs than overall population density, and this aligns with previous research on human use in the Bow Valley (Gibeau et al. 2002, Hojnowski 2017).

Projected HBI Occurrence Models

When projected across the study area, the spatial distribution of grizzly bear incidents differed noticeably from sightings (Figure 12). Areas with the highest probability of incidents occurred in dense trail networks with high quality vegetation, including the northern tip of the Nordic Centre trail network and trails south of Dead Man's Flats. In contrast to incidents, grizzly bear sightings were predicted to occur most often very near roads, trail heads, and satellite neighbourhoods, such as Harvie Heights (Figure 12). Increased likelihood of incidents where high quality bear habitat overlaps human activity and attractants is well-known (Wilson et al. 2006, Merkle et al. 2011b, Evans et al. 2014, McFadden-Hiller et al. 2016, Smith and Herrero 2018) but the differences in the projected distribution of sightings and incidents suggests that management techniques or effectiveness could vary over space – this is an area requiring further research into the human-dimensions of HBIs.

The spatial distribution of black bear incidents and sightings differed little in spring and fall but were noticeably different during summer. In spring and fall, black bear HBIs were most likely near towns, recreational centres, trailheads, and parking lots. During summer, sightings were most likely in these same places, but the distribution of incidents differed. During the summer, incidents with black bears were most likely in trail networks and where variation in

NDVI was high, i.e. overlapping high quality bear habitat and recreational activity. These areas occur near the Canmore Nordic Centre, surrounding suburban developments on the borders of Canmore, and in a large, well-used recreational area south of Dead Man's Flats. The increase in incidents potentially overlaps with summer green-up along trails and open spaces near suburban developments and coincides with peak outdoor recreation and visitation. Black bears often tolerate non-motorized recreation (Kasworm and Manley 1990, MacHutchon et al. 1998, Costello et al. 2013, Ladle et al. 2018) and grizzly bears in the Bow Valley have been shown to be closer to trails in high quality habitat than expected during human inactive periods (Gibeau et al. 2002). Any bear behavior that results in bears closer to human recreational use increases the potential for HBI to occur, particularly when people recreate outside of peak hours (Costello et al. 2013).

Across species and seasons, HBI prediction success improved when incidents and sightings were modelled together (Table 9). As well, sightings and incident models differed in the strength and combination of the predictors but did not differ in coefficient signs. Merkle et al. (2011b) also found high predictive power in their HBI model that included both sightings and incidents, even when applied to an adjacent system. In my study, the convergence of the model structures for sightings and incidents suggests that combining HBI types can be helpful when quantifying factors leading to rare events, such as incidents involving grizzly bears.

Latent Selection Difference Analysis

Spearman rank correlations between the observed occurrence of HBIs and available locations suggested LSD models had moderate to poor predictive power (Table 9). Black bear summer and fall models performed the best out of all LSD models. During summer, black bear incidents were significantly more likely than sightings away from roads and official trails. Bears who use habitat near roads and trails, particularly when humans are active, may be more likely to be habituated to human presence, and therefore less likely to charge humans (Herrero et al.

2005). As well, visibility, predictability of human activity, and education signage is likely better at roads and in official trail networks, meaning that humans are better prepared for HBI and that bears may be better able to avoid human activity. During fall, incidents with black bears were significantly more likely than sightings where variation in NDVI was high (i.e., areas with seasonal green-up) and in short corridors. This supports my hypothesis that increasing high quality habitat will increase the occurrence of incidents due to foraging bears defending food sources or being more difficult to see amongst dense cover, and that decreased corridor size would increase incidents due to less space for bears and people to segregate.

In support of my predictions, the grizzly bear LSD model also indicated that incidents were more likely than sightings where variation in NDVI was high, or where habitat quality and food availability is higher. Bears are highly food motivated (Herrero 1972, Baruch-Mordo et al. 2014, Lamb et al. 2017) and grizzly bears may be more likely to tolerate human presence (such as recreational trails) when in high quality habitat (Gibeau et al. 2002, Chruszcz et al. 2003, Herrero (editor) 2005). As well, where food availability is high, conflicts and human-caused grizzly bear mortality are higher (Herrero and Fleck 1990, Suring and Frate 2002, Wilson et al. 2005, Lamb et al. 2017). These findings support the need for limiting of human use where high quality bear habitat overlaps with recreational trail networks. Balancing the foraging and habitat requirement of bears with human recreation is highly relevant in the Bow Valley where secure bear habitat is limited and threatened grizzly bears persist in a highly developed landscape (Gibeau et al. 2001).

Spatial correlation of sightings and incidents

Sightings and incidents occurred in many of the same places for black bears, particularly during spring and summer, indicating the value of combining all HBI types when modelling relatively rare events like incidents. Most previous research that has included both sightings and incidents has not tested whether HBI types were correlated (e.g. Merkle et al. 2011b, Larson

2017), but Wilton et al. (2014) found that the distribution of black bear occurrences and incidents were positively correlated across a landscape of forest, farms, and parks in Missouri, USA.

Grizzly bear sightings and incidents were only moderately correlated, suggesting that there may be differences in the spatial distribution of sightings and incidents, but small sample sizes and pooled grizzly bear HBI data across seasons limits my ability to draw conclusions from these results. Considering that grizzly bears are generally less tolerant of human disturbance than black bears (Kasworm and Manley 1990, MacHutchon et al. 1998, Schwartz et al. 2010a), it is possible that non-habituated or non-tolerant animals avoid human use areas, and when they encounter humans far from town centres and roads, they may be more likely to charge (Herrero et al. 2005) or people may be more likely to take evasive action in surprise. Conversely, habituated or tolerant grizzly bears nearer to human use areas would not consider humans as much of a threat (Herrero et al. 2005, Smith et al. 2005), increasing the likelihood of sightings over incidents. A larger grizzly bear HBI dataset or GPS collar data would allow for more rigorous testing of these hypotheses.

2.3.3 Study Limitations

2.3.3.1 Activity Models

Inferences from the spatially-explicit activity models need to consider the non-random distribution of camera traps in the study area. Trap locations were mostly at low elevations and areas near roads and trails (Figure 3), likely due to accessibility constraints and AEP’s focus on covering human use areas. This distribution meant that resource selection models for the entire study area were not measurable with the camera data available (Burton et al. 2015). For this reason, I specifically modelled bear activity only, and do not suggest that these activity models indicate bear habitat selection across the valley.

Since black bears are more numerous in the area and involved in more HBI than grizzly bears (Table 6; Alberta Environment and Parks 2016b, Morehouse and Boyce 2017), I wanted a consistent measure of bear activity for both species. Black bear habitat selection studies are lacking in Alberta outside of national parks, and the most recent estimate of black bear density dates back to the1980’s (Alberta Environment and Parks 2016b). Due to the lack of recent black bear habitat and movement research, the activity models do provide a unique insight into bear presence in the Bow Valley and have the potential to reveal the conditions that contribute to bears interacting with people.

Black bear activity was not a good predictor of HBIs in post-berry season models, but I believe this reflects the camera trap distribution rather than ecological processes. Cameras were focused at low elevations and for the black bear post-berry activity model. In this model, human population density was a positive predictor of black bear activity, which resulted in the highest predicted activity occurring nearest dense urban centres, such as downtown Canmore. While black bears will tolerate human presence, I do not expect bear activity to peak in downtown Canmore. The projected black bear activity model (Figure 11), and therefore the bear activity input for the HBI post-berry occurrence models, likely showed an incorrect representation of the areas with highest bear use in the valley. To try to mitigate this effect, I included a high human population density mask before projecting the post-berry model.

The spatially-explicit bear activity models I produced for this study provide important insight into where and why HBIs occur but future analyses would ideally be able to model bear habitat selection and movement corridors using gridded camera traps or GPS collar data for both grizzly bears and black bears. GPS collar data would also allow for fine-scale modelling of variation in movement or activity by time of day. In conclusion, I recommend that the activity model results be applied conservatively beyond the scope of this study and the prediction of local HBIs.

2.3.3.2 Categorization of HBI

Universal systems of categorizing human-wildlife interactions allow for better comparison of human-wildlife coexistence between studies, systems, and species. There have been many proposed definitions of HBI (e.g., Bath and Enck 2003, Herrero and Higgins 2003, Smith et al. 2005, Wilson et al. 2005, Baruch-Mordo et al. 2008, Wilton et al. 2014) while other research does not explicitly define terms such as conflict (e.g. Hristienko and McDonald 2007, Spencer et al. 2007, Kubo and Shoji 2014). A lexicon for North American human-bear management set out by Hopkins III et al. (2010) has been referenced in at least 75 ecological studies as of May 2020, indicating its utility for understanding the complex set of interactions that can occur between humans and bears. While this lexicon (hereafter, Hopkins lexicon) was instrumental in shaping the methodology of my thesis, potential limitations to its utility became evident during analysis.

The Hopkins lexicon is arguably human-centric. While differentiation between reasons for bear aggression is noted within the lexicon (i.e., defensive-aggressive versus offensive-aggressive bears), the core rules for categorization define incidents and conflict from a human perspective. For instance, an incident occurs when ‘when a bear exhibited stress-related or curious behavior, causing a person to take extreme evasive action’, or bears cause property damage, access anthropogenic food, are hit by cars, or are intentionally harmed by people (Hopkins III et al. 2010). Note that a bear exhibiting stress-related behaviour is only categorized as an incident if humans then took extreme evasive action in response to the encounter.

Hopkins lexicon is potentially very useful for managers looking to understand the outcomes of HBIs and how humans react to interactions with bears but it does not capture the potential subtle negative impacts of HBIs on bear habitat security and behaviour. Consider the following scenario: a bear is foraging on native vegetation in a backcountry habitat patch alongside an unofficial trail and encounters a hiker. Both bear and human are surprised by this encounter, resulting in the bear being disrupted from foraging and running to cover, while the human stands their ground until the bear disappears, then cautiously resumes their hike. This HBI would be categorized as a sighting using Hopkins lexicon since the person did not have to take extreme evasive action, the bear did not access anthropogenic food, and the bear was not intentionally harmed. Hypothetically, this type of sighting could occur many times throughout the season, meaning the bear is continuously disrupted from foraging on high quality food and experiences a reduction in forage and secure habitat. While sightings of this nature may be of little concern to managers focused on keeping humans safe and keeping bears from being involved in serious conflict, it may be having significant impacts on bear fitness and habitat selection (Coleman et al. 2013). It is unclear if a high frequency of such interactions should be considered coexistence or is simply a by-product of coexistence. Either way, the absence of conflict reports within high quality bear habitat or wildlife corridors should not be interpreted as a lack of conflict from a bear's perspective.

2.3.3.3 Reporting Biases

Several fields in the HBI databases I received were empty, making it challenging to interpret if there was an absence of data or an absence of an observed event. Gaps in the databases may be due to the ambiguous nature of HBI reports from the public, or they could be due to dispatcher or officer patterns of asking for specific details. For instance, there was no attractant reported for the majority of both incidents and sightings. To be clear, this is different than an unknown attractant; the attractant was noted as 'none' if an attractant was not mentioned at all in the report. Bears are highly food motivated, particularly during summer and fall (i.e., hyperphagia, or a period of increased calorie consumption; Nielsen et al. 2004a), when they eat virtually nonstop to meet their winter fat requirements for hibernation. As such, it is likely that there were attractants present in HBIs more frequently than reported, such as a bear grazing on grass on a golf course reported as 'bear seen near 8th hole' or a bear foraging for berries in a backyard reported as 'bear went through backyard'.

I also expect that sightings were underreported. People may choose to not report sightings to management agencies due to previous non-negative personal experience with bears or strong belief in the value of bears (Siemer et al. 2009), or even a belief that management agencies are doing a good job (Wilbur et al. 2018). Research interpreting bias in HBI reports is in its infancy and explanations of bias in HBI reports are so far unclear. Wilbur et al. (2018) suggest that assessing HBIs using multiple sources or types of data will help to address biases that are present. I address potential bias by using both sightings and incident interactions, testing the explanatory power of models with *k*-fold cross validation, and by recommending a limited interpretation of results across other study areas where biases may be different.

Certain types of conflict may have also been underreported due to relative frequency of HBIs in the Bow Valley where residents may consider certain incidents to be of lesser concern, such as bears foraging on fruit trees in residential areas. There is also the possibility that residents avoid reporting conflict because they want to avoid perceived aggressive management action to be taken against the bear involved, or to avoid fines levied against themselves for unsecured attractants, but I expect unreported incidents to be far fewer than unreported sightings.

2.3.3.4 Complexity of predicting HBIs

The moderate predictive power for incidents models (Table 7) and the complexity of sightings and all HBI models indicate that there may be important explanatory mechanisms I did not analyze, such as individual bear behaviour (e.g. Lewis et al. 2015a, Cristescu et al. 2016a, Elmeligi 2016), detailed human attractant mapping (e.g. Wilson et al. 2005, Johnson et al. 2018), or social factors, such as recreational user types (e.g. tourist versus local, walking versus biking) (e.g. Lackey and Ham 2004, Coltrane and Sinnott 2015, Elmeligi 2016, Smith and Herrero 2018). Research that explores HBI's through the lens of social science highlights the need for an understanding of human tolerance and behaviour (Siemer et al. 2009, Merkle et al. 2011a), measurements of the efficacy of management actions (Baruch-Mordo et al. 2011, Merkle et al. 2011a, Johnson et al. 2018), and the difference between real and perceived conflict (Majic et al. 2011, Dorresteijn et al. 2014). Finally, cross-disciplinary work, such as agent-based models that take fine-scale human and bear decisions into account, provides further detailed and system-specific insights. For instance, Marley et al. (2019) found that management actions could be optimized throughout Whistler, BC rather than applying many actions at once to decrease the creation of 'problem' bears. Lischka et al. (2018) found that by examining social and ecological factors behind HBI in tandem, they could identify novel relationships and feedback mechanisms influencing HBI in Durango, Colorado. Since human-carnivore coexistence is inherently a social-ecological challenge, collaboration across disciplines and acknowledgement of the complexity of the human-carnivore coexistence will deepen our understanding of the drivers of HBI (Pooley et al. 2017, Lischka et al. 2018, König et al. 2020).

Chapter 3: Management Recommendations and Conclusion

3.1 Management Recommendations

Through this research, I have developed the following management recommendations. These recommendations are focused on ecological research, human dimensions research, and applied management techniques. There is also currently a multi-stakeholder effort underway to better manage human-wildlife coexistence in the Valley and high-level recommendations for enhanced HBI management were developed (Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018). My reccomendations strive to support this ongoing work. Note that the order of the following reccomendations does not represent order of importance.

- **Quantify the effect of management removals on black bear populations**. The majority (75%) of HBI occurred with black bears resulting in high numbers of management actions (Honeyman 2007, Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018). While black bear populations are estimated to be stable or increasing based on estimates developed in the 1970's and 1980's (Alberta Environment and Parks 2016b), recent estimates do not exist for Alberta. The impact that the high numbers of bears destroyed or translocated in response to HBI could have on black bear population stability outside of National Parks is unknown. Hebblewhite et al. (2003) found that black bear survival in Banff National Park decreased once bears became management problems and this is likely true on the adjacent habitat in the study area as well. Baruch-Mordo et al. (2014) caution that removing urban bears during natural food failure events will negatively affect black bear populations. The Bow Valley is a regionally important movement corridor for large carnivores, and black bears may be experiencing disproportionate impacts on local populations due to the high number of HBIs that occur.

- **Increase inclusion of sightings reports in research and management decisions.** The majority of HBIs that occur are benign (88% in the study area) meaning there is a significant amount of data that is being excluded from analysis of HBIs that traditionally focuses on incidents only. The inclusion of sightings in predictive models improved their predictive power over incidents alone across seasons and species. This could be particularly important for understanding rare events, like incidents with grizzly bears. These incidents appear to drive much of the public conversation in the Canmore area, yet incidents are very rare relative to sightings. This rarity means the degrees of freedom and the strength of inference is quite low. In the Bow Valley, quantification of changes in sightings versus incidents may allow managers to understand the impact of native vegetation removal, education campaigns, and behaviour of conflict versus non-conflict bears. Finally, tracking sightings will allow for the mapping of bear habitat where conflicts from a human perspective are absent, but where bears may experience a deterioration in habitat quality and foraging efficiency.
- **Evaluate human dimensions of HBIs in the Bow Valley.** Differences in the projected distribution of grizzly bear incidents versus sightings and the complexity of sightings models could potentially be explained by evaluating the human dimension of HBI. HBI management is inherently a social-ecological issue, and ecological solutions will not succeed without an understanding of human behaviour. Multiple jurisdictions across North America, including some work already completed in the Bow Valley, have gained key insight into managing HBIs by combining social and ecological data (Wilson et al. 2014, Elmeligi 2016, Johnson et al. 2018, Marley et al. 2019). As well, despite the existence of multiple Bow Valley organizations promoting safe behaviour while recreating in bear country, bear spray was only deployed in one serious incident and multiple people 'ran away' during an HBI. An evaluation of the effect that education has

on human behaviour could increase the impact and use of education techniques provided by bear safety organizations.

- **Limit human use where it overlaps high-quality or high-activity bear habitat.** Increasing grizzly bear activity was correlated with incidents in the Bow Valley. This provides support for trail or area closures when grizzly bears are active or sighted in an area and would increase grizzly bear forage access as well. HBIs increased near trails, at high trail densities, and above moderate levels of human use, particularly in wide corridors for grizzly bears. Limiting trail use, capping trail density in bear habitat, or decommissioning unofficial trails in high use areas may contribute to a decrease in HBIs. This would potentially allow increased space for bears and people to segregate, increasing both human and bear safety.
- **Increase corridor width near roads and dwellings.** Black bear activity and HBIs increased in narrow corridors near roads and human structures. Black bear HBIs also increased near human greenspaces. Wider corridors adjacent to roads and structures, particularly where fencing is absent, may decrease human-black bear interactions by allowing for increased cover and security for bears during foraging and movement near these features.
- **Continue addressing attractant management.** Incident models were best explained by human presence covariates and this is supported in other work that finds that incidents are often associated with habituated bears or where high value anthropogenic attractants, like garbage, are present (Herrero and Fleck 1990, Wilson et al. 2006, Wilton et al. 2014, Miller et al. 2016a). Black bears accessed a wide variety of anthropogenic attractants during this study. Fruit trees were a common attractant for black bears and humans did not take extreme evasive actions during these encounters. This indicates that fruit trees represent an important attractant for bears and that people may be underestimating the risk associated with bears foraging on these trees. Efforts to decrease the number of unsecured attractants in the Town of Canmore is ongoing and

bylaws prohibiting feeding of wildlife exist there, but this is not the case in for the Municipal District of Bighorn or on Provincial land outside parks. Providing a mechanism for managers to enforce good attractant management via additional laws may decrease bear access to anthropogenic attractants, particularly when paired with monitoring and human dimensions research.

3.2 Conclusion

Alberta's Bow Valley has served as a global template for human-wildlife coexistence, from wildlife fencing and crossings, to early GPS collar research, to aggressive attractant management. It is one of the only areas where grizzly bears and large numbers of people coexist and is a continentally-important corridor for large carnivore movement. As human population densities, visitation, and development increase, there may be a crossroads approaching where large carnivores will no longer be able to persist in the Bow Valley. To avoid loss of carnivores from the study area, the strong history of innovative research and management must continue and push forward into new frontiers of human-wildlife coexistence.

Efforts to address the need for continued insight into human-carnivore coexistence are ongoing, including the recent landmark work on human-wildlife coexistence in the Bow Valley (Bow Valley Human-Wildlife Coexistence Roundtable and Technical Working Group 2018). This thesis aimed to support both proven and novel techniques. I aimed to broaden the use and understanding of an existing and underutilized resource: HBI reports inclusive of sightings and incidents. By including a spatial analysis of both sightings and incidents, I provide a unique insight into the study, monitoring, and management of HBIs.

I achieved my objective of determining factors which contribute to HBIs and developed predictive models of these interactions and their outcomes. I found clear support for my first overarching hypothesis, that the distribution of HBIs could be predicted across space and time using bear activity, human presence, and the environment. HBIs were driven by increasing bear activity, increasing human presence (except for human population density which was negatively associated with HBI), and increasing habitat quality and food availability. I did not find support for my optimal conditions hypothesis. However, there was an asymptotic relationship between HBIs and human activity, indicating that HBI were very likely anywhere above moderate human use. I also found that predictive models that included both sightings and incidents have higher predictive power than sightings alone.

I did not find clear support for my second overarching hypothesis that the factors that predict sightings and incidents differ. LSD analyses provided some directions for potential future research on HBI outcomes and comparison between sightings and incidents distributions, such as the impact of NDVI on increasing the likelihood of sightings over incidents and the increasing potential for incidents over sightings far from roads and official trails. The distribution of sightings and incidents were highly correlated for black bears, but less so for grizzly bears. Performing similar tests in other systems and with higher numbers of incident reports will elucidate how closely correlated sightings and incidents are. Based on these results, I suggest that sightings reports be included in future analyses of HBIs.

Potential limitations of this research include the non-random camera trap distribution used for the bear activity estimates, the choice of lexicon and categorization rules for sightings versus incidents, the potential reporting bias present when using unsolicited HBI reports, and the complexity of predicting HBIs. While these limitations may affect the robustness or reliability of conclusions, I took all precautions possible and elaborated on my methods to address biases or assumptions where necessary. In reference to the bear activity models, while the input camera trap data was non-random, the resulting spatial output provides novel insight into black bear presence in the Bow Valley, and allowed for direct comparison between black bear and grizzly bear activity and HBIs.

To increase understanding of coexistence beyond conflict, future research on HBIs should include both sightings and incidents. Sightings data may be useful for predicting incidents and increasing predictive power of models, for identifying areas where bear habitat security is threatened where conflict is absent, or for better understanding human behaviour. As well, increasing focus on species involved in the greatest number of interactions with people will allow managers to proactively manage for impacts on carnivore populations and prioritize human safety. In the Bow Valley, this means an emphasis on understanding the population and behavioural impacts that high numbers of HBIs are having on black bears.

Human-wildlife coexistence is an exciting field where innovation in both research and management has allowed for large carnivores to persist in landscapes such as the Bow Valley. To ensure that these large carnivore populations persist into the future and that the risks to human safety are managed, novel techniques and challenging of biases in traditional coexistence research must be considered. Exploring factors related to both sightings and incidents and how non-conflict interactions shape the relationships between carnivores and people provides an avenue for understanding of the complex, dynamic, and evolving nature of human-wildlife coexistence.

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Appendices

Appendix A: Data Dictionary for Human-Bear Interaction Database

Table A.1: Data dictionary used to categorize human-bear interaction database. Adapted from data dictionary used by Alberta Environment and Parks.

Field Name	Definition
int_ID	Unique ID number referring to an individual interaction
Wildlife.Obs.Date	Date that interaction occurred; where date unknown, enter 'NA'
Wildlife.Obs.Time	Time that interaction occurred; where time unknown, enter 'NA'
Time_Type	Specifies the accuracy of the 'Wildlife.Obs.Time'
Exact	Report notes specify the exact time of the incident (e.g. 10 minutes ago, at noon, about an hour ago)
Day	Call notes do not specify an exact time, but daytime is noted (e.g. this morning, this afternoon, sometime yesterday)
Night	Call notes do not specify exact time, but night (i.e., between sunrise and sunset) is noted (e.g. last night, too dark to see, before sunrise)
Unknown	Insufficient information to assign any time code
Species	Bear species involved in interaction; where a report from a conservation officer exists for a particular interaction, use the CO's species first, then the reporting person
Black Bear	'Black-coloured bear' classed as "Unknown Bear"
Grizzly Bear	Where caller noted large shoulder hump, classify as grizzly bear
Unknown Bear	Insufficient information to assign a bear species
UTM.East.Final	UTM coordinates of actual interaction
UTM.North.Final	UTM coordinates of actual interaction
Loc_Type	Specifies the confidence in the UTM coordinates
Exact	Report notes specify exact location of interaction (e.g. at Winter Junction 5, ~200 m up X trail, on X trail where the alpine starts)
Within 500m	Report notes a little vague on exact location of interaction (e.g. halfway down X trail, between Hgwy offramp 10 and 11)
Greater than 500m	Report notes very vague on exact location of interaction (e.g. at Canmore Nordic Centre, in Exshaw, on X trail)
Unknown	Insufficient information to assign any UTM coordinates
Primary Attractant	If secondary attractant present, was recorded in 'Notes' column
Garbage	Human associated refuse
Ornamental Fruit Trees	Non-native fruit bearing tree or shrub
Birdfeeder	Non-natural bird feed mix intended to attract wildlife including suet and sweetened water
Pet Food	Domestic pet food
Compost	Any foods mixed for the purposes of decomposing
BBQ	Domestic BBQ's including firepit grills
Human Food	Domestic human food; includes human food containers e.g. coolers, freezers.
Grain (Railway)	Any unnaturally deposited rail car attractant
Grain (Agric)	Any agriculturally grown food product either in the field or stored e.g. oats, barley, wheat
Livestock	Any domesticated livestock (e.g. cattle, sheep, horses, goats, chickens, donkeys, llamas etc.)

Natural Veg (berries)	Native trees and shrubs that are considered a wildlife attractant (e.g. roots, buffaloberry, saskatoon, dogwood, chokecherry etc.)
Natural Veg (other)	All other naturally occurring vegetation besides berries where plant is not specified (e.g. bear grazing, eating grass in the meadow, etc.)
Unnat Veg (clover, dandelions)	Non-native vegetation including clover, dandelions, lawn grass.
Carcass (Natural)	Native carrion (elk, deer, moose, bighorn sheep, rabbits etc.)
Carcass (Livestock)	Domestic carrion (cows, sheep, horses, pigs)
Domestic Wildlife	Dogs, cats, non-native rabbits
Garden	Residential garden - either vegetable or flowering
Wildlife	Any wild animals (elk, deer, moose, ground squirrel etc.)
Human	Human consumed (partially or entirely) in wildlife altercation
Insects	Any diggings associated with access to insects e.g. ants
Other	Not covered by above (specify in 'Notes' column)
Unknown	Not enough information to assign a Feeding category, e.g. "bear was eating something"
None	No attractant seen or noted
Human_Activity	
Hiking/Walking	Walking in both frontcountry and backcountry areas
Driving	Roads designated for highway approved vehicles (not ATV's)
Biking	Road or mtn biking
ATV	Off road vehicle use
Running	Jogging in frontcountry and backcountry areas
Hunting	Big game, small game, bird hunting
Fishing	Angling in both frontcountry and backcountry
Camping	Frontcountry or backcountry camping at exact time of incident
Equestrian	Riding on horseback
Inside human structure	Inside house, vehicle (ONLY if not moving or unspecified), apartment, cabin, store, etc. or on porch/deck
Other	Activity not covered above (note the activity was in 'Notes' column)
Unknown	Not enough information to assign a Human_Activity
Domestic_dog_present	
0	No dog mentioned during interaction
1	Dog present during interaction (specify in ‘Notes’ on- or off-leash)
Human_Action	
Play dead	Display non-aggressive, passive response to wildlife interaction
Discharge-lethal projectiles	Discharge of live rounds with intent to kill bear
Discharge-noise	Discharge of noisemakers (crackershells, screamers) or yell with intent to scare bear away
Discharge-nonlethal projectiles	Discharge non-lethal pain stimuli (bean bag, rubber bullet rounds, rocks) with intent to scare bear away
Discharge- Bear Spray	Discharge bear spray at animal with intent to scare it away
Fight back	Display aggressive behaviour towards bear at close quarters
Increase distance	Move away from bear in a non-aggressive manner
Stand ground	Neither closes distance nor approaches bear during interaction
Close Distance	Person moves towards bear during interaction
Runs Away	Person runs away from bear at onset of interaction
Unknown	Not enough information to assign a Human_Action

Animal_REAC	
Unaware	Bear is unaware of person
Indifferent	Bear aware of persons presence but continues activity
Alert	Bear acknowledges person's presence by staring, standing up, sniffing air etc. and stops activity it was engaged in prior to persons arrival but does not close distance or retreat
Retreat walk	Bear increases distance from person by walking but does not go into cover (default when only 'retreat' is noted)
Retreat run	Bear increases distance from person by running but does not go into cover
Retreat to Cover walk	Bear increases distance from person by walking and goes to cover
Retreat to Cover run	Bear increases distance from person by running and goes to cover
Property Damage	Bear causes damage to property (would include destruction of fruit trees, beehives etc.)
Close Distance	Bear closes distance on person (would include head-on approach or following)
Predatory attack	Bear closes distance on person with apparent intent to kill or consume person (non-surprise encounter)
Charge-no contact	Bear closes distance on person in aggressive manner (surprise encounter) without making contact with person; includes bluff charge
Charge-contact	Bear closes distance on person in an aggressive manner (surprise encounter) and makes contact with person
Stands ground	Bear does not retreat or close distance on person but exhibits agitated behaviour (vocalizing, swatting ground, jaw popping)
Unknown	Insufficient information to assign an Animal_REAC category
cubs_present	
0	No cubs noted by caller or conservation officer
1	One or more cubs (YOY or YLY, i.e. up to 2 years old) present during interaction
bear_mortality_injury	
0	No mention of bear injury/mortality
1	Bear injury/mortality resulting from interaction (e.g. hit by car)
time_out	
0	Confident in loc_type allocation
1	Could not determine location within 5 minutes online searching
Notes	Justification for decisions, concerns, thoughts

Appendix B: Competing Top Human-Bear Interaction Models within ΔAIC 2

Note that a comparative table was not produced for black bear berry incident occurrence because there was only 1 top model within ΔAIC of 2.

Table B.1: Top black bear pre-berry incident occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Bear activity + Distance to human greenspace + Distance to secondary roads + Distance to official trails + human population density	6	47.48	0.00	0.20
Distance to human greenspace + Distance to secondary roads + Distance to official trails + human population density	5	47.92	0.43	0.16
Distance to human greenspace + Distance to secondary roads + Distance to official trails + human population density + Distance to secondary roads x Distance to official trails	6	48.27	0.78	0.13
Mean NDVI + Distance to human greenspace + Distance to secondary roads + Distance to official trails + human population density	6	49.16	1.67	0.08
Corridor Length + Distance to human greenspace + Distance to secondary roads + Distance to official trails + human population density	6	49.44	1.96	0.07

Table B.2: Top black bear pre-berry sighting occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Bear activity + Mean NDVI + Variance in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to all trails + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density	12	587.71	0.00	0.11
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to all trails + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density	11	588.56	0.84	0.07
Bear activity + Mean NDVI + Variance in NDVI + Corridor width + Distance to secondary roads + Distance to all trails + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density	11	588.96	1.25	0.06
Bear activity + Mean NDVI + Variance in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to all trails + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density + Distance to secondary roads x Trail density	13	589.02	1.30	0.06
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to all trails + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density	10	589.31	1.60	0.05
Bear activity + Mean NDVI + Variance in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to all trails + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density + Mean NDVI x Variance in NDVI	13	589.65	1.94	0.04

Table B.3: Top black bear pre-berry all interactions occurrence models below ΔAIC of 2.

Model	**df**	**AICc**	**Δ AICc**	**AIC weight**
Bear activity + Mean NDVI + Variation in NDVI + Corridor Width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density + Distance to secondary roads x Trail density + Mean NDVI x Variation in NDVI	13	703.47	0.00	0.13
Bear activity + Mean NDVI + Variation in NDVI + Corridor Width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density + Mean NDVI x Variation in NDVI	12	703.74	0.27	0.11
Bear activity + Mean NDVI + Variation in NDVI + Corridor Width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Corridor width x Distance to secondary roads + Corridor width x Trail density + Distance to secondary roads x Trail density + Mean NDVI x Variation in NDVI	12	703.95	0.48	0.10
Bear activity + Mean NDVI + Variation in NDVI + Corridor Width + Distance to secondary roads +Distance to TransCanada Highway + Trail Density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density + Mean NDVI x Variation in NDVI	11	704.80	1.33	0.07
Bear activity + Mean NDVI + Corridor Width + Distance to secondary roads + Trail Density + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density	9	705.18	1.71	0.06
Bear activity + Mean NDVI + Corridor Width + Distance to secondary roads + Trail Density + Distance to TransCanada Highway + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density	10	705.35	1.89	0.05
Bear activity + Mean NDVI + Variation in NDVI + Corridor Width + Distance to secondary roads + Trail Density + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density + Mean NDVI x Variation in NDVI	11	705.40	705.40	0.05

Table B.4: Top black bear berry sighting occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Bear activity + Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Distance to secondary roads x Trail Density	7	611.49	0.00	0.05
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail Density	9	611.77	0.28	0.04
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Corridor width x Distance to secondary roads + Corridor width x Trail density	9	612.34	0.85	0.03
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Trail Density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density	8	612.60	1.11	0.03
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Trail Density + Corridor width x Distance to secondary roads + Corridor width x Trail density	8	612.94	1.45	0.02
Bear activity + Mean NDVI + Distance to secondary roads + Trail Density + Distance to secondary roads x Trail Density	6	613.24	1.75	0.02
Bear activity + Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Trail Density	8	613.28	1.79	0.02
Bear activity + Mean NDVI + Variance in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Distance to secondary roads x Trail Density	8	613.41	1.92	0.02
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Corridor width x Distance to secondary roads + Corridor width x Trail density + Distance to secondary roads x Trail Density	10	613.44	1.95	0.02
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Distance to secondary roads x Trail Density	8	613.46	1.97	0.02
Mean NDVI + Distance to secondary roads + Trail Density + Distance to secondary roads x Trail Density	5	613.47	1.98	0.02
Bear activity + Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail Density	10	613.48	1.99	0.02

Table B.5: Top black bear berry all interactions occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Distance to secondary roads x Trail density	9	672.58	0.00	0.05
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Corridor width x Trail Density	9	672.74	0.16	0.05
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Corridor width x Trail Density	10	673.09	0.52	0.04
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Distance to secondary roads x Trail density	10	673.11	0.53	0.04
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Corridor width	9	673.33	0.75	0.04
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width	8	673.34	0.76	0.04
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Corridor width + Distance to secondary roads x Trail density	10	673.53	0.96	0.03
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Corridor width + Corridor width x Trail Density	10	673.76	1.19	0.03
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Corridor width	10	673.87	1.29	0.03
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Corridor width + Distance to secondary roads x Trail density	11	673.96	1.39	0.03
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width	9	674.03	1.46	0.03

Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Corridor width x Trail Density + Mean NDVI x Variation in NDVI	11	674.05	1.47	0.03
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Distance to secondary roads x Trail density + + Mean NDVI x Variation in NDVI	11	674.05	1.48	0.03
Bear activity + Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Distance to secondary roads x Corridor width + Corridor width x Trail Density	11	674.07	1.49	0.03
Bear activity + Corridor width + Mean NDVI + Distance to secondary roads + Trail Density + Human population density + Distance to secondary roads x Corridor width + Distance to secondary roads x Trail density + Corridor width x Trail Density	10	674.33	1.75	0.02

Table B.6: Top black bear post-berry incident occurrence models below ΔAIC of 2.

Model	**df**	**AICc**	**Δ AICc**	**AIC weight**
Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human Use Density	4	88.25	0.00	0.09
Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Human Use Density + Corridor width x Human Use Density	5	88.42	0.18	0.08
Distance to secondary roads + Distance to TransCanada Highway + Human Use Density	5	89.30	1.05	0.05
Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human Use Density	5	89.36	1.12	0.05
Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human Use Density	6	89.46	1.22	0.05
Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human Use Density + Distance to secondary roads x Human Use Density	6	89.48	1.24	0.05
Mean NDVI + Distance to secondary roads + Distance to TransCanada Highway + Human Use Density	5	89.59	1.35	0.05
Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human Use Density + Human Population Density	6	89.71	1.46	0.04

Table B.7: Top black bear post-berry sighting occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Distance to official trails + Human population density + Corridor width x Distance to secondary roads + Mean NDVI x Variation in NDVI	9	796.38	0.00	0.16
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Distance to official trails + Human population density + Corridor width x Distance to secondary roads	8	797.90	1.52	0.08
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail Density + Mean NDVI x Variation in NDVI	11	797.91	1.53	0.08
Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Trail Density + Human population density + Corridor width x Distance to secondary roads + Distance to secondary roads x Trail density	9	798.04	1.66	0.07
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Trail Density + Human population density + Corridor width x Distance to secondary roads + Corridor width x Trail density + Distance to secondary roads x Trail Density + Mean NDVI x Variation in NDVI	10	798.13	1.75	0.07
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human population density + Corridor width x Distance to secondary roads + Mean NDVI x Variation in NDVI	10	798.28	1.90	0.06
Mean NDVI + Corridor width + Distance to secondary roads + Distance to official trails + Human population density + Corridor width x Distance to secondary roads	7	798.31	1.93	0.06

Table B.8: Top black bear post-berry all interactions occurrence models below ΔAIC of 2.

Model	**df**	**AICc**	**Δ AICc**	**AIC weight**
Mean NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human population density + Distance to secondary roads x Corridor width	8	880.54	0.00	0.18
Mean NDVI + Corridor width + Distance to secondary roads + Distance to official trails + Human population density + Distance to secondary roads x Corridor width	7	881.71	1.17	0.10
Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human population density + Distance to secondary roads x Corridor width	7	881.78	1.25	0.10
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human population density + Distance to secondary roads x Corridor width	9	882.18	1.64	0.08
Mean NDVI + Variation in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human population density + Distance to secondary roads x Corridor width + Mean NDVI x Variation in NDVI	10	882.25	1.72	0.08
Variation in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Distance to official trails + Human population density + Distance to secondary roads x Corridor width	8	882.29	1.76	0.07

Table B.9: Top grizzly bear incident occurrence models below ΔAIC of 2.

Model	**df**	**AICc**	**Δ AICc**	**AIC weight**
Bear Activity + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail Density / 4 km	6	62.02	0.00	0.22
Bear Activity + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Distance to Official Trails	6	63.42	1.40	0.11

Table B.10: Top grizzly bear sighting occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Corridor width + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density + Corridor width x Human Use Density	10	520.50	0.00	0.08
Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density + Corridor width x Human Use Density	9	520.89	0.39	0.06
Corridor length + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density	9	520.96	0.46	0.06
Variation in NDVI + Corridor width + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density + Corridor width x Human Use Density	11	521.46	0.96	0.05
Corridor length + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density	8	521.68	1.18	0.04
Corridor width + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density	9	521.88	1.38	0.04
Variation in NDVI + Corridor length + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density	10	522.08	1.58	0.03
Corridor width + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density + Corridor width x Human Use Density	11	522.31	1.81	0.03
Grizzly bear activity + Corridor width + Distance to human greenspace + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails + Distance to secondary roads x Human use density + Corridor width x Human Use Density	11	522.39	1.89	0.03
Variation in NDVI + Corridor width + Distance to secondary roads + Distance to TransCanada Highway + Human use density + Human population density + Distance to official trails	10	522.45	1.95	0.03

+ Distance to secondary roads x Human use density + Corridor width x Human Use Density				

Table B.11: Top grizzly bear all interactions occurrence models below ΔAIC of 2.

Model	df	AICc	Δ AICc	AIC weight
Corridor width + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail density + Human population density + Distance to secondary roads x Trail density + Corridor width x Trail density	9	599.19	0.00	0.14
Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail density + Human population density + Distance to secondary roads x Trail density + Corridor width x Trail density + Mean NDVI x Variation in NDVI	11	599.83	0.64	0.10
Corridor width + Mean NDVI + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail density + Human population density + Distance to secondary roads x Trail density + Corridor width x Trail density	10	601.00	1.80	0.06
Corridor width + Variation in NDVI + Distance to secondary roads + Distance to TransCanada Highway + Trail density + Human population density + Distance to secondary roads x Trail density + Corridor width x Trail density + Distance to secondary roads x Corridor width	10	601.12	1.93	0.05

Appendix C: Parameter Estimates for Top Generalized Linear Models of Human-Bear Interaction Occurrence

Table C.1: Parameter estimates for top generalized linear regression models based on HBI records for black bears during the pre-berry season from 2016 and 2017 in Alberta's Bow Valley, Canada. *Note:* NDVI, Normalized Difference Vegetation Index.

	Predictor	Estimate	Std. Error	p-value
Black bear, pre-berry season				
Incident	Bear Activity	4.72	3.07	0.12
	Distance to human greenspace	-6.76	2.28	<0.01
	Distance to secondary roads	-4.82	1.73	<0.01
	Distance to official trails	-8.13	3.08	<0.01
	Human population density	-1.92	0.89	0.03
Sighting	Bear Activity	3.1	0.57	<0.001
	Mean NDVI	0.53	0.24	0.03
	Variation in NDVI	-0.26	0.15	0.09
	Corridor width	-1.08	0.3	<0.001
	Distance to secondary roads	-4.82	0.52	<0.001
	Distance to Trans Canada Highway	0.84	0.47	0.07
	Distance to trails	-1.57	0.76	0.04
	Trail density (per 1km radius)	0.69	0.13	<0.001
	Human population density	-0.19	0.09	0.03
	Corridor width x Distance to secondary roads	1.39	0.41	<0.001
	Corridor width x Trail density (per 1km radius)	0.4	0.11	<0.001
All	Bear Activity	3.05	0.69	<0.001
	Mean NDVI	0.7	0.22	<0.001
	Variation in NDVI	0.04	0.16	0.8
	Corridor width	-0.75	0.28	<0.01
	Distance to secondary roads	-4.91	0.55	<0.001
	Distance to Trans Canada Highway	0.97	0.46	0.04
	Trail density (per 2km radius)	0.36	0.17	0.03
	Human population density	-0.11	0.08	0.16
	Mean NDVI x Variation in NDVI	0.51	0.22	0.02
	Corridor width x Distance to secondary roads	1.16	0.37	<0.01
	Corridor width x Trail density (per 2km radius)	0.19	0.12	0.13
	Distance to secondary roads x Trail density (per 2km radius)	1.06	0.38	<0.01

Table C.2: Parameter estimates for top generalized linear regression models based on HBI records for black bears during the berry season from 2016 and 2017 in Alberta’s Bow Valley, Canada. Note: NDVI, Normalized Difference Vegetation Index.

	Predictor	**Estimate**	**Std. Error**	**p-value**
Black bear, berry season				
Incident	Mean NDVI	1.91	0.86	0.03
	Corridor width	-2.12	1.00	0.03
	Distance to secondary roads	-5.02	1.79	<0.01
	Trail density (per 100m radius)	1.07	0.34	<0.01
	Corridor width x Distance to secondary roads	3.44	1.23	<0.01
Sighting	Bear Activity	1.34	0.63	0.03
	Mean NDVI	0.46	0.20	0.02
	Distance to secondary roads	-4.9	0.50	<0.001
	Distance to Trans Canada Highway	-0.91	0.47	0.05
	Trail density (per 1km radius)	0.92	0.17	<0.001
	Distance to secondary roads x Trail density (per 1km radius)	0.85	0.32	<0.01
All	Bear activity	1.57	0.59	<0.01
	Mean NDVI	0.52	0.21	0.01
	Corridor width	-0.49	0.23	0.04
	Distance to secondary roads	-5.17	0.52	<0.001
	Trail density (per 1km radius)	0.93	0.17	<0.001
	Human population density	-0.16	0.08	0.03
	Corridor width x Distance to secondary roads	1.02	0.36	<0.01
	Distance to secondary roads x Trail density (per 1km radius)	0.53	0.32	0.1

Table C.3: Parameter estimates for top generalized linear regression models based on HBI records for black bears during the post-berry season from 2016 and 2017 in Alberta's Bow Valley, Canada. Note: NDVI, Normalized Difference Vegetation Index.

	Predictor	Estimate	Std. Error	p-value
Black bear, post-berry season				
Incident	Distance to secondary roads	-4.80	1.07	<0.001
	Distance to Trans Canada Highway	-3.38	1.09	<0.01
	Distance to official trails	-1.55	1.14	0.17
	Human use density (per 1km radius)	0.92	0.38	0.01
Sighting	Mean NDVI	0.42	0.20	0.03
	Variation in NDVI	-0.09	0.15	0.56
	Corridor width	-0.84	0.21	<0.001
	Distance to secondary roads	-5.21	0.44	<0.001
	Distance to official trails	-2.57	0.32	<0.001
	Human population density	-0.25	0.07	<0.001
	Mean NDVI x Variation in NDVI	0.34	0.19	0.07
	Distance to secondary roads x Corridor width	1.59	0.29	<0.001
All	Mean NDVI	0.30	0.17	0.08
	Corridor width	-0.83	0.19	<0.001
	Distance to secondary roads	-5.19	0.42	<0.001
	Distance to Trans Canada Highway	-0.60	0.33	0.07
	Distance to official trails	-2.79	0.30	<0.001
	Human population density	-0.11	0.05	0.04
	Corridor width x Distance to secondary roads	1.66	0.27	<0.001

Table C.4: Parameter estimates for top generalized linear regression models based on HBI records for grizzly bears from 2016 and 2017 in Alberta's Bow Valley, Canada. Note: NDVI, Normalized Difference Vegetation Index.

	Predictor	Estimate	Std. Error	p-value
Grizzly bear, 3-season				
Incident	Bear activity	18.26	5.84	<0.01
	Variation in NDVI	1.65	0.5	<0.01
	Distance to secondary roads	-4.42	1.46	<0.01
	Distance to Trans Canada Highway	-4.97	1.53	<0.01
	Trail density (per 4km radius)	1.33	0.44	<0.01
Sighting	Corridor width	0.37	0.16	0.02
	Distance to human greenspace	-0.58	0.37	0.12
	Distance to secondary roads	-4.27	0.47	<0.001
	Distance to Trans Canada Highway	-1.43	0.37	<0.001
	Distance to official trails	-2.92	0.44	<0.001
	Human use density (per 100m radius)	-0.73	0.27	<0.01
	Human population density	-0.21	0.09	0.01
	Distance to secondary roads x Human use density (per 100m radius)	2.22	0.66	<0.001
	Corridor width x Human use density (per 100m radius)	-0.33	0.18	0.07
All	Variation in NDVI	0.23	0.11	0.03
	Corridor width	0.6	0.16	<0.001
	Distance to secondary roads	-4.53	0.45	<0.001
	Distance to Trans Canada Highway	-2.31	0.36	<0.001
	Trail density (per 500m radius)	0.09	0.24	0.7
	Human population density	-0.16	0.08	0.05
	Distance to secondary roads x Trail density (per 500m radius)	2.15	0.55	<0.001
	Corridor width x Trail density (per 500m radius)	-0.54	0.16	<0.001

Appendix D: Significant Statistical Interaction Terms from Top Human-Bear Interaction Occurrence Models (excluding those included in Results)

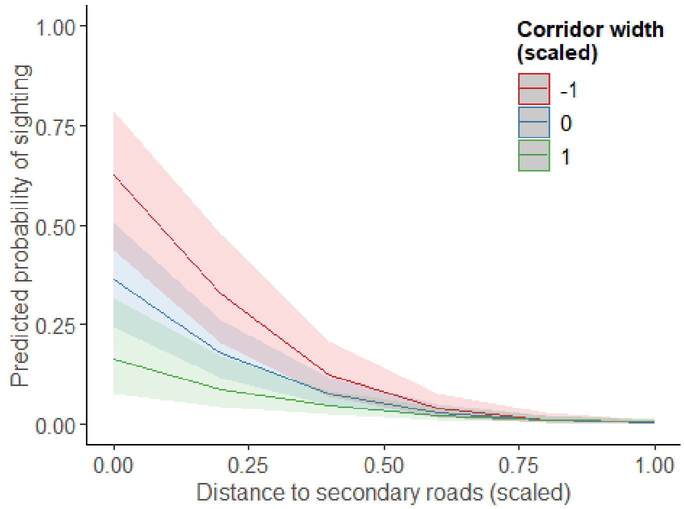

Figure D.1: Marginal effects plot of the statistical interaction between corridor width and distance to secondary roads for top black bear pre-berry season sighting occurrence model. Shaded regions indicate 95% confidence intervals.

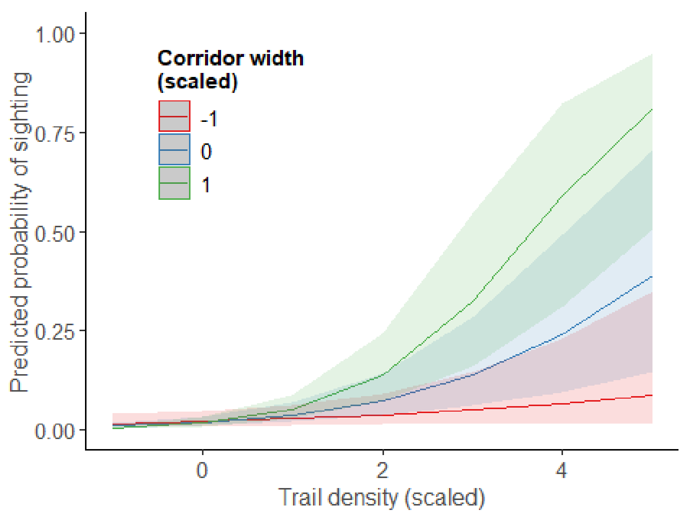

Figure D.2: Marginal effects plot of the statistical interaction between corridor width and trail density (1 km radius) for top black bear pre-berry season sighting occurrence model. Shaded regions indicate 95% confidence intervals.

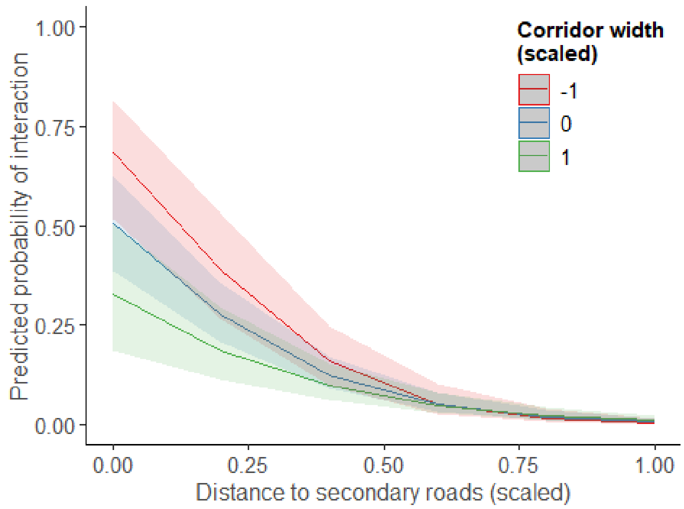

Figure D.3: Marginal effects plot of the statistical interaction between corridor width and distance to secondary roads for top black bear pre-berry season all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

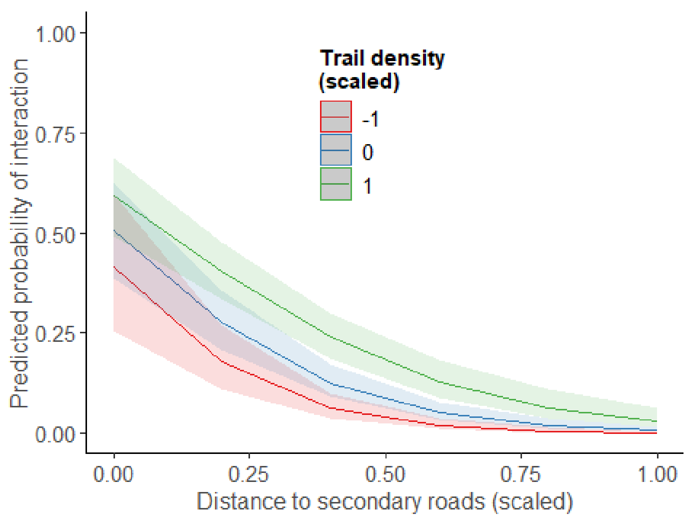

Figure D.4: Marginal effects plot of the statistical interaction between trail density (2 km radius) and distance to secondary roads for top black bear pre-berry season all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

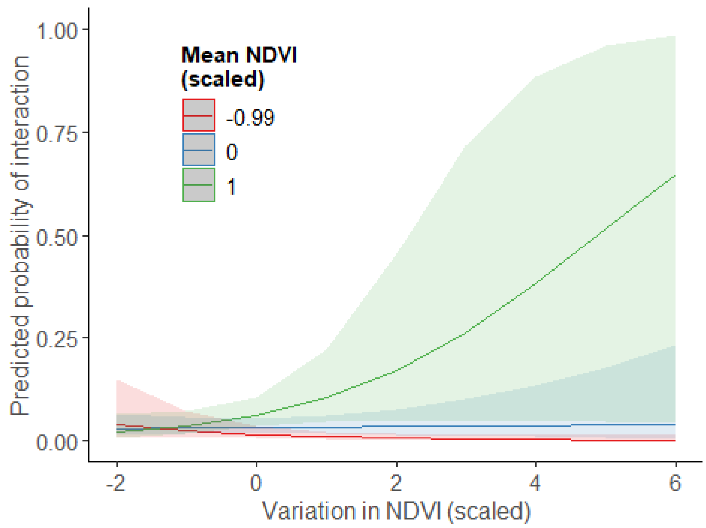

Figure D.5: Marginal effects plot of the statistical interaction between mean NDVI and variation in NDVI for top black bear pre-berry season all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

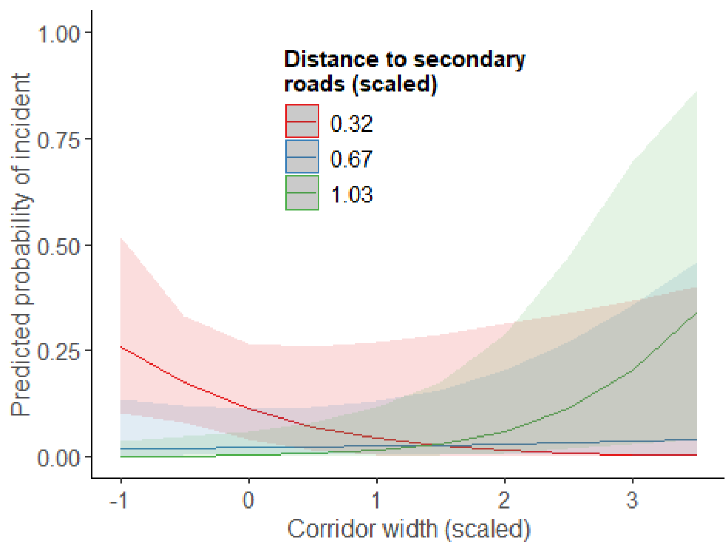

Figure D.6: Marginal effects plot of the statistical interaction between corridor width and distance to secondary roads for top black bear berry season incident occurrence model. Shaded regions indicate 95% confidence intervals.

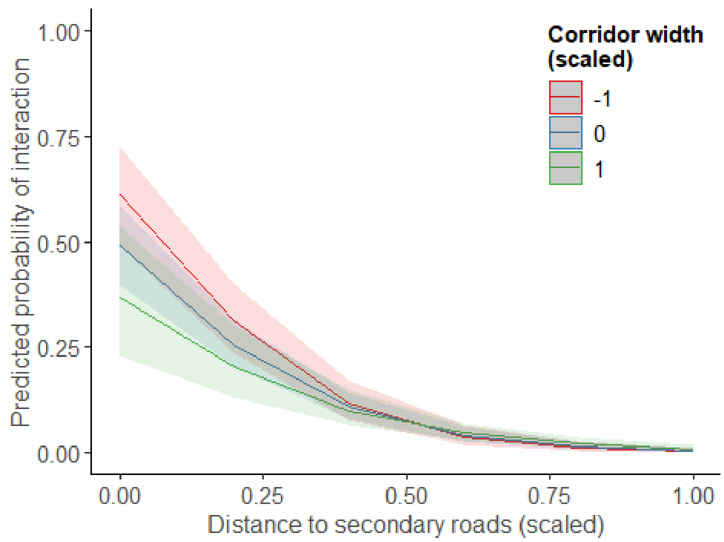

Figure D.7: Marginal effects plot of the statistical interaction between corridor width and distance to secondary roads for top black bear berry season all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

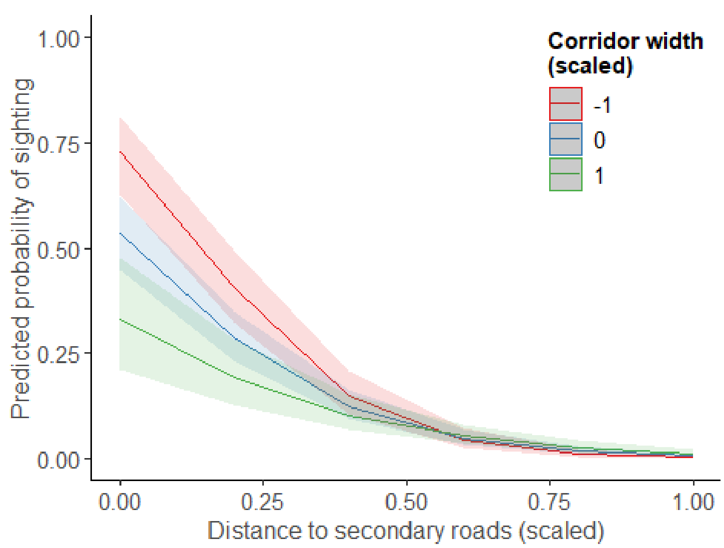

Figure D.8: Marginal effects plot of the statistical interaction between corridor width and distance to secondary roads for top black bear post-berry season sightings occurrence model. Shaded regions indicate 95% confidence intervals.

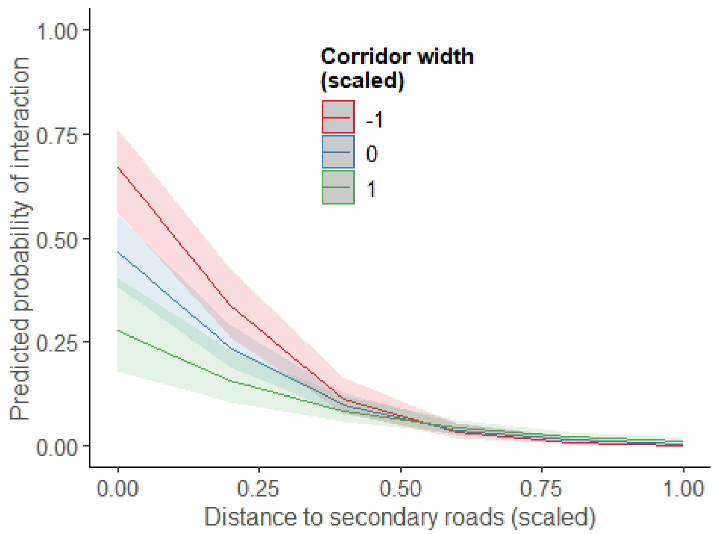

Figure D.9: Marginal effects plot of the statistical interaction between corridor width and distance to secondary roads for top black bear post-berry season all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

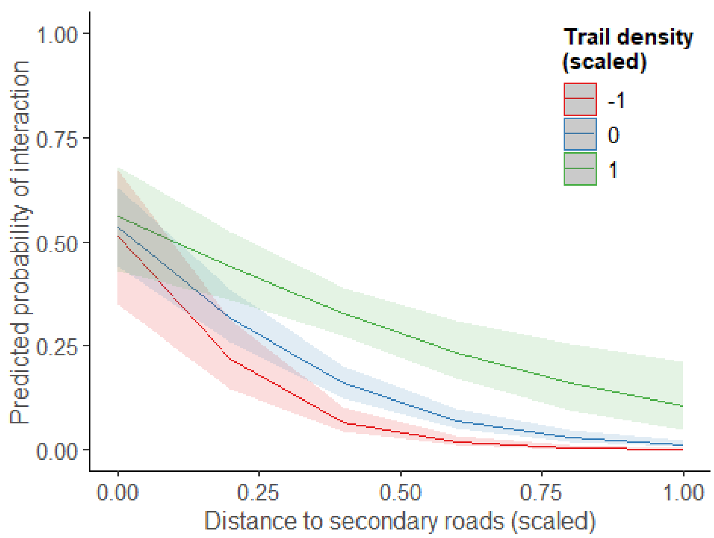

Figure D.11: Marginal effects plot of the statistical interaction between trail density (500 m radius) and distance to secondary roads for top grizzly bear all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

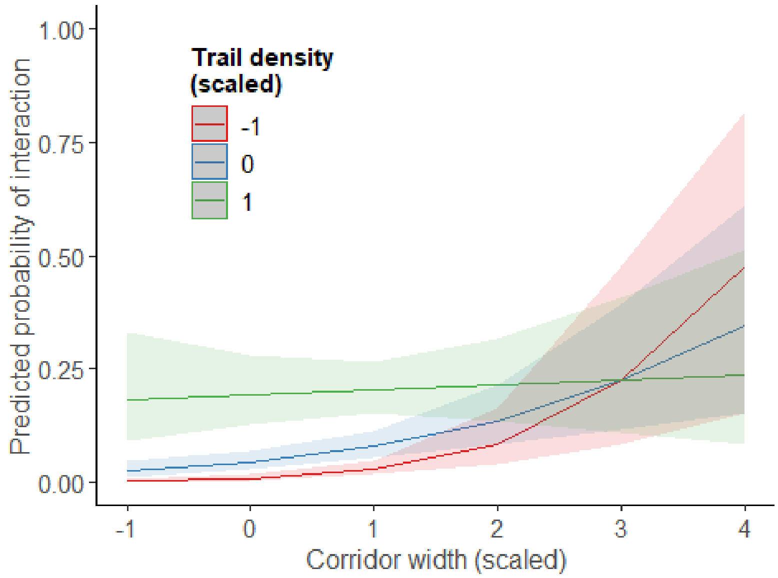

Figure D.12: Marginal effects plot of the statistical interaction between trail density (500 m radius) and corridor width for top grizzly bear all interactions occurrence model. Shaded regions indicate 95% confidence intervals.

Appendix E: Fine-scale Map of Narrow Corridors around Canmore, Alberta

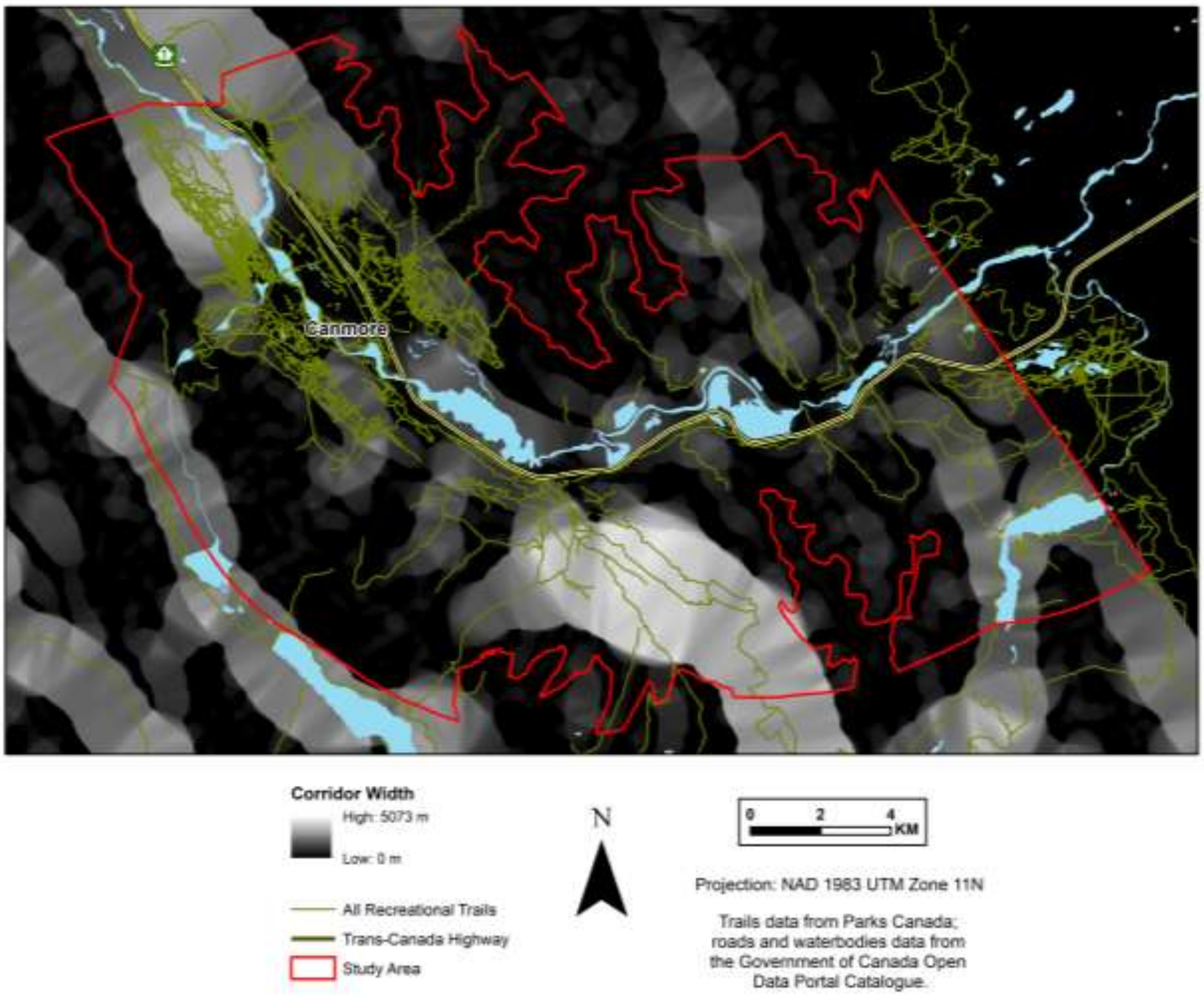

Figure E.1: Map of corridor width overlaid by all recreational trails in Alberta's Bow Valley, Canada. Corridor width is defined the maximum distance as bear can travel without encountering significant barriers to movement, i.e., no steep slopes, no major highways, and no human structures or industrial development. Note that corridor width was not calculated past eastern boundary of study area.