Planning for coexistence: Assessing predictors of human-carnivore conflict on Southern Vancouver Island

by

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

Planning for coexistence: Assessing predictors of human-carnivore conflict on Southern Vancouver Island

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in   Forestry

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Abstract

The urban-wildland interface is growing as human development expands, potentially increasing human-wildlife conflict. Conflicts include animals accessing garbage, damaging agricultural crops, or depredating livestock. For mammalian carnivores this often leads to lethal mitigation. Mortality from conflict represents a major threat to carnivores who miscalculate the risk of human-dominated areas. By contrast, carnivores that adapt to these novel anthropogenic environments may facilitate human-wildlife coexistence.

Human-carnivore conflict is an increasing issue on Vancouver Island, British Columbia, due to rapidly expanding development and high concentrations of black bears (*Ursus americanus*) and cougars (*Puma concolor*). To reduce these conflicts and promote coexistence, it is critical to target proactive mitigations using reliable evidence to distinguish where conflict is probable from where carnivores are adapting to coexist.

I modelled relative conflict probability using seven years of reported conflicts and GIS data to investigate which anthropogenic and environmental predictors best explained the spatial and temporal distribution of conflict in Victoria's Capital Regional District. I found that the probability of conflict for both species increased along the urban-wildland interface, where human disturbance adjoined natural habitat. Black bear conflict also increased in rural areas in autumn before winter denning.

I subsequently used a camera trap survey to see when and where bears were active across a gradient of human disturbance and compared bear habitat use to the previously estimated probabilities of conflict. For much of the year, bears used areas of low to medium conflict, such as forests near urban areas, avoided areas of higher human density, and were more nocturnal in urban and rural areas compared to wild. However, in autumn, bears were more active in areas of

high conflict probability, specifically rural lands with ripe crops. This suggests that bear behaviour may allow for coexistence in most seasons by spatially and temporally avoiding humans, except in autumn when hyperphagia and peak anthropogenic crop availability increase the risk of human-bear conflict.

Overall, I recommend proactive conflict mitigation to secure anthropogenic attractants against multiple carnivore species, and a particular focus on mitigations during seasonal peaks in attractive human food resources.

Lay Summary

As human development expands into wild areas, it is crucial to prevent increasing conflict between humans and carnivores. My research used southern Vancouver Island, BC, to examine where conflict was likely to occur with black bears and cougars, and whether bear behaviour changed in human environments. I found conflict with both species increased in more densely populated areas next to forest, where humans and carnivores overlapped the most, and that bear conflict was most likely in rural areas in autumn, when crops provided an abundant source of food. However, bears predominantly avoided people by selecting forested habitat and switching activity to nighttime in urban areas. Only in autumn did bears spend more time in high-conflict rural areas, as they prepared for winter denning. Therefore, I recommend that to reduce conflict, human food resources be secured in communities near prime wildlife habitat, particularly in seasons when agricultural resources are most abundant.

Preface

Chapter 2 used previously obtained reports of human-carnivore conflict from the British Columbia Conservation Officer Human Wildlife Conflict Reporting Database provided by Mike Badry, Wildlife Conflict Manager. GIS data were provided by Todd Golumbia at CRD Regional Parks. Use and storage of personal information from reports of conflict was approved by UBC Behavioural Research Ethics Board (H18-01677).

Chapter 3 used camera trap data sampled in a study design developed by Cole Burton (UBC) and myself. This project was partially funded by a National Geographic early career grant. Field data collection was conducted by myself with assistance from Joanna Burgar, Erin Tattersall, Meghna Bandyopadhyay (Wildlife Institute of India), Paige Monteiro (FLNRORD), Alexia Constantinou, Jacqui Sunderland-Groves, Aisha Uduman, and Taylor Justason (all UBC unless otherwise specified). Additional GIS data were provided by Laura Hooper and Brian Goble from the District of Sooke. Camera trap images were processed at UBC by Emily Siemens, Lauren Kasper, Zach, Brunton, Avril Hann, Micaela Anguita, HyunGu Kang, and myself. The camera trap sampling was approved by the Canadian Council of Animal Care administered by UBC (A18-0234), and the management of camera trap photos containing humans was approved by UBC Behavioural Research Ethics Board (H18-01677).

Chapter 2 has been adapted for publication, co-authored with Cole Burton, Mike Badry, Adam Ford, and Todd Golumbia. Cole Burton developed the original research question and I defined specific hypotheses. All co-authors provided edits and feedback. Chapter 3 is also being adapted for publication. Cole Burton and I developed the research question and I defined specific hypotheses. I performed all data analysis and wrote the original drafts of each chapter with edits and feedback from my committee members, Cole Burton, Peter Arcese, and Adam Ford.

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Acknowledgments

I would like to start by acknowledging and appreciating that my research took place in the traditional, ancestral, and unceded territories of the Coast Salish, Strait Salish, and Nuu-chah-nulth peoples, and that my third chapter fieldwork was within T'Sou-ke Nation's traditional lands. During this degree I am thankful to have lived and studied on the territory of the xwməθkwəy̓əm (Musqueam) People.

I'm so incredibly grateful for everyone who has buoyed me and helped make this thesis a reality. I have to start by thanking my supervisor, Cole Burton, who replied quickly and enthusiastically to my interest email and has maintained that energy through a busy couple years! In that same vein, the WildCo lab has been the best support system through the roller coaster of a degree, providing the positive feedback needed to stay motivated for semesters on end. Thank you to the post-docs and researchers for their infinite wisdom (Joanna Burgar, Jacqui Sunderland-Groves, Greg Rickbeil, Chris Beirne, and Cat Sun), the PhD's for their recent memories and advice about Master's degrees (Cheng Chen and Cindy Hurtado), the fellow Master's for their comradery (Erin Tattersall, Aisha Uduman, Francis Aurich, Caroline Seip, Alexia Constantinou, Michael Procko, Chris Stinton, and Chris Colton), and the undergrads for their energy (Taylor Justason, Mitch Fennell, and Katie Tjaden-McClement). Thank you also to the Arcese and Martin labs for welcoming me when our lab was still small. And thank you to my committee for their feedback these past years: Peter Arcese and Adam Ford.

My research project would not have been possible without the previous and continuing efforts of the Coexisting with Carnivores Alliance and Wild Wise Sooke who work tremendously hard to support carnivores and residents on Vancouver Island. I was very lucky to attend one Coexisting with Carnivores meeting, as I came away with 50 camera traps and the

Dedication

To my parents for all their support,

my Grandpa Leo Klees, our family's first forester,

the carnivores of Vancouver Island,

and the dogs of Forestry.

Chapter 1: General introduction

1.1 Human-carnivore conflict

As human development spreads further into previously wild habitat, it is crucial to predict and mitigate negative human-wildlife interactions (Woodroffe, Thirgood, and Rabinowitz 2005). Negative interactions – conflicts – can take many forms, including wildlife accessing human food, damaging property, depredating livestock, physical attacks, and car accidents. These conflicts are responsible for billions of dollars of damages, loss of livelihoods, human injuries and death, and often reactive killing of the animals (Nyhus 2016). The frequency of these harmful conflicts is likely to grow as people spread into wild areas, so there is an increasing need to reduce conflicts and protect both people and animals.

Conflicts between humans and carnivores (Order Carnivora) are especially important to consider as they are typically perceived as being more serious, often involving loss of livestock or human safety, and thus the responses can be more severe and have long-ranging effects on carnivore populations. Historically, responses to human-carnivore conflicts often involved eradication, such as seen with large carnivore species across the United States (Woodroffe, Thirgood, and Rabinowitz 2005). As carnivores are at the top of the food chain, they exist in lower numbers which makes eradication more feasible than with more abundant species (e.g. rodents, deer). However, losing top-down trophic control can allow herbivore populations to increase unchecked. Deer overabundance in North America due to decreased predation and increased forage availability has damaged forestry and agriculture, increased the transmission of tick-borne zoonoses (diseases spread from animals to humans), and led to increased vehicle accidents (Côté et al. 2004). Additionally, if the removal of a territorial carnivore is incomplete, immigration of new individuals competing for vacant territories can actually increase conflicts

(McManus et al. 2015). Ultimately, eradication of carnivores is neither socially desirable nor ecologically effective, and thus there is a need to transition to different methods for mitigating human-carnivore conflict.

1.2 Conflict mitigation

Approaches to conflict mitigation can be split into two main categories: proactive and reactive (Karlsson and Johansson 2010). Proactive mitigation consists of practices that prevent conflicts from occurring, such as removing attractants, installing fencing or other deterrents, or using guardian animals (Treves, Krofel, and McManus 2016). Reactive mitigation occurs post-conflict but attempts to reduce the risk of further conflict, such as killing the animal involved, rapid removal of livestock carcasses to reduce repeat attacks, or compensation programs for property damage and livestock lost (Treves, Krofel, and McManus 2016).

Proactive mitigation can create coexistence between people and carnivores, where coexistence is defined as people and animals using the same spaces without unsustainable death or costs to each other (Carter and Linnell 2016). This definition differs from that of coexistence in the context of community ecology, whereby species can live in the same ecosystem by niche partitioning or otherwise avoiding competitive exclusion (Chesson 2000; Huston 1994). Within a human-wildlife conflict framework, coexistence is posited as the opposite of conflict, and includes the social tolerance of risk to allow for the inclusion of costs to humans that do not necessarily cause changes to fitness (Nyhus 2016). One way that proactive mitigation can facilitate coexistence is by building boundaries with territorial carnivores, such as through guardian animals in a livestock herd. This keeps the same carnivore individuals in an area and teaches them to avoid conflict behaviours, rather than continuing conflict with new individuals as

territory opens up to compensatory immigration every time a "problem" carnivore is killed (Cooley et al. 2009).

Proactive mitigation may also be a cheaper and more enduring solution to human-carnivore conflict. An experiment on caracals, jackals, and leopards in South Africa that contrasted reactive lethal control with proactive guardian animals and collars to protect livestock found that reactive lethal control was more expensive once the cost of losing livestock was taken into account (McManus et al. 2015). However, any mitigation method costs time and money. For instance, a common proactive method is electric fencing around attractants that need protection. In addition to initial start-up costs, fences need regular maintenance to ensure they have not been shorted or by-passed by growing vegetation, or damaged by animals attempting access (Breitenmoser et al. 2005). Such expenses may pose a barrier to effective use. Therefore, to minimize unnecessary expenditures, mitigations should be targeted to where and when conflicts are likely to occur.

Recommendations and best practices for attractant management and other conflict mitigations exist in many areas. In North America, bear management programs are especially prolific, as human-black bear conflicts make up the majority of reported conflicts (Spencer, Beausoleil, and Martorello 2007), and both grizzly and black bears have omnivorous diets which allow for a broader spectrum of food-related conflicts (including over livestock, garbage, fruit, animal feed, etc.; Beckmann and Berger 2003a; Gunther et al. 2014). Management recommendations come from a combination of research on carnivore biology, previous tests of mitigation effectiveness, and local knowledge. For instance, in Yellowstone National Park, grizzly and black bears were known to be attracted to local garbage dumps, therefore managers closed the five dumps around the park (in addition to previously implemented reactive lethal

control and translocation) which reduced human injuries from an average of 45 incidents per year to one (Gunther 1994). This success then served as evidence of the effectiveness of securing attractants for other areas.

Often, conflict mitigation recommendations come in the form of management programs that are multi-step, including problem assessment, plan implementation, and monitoring. For example, the Bear Smart program used in parts of British Columbia, Canada, requires three phases: 1) problem analysis, where a bear stewardship committee gathers information on current hazards and potential solutions that must include education and waste management, and optionally bylaws; 2) management plan implementation; and 3) monitoring the outcome (Davis, Wellwood, and Ciarniello 2002). Communities that follow these guidelines do experience reduced conflict (British Columbia Conservation Officer Service, *unpublished data*); nevertheless, even with education, waste management, and enforcement, conflicts continue to occur. These continued conflicts may be due to the presence of unsecured attractants even after education and enforcement. However, there are also disagreements and gaps in the peer-reviewed literature as to the efficacy of recommended mitigations. For instance, education is a main component of most conflict management programs, but a study in Colorado found it was ineffective at changing human behaviour towards securing attractants without bylaws and enforcement (Baruch-Mordo et al. 2011). And while electric fences are touted as effective at deterring cougar depredation, there is a lack of scientific evidence (Breitenmoser et al. 2005). Additionally, mitigations that work in one area may not be as effective in another. Due to the prescriptive nature of conflict management plans, there is little room for region-specific information. In the Bear Smart program, a preliminary hazard assessment must list neighbourhoods that may have greater attractant availability, but detailed maps or further data

collection is optional. Government agencies often have existing data that could be used to better inform mitigation implementation. For example, reports of conflict can be mapped to show spatial patterns, and linked to environmental variables to identify underlying drivers of conflict. Given limited funds for wildlife management, it could be argued that communities should adopt current best practices without a need for further research; however, management recommendations are typically updated with results from research studies, suggesting that implementation and investigation of conflict mitigations should be complementary objectives.

One way to estimate conflict probability is through predictive spatial models. These are models which distinguish areas that have the conditions necessary for conflict (e.g. areas with a high probability of animal use and human presence) from those with low probability of conflict (Treves et al. 2011). They are growing in popularity due to the increasing availability of GIS data on environmental and anthropogenic variables needed to parameterize the models. Predictive spatial models can be developed with presence-only conflict locations, which is often the information already recorded by land managers or conservation officers (Merkle et al. 2011). Therefore, these models avoid the time and resource barriers of other methods, such as presence-absence models which would need fieldwork to acquire absence points (i.e. areas where it is known with some certainty that conflict did not occur). Even when using data collected for other purposes, models of conflict probability have been found to produce useful predictions for up to five years (Treves and Rabenhorst 2017). These models provide land managers with a tool they can use to deploy mitigations in locations where they are most likely to reduce conflicts. However, it is also important to understand if and how carnivores are changing their behaviours or otherwise adapting to human-dominated landscapes in order to understand how the dynamics of conflict may change over time.

To know if carnivores in the urban-wildland interface are adapting to humans, in ways that make conflict either more or less likely, an understanding of when and where they are spending their time is required. Animals select habitats from those available and typically spend more time in areas that meet their needs for food, mates, shelter, and territory (Manly et al. 2002), but avoidance of or attraction to human areas can disrupt patterns of habitat selection. Many mammals have been found to reduce movement (Tucker et al. 2018) and increase nocturnal activity (Gaynor et al. 2018) when using areas dominated by people. If these behavioural changes reduce interactions with people and their property, they may support human-wildlife coexistence. But, if the changes in bear behaviour lead to increased conflicts, such as through accessing livestock at night when farmers are asleep, further mitigation is required.

One way to assess animal habitat use is through camera trap surveys (reviewed by Burton et al. 2015). Since they operate remotely, camera traps can capture natural animal behaviours and activity patterns, even in places and times when human sightings of carnivores are unlikely, (Caravaggi et al. 2017). These detections can then be used to compare the relative amount of a time a species spends in each type of available habitat, adjusting for different seasons and times of day. This information allows land managers to see which habitats are selected, and to deploy mitigations in those areas if they have a high probability of conflict.

One region with high levels of conflict between people and multiple species of carnivore is Vancouver Island, BC, Canada. Vancouver Island is home to the highest density of cougars (*Puma concolor*) in the world (Teichman, Cristescu, and Nielsen 2013), as well as large populations of black bears (*Ursus americanus*) and grey wolves (*Canis lupus*). Vancouver Island is also thought to have one of the highest rates of human-bear and human-cougar interactions in North America (Campbell and Lancaster 2010). A large proportion of this overlap occurs in the

Capital Regional District (CRD) around Victoria, which is a hotspot of conflict due to the rapid

expansion of human development into carnivore habitat. There is currently a lack of bylaws

throughout the CRD targeting attractant management or other conflict mitigations, as well as an

absence of financial support for deploying mitigations such as electric fences or reimbursement

for lost livelihood due to depredation (Debb Read, *personal communication*). Therefore, this

region provides a prime study system for predicting conflict and testing the current state of

carnivore behaviour in the presence of humans to inform evidence-based changes to conflict

management in the future.

1.3 Thesis objectives and hypotheses

To reduce human-carnivore conflicts and promote coexistence with carnivores, it is critical to

have reliable evidence documenting where conflict is occurring now and how that relates to

carnivore habitat use. My research tackled these objectives at two spatial scales. Firstly, I

modelled anthropogenic and environmental predictors of reported conflict across the entire CRD

to estimate and map the probability of conflict. Secondly, I determined local carnivore habitat

use along a gradient of human disturbance, from urban to wild, within a key hotspot of conflict:

the rapidly growing municipality of Sooke. Finally, I compared habitat use to conflict probability

to determine if carnivore spatial behaviour indicates adaptation for coexistence or conflict. By

combining evidence of human-carnivore conflict probability and carnivore habitat use, I began

the first steps in preparing for the effective mitigation of conflict.

In Chapter 2, I combined public reports of negative interactions with carnivores and

hypothesized predictors of conflict to develop predictive spatial models of the timing and

distribution of conflicts with black bears and cougars in the CRD. Predictors of conflict are key

anthropogenic and environmental variables that are associated with the occurrence of conflict.

Previous research has found that conflict probability increases when human disturbance (in the forms of increasing human density, Treves et al. 2011; trail density, Wynn-Grant et al. 2018; proximity to roads, Carter et al. 2010; Teichman, Cristescu, and Nielsen 2013; and farms, Treves et al. 2011) is adjacent to carnivore habitat (e.g. forest cover, Kertson et al. 2011; Treves et al. 2011). Additionally, predictors may change seasonally for species that den or follow seasonal food sources (Beckmann and Berger 2003b; Davis et al. 2006). Therefore, I hypothesized that conflict probability would peak in the areas of highest human-carnivore overlap, at the interface of development and forest. I also expected bears to have a seasonal difference in conflict because of denning and seasonal foods, with conflict absent during the winter denning period and reduced when natural foods are most abundant (e.g. salmon and berries).

In Chapter 3, I concentrated on the municipality within the CRD that reports the greatest amount of conflict to understand how black bears used space across a gradient of human disturbance from urban to wild. Other studies have found that bears typically avoid people (Carter et al. 2010), selecting for forested habitat (Carter et al. 2010; Lyons, Gaines, and Servheen 2003), close to edges and low elevations where they can access vegetation in meadows and riparian areas (Lyons, Gaines, and Servheen 2003). However, in the urban-wildland interface, some bears have shifted behaviours to access human food attractants (Merkle et al. 2013), which suggests they are adapting in a way that causes conflicts. This can lead to higher mortality when reactive mitigation is implemented to kill the offending animal, causing an ecological trap whereby an area that appears suitable (i.e. higher food abundance) actually decreases survival (Lamb et al. 2017). I used the relative abundance of black bears measured from camera traps as an index of bear habitat use to determine where bears were most active along the urban-wildland gradient. I also compared the pattern of human-bear conflicts to habitat

use to determine the relationship between bear use and conflict. I then tested if bears in human-dominated landscapes were more active at night compared to when they were in wild areas. I predicted that if bears were unable to perceive the mortality risk posed by humans, they would not show avoidance behaviours spatially or temporally, which is consistent with the potential for increased conflicts and an ecological trap. Thus, I expected bears to be most active in rural areas, which have the broadest spectrum of human attractants. Since I expected conflict to be highest in the urban-wildland interface in Chapter 2, here I expected conflict probability to have a positive relationship with bear use. Additionally, if humans were not perceived by bears as threats, I expected to see no difference in the degree of nocturnal behaviour exhibited by bears across the interface.

In my concluding chapter, I synthesized the results from my research and contextualized it within the broader field of literature. I provided suggestions for application of this research, while highlighting its strengths and acknowledging its limitations. Lastly, I concluded with ideas for future studies in this study system, and the broader field of human-carnivore coexistence, to take advantage of this project and the wealth of knowledge available from studying human-carnivore conflict on Vancouver Island.

Chapter 2: Predicting human-carnivore conflict at the urban-wildland interface

2.1 Introduction

Carnivores (i.e., species in the order Carnivora) are important for ecosystems and the people in them. For instance, carnivores serve as natural controls against herbivore over-population which can destroy plant communities (Ripple et al. 2014) or cause car accidents (Gilbert et al. 2017). However, where people and carnivores co-occur, they interact and may compete for resources and space, leading to conflict (Woodroffe, Thirgood, and Rabinowitz 2005; Teichman, Cristescu, and Nielsen 2013). Conflicts include many forms of interaction, from food conditioning, to property damage, to injury or death of livestock, pets, or people. To minimize harmful interactions, people often try to influence carnivore behaviour or to kill those animals deemed incompatible with human needs (Woodroffe, Thirgood, and Rabinowitz 2005).

Conflict-related killing represents a major threat to the viability of many carnivore populations (Ripple et al. 2016). For example, killing over real and perceived conflict contributed to the range collapse of North American grey wolves and the extinction of the thylacine (*Thylacinus cynocephalus*; Woodroffe, Thirgood, and Rabinowitz 2005). These declines in carnivore populations can have negative consequences for ecosystems and humans as carnivores can regulate lower trophic levels (Ripple et al. 2016). For example, the decline of African lions reportedly caused an increase in olive baboon populations in West Africa, leading to greater competition with humans for both animal protein and plant food (Brashares et al. 2010). Therefore, proactively mitigating conflict can not only protect carnivore populations but may also improves outcomes for humans.

Proactive measures to mitigate human-carnivore conflict include animal deterrents, public education, and policy (Swan et al. 2017). Common deterrents include guardian dogs, electric

fences, and sound or light deterrents. All three methods can reduce conflict through negative reinforcement, where the carnivores are taught to reduce certain behaviours rapidly through an unwanted experience (i.e. an interaction with a dog, electric shock, or sudden visual and auditory stimuli; Smith et al. 2000). Simulation models have suggested that education programs focused on reducing attractants, such as garbage, can be effective at decreasing conflict with bears (Marley et al. 2017). However, empirical evidence of their effectiveness is more limited; for instance, in Colorado, education programs did not change human behaviour towards attractant management (Baruch-Mordo et al. 2011). Local bylaws and policy may then be required to incentivize rapid change, such as securing garbage (Morehouse and Boyce 2017).

By being proactive, humans can avoid reactive carnivore relocation or lethal mitigation (i.e. animal destruction). Relocation of "problem" carnivores is often preferred to lethal mitigation by people directly impacted by conflict (Don Carlos et al. 2009). However, relocated carnivores often return and "re-offend", or experience higher than expected rates of mortality due to competition or a lack of access to resources in their new territory (Linnell et al. 1997). To avoid prolonging conflict or animal suffering, people often resort to lethal mitigation after a conflict has occurred (Baruch-Mordo et al. 2014).

Human-carnivore conflict is non-random across space and time as it requires people and carnivores to co-occur and compete in the same area (Treves et al. 2011). Since humans tend to aggregate in naturally resource-rich areas, and also bring other food sources with them like livestock and garbage, optimal foraging theory suggests that wild animals should select these areas over others (Holmes and Laundré 2006). Thus, patterns in conflict occurrences may be found and mitigation can be specifically targeted towards conflict "hotspots", which reduces

management costs and increases mitigation effectiveness (Treves et al. 2011; Broekhuis, Cushman, and Elliot 2017).

Predictors of conflict are anthropogenic and environmental variables associated with conflict that can be used to build predictive spatial models of relative conflict probability. Previous studies have found that spatial variation in conflict can be predicted by: increasing human density (Treves et al. 2011), trail density (Wynn-Grant et al. 2018), and proximity to roads (Teichman, Cristescu, and Nielsen 2013; Wynn-Grant et al. 2018), farms (Treves et al. 2011), and forest cover (Broekhuis, Cushman, and Elliot 2017; Kertson et al. 2011; Treves et al. 2011). However, in some cases conflicts were found to be higher in medium human density urban environments near wild areas (e.g. for black bears (*Ursus americanus*), Baruch-Mordo et al. 2008), suggesting that conflict may have a non-linear relationship with human density. Likewise, Teichman et al. (2013) found that human-cougar (*Puma concolor*) conflict was best explained at intermediate elevations. Predictors of conflict may also change seasonally for species who den or follow seasonal food sources such as black bears and grizzly bears (Beckmann and Berger 2003b; Davis et al. 2006).

In British Columbia, predictors of provincial-scale human-cougar conflict included proximity to roads, intermediate elevation, and human density (Teichman, Cristescu, and Nielsen 2013). However, it is unknown which human and environmental predictors are linked to conflict for multiple large carnivore species at the regional and local scales at which management actions are implemented.

2.1.1 Study objectives

Here, I used conflicts reported by residents of southern Vancouver Island—a carnivore conflict hotspot—to model the timing and distribution of conflicts with black bears and cougars. I tested associations between reported conflicts and hypothesized anthropogenic and environmental drivers of conflict. I hypothesized that conflict would increase in areas with high human-carnivore overlap, decrease away from areas of overlap, and be highest in areas of medium human density and at moderate elevations (Teichman, Cristescu, and Nielsen 2013; Baruch-Mordo et al. 2008). I also expected bears to have a seasonal difference in conflict because of denning and alternate food availability, with conflict being absent during the winter denning period (November to April, Davis 1996), and reduced during peak availabilities of salmon (October) and berries (June to October, depending on the berry species; Davis et al. 2006).

2.2 Materials and methods

2.2.1 Study area

The Capital Regional District (CRD) is the government administrative area for the southern end of Vancouver Island, Canada (Fig. 2.1). It includes British Columbia's capital city, Victoria, and twelve other municipalities (the scope of this research excludes the Gulf Islands to the east, although they are a part of the CRD). Mainland CRD encompasses 2,000 km^2 and has a growing human population currently of 383,000 individuals. Vancouver Island is part of the Pacific Maritime ecozone, which is characterized by a warm and wet climate (Canada 1986).

In the CRD, most reported human-carnivore conflict is with black bears (89.5%; British Columbia Conservation Officer Service, *unpublished data*), but Vancouver Island has the

world's highest level of human-cougar conflict (Teichman, Cristescu, and Nielsen 2013). The British Columbia Conservation Officers Service (COS) rarely relocate animals, so in cases of repeated or dangerous conflict, the problem animal is destroyed. Between 2011-2017, 60 black bears and 34 cougars were killed due to conflict in the CRD.
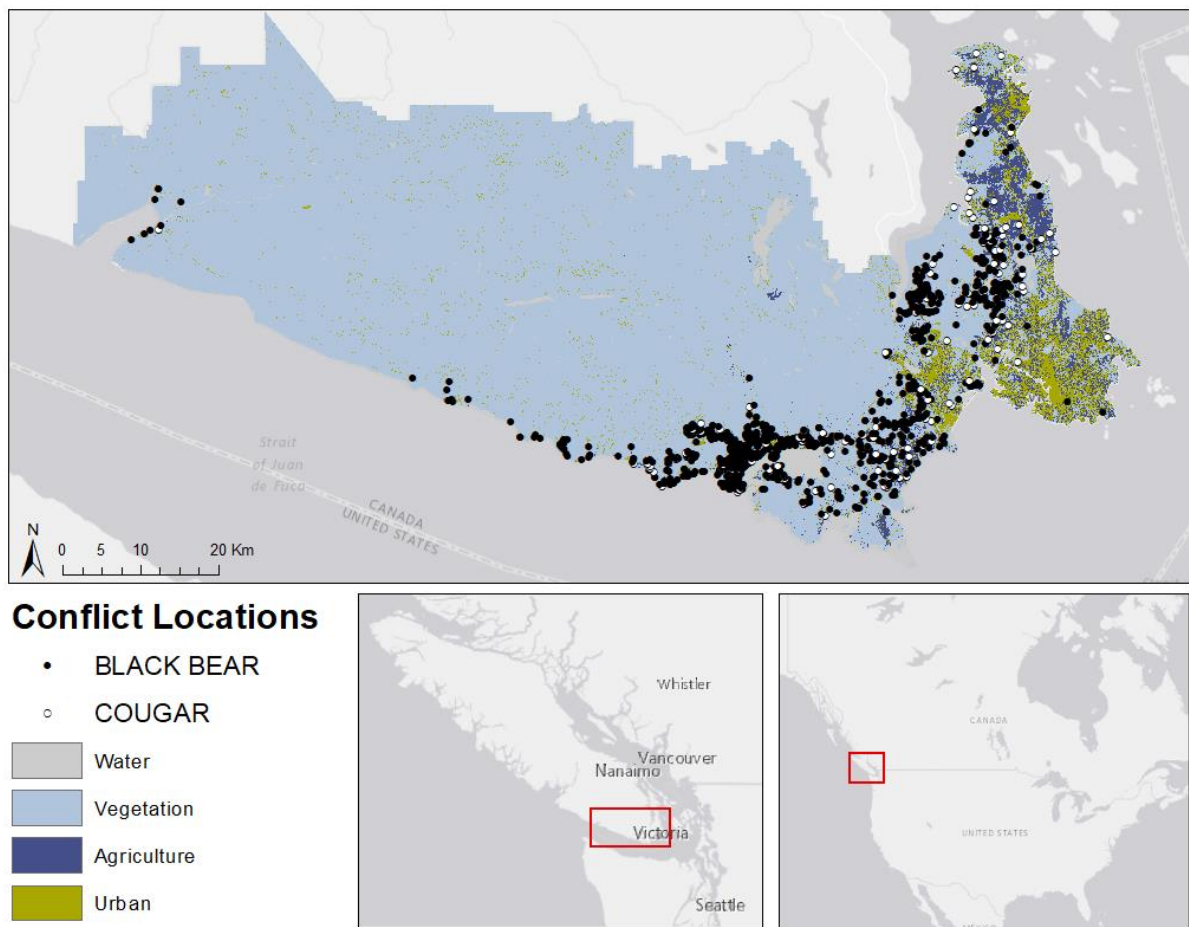
Figure 2.1: Locator map for the Capital Regional District on Vancouver Island, BC, Canada. Circles represent locations of human-carnivore conflict with black bears and cougars from 2011-2017. Vegetation includes coniferous and deciduous forest, shrubs, herbs, and grass. Land cover adapted from CRD Regional Parks (Caslys Consulting Ltd 2017).

2.2.2 Carnivore conflict data

I used reports of conflict with black bears and cougars from 2011 to 2017 in the CRD that were recorded in the COS's Human Wildlife Conflict Reporting Database (HWCRD). This database contains reports about interactions with wildlife that are phoned in by BC residents to the COS call centre (British Columbia Conservation Officer Service 2019). Reports include a description of the interaction with wildlife, the species involved, and the location, date, and time. The HWCRD is unlikely to represent a complete record of all conflicts occurring in the CRD, as some residents may not report interactions with black bears or cougars for a variety of reasons (e.g. different perceptions of conflict, awareness of the Conservation Office program). However, previous research in other jurisdictions has found that demographic factors (such as age, gender, socioeconomic status) have little influence on the likelihood of a person reporting a conflict with black bears (Wilbur et al. 2018). I therefore assumed that the HWCRD reports represent an unbiased sample of conflicts occurring across the CRD.

I re-categorized the interactions from the HWCRD into instances of human-carnivore conflict or non-conflict. I defined conflict as any interaction between one or more carnivores and one or more humans (or their property/possessions/livelihoods) that was negative (causing financial or physical harm) for one or both parties. Non-conflict interactions were those that were positive or neutral, which were predominantly carnivore sightings. I converted street addresses for reported interactions to UTM coordinates using the DataBC's batch geocoder (British Columbia 2017, Fig. 2.1).

The HWCRD included 1261 reported conflicts with black bears between 2011-2017 (Appendix 1). The number of conflicts reported was similar in each year, with a mean of 180.1 (sd = 42.2). Most conflicts occurred in the summer (41%) and autumn (37%), followed by winter

(16%) and spring (6%; Appendix 1). The HWCRD also included 140 cougar conflicts between 2011-2017 (Appendix 1), with greater variability between years than with black bears (mean = 20.0, sd = 10.6).

2.2.3 Predictor variables

I selected anthropogenic and environmental variables expected to influence the probability of carnivore conflict based on previous research (Appendix 2). I developed raster layers describing distances to the following land cover classes: agriculture, urban, intact forest and forest patches, using a 2017 3m resolution land cover raster from CRD Regional Parks resampled to 5m to reduce mapping error (Caslys Consulting Ltd 2017). I separated intact forest and forest patches as black bears have been found to use core habitats differently than disturbed patches (Larkin et al. 2004). I distinguished small patches of forest from contiguous forest (hereafter "patch" and "intact" forest, respectively) based on a break point in size classes of forest areas at 300 m^2.

I extracted elevation from the ASTER Global Digital Elevation (NASA/METI/AIST/ 2009) and human density from the Gridded Population of the World (projected to 2015; CIESIN 2017). Road and trail densities (accessed from BC provincial and CRD Parks GIS layers, respectively) were generated using the Line Density tool in ArcGIS 10.6.1 (ESRI 2018). All GIS variables were extracted in a weighted buffer around the conflict points at two scales: 150 and 500m. Given the potential for locational error when converting street addresses to points, I used a buffer with a radius equal to the length of an average suburban block length (150m) to represent the conflict location (Morehouse and Boyce 2017). The larger buffer of 500m represented the area surrounding a conflict point, allowing for potentially different scale selection by carnivores for different variables (Fisher, Anholt, and Volpe 2011). Extracted variables were standardized by subtracting the mean and dividing by 1 standard deviation, to allow for direct comparison of

estimated coefficients. I acknowledge that there is a potential mismatch in time between the conflicts and spatial variables; however, the 2015 human density projection matches the 2016 census results for the CRD well, and the land cover raster was created using new remote sensing in conjunction with previous land cover datasets from 2005 and 2011.

2.2.4 Analysis

I modelled the relative probability of conflict with black bears and cougars using generalized linear models (GLMs) in a Resource Selection Function (RSF) use-availability framework (Johnson et al. 2006). Models were implemented in R statistical software using the *glm* function (R Core Team 2018). In order to compare locations where conflict was reported with a sample of "available" locations where conflict was possible, I created a polygon around all known locations of interactions with carnivores in the HWCRD (both conflict and non-conflict, n = 4543) by buffering point locations by the average home range of female black bears on the island (7.83 km^2; Davis et al. 2006) and merging those buffered areas into a single polygon. I chose the female black bear home range to be conservative as bears typically have smaller home ranges than cougars, and females have smaller ranges than males (Carter et al. 2010). I randomly selected 10,000 random points within the polygon with a minimum distance of 1 metre (mean = 126 metres) between adjacent points to avoid complete overlap (Northrup et al. 2013). I chose to use 10,000 points based on recommendations from the literature, which found a larger proportion of available points were more reliable for regression models (Barbet-Massin et al. 2012), especially with regards to improving the approximation of the likelihood function (Aarts, Fieberg, and Matthiopoulos 2012). A larger set of availability points also provides an accurate representation of the range of variable values in the study area (Northrup et al. 2013). Finally, this is a similar ratio of conflict to availability points used in another model of black bear conflict

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probability (Merkle et al. 2011; for further discussion of the modelling approach see Chapter 4). My response variable was the presence of a reported conflict or an available location with no conflict reported, modelled as a binomial random variable.

I first ran univariate models for each of the spatial variables at the 150 and 500m scales against conflict with black bears or cougars and compared them against a null model (intercept only) using Akaike's Information Criterion (AIC; Burnham and Anderson 2002). For each variable, the scale within the univariate model with the lowest AIC was used in the full model. I ran a correlation matrix across all predictor variables at their selected scales for each species to ensure no variables had an r > 0.7 (Hosmer and Lemeshow 2000).

I established a set of candidate models representing hypotheses about the variables that would best predict reported conflict for both species. The candidate models included: a) a model with additive effects of all predictor variables, representing the hypothesis that all variables identified in the literature were important in explaining conflict in my study area; b) all variables with either or both human density and elevation as quadratic functions to test if conflict is more probable at medium human disturbance or elevation; c) all variables with an interaction between human and trail density to test if human areas accessible by trails experience more conflict; and d) a full model with all variables and both quadratic and interaction terms (Appendix 3). I again used AIC to identify the best-supported model (Burnham and Anderson 2002). I ran models for black bear and cougar conflict separately and also tested whether black bear conflict locations differed by season by running separate models for spring (February to April), summer (May to July), autumn (August to October), and winter (November to January; Beckmann and Berger 2003b; Davis et al. 2006).

Given that the home range size of individual bears and cougars would encompass an area much larger than my 150-500m buffers around conflict points, I tested for non-independence in terms of spatial autocorrelation in the residuals from best-supported models using Moran's I test (Plant 2012). I used K-fold cross validation to evaluate how well the best-supported models for species and seasons predicted conflict locations (Boyce et al. 2002; Merkle et al. 2011). I divided the dataset for each model into 5 folds, training the model on 80% of the data and testing it against the last 20% (Boyce et al. 2002). I separated predicted values into 10 equal ranked bins and used Spearman rank correlations (r_s) to compare the number of known correct conflict locations from the withheld 20% within each bin to the bin rank, where r_s can range from -1 to 1, with zero meaning no association (Boyce et al. 2002). Calculations were done using the R package "hab" (Basille 2015; J. Merkle, *personal communication*).

Using the coefficients from my best-supported models for species and seasons, I projected (mapped) the relative probability of conflict across the study area on standardized raster layers. I then converted likelihood of conflict on the logit scale to the relative probability of conflict using Raster Calculator (ESRI 2018) and the formula from Johnson et al. (2006):

$$Relative\ probability = \ \exp{(X\widehat{\beta})}$$

Where relative probability is the exponent of the model outputs of observations, *X*, and estimated coefficients, $\hat{\beta}$. And finally, I rescaled relative probability values from 0-100 using Rescale by Function in ArcMap (ESRI 2018)

2.3 Results

2.3.1 Human-Black Bear Conflict

The best-supported model explaining black bear conflict in all seasons included all predictor variables, quadratic terms for both human density and elevation, and an interaction between human density and trail density (Table 2.1). A Moran I test on the residuals of this model rejected the null hypothesis of no spatial autocorrelation (Moran I = 0.008, p-value = 0.018).

The relative probability of conflict increased with road density and proximity to urban, intact forest, and forest patches (Fig 2.2). Conflict decreased with increasing elevation, trail density, and the interaction between human and trail density. Conflict peaked at medium-low human density. The linear effect of human density, distance to agriculture, and the quadratic form of elevation were not statistically significant as their 95% confidence intervals crossed 1 (no effect; Fig. 2.2). The K-fold cross validation Spearman rank correlation was close to 1 which suggests the model had good predictive power (r_s = 0.981, SE = 0.013, Fig. 2.3).

The top models for black bear conflict in summer, autumn, and winter had the same variables as the top non-seasonal model, while the top model for conflict in spring did not include the quadratic term for elevation and the interaction between human and trail density (Table 2.1). The seasonal models followed a similar pattern of associations to anthropogenic and environmental variables as the non-seasonal model; however, in spring, conflict was associated with medium human density, high road density, proximity to intact forest, and lower trail density, with all other variables being non-significant (Appendix 4). This difference in significant variables is illustrated in the map of spatially projected conflict probability, showing conflict predominant in urban centres (Fig. 2.4a). For conflicts in summer, lower elevation and proximity to urban areas were also important (Appendix 4). The concentrations of conflict in summer in urban areas were

similar to the patterns found for conflict in spring, with increased conflict probabilities in suburban and rural areas (Fig. 2.4b). Associations with predictor variables in winter matched the results for summer, except the elevation estimates for both the linear and quadratic terms were non-significant (Appendix 4). This resulted in lower conflict probabilities outside of urban centres (Fig. 2.4d). In contrast, for conflict in autumn, the effect of the linear variable for human density was not significant and the effect size for the quadratic term of human density decreased compared to spring. Autumn was also the only season where distance to forest patch was significant (Appendix 4). In the projected maps, this appears as a decrease in conflict probability in urban centres with a corresponding increase in rural areas (Fig. 2.4c). The Spearman rank correlations showed weaker predictive power for seasonal models than for the model with all seasons combined, but r_s remained close to 1 and was higher for seasons with greater sample sizes of conflicts (spring, $r_s = 0.767$, SE = 0.196; summer, $r_s = 0.974$, SE = 0.021; autumn, $r_s = 0.926$, SE = 0.076; and winter, $r_s = 0.895$, SE = 0.042). There was no evidence of spatial autocorrelation in the residuals of the seasonal models (spring, Moran I = -2.98 x 10^{-4}, p-value = 0.519; summer, Moran I = -4.74 x 10^{-6}, p-value = 0.491; autumn, Moran I = -1.41 x 10^{-4}, p-value = 0.504; and winter. Moran I = 0.003, p-value = 0.249).

2.3.1 Human-Cougar Conflict

The best supported model for cougars included all variables, with human density as linear, elevation as quadratic, and no interactions (Table 2.1). The Moran I test was non-significant suggesting there was no spatial autocorrelation (0.001, p-value = 0.365).

Similar to black bears, cougar conflict increased with proximity to urban areas and forest (intact and patch), decreased with increasing trail density, and peaked at medium elevation (Fig. 2.5). However, cougar conflict decreased with increasing human density. Road density, linear

elevation, and distance to agriculture did not have significant effects on cougar conflict (Fig.

2.5). The predictive power of the model was also close to 1 suggesting good predictability (r_s =

0.875, SE = 0.126, Fig. 2.6).

Table 2.1: Candidate models within 2 AIC for probability of human-black bear conflict (seasonally and non-seasonally) and cougars. Top models indicate which predictor variables best explain location of conflicts for each species/season. HD = human density, RD = road density, DAg = distance to agriculture, DUrb = distance to urban, DFP = distance to forest patch, DFI = distance to intact forest, Ele = elevation, TD = trail density. Values following variable names represent the buffer radius (in m) used to measure the variables around conflict points. Df is the degrees of freedom of the model, ΔAIC is the difference in AIC scores from the top model.

Species/Season	Predictor Variables	df	ΔAIC
Black Bear – All seasons	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Black Bear - Spring	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	10	0.0
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	11	1.7
Black Bear - Summer	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Black Bear - Autumn	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Black Bear - Winter	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Cougar	$HD500 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + Ele150^2 + TD150$	10	0.0
	$HD500 + HD500^2 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + Ele150^2 + TD150$	11	2.0
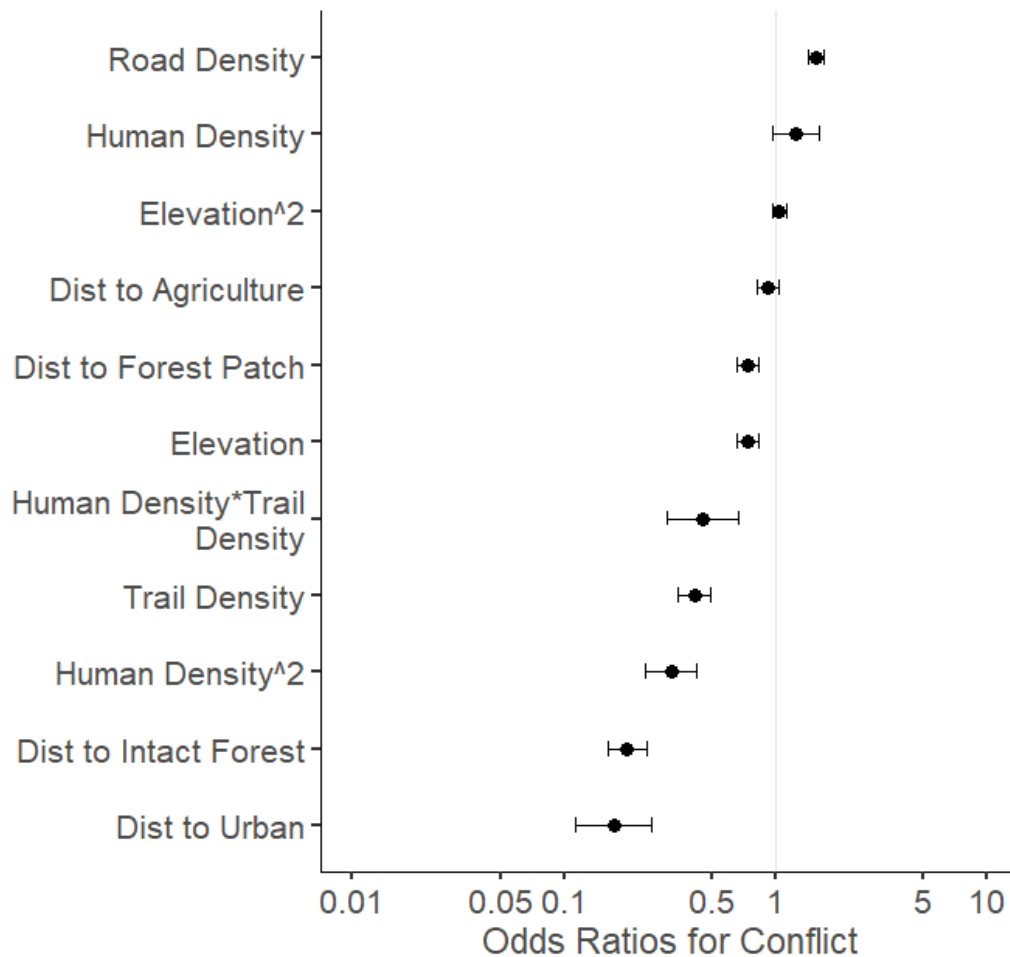
Figure 2.2: Estimated effects of human and environmental variables on human-black bear conflict in the Capital Regional District (CRD), BC, Canada. Coefficient estimates (mean and 95% confidence intervals) from best-supported resource selection function of conflict locations between 2011-2017, back transformed from the logit scale to odds ratios (OR). Predictor variables have been standardized to a mean of zero and standard deviation of one to allow for direct comparison. Distance-to coefficients <1 OR represent selection for that feature.
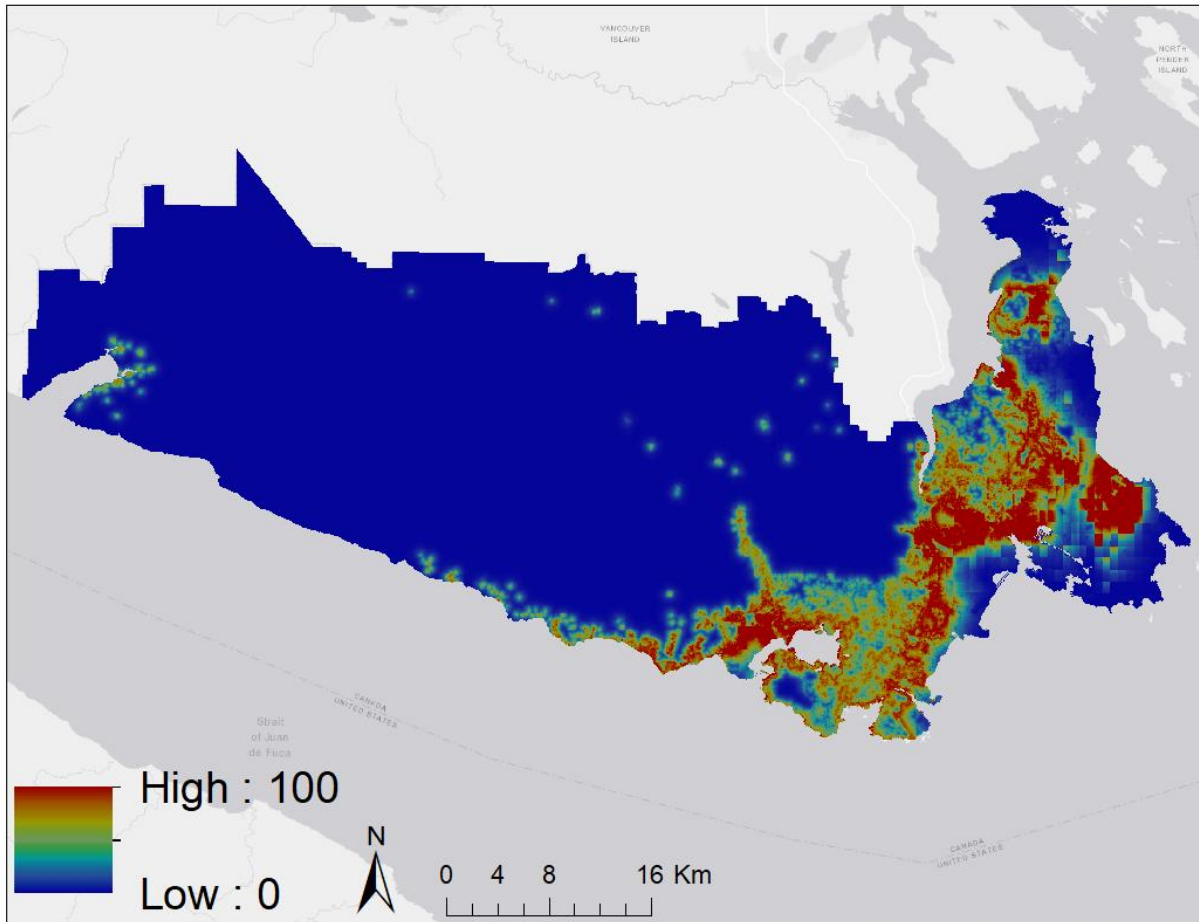
Figure 2.3: Probability of human-black bear conflict in the Capital Regional District (CRD), BC,
Canada. Probabilities estimated from resource selection function using human density, elevation,
distance to agriculture, distance to urban, distance to forest patch, distance to intact forest, road
density, and trail density as variables. Model developed from conflict locations collected
between 2011-2017 in the CRD (Fig 2.1).
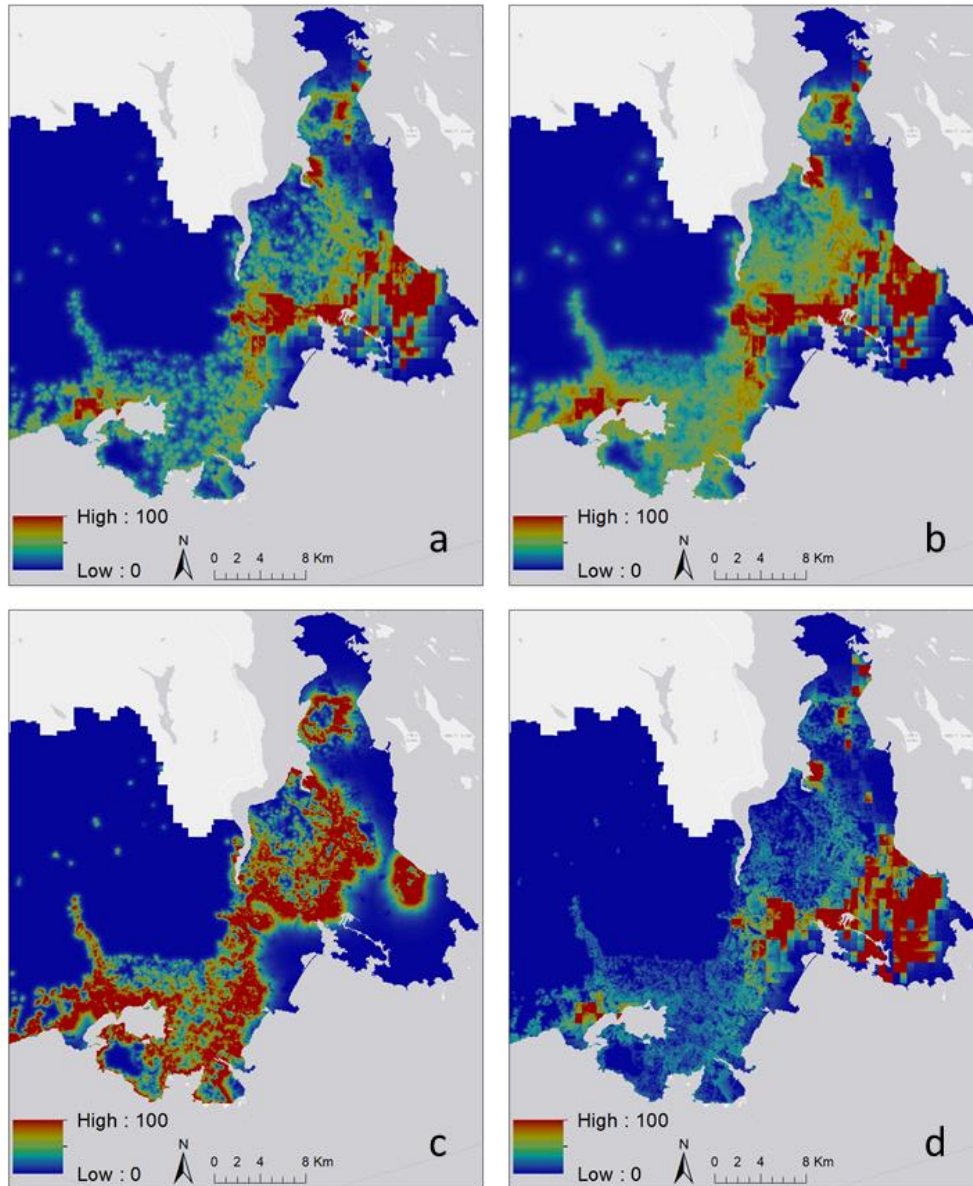
Figure 2.4: Probability of human-black bear conflict in the Capital Regional District (CRD), BC, Canada in four seasons: a) spring: February-April, b) summer: May-July, c) autumn: August-October, and d) winter: November-January. Probabilities estimated from resource selection functions using human density, elevation, distance to agriculture, distance to urban, distance to forest patch, distance to intact forest, road density, and trail density as variables. Model developed from conflict locations collected between 2011-2017 in the CRD.
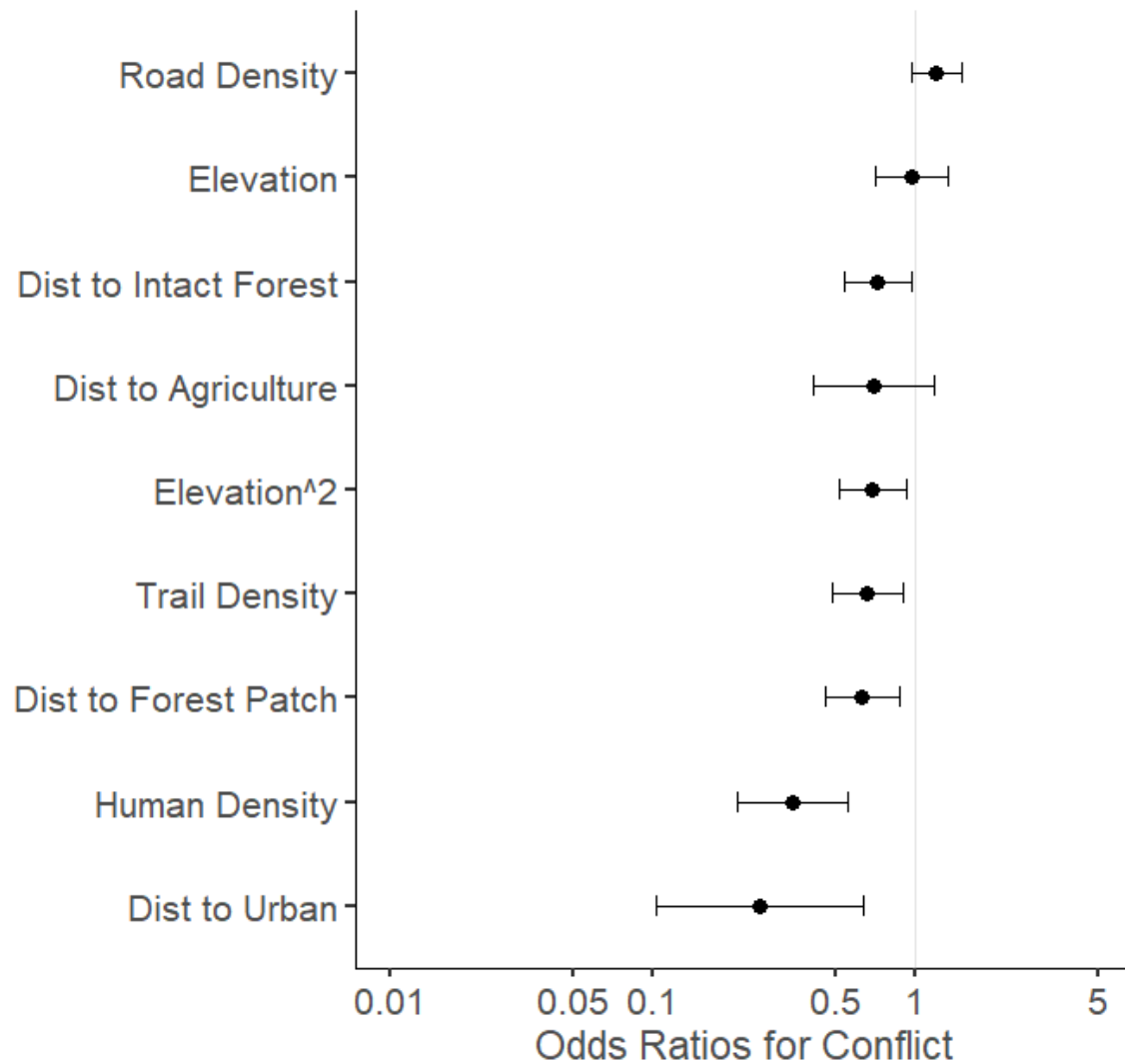
Figure 2.5: Estimated effects of human and environmental variables on human-cougar conflict in the Capital Regional District (CRD), BC, Canada. Coefficient estimates (mean and 95% confidence intervals) from best-supported resource selection function of conflict locations between 2011-2017 back transformed from the logit scale odds ratios (OR). Predictor variables have been standardized to a mean of zero and standard deviation of one to allow for direct comparison. Distance-to coefficients <1 OR represent selection for that feature.
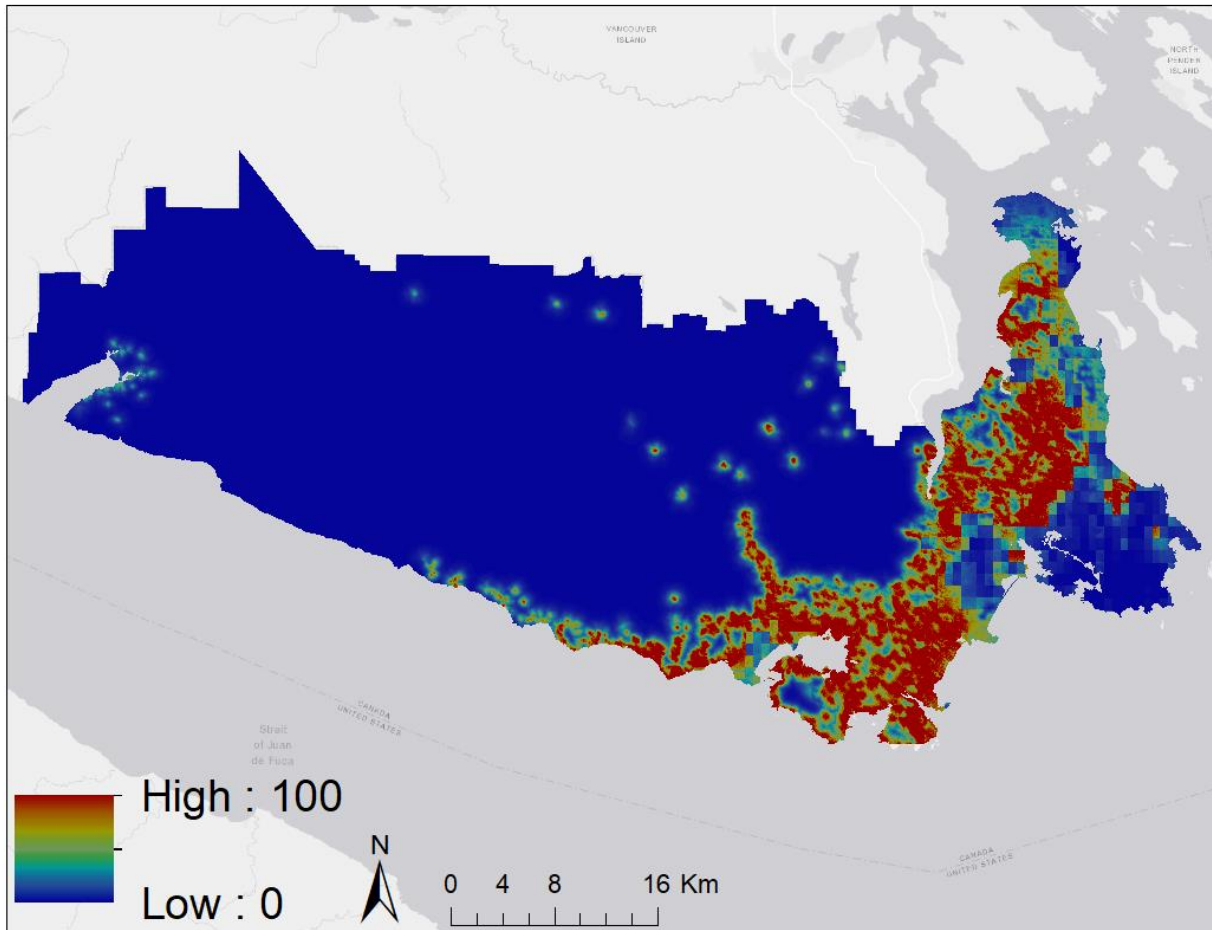
Figure 2.6: Probability of human-cougar conflict in the Capital Regional District (CRD), BC, Canada. Probabilities estimated from resource selection function using elevation, distance to agriculture, distance to urban, distance to forest patch, distance to intact forest, road density, and trail density as variables. Model developed from conflict locations collected between 2011-2017 in the CRD.

2.4 Discussion

Black bear and cougar conflicts made up 99% of the reported conflicts with large carnivores in the CRD, with black bear conflicts being nine times more common than cougar conflicts. I combined known conflict locations with previously available spatial variables describing anthropogenic and environmental features to model and map variation in the probability of conflict across the region. This variation was associated with several key features.

I found that conflict with black bears was positively associated with increasing road density. This is consistent with my hypothesis based on previous studies where black bears avoided main roads because mortality risk increased with road density due to car accident conflicts (Wynn-Grant et al. 2018). While the parameter estimate for road density in the model of cougar conflict was not significant, a provincial study found that cougars experienced more conflict in BC close to roads (Teichman, Cristescu, and Nielsen 2013). Although higher mortality may decrease use of an area by a carnivore species, the attraction of roads as travel routes (Carter et al. 2010), or the necessity of crossing them to find better habitat, may explain the continued use of roads by carnivores.

The relative probability of conflict increased with proximity to intact and patch forests for both black bears and cougars. This shows that conflict is more likely close to forest edges as they represent areas of human-carnivore overlap and anthropogenic food attractants (Treves et al. 2011). The importance of both intact forest and patches suggests that carnivores in the CRD are using forested areas regardless of size, which differs from Merkle et al. (2011) who found that forest patches were not a significant predictor of black bear conflict. They concluded land planners may not need to consider the impact of forested urban parks on conflict, while my

results suggest forest patches are used by carnivores and should be considered in conflict management planning.

I hypothesized that black bear and cougar conflict would increase with trail density, but found the opposite. This could be because trails interrupt natural habitat for these carnivores and make it less likely for them to use an area. However, grizzlies and wolves in northern Canada use seismic lines as movement highways (Finnegan et al. 2018). My result could also suggest that humans living near heavily-trailed systems are more used to carnivores and thus more likely to reduce or remove attractants. Alternately, people who frequently see carnivores may become desensitized and less likely to report conflicts they perceive as minor, though Wilbur et al. (2018) found that repeated sightings motivated reporting.

Conflict with black bears and cougars increased with proximity to urban land cover. Urban areas may have more unsecured attractants, and thus more conflicts, than rural areas where residents may expect carnivore occurrences. Communities unprepared for carnivores may have a lower tolerance for carnivores or may experience more severe interactions (i.e. those relating to safety or property damage), which have the greatest impact on reporting (Wilbur et al. 2018).

Conflict had a negative relationship with elevation for black bears and a non-linear relationship for cougars, with conflict peaking at medium-low elevation. This matches previous results for human-cougar conflict in BC (Teichman, Cristescu, and Nielsen 2013). In the CRD, lower elevations typically have more human disturbance and density, so black bears may be attracted to urban anthropogenic food sources such as garbage. Locations at medium elevation would be an intermediate distance from high human development, that is, areas on the wildland interface that are more likely to contain multiple types of attractants including livestock attractive to cougars.

Human density was included in the top black bear models and followed my hypothesized non-linear relationship with conflict, with higher probabilities of conflict at medium human densities (Merkle et al. 2011; Baruch-Mordo et al. 2008). By contrast, the top cougar model had a linear decrease between conflict and human density. Humans in suburban and rural areas often have more land for growing food and livestock, while also having de-centralized garbage removal systems that may lead to available food for bears. These areas may also represent intermediate risk to bears as they can access attractants while remaining close to secure cover. For cougars, conflict probability declined with human density as they are a more elusive species that avoids people (Dellinger et al. 2019). Cougars are also obligate carnivores (Morrison et al. 2014), thus urban areas without livestock may be less attractive. This is not consistent with results found by Teichman et al. (2013) at the provincial scale which found that male cougars experienced more conflict at high human densities, but was similar to the finding that females had less conflict in more heavily populated areas.

The best model for black bear conflict also included a negative interaction between human and trail densities. Again, this may suggest that humans living closer to parks with trails are better informed or more motivated to reduce conflict through attractant removal or other mitigations and may also be less likely to report conflicts.

In terms of seasonality in conflict, I hypothesized that black bear conflict would be highest in summer, after the winter denning period and before natural foods such as salmon and berries hit their peaks (Davis et al. 2006; Davis 1996). This may be when human food sources are most attractive as an efficient way to meet energetic requirements. Conflict with bears did peak in summer; however, conflict was present in all seasons as some bears on Vancouver Island are not denning due to available food year round and warmer winter temperatures (Johnson et al. 2017).

Conflict probability was highest in urban areas during winter, spring, and summer, which I suggest is due to the higher availability of garbage in these areas. Garbage is attractive to bears because it is available year-round, predictable, renewable, and has a clumped dispersion, making it a high energy reward at low effort (Beckmann and Berger 2003). In autumn, conflict probability increased in rural areas, which may relate to the greater presence of natural foods or agricultural harvest in these areas at these times. The ratio of conflicts associated with non-garbage human foods (compost, animal feed, or fruit; as reported in the HWCRD) also increased as these are more available in rural landscapes in autumn. Merkle et al. (2013) found that bears foraged on human foods even when natural options were available, which may suggest they are changing their seasonal behaviour to adapt to anthropogenic environments. In the autumn, bears that are preparing to den through hyperphagia may instinctually choose the highest density of calories which is often aggregated human attractants (Baruch-Mordo et al. 2014).

On the whole, my results provide targets for efficient deployment of conflict mitigations. While the maps are spatial depictions of the modelled associations, some care is required in their interpretation. For example, areas predicted to have high conflict probability in Figs 2.3 and 2,4 have values of the anthropogenic and environmental variables associated with observed conflicts; however, some may experience lower conflicts if they are not frequently used by carnivores. Understanding carnivore movement and habitat use is required to have a fuller understanding of conflict probability (see Chapter 3). Therefore, the maps (and underlying models) can be used as general guides for considering mitigation measures, but should be combined with local knowledge of managers and residents. Conservation officers, educators, and land managers can target communities along the borders of forests to contain their garbage in bear-resistant bins and deploy electric fences set to deter multiple species (i.e. multi-strand

fences for bears with high walls to deter jumping cougars). Other deterrents that protect livestock against multiple carnivore species, like guardian dogs, may also be appropriate (Breitenmoser et al. 2005). Temporally, rural attractants increase in importance for bears in the autumn, so focus should shift from urban garbage to rural compost containment and fruit removal. These results support the current recommendations of BC governmental programs such as Bear Smart and WildSafe BC, which advise securing or removing food attractants (Davis, Wellwood, and Ciarniello 2002). However, the explicit need to consider deterring multiple carnivore species from common attractants such as livestock is an important outcome of this project.

This project was designed to use readily available information to allow land managers to continue updating these models with new conflicts and use the results to target proactive mitigation. However, to improve model performance, especially for cougars, further information would be beneficial. Cougar habitat selection is often driven by prey (particularly deer; Gladders 2003; Kertson et al. 2011), so knowledge of prey distribution may help in predicting the likelihood of cougar conflicts. For bears, data on berry crops, salmon timing and abundance, and the location of all salmon bearing rivers/streams could help tease apart the degree to which patterns of conflict in are influenced by those natural food sources relative to agriculture harvest. Additionally, rivers and stream locations were important predictors of conflict in other black bear models because of the large role of riparian vegetation in black bear diets (Merkle et al. 2011). It would also be interesting to further explore the relationship between trail density and conflict to see if reporting bias explains the relationship or if carnivores are avoiding heavily trailed areas.

The conflict probability maps for black bears showed conflict hotspots in downtown core areas with low actual conflicts reported in spring, summer, and winter. This may be due to the presence of variables conducive to conflict (e.g. high human density), but a lack of connectivity

for carnivores to access the urban cores, combined with swift conservation officer attention to any animals getting close to urban centres. Physical barriers to entering cities include major highways, lack of connected forest, and high human activity both day and night which can scare off carnivores. Further research could map connectivity to remove isolated areas from the conflict probability map, improving the targeting of mitigation location priorities. The maps also extrapolate beyond the range sampled by the availability points for elevation and the distance-to metrics. Therefore, the illustrated probabilities far from conflict locations in the upper left of the CRD should be interpreted with caution. However, due to their remoteness, the predicted low conflict probabilities are expected.

The overall black bear conflict model had a significant Moran I value suggesting there was spatial autocorrelation in the model residuals. By contrast, residuals from the seasonal models were not spatially autocorrelated, which may suggest seasonal differences in black bear conflict meant that explanatory variables in the non-seasonal model were unable to account for all the spatial autocorrelation in conflict locations. Future models could include another variable that changes seasonally, or a spatial autocovariate that explicitly includes spatial autocorrelation in the model (Augustin, Mugglestone, and Buckland 1996). However, given the similarity in variable associations and conflict maps for the overall black bear model versus the seasonal models, it is unlikely spatial autocorrelation had a large effect on the results.

Understanding these spatial and temporal patterns of conflict is critical to facilitating coexistence between carnivores and human communities. On Vancouver Island, black bears are perceived as less dangerous but more troublesome than cougars (Campbell and Lancaster 2010), meaning residents do not want bears to be killed (Don Carlos et al. 2009). This can lead to antagonistic relationships between local residents and conservation officers, making residents

less likely to report minor conflicts that escalate into situations where an animal is killed for public safety. Therefore, if carnivore deaths are reduced by proactive mitigation of conflict, it also increases the public trust that conservation officers are protecting both people and wildlife (Can et al., 2014).

As humans expand further into carnivore ranges, conflict with carnivores will increase and spread over a greater area, and even more so if anthropogenic attractants are available (Beckmann and Berger 2003b; Baruch-Mordo et al. 2008). Given the wide interface of human-carnivore overlap, proactive measures such as education, bylaw enforcement, or electric fencing need to be deployed efficiently. By using available data on conflict and its spatial predictors, the underlying drivers of conflict can be understood at local scales where it is critical that conflict management actions achieve more effective outcomes.

Chapter 3: Factors influencing black bear habitat use and conflict along an urban-wild gradient

3.1 Introduction

The urban-wildland interface, where human development transitions to wild lands, is increasing as human development expands (Woodroffe, Thirgood, and Rabinowitz 2005). Some animals are displaced by this change while others are able to adapt their behaviours to use the interface (Wolf and Ripple 2017). For instance, many mammals have been found to reduce movement (Tucker et al. 2018) and increase nocturnal activity (Gaynor et al. 2018) when using areas dominated by people. These behavioural adaptations may function to reduce contact with humans, such as limiting activity to times when people are not present, or reflect the constraints imposed by anthropogenic habitat fragmentation. Behavioural changes that decrease negative interactions may lead to coexistence, where humans and wildlife share landscapes without unsustainable risk of death, injury, or significant cost to either party (Carter and Linnell 2016). However, these adaptations could also represent attempts by animals to access calorie-rich human foods at night when risk of human confrontation is lower, thereby meeting caloric needs faster and reducing incentives to move. This could increase conflict, which I define as interactions between carnivores and people (including their property/possessions/livelihoods) that are negative for one or both parties. This suggests that the same behavioural adaptation, such as increased nocturnality, could lead to either coexistence or conflict.

As the expanding interface is causing increased human-wildlife conflict (Nyhus 2016), it is important to understand whether animals are adapting to human influences in a manner that promotes coexistence or conflict. A study on tigers in Nepal found that tigers using the same trails as humans outside a national park switched to more nighttime activity, avoiding the direct

contact which was often linked to attacks on humans and tiger poaching (Carter et al. 2012). This change in temporal activity by tigers suggests behaviour that promotes coexistence. In contrast, cougars in California, USA, also increased nocturnal behaviour in human-dominated landscapes, but at the cost of increasing their movement and thus their caloric expenditure. In this case, the behavioural change increased their need for food and potentially the likelihood that they would pursue human attractants such as livestock (Wang, Smith, and Wilmers 2017). If an animal is changing behaviours in a way that is detrimental to their fitness, either through direct health consequences or increased risk of reactive killing in response to conflict, the adaptation is less likely to result in coexistence over the long term.

Anthropogenic food attractants are a common source of human-wildlife conflict (Woodroffe, Thirgood, and Rabinowitz 2005). Other conflicts, such as attacks on humans, are often defensive rather than beneficial for the animal, so they are more likely to avoid expending that energy and risking harm to themselves (as in the tiger example above; Carter et al. 2012). But, human food resources like garbage are attractive and appear beneficial as they are consistent at least weekly and year round, can be high in calories, and are spatially aggregated, thus requiring less foraging effort (Beckmann and Berger 2003b). This can draw animals in from surrounding wild areas and create conflict if they are able to access the food. For potentially dangerous animals like carnivores, management responses to these conflicts typically involve relocating or destroying the animal (Spencer, Beausoleil, and Martorello 2007; Merkle et al. 2013). If mortality is higher in areas of greater conflict compared to wild areas with low or no conflict, this represents an ecological trap whereby an animal selects the area based on its resources but experiences unexpectedly high mortality and lowered fitness (Lamb et al. 2017). These ecological traps

function as population sinks which have negative impacts on long-term population persistence (Beckmann and Lackey 2008).

The impact of an ecological trap can be greater for carnivores than species at lower trophic levels. Carnivores tend to have larger home ranges, which may increase the distance a carnivore could be attracted to an urban area from (Lamb et al. 2017). They often lack natural predators and thus may be less likely to perceive risk (Lamb et al. 2017). And carnivores typically have slower recruitment rates which may decrease their ability to adapt to increased mortality (Beckmann and Lackey 2008). For example, when ungulates were depleted by European colonizers in North America, grey wolves turned to livestock, moving out of wild lands into agricultural areas (Breck and Meier 2004). The real and perceived risk of wolf depredation of livetock, in addition to fears for human safety, catalyzed extermination campaigns that swiftly led to wolf population declines across most of the United States (Woodroffe, Thirgood, and Rabinowitz 2005).

Carnivores may be able to coexist with humans if anthropogenic food attractants are secured or the mortality risks associated with human-dominated areas are clear. Often this requires proactive mitigation from people to create an environment that is either free of attractants or hostile to carnivores. For instance, if securing all livestock indoors is not an option, setting up an electric fence to deter carnivores can reduce conflict (Breitenmoser et al. 2005). To know whether new mitigations are required or if current mitigations are working, we need to understand how carnivores are using habitat within the urban-wildland interface and how that relates to conflict.

Black bears (*Ursus americanus*) are a useful species for this research question as they often occupy the urban-wildland interface and have been found to change their natural behaviours

spatially and temporally as a result of human disturbance. They are a forest-adapted species but have generalist diets and the ability to alter their foraging patterns quickly to access new food sources (Beckmann and Berger 2003b; Don Carlos et al. 2009; Merkle et al. 2013). As a hibernating species, black bears exhibit hyperphagy, where they excessively eat to store energy over the summer and fall in order to survive the winter (Spencer, Beausoleil, and Martorello 2007). Unlike many other members of Order Carnivora, bears are omnivores, which opens up more avenues for human-bear conflict over food in human landscapes, as bears may eat not only livestock, but also garbage, compost, bird feed, and fruit. Anthropogenic food sources are often selected over wild ones by bears (Merkle et al. 2013), suggesting food-conditioning may be responsible for changes in bear behaviour in the urban-wildland interface. In Nevada, black bears in urban spaces differed from their wild counterparts by being less active each day (as they met their caloric intake faster), switching from diurnal to nocturnal activity to avoid direct human encounters, and spending shorter periods in dens (i.e. entering dens significantly later and leaving earlier; Beckmann and Berger 2003b). Evidence suggests that some bears do not hibernate at all if they live in moderate climates and have continuous food sources like garbage in the winter (H. E. Johnson et al. 2017).

Human-bear conflicts peak in the late summer and early fall, when bears go into hyperphagia (Spencer, Beausoleil, and Martorello 2007). Conflicts may also be higher in urban environments with intermediate human density that are near wild areas (Baruch-Mordo et al. 2008, Chapter 2.). A study surveying black bear managers across North America found that 69% ranked garbage/food attractants as the most common reason for conflict (Spencer, Beausoleil, and Martorello 2007), and another study found that the number of conflicts per year is increasing (Baruch-Mordo et al. 2008). Management responses to these conflicts typically involve

relocating or destroying the bear (Spencer, Beausoleil, and Martorello 2007; Merkle et al. 2013). Understanding where bears are using space and how that relates to their probability of conflict, would allow land managers to direct mitigation to areas in need and evaluate if current mitigations are effective. This could lower the mortality cost of bears that use the urban-wildland interface, and ultimately remove a potential ecological trap.

Previous research on black bear habitat use has found that bears typically avoid people by spending less time in developed areas or near roads (Carter et al. 2010), and instead select for forested habitat (Carter et al. 2010; Lyons, Gaines, and Servheen 2003), close to edges and low elevations where they can access vegetation in meadows and riparian areas (Lyons, Gaines, and Servheen 2003). By preferring edges they are already primed to thrive in the urban-wildland interface as rural and suburban development creates more edge habitat which may increase natural foods like berries (Davis et al. 2006) and bring in new anthropogenic food attractants. The interface is also where conflict was most probable in my Chapter 2 analysis of human-black bear conflict. I found that conflict probability increased when human disturbance (urban land cover) adjoined natural habitat (intact forest and forest patches), and in areas with medium human density. However, in autumn, high-conflict probability expanded into rural/agricultural areas, and reports of human-bear conflict shifted from primarily garbage to fruit, compost, and other rural attractants. Carter et al. (2010) found that male bears selected for agricultural lands, but these patterns may shift during years of high natural food productivity (Baruch-Mordo et al. 2014). It is also likely that seasonal conditions affect the attractiveness of human areas, as is seen with the increase of rural conflicts during summer and autumn when crops ripen. Thus it is important to study bear habitat use both spatially and temporally to understand the implications for conflict.

3.1.1 Study objectives

In this study, I aimed to understand the spatial and temporal dynamics of black bear habitat use along a gradient of human disturbance from urban to wild. I used camera traps to estimate the relative abundance of black bears as an index of bear habitat use to determine if bears were more active in urban, rural, or wild areas over a full year. I also compared the predicted relative probability of human-black bear conflict (from Chapter 2) to habitat use to determine the relationship between bear use and conflict. And finally, I tested if bears in human-dominated landscapes were more active at night compared to when they were in wild areas.

I predicted that if bears were unable to perceive the mortality risk posed by humans, they would not show spatial or temporal avoidance behaviours, and would be more likely to experience conflicts. Thus, I expected bears to be most active in rural areas (i.e., the interface between urban and wild) where they had access to a broader spectrum of human attractants, such as garbage and bird feeders, but also unique attractants like livestock and food crops in addition to wild resources. Following this logic, I expected bear habitat use to be best modelled by the same variables used in Chapter 2 to model variation in conflict (with the same variable associations suggesting the bears were selecting areas that have a higher conflict probability), by anthropogenic variables such as being strongly associated with higher human density, or by environmental variables such as negative associations to forest or high elevation. I hypothesized that if bear habitat use was greater in high-conflict or human-dominated areas, this would suggest the bears were not coexisting (by avoiding people) and Sooke could be an ecological trap. Since conflict was also highest in the urban-wildland interface (Chapter 2), I expected conflict to have a positive relationship with bear use. Additionally, if human landscapes were not

perceived by bears to be risky, I expected no difference in the amount of nocturnal behaviour in urban versus wild areas.

As an alternative hypothesis, if bears were adapting for coexistence or if effective mitigation was in place allowing the bears to learn there was no longer a benefit of using human areas, I predicted bears to be spatially and temporally avoiding people (Gaynor et al. 2018; Beckmann and Berger 2003b). Accordingly, I expected habitat use to be best modelled by either environmental variables only with positive associations, anthropogenic variables only with negative associations, or by the same variables as used to model conflict but with opposite associations than in Chapter 2, such that bears were avoiding conflict areas. If habitat use was greater in low-conflict areas, away from humans, or best modelled by environmental variables, this would be consistent with the idea that bears were learning from or adapting to humans (and potentially their mitigation measures), and thus coexisting. Therefore I expected the areas of greatest space use to be those with a low-conflict probability. I also predicted bears would be more active at nighttime in urban and rural areas than in wild areas.

3.2 Methods

3.2.1 Study area

The municipality of Sooke, west of Victoria on Vancouver Island, British Columbia, has a current human population of approximately 13,000 and is the second fastest growing municipality in the Capital Regional District (CRD 2016), resulting in forested land being converted into new housing developments. Sooke has 60% of the reported human-bear conflicts in the CRD, with over double the number of calls to the conservation officers than any other municipality (Conservation Officer Service, *unpublished data*). Sooke also has the highest conflict-related mortality for black bears, accounting for 38 of the 60 bear deaths reported

between 2011-2017. These deaths were all management actions in response to conflict, primarily through trapping and euthanizing the bears.

3.2.2 Camera traps

I used a camera trap survey to assess spatial and temporal variation in bear occurrence. I set 54 camera traps in and adjacent to Sooke along a gradient of human disturbance from urban to wild, covering an area of 80 km^2 (Fig. 3.1). Camera traps are an established tool for monitoring large terrestrial animals with minimal human influence on behaviour, and can be as effective as other methods such as collaring depending on research objectives (Caravaggi et al. 2017). Camera trapping is non-invasive and thus safer for both the animals and researchers (Burton et al. 2015).

Cameras were deployed following a stratified design to allow for representative allocation of cameras based on the proportion of the 80 km^2 survey area falling within one of three strata: urban (11 cameras), rural (19), or wild (24; Morrison et al. 2008). Urban and rural camera sites were located on private properties selected from a candidate list of residents to maintain 200-500 m between cameras, which I deemed sufficient for spatial independence (following EMammal 2017). Wild sites were those in Sea to Sea Regional Park and T'Sou-ke Nation lands. To randomize sampling locations within the regional park while maintaining accessibility, a 500 x 500m grid was overlaid on trail maps and 10 random cells that contained a trail were selected. For areas with only one main trail, cameras were set off the main trail, 200-500m apart. Deployment occurred between early July 2018 and August 2018. In order to sample seasonal variation in black bear habitat use (Davis et al. 2006), all cameras remained deployed for a full year, and were retrieved in July 2019. I used a combination of three models of camera trap: Reconyx PC900, Reconyx HC600, and Browning Strike Force HD Pro. To reduce potential

effects of different detectability between camera models, they were randomly allocated across

strata.
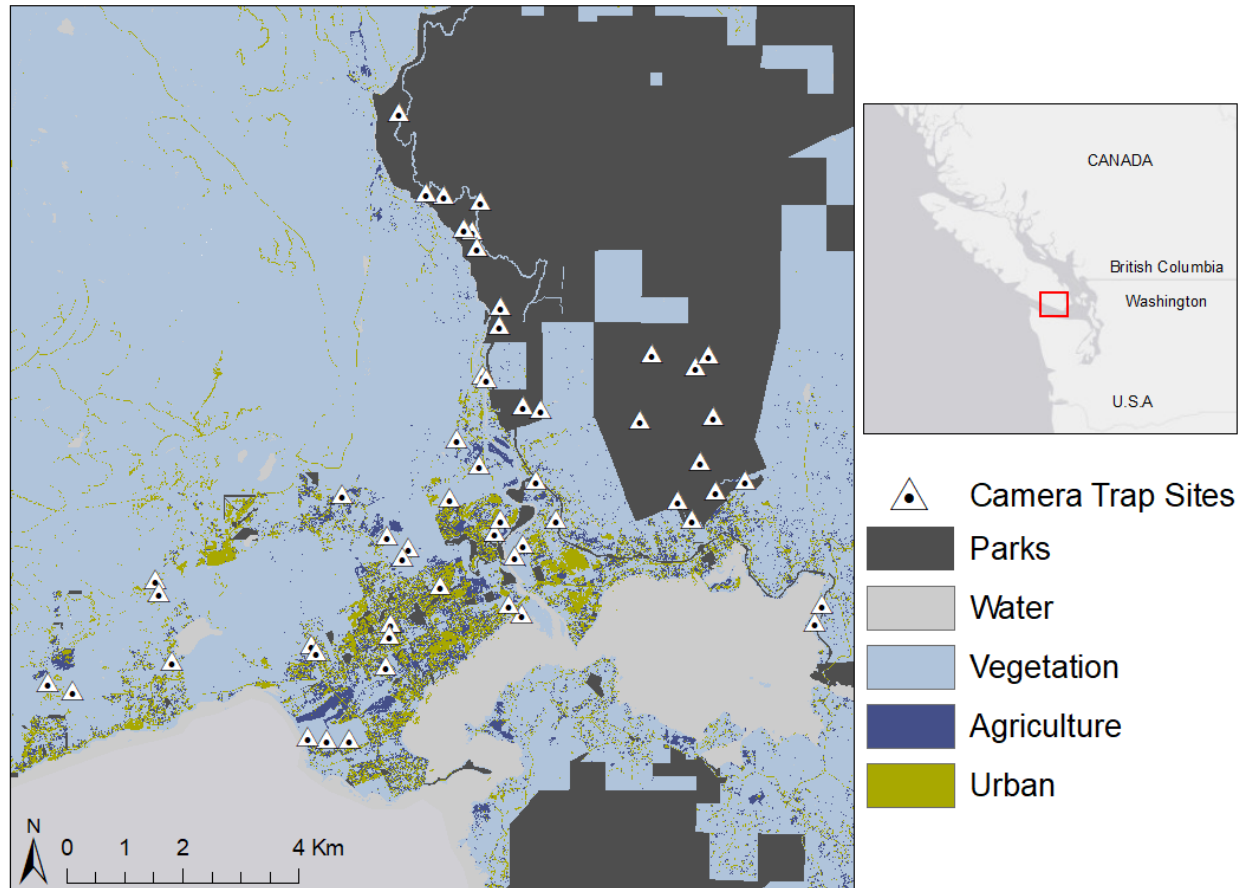
Figure 3.1: Location of camera traps used to sample black bear relative abundance in and around
the municipality of Sooke on Vancouver Island, BC, Canada. Vegetation includes coniferous and
deciduous forest, shrubs, herbs, and grass. Land cover adapted from CRD Regional Parks
(Caslys Consulting Ltd 2017).

Within a selected property or sampling cell, I set cameras at locations chosen to maximize

the probability of detecting bears that occurred there, using local knowledge of where bears

moved across properties, or the presence of animal trails and sign. One camera per site was set

on a tree approximately one metre above the ground, at high sensitivity, with a one second delay

between triggers (one image per trigger), and facing open spaces such as meadows, lawns, or animal trails. Cameras were also set on unofficial low-use human trails as black bears have shown a preference for using low-use human paths because of the ease of movement and increased shrub vegetation containing berries (Davis et al. 2006; Latham, Latham, and Boyce 2011). If possible, cameras faced an intersection of multiple animal and/or low-use human trails.

I visited the camera traps every 2-3 months to download images, check functionality and replace batteries as needed. I used Timelapse Image Analyzer 2.0 (Greenberg and Godin 2015) to classify all camera trap images of black bears. I defined independent detection events as those separated by at least 30 minutes to avoid pseudoreplication as individual bears were not uniquely identifiable (Burton et al. 2015). I summed the number of events at each camera site for each month (702 observations: 13 months x 54 cameras) to calculate the index of relative abundance as a proxy for habitat use.

3.2.3 Modelling framework

I used a zero-inflated generalized linear mixed modelling (GLMM) framework in R (R Core Team 2018) to model bear habitat use. My dependent variable was the calculated relative abundance of black bears at each camera monthly (a count of independent detections). Some cameras did not detect bears every month and others never detected a bear, leading to 80% zeros in the dependent variable, therefore I used zero-inflated modelling (Zuur and Ieno 2016). To address overdispersion in the Poisson distribution, I used a negative binomial regression model. I used Akaike's Information Criterion (AIC) to compare models and selected the lowest AIC as my top model (Burnham and Anderson 2002). To control for the fact that bear detections at a site were not independent across months (i.e. repeated measures), I included a random intercept for

camera site in all of my models. Some cameras experienced failures which I accounted for in my models by including a variable of active days per month for each camera.

3.2.4 Predictor variables

To relate bear detections to environmental and anthropogenic features, I extracted a suite of independent variables at each camera trap location. I included the same variables as in my Chapter 2 analysis on predictors of conflict to allow for direct comparison of the importance of these variables in explaining reported conflicts at the regional scale versus bear habitat use at the local scale. Specifically, the variables were human density, trail density, road density, elevation, and distance to agriculture, urban, intact forest, or forest patches (details in Appendix 5). All variables were extracted within a weighted 150m buffer around each camera site. However, I thought that the distance-to variables from Chapter 2 might be missing some fine-scale variability in Sooke. Since all cameras were set within forest patches, I evaluated the explanatory benefit of replacing the distance-to-forest variables with the Enhanced Vegetation Index (EVI) from MODIS's 250m 16-day layers (MOD13Q1), which characterizes variation in vegetation greenness, leaf area and canopy architecture. Unlike other common vegetation indices, EVI does not saturate in high biomass areas like forests, remaining sensitive to variation (Huete et al. 2002), so it can be used to compare sites that are all forested but might have differences in productivity. EVI can also be used as a proxy for fruit in rural areas as ripeness peaks at the same time (Fraga et al. 2017). I used a weighted average based on number of days the 16-day MODIS window had within my focal calendar month of analysis and the amount each raster cell fell into a 150m buffer around each camera site. I also calculated a new land cover variable describing the proportion of area developed around each camera site, by summing the proportion of urban,

agriculture and grass land cover classes (Caslys Consulting Ltd 2017). This variable could replace distance-to-agriculture and -to-urban since they did not account for developed areas in Sooke with manicured lawns or pastures. However, it was highly correlated with human density ($r = 0.85$) while the distance-to variables were not, so they were not replaced. To assess if the alternative EVI improved upon the "distance-to-forest" variables, I ran competing regression models with the original variables and the alternative variables and compared them using AIC (Appendix 6). The model using the alternative variables had a lower AIC so all further model selection used those.

I also generated additional Sooke-specific variables to account for some natural food occurrence and recent conflict reports. I included distance to freshwater, as riparian vegetation has been shown to be important for black bears (Merkle et al. 2011), presence/absence of salmon at sites near salmon-bearing water (Charters Creek Hatchery, *unpublished data*), and number of reported conflicts within a 500 m buffer of a camera site within the study year (British Columbia Conservation Officer Service 2019).

All predictor variables were standardized by subtracting the mean and dividing by 1 standard deviation, to allow for direct comparison of estimated effect sizes on bear habitat use. I ran a correlation matrix across all predictor variables for the selected scales to ensure no variables were collinear at $r > 0.7$ (Hosmer and Lemeshow 2000, correlation matrix in Appendix 7). I also tested for non-independence in terms of spatial autocorrelation in the residuals from best-supported models using Moran's I test (Plant 2012).

3.2 5 Candidate models

I specified a set of candidate models to explain spatial and temporal variation in black bear habitat use (Appendix 6). The first model used the same variables as in Chapter 2 (where I

modelled conflict probability using both anthropogenic and environmental variables), but with

EVI instead of the distance-to-forest variables as discussed above, to test if bears were selecting

areas with conditions that increase conflict probability (the "conflict" model). The second model

used only anthropogenic variables to test if bears selected areas based on human attractants and

disturbance ("human disturbance"). The third model included only environmental variables to

test if bears were using areas based on natural food occurrence and security cover

("environmental"). The final model was a full model with all covariates. I also included a

quadratic term for human density in all candidate models with anthropogenic variables, to allow

for bear selection of intermediate values targeting rural areas, as well as an interaction between

human and trail density to test if human areas near trails had increased bear activity due to

accessibility.

I used the package *glmmTMB* which includes two types of negative binomial distributions

(Nbinom1 and Nbinom2) that differ in the way they treat the variance: linearly or quadratically,

respectively (Brooks et al. 2017). All candidate models were fit using both negative binomial

distributions and compared using AIC, with Nbinom2 fitting best and thus being used for

inferences.

3.2.6 Habitat use vs. conflict probability

I compared black bear habitat use (relative abundance) to the probability of human-black

bear conflict (predicted from my Chapter 2 analysis, map in Appendix 8), as an indicator of

spatial variation in the probability of conflict, to see if habitat use was higher in areas of greater

conflict probability. Given that black bear habitat use is expected to vary seasonally following

food availability, I used seasonal conflict probability outputs and grouped monthly relative

abundance into four seasons to match these outputs (spring: February-April, summer: May-July,

autumn: August-October, and winter: November-January). I then converted relative abundance

to the log scale to reduce the clumping around zero, adding 1 to each relative abundance value to

allow zeros to stay at zero. I categorized conflict probability at each camera site from Chapter 2

model outputs predicted to raster cells in Sooke using the same 150m buffer explained above. I

divided the probability of conflict into three equal bins (high-, medium-, and low-conflict)

determined by dividing the maximum conflict probability value into three equal groups. In Sooke

the maximum value was 55 out of 100, resulting in binned conflict probabilities of 0-18.3, 18.4-

36.6, and 36.7-55. I used violin plots to visually compare seasonal habitat use by bears across

each level of conflict probaility.

3.2.7 Nocturnality

To test if human disturbance is influencing nocturnality in black bears, I compared the

percent of bear activity that occurred at night between areas of high vs. low disturbance areas

(Gaynor et al. 2018). I calculated a "risk ratio" as $RR = \ln(X_h/X_l)$, where X_h is percent nighttime

activity (i.e., the proportion of nighttime detections out of all detections) at high disturbance and

X_l is percent nighttime activity at low disturbance. A positive RR would suggest a greater degree

of nocturnality in response to humans, whereas a negative RR would indicate reduced

nocturnality. I classified all independent bear detections as occurring either during the "day"

(between sunrise and sunset) or "night" (between sunset and sunrise), with daily sunrise/sunset

values for the study area obtained from the R package *suncalc* (Thieurmel and Elmarhraouli

2019).

3.3 Results

Camera traps detected black bears in all months of the survey (N = 548 independent detections over 16,546 camera trap days; example camera trap images in Appendix 9), averaging 42 monthly detections, with the most detections in September 2018 (n = 148) and the least in February and March of 2019 (n = 1 each; Fig. 3.2).

Patterns of habitat use by black bears in Sooke were best explained by the "conflict" model, i.e., the same anthropogenic and environmental variables that explained broader patterns of conflict in the CRD (with the substitution of EVI for the distance-to-forest variables; Table 3.1). A Moran I test on the residuals of the conflict model failed to reject the null hypothesis of no spatial autocorrelation (Moran I = -0.050, p-value = 0.999).

Bears were more active in areas with high vegetation productivity (EVI, Fig. 3.3), which is parks and crown land forest in winter and spring, but rural areas in summer and autumn (Fig. 3.4). Bears avoided areas with high human density and preferred low elevations. Road density, distance-to-urban and -agriculture, and trail density were not significant as they had 95% confidence intervals that included zero, although the negative mean for trail density may suggest a negative effect on habitat use. As expected, monthly detections of bears increased with sampling effort at a camera station (active days).

Relative abundance and seasonal probability of conflict were unrelated in spring, summer, and winter (Fig. 3.5, mean, range and SD in Appendix 10), as there were few detections in spring and the majority of detections for summer and winter occurred in areas classified as medium-conflict probability. However, in autumn, habitat use seemed to increase with conflict probability in Sooke. This matches the above finding that bears followed high EVI into rural areas which have high-conflict probability in the autumn.

The risk ratio for nighttime activity in urban versus wild areas was positive (0.823, Appendix 11; I also attempted calculating RR for different seasons but sample size was low, see Appendix 12), suggesting more nocturnal behaviour in urban areas. The same trend was seen in rural versus wild areas (0.712). This supports the hypothesis that bears are coexisting by avoiding direct encounters with humans.

Table 3.1: Candidate models for relative abundance of black bears measured from 54 camera traps sampled in and around Sooke, BC, Canada from July 2018 – July 2019 using zero-inflated GLMMs. Evaluated covariates include HD = human density, RD = road density, TD = trail density, EVI = enhanced vegetation index, DUrb, = distance to urban, DAg = distance to agriculture, Con = conflict, DW = distance to water, Sal = salmon, Ele = elevation, and AD = active days. Values following variable names represent the buffer radius used to measure the variables. Df is the degrees of freedom of the model, ΔAIC is the difference in AIC scores from the top model. All models also have a random intercept for camera trap site.

	Predictor Variables	df	ΔAIC
Conflict	HD150 + HD150^2 + RD150 + EVI150 + DUrb150 + Dag150 + Ele150 + TD150 + TD150*HD150 + AD	14	0.0
Full Model	HD150 + HD150^2 + RD150 + EVI150 + DUrb150 + Dag150 + Con500 + DW150 + Sal + Ele150 + TD150 + TD150*HD150 + AD	17	2.1
Human Disturbance	HD150 + HD150^2 + RD150 + DUrb150 + Dag150 + Con500 + TD150 + TD150*HD150 + AD	13	5.2
Environmental	EVI150 + DW150 + Sal + Ele150 + AD	9	11.3
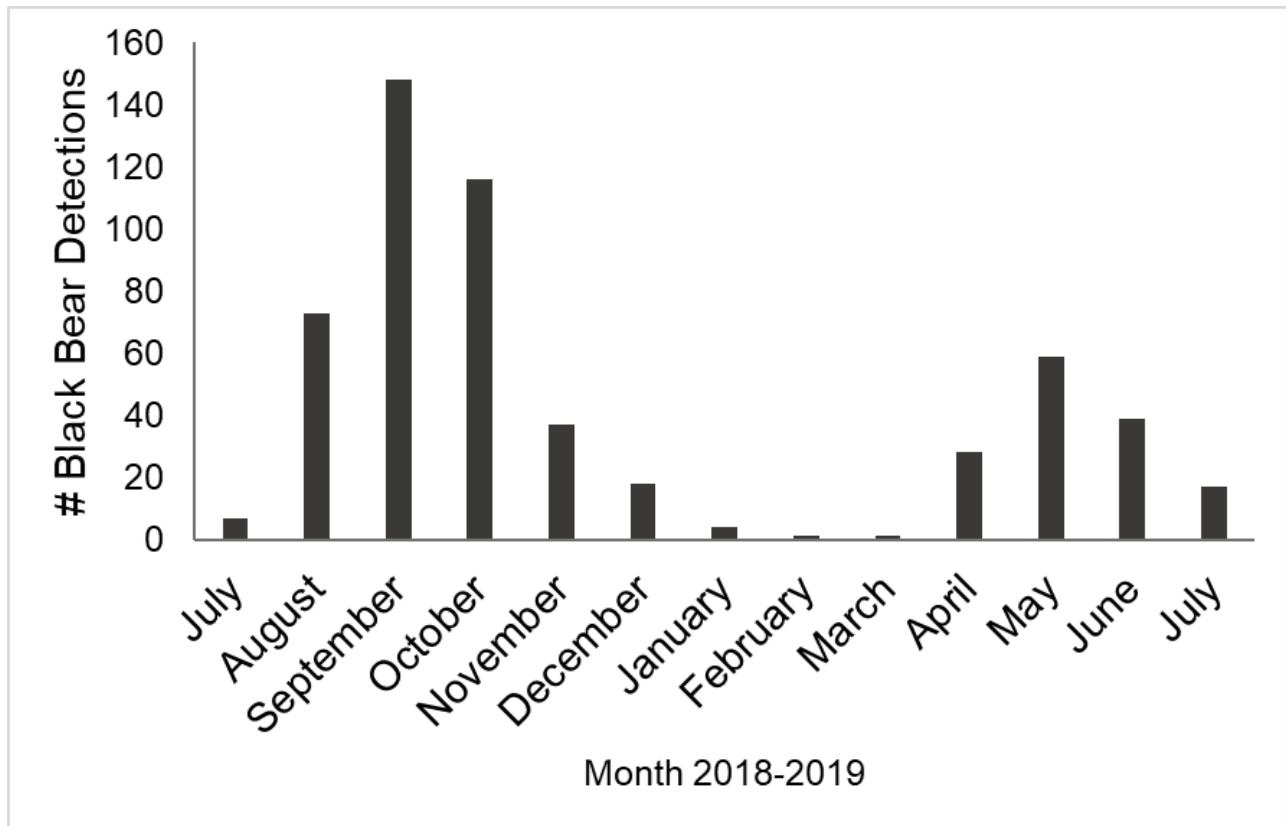
Figure 3.2: Bar chart of the number of independent black bear detections from 54 camera traps in

Sooke, BC, per month from July 2018 - July 2019.
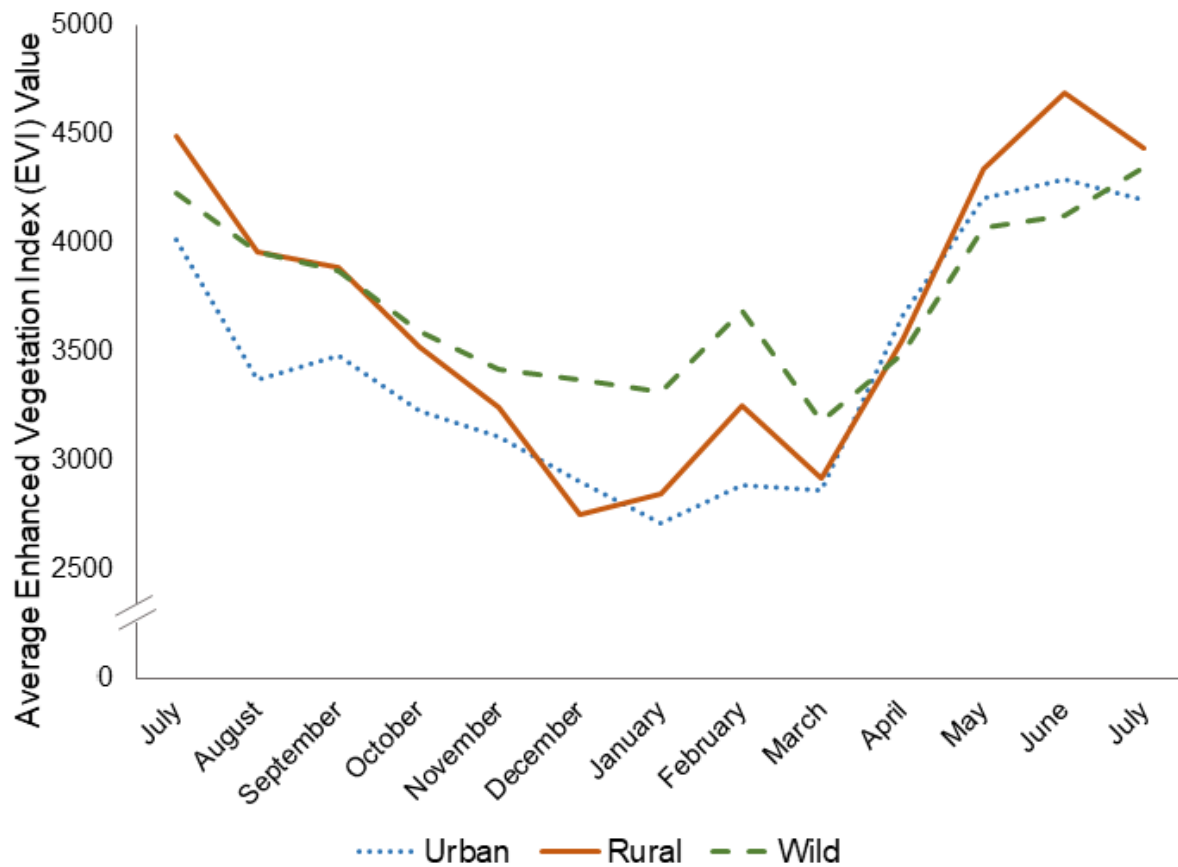
Figure 3.3: Average Enhanced Vegetation Index (EVI) extracted to 54 sites in Sooke, BC, Canada sampled from July 2018-2019 averaged by strata type (urban, rural, or wild) to account for sampling effort differing between strata. EVI value based on number of days the 16-day MODIS satellite window had within a calendar month and the amount each raster cell fell into a 150m buffer around each site.
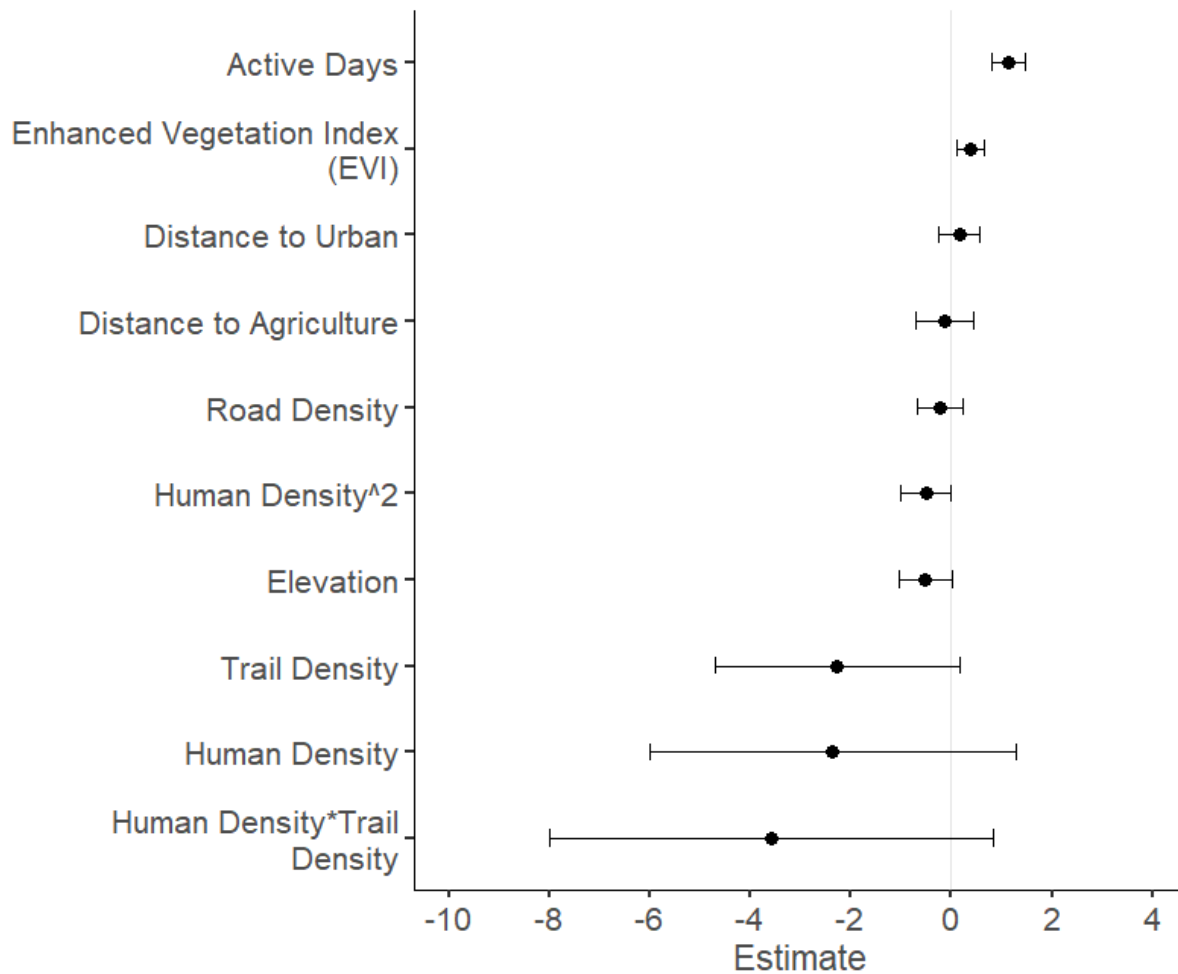
Figure 3.4: Estimated effects of human and environmental variables on black bear relative abundance in Sooke, BC, Canada. Coefficients from best-supported zero-inflated negative-binomial GLMM of monthly detections from 54 camera traps sampled July 2018-2019 illustrated as mean and 95% confidence intervals. Predictor variables have been standardized to a mean of zero and standard deviation of one to allow for direct comparison.
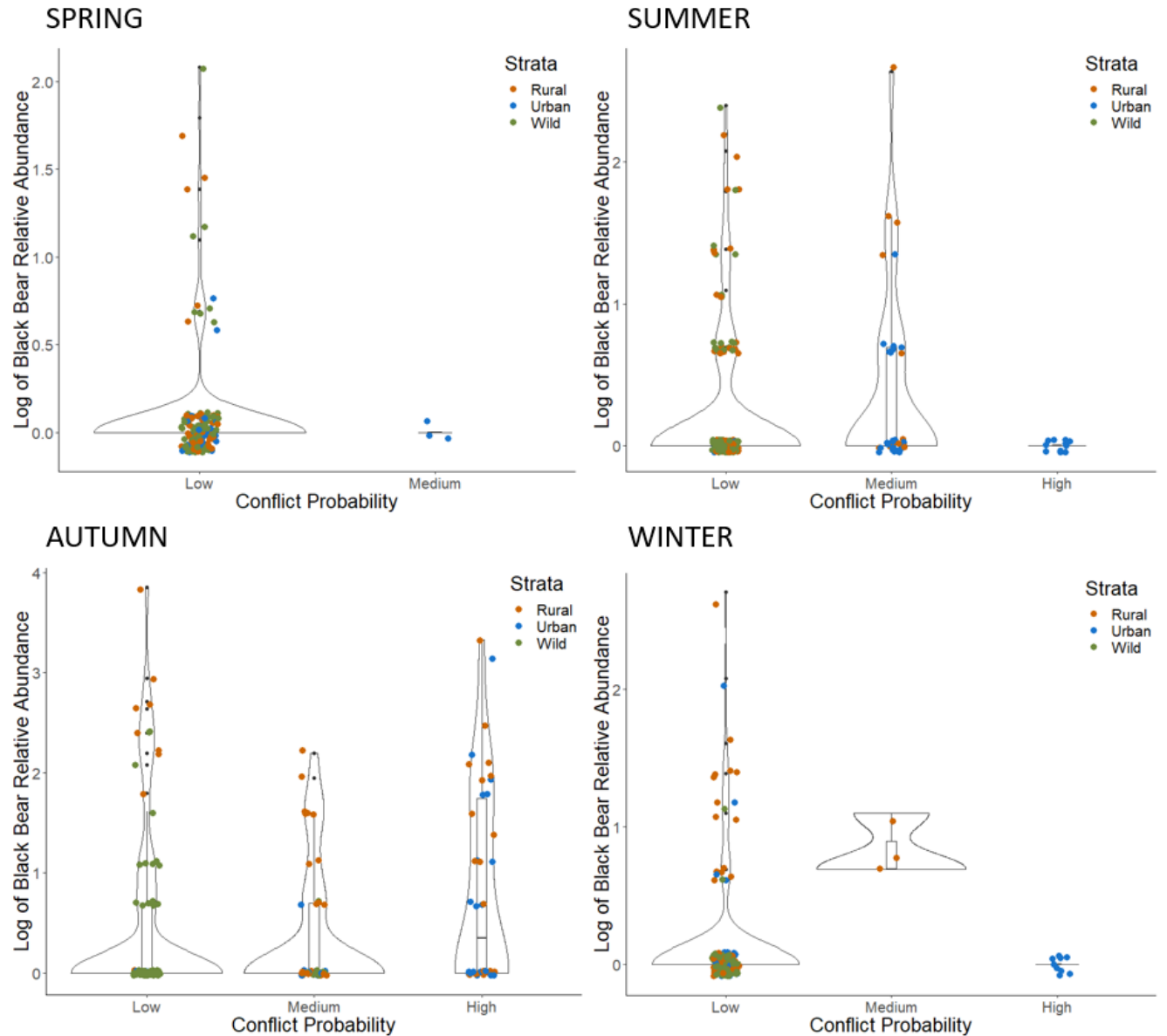
Figure 3.5: Relationship between conflict probability and black bear habitat use (relative abundance) in Sooke, BC, Canada from 54 camera traps sampled from July 2018-2019. Violin plots represent the relationship between log-transformed relative abundance (data shown by dots coloured by strata: urban, rural, or wild) and model-estimated seasonal conflict probability binned into three levels of conflict probability in spring: February-April, summer: May-July, autumn: August-October, and winter: November-January.

3.4 Discussion

My results suggest that black bears in Sooke are changing their behaviours in response to human presence. The municipality of Sooke has the highest reported rates of human-bear conflict and conflict-related bear mortality on Vancouver Island, which is already known for having one of the highest rates of human-bear interactions in North America (Campbell and Lancaster 2010). Therefore, Sooke represents an opportunity to investigate whether bears are changing their behaviours to coexist or conflict with people. I used camera traps and previously modelled probability of conflict to show that bears are shifting their habitat use spatially by season and increasing their nocturnal activity in human spaces.

Taken together, my results suggest that bears are spending most of the year in forests on the edge of the urban-wildland interface rather than in rural areas. This allows bears to access natural foods most abundant in edge habitat, such as berries (Davis et al. 2006), while also providing the opportunity to supplement their diet with human food resources in rural and forest-adjacent urban landscapes. When venturing into human spaces, bears adjust their temporal activity to become more nocturnal, and thereby reduce the chance of interactions with people, but not to avoid other types of conflict such as accessing garbage or fruit. In spring, summer, and winter bears spend most of their time in areas of low- or medium-probability of conflict, but in autumn they use areas of high conflict probability. This suggests that the natural drive to prepare for denning, coupled with the peak of anthropogenic crop ripeness, provides a greater risk of human-bear conflict. If these conflicts are leading to increased risk of bear mortality, autumnal attractants may be creating an ecological trap.

I hypothesized that if bears were able to perceive the mortality risk associated with human areas, they would avoid people spatially and temporally. Indeed, my results suggest that habitat

use increased away from human density and potentially trail density across the urban-wildland interface. This matches a study in Michigan which found that black bears avoided people (based on metrics of developed lands and roads; Carter et al. 2010). Interestingly, my variables for distance-to-urban and to-agriculture and road density were non-significant, which may suggest bears in Sooke are avoiding direct human encounters rather than landscape disturbance.

Bear activity was more nocturnal in urban and rural areas than at wild sites, further suggesting they are avoiding direct interactions with humans and possibly facilitating human-wildlife coexistence (Gaynor et al. 2018). However, nocturnal activity could increase a bear's ability to access food attractants like garbage, compost, or livestock, which may be less guarded at night when most people are asleep. This is supported by research from Colorado which found that in years of poor natural food availability, bears became more nocturnal as they used higher human density areas to access anthropogenic food sources (Baruch-Mordo et al. 2014). And nighttime activity in bears has been found to peak in spring, when food is scarce, and in autumn, when energetic requirements are high, further suggesting it is an adaptation to access human resources (Zeller et al. 2019). Therefore, despite the change in behaviour, conflicts could still be detrimental to bear fitness if they damage property and result in reactive management in the form of killing the conflict bear, which would lead to mortality regardless of nocturnal activity. Consequently, while nocturnality may be an adaptation for coexistence in that it reduces face-to-face encounters between bears and people, bears may not be truly coexisting unless people secure attractants at night to reduce food-related conflicts. Additional research on individual fitness in wild versus human areas would be required to determine if coexistence is occurring.

I found results consistent with a lack of human-bear coexistence in autumn, when rural areas have the broadest spectrum of anthropogenic food attractants. Bear habitat use increased in areas

with greater EVI, which corresponds to wild, intact forest in winter and spring. The selection for forest is unsurprising as it supports other studies that have found bears select forested habitat (Carter et al. 2010; Lyons, Gaines, and Servheen 2003). As a forest-adapted species, black bears use forest for shelter as well as natural foods. However, EVI also captures seasonal changes in the spatial variation in productivity, and the peaks in EVI switched to rural areas in summer and autumn. My sites were all within forests, but the 150m buffer around sites, in addition to the 250m raster cell size of the EVI layers, sampled the rural lands around the cameras as well, which included crops, orchards, and naturally occurring berries along the forest margins. While EVI does not directly account for fruit, a study comparing EVI to grape ripeness found they peaked at the same time (Fraga et al. 2017). Bears may then be drawn into human areas as they are attracted to crops coming into season. Fruit especially has been found to be selected over natural and other anthropogenic attractants by black bears in Nevada (Merkle et al. 2013) and grizzly bears in Canada (Lamb et al. 2017).

Habitat use by bears decreased with increasing elevation. This may suggest bears are selecting for natural food sources such as fish and riparian vegetation along rivers and shoreline, however distance to water was not highly correlated with elevation and rivers were present across the study area. In Sooke, human-dominated areas are concentrated along the coast at low elevations and intact forest is present at higher elevations. This suggests the bears are still selecting for areas near people. By spending most of their time in shelter cover and avoiding human interactions, bears could still function undisturbed. However, by remaining close to people they have the option to move briefly into human areas and access food attractants. Indeed, black bears have been found to base their home ranges on food abundance, but within that range they select security habitat close to edges as they often naturally feed in meadows and riparian

areas (Lyons, Gaines, and Servheen 2003). This behaviour could also extend to human food resources, suggesting bears choose habitat near people to exploit anthropogenic attractants.

Given results from the bear habitat use models that maintain plausibility for both my coexistence and conflict hypotheses, the observed relationship between use and conflict probability provides some clarity. Black bears spent more time in areas of medium- and low-conflict probability in spring, summer, and winter. However, in the autumn, activity increased in high-conflict spaces. The overall probability of conflict increased in the autumn, but this was modelled using a history of seven years of conflicts in Chapter 2, thus it may reflect bears following the EVI peak into rural lands. As discussed above, the addition of orchard fruits as an attractant when they ripen in the late summer and autumn may be more attractive to bears than garbage or natural foods. As this is the time of year that bears go into hyperphagia to prepare for hibernation (Baruch-Mordo et al. 2014), they are more food-motivated and thus even if they perceived the mortality risk of human areas they may be willing to access the anthropogenic food regardless.

Overall, I suggest that the inferred bear behavioural changes to avoid humans spatially and temporally within the human-wildland interface represent a step towards coexistence. Specifically, the fact that bears are preferring forest away from human-use trails and avoiding daytime encounters with people matches their natural behaviours. However, they are not avoiding the risk associated with food-related conflicts. Therefore, to have true coexistence, humans must also adjust to living with bears. Coexistence with carnivores necessitates some tolerance of conflict risk as it will always exist if carnivores are present, but to reduce that risk to an acceptable level, mitigation is required (Carter and Linnell 2016). For instance, securing

potential bear attractants in all seasons, with an emphasis on fall resources, such as by picking fruit in a timely manner.

Given the relatively small size of the Sooke study area, it is likely that the bears detected across the human disturbance gradient are the same individuals moving around, as black bears are not territorial (Horner and Powell 1990) and female home ranges on Vancouver Island have been estimated at 7.83 km^2 (Davis et al. 2006) with male ranges typically being larger (Carter et al. 2010). Thus, bears in Sooke have already shown behavioural plasticity by shifting their temporal activity as they venture into human-dominated spaces. Previous research has shown other bear behaviours can switch as well. In Colorado, a study found that black bears used human food more when there was a natural shortage, but that these trends reversed in subsequent years as natural food came back (Baruch-Mordo et al. 2014). These food shortages may increase with climate change. Along the west coast of North America, climate models suggest huckleberry (*Vaccinium membranaceum*) ranges are going to contract and shift, with ripening occurring earlier, throwing off the historical patterns to which bears have adapted (Prevéy et al. 2020). And, carrying capacities for Pacific salmon have been projected to decline with climate change (Kaeriyama, Seo, and Kudo 2009). If such declines occur with a range of natural bear food resources, the drive to access rich human foods and thus the probability of conflict and mortality will likely increase as bears try to meet their energetic requirements. In Colorado, a natural food shortage caused a 57% decline in female bears as reactive management removed those that were involved in conflicts as they were adjusting to an unexpected change (Laufenberg et al. 2018). This represents an ecological trap, where the human areas were selected due to food resources, but they come with a higher mortality rate. If urban areas are attractive to wild bears

and have the potential to decrease home range size and increase density (Beckmann and Berger 2003a), these areas could be a population sink that could affect a wider region (Doak 1995).

My study represents important foundational work for future research on human-bear interactions in this regional hotspot of conflict. Useful next steps would be to estimate bear densities in the urban-wildland interface compared to wild regions, and to track individual movements to determine if bears are being drawn to urban spaces from wilder areas, and whether a few "problem" individuals are responsible for the majority of conflicts. These results would benefit our understanding of whether the mortality risk of conflict for bears in the urban-wildland interface affects baseline survival. Extending the sampling period of the current design while adding finer scale data on natural bear foods – particularly salmon and berries – could also provide information on how dependent bear conflict behaviours are on natural food availability.

It is important for land managers to know if animal behavioural adaptations to human presence are creating coexistence or increasing mortality through conflict. If the latter, behavioural plasticity may mean that securing animal attractants would allow wildlife to switch back to accessing natural food resources (Baruch-Mordo et al. 2014). As the urban-wildland interface expands, coexistence will require both humans and wildlife to adapt to avoid conflict (Carter and Linnell 2016). For humans, this entails proactive mitigation such as containing rural attractants in peak season. But the specific mitigations required will vary by species and socio-ecological context, so research should begin by determining the patterns of space use by wildlife in human-dominated areas and relating them to conflict outcomes.

Chapter 4: Conclusion

4.1 Synthesis and conclusions

Globally, carnivore ranges are declining and wild areas are shrinking as human development expands into new areas (Wolf and Ripple 2017). However, some species are adapting to living in human-dominated landscapes, either by avoiding negative interactions with people (Gaynor et al. 2018; Tucker et al. 2018) or by accessing anthropogenic food resources to survive in a novel system (Baruch-Mordo et al. 2014). The latter can be a type of human-carnivore conflict which is often met with lethal reactions to the animal in response to perceived or real risk to livelihoods and safety (Treves, Krofel, and McManus 2016). But since carnivores have important functional roles within healthy ecosystems, exerting top-down controls on other trophic levels, mortality from conflict management can have negative repercussions for not only the carnivore species, but the whole ecosystem, including people (Ripple et al. 2014). Therefore, conflict mitigation is required to sustain carnivore populations while protecting human investments. Some mitigation methods have been successfully tested, and new ones come out frequently, but all require time and money (Treves, Krofel, and McManus 2016). Even in a developed country, these costs may fall on underfunded local governments or residents themselves. Therefore, research is needed to investigate where conflict is probable and if carnivores are learning from or adapting to human-dominated landscapes. This research can in turn inform outlooks for future conflicts and their prevention through efficient mitigations.

My thesis used conflict reports, GIS data, and camera trap detections to investigate human-carnivore conflict and carnivore habitat use across local and regional spatial scales and seasonal temporal scales. By understanding where carnivores are, and what potential risk they bring if present, mitigation can be thoughtfully placed on the landscape to best reduce conflict. I

demonstrated how available data can be used to understand the distribution of conflict probability, how camera traps can be used to assess patterns of habitat use, and ultimately how both can support efficient deployment of proactive mitigations. I found that human-carnivore conflict and carnivore habitat use both occur primarily in the urban-wildland interface, however they vary spatially and temporally, and thus studies should consider the dynamics of both scales.

In Chapter 2, I tested a suite of anthropogenic and environmental predictors to model the probability of human-black bear and human-cougar conflict. Black bear conflict reports increased in the urban-wildland interface where high human disturbance and intermediate human density bordered natural habitat. This pattern may result from a trade-off for bears between the energetic benefits of suburban food attractants and access to safety in the forest (Lyons, Gaines, and Servheen 2003). However, in autumn, the effect of human density declined and conflict increased in rural/agricultural areas. This occurred during hyperphagia, as the bears store fat for winter, which incentivizes high-calorie, clumped human foods (Beckmann and Berger 2003a). In contrast, cougar conflict declined with increasing human density, likely due to this elusive species' tendency to avoid people (Dellinger et al. 2019). But conflict was still most probable in the interface, close to both forests and urban areas, as the main food attractant for cougars is livestock living on the margins of human-occupied land (Teichman, Cristescu, and Nielsen 2013) or deer selecting human habitats (Muhly et al. 2011). These results provide targets for efficient mitigation deployment. Spatially, communities along the border of forests need funding or other support to contain their garbage in bear-resistant bins (as has been successful in Whistler and Port Coquitlam, BC), and, since black bears and cougars were found to eat the same livestock species (Peter Pauwels, BC Conservation Officer Service, *personal communication*), depredation mitigations that are sufficient to defend against both species (e.g. tall electric fences;

Breitenmoser et al. 2005). Temporally, rural attractants increase in importance for black bears in the autumn, so the focus should shift from urban garbage to rural compost containment and fruit removal. Whether mitigation is paid for and maintained by government, NGOs, or residents, these predictors will aid in implementing mitigations only where needed.

In Chapter 3, I investigated black bear habitat use to determine where they spent their time along a gradient of human disturbance from urban to wild, and how that related to the probability of conflict on that gradient. For most of the year, bears avoided humans spatially and temporally, preferring wild forests at low- or medium-conflict probabilities, and shifted to more nighttime activity in urban and rural areas. However, as with conflict in Chapter 2, this pattern switched in autumn when bears increased activity in high-conflict regions, likely due to hyperphagia leading to reduced fear of people in response to the draw of ripe fruit and crops. Thus, bear behaviour may be changing in the urban-wildland interface in a way that predominantly leads to coexistence, but food-related conflicts, especially in autumn before denning, need to be mitigated by humans. Together, this research suggests that for black bears, conflict probability is greater than zero in all seasons, but the mirroring of habitat use and conflict probability in rural areas in autumn means that this is the season and stratum most in need of mitigation. So far, educational outreach about human-bear coexistence has mainly focused on garbage management (Spencer, Beausoleil, and Martorello 2007). My results could suggest that efforts to reduce garbage availability have been effective and led to bears staying in their natural environment, or conversely they could indicate that seasonally varying attractants are a more important target. The latter would support another black bear study which found that they selected fruit over garbage and natural foods (Merkle et al. 2013). Therefore, further studies of animal space use are

needed to understand if adaptations to mitigations are occurring or if education needs to be adjusted.

4.2 Research applications, strengths, and limitations

This thesis is the first study to map and compare conflict with both black bears and cougars, which co-occur along the length of western North America. The predictive spatial models from Chapter 2 were designed to use previously available reports of conflict and GIS data to allow for land managers to continue updating the models in the future. As new reports of human-carnivore conflict are obtained and new GIS data becomes available, these models can be further tested, updated, and used even as the landscape changes, continuously validating the models and improving their accuracy over time (Burton et al. 2014). This study only modelled conflict with black bears and cougars, but grey wolves are recolonizing in the study area and a couple reports of conflict have already been noted. If that continues, these models could be extended to wolves given enough conflict reports are available to model the associations with hypothesized predictor variables. Beyond the study area, this research shows that using available data is a cost- and time-effective way of providing important applied answers for human-carnivore conflict.

Nevertheless, complementing data on reported conflicts with new data on carnivore occurrence is valuable, since the predictive models show the probability of conflict given a carnivore is present, which is not constant. In Chapter 3, I found black bears spent most of the year in low- and medium-conflict probability areas, despite the presence of modelled high conflict probability in urban areas. Therefore, despite the spring hotspot of conflict in urban areas illustrated on mapped conflict probability (Fig. 2.4), actual likelihood of a conflict occurring may be low. The only season for which bear habitat use and conflict probability were positively

associated was autumn, when bears were more active in rural areas which also had high levels of predicted conflict.

Additionally, my models of conflict probability are based on data generated by public reporting of conflicts, which could be influenced by many factors including different tolerance levels in regards to conflict, or the perceived trustworthiness of conservation officers. However, previous research has found that conflict reporting by residents was not strongly associated with demographic factors such as gender, age, or homeowner status (Wilbur et al. 2018). This suggests that the reporting database may represent an unbiased sample of conflicts in the region; however, I recommend that this be investigated further in future studies, such as through interviews or questionnaires of a random sample of residents in the area, including a comparison between the probability of reporting conflicts for urban versus rural residents.

I was also limited in the types of environmental and anthropogenic predictor variables available for use in my study as I chose those available to land managers, either through their own organizations (i.e. local government land cover layers) or global datasets (e.g. Gridded Population of the World for human density). This led to a lack of certain variables of importance, such as direct measures of natural and anthropogenic food availability (e.g. berry availability, household garbage containment, or livestock husbandry).

By using conflict data collected over seven years, and camera trap detections for a full year, I was able to analyze the effect of season on conflict and habitat use for black bears. This is a new way to model conflict probability for bears, and was an important consideration for habitat use as bears changed their spatial activity patterns over time. However, as previous studies have found bear habitat use also varies with differences in annual natural food availability (Baruch-Mordo et al. 2014), the camera trap study would improve with multiple years of data collection as cyclical

foods such as salmon runs can change year-to-year or environmental change like droughts can affect berry availability. Additionally, given that I could not identify individual bears from camera trap images, I do not know the extent to which my results reflect common behaviours in the local bear population versus a bias towards a small number of more urban-adapted bears.

4.2.1 Caveats and interpretations of predictive spatial models for management practice

The mapped outputs from the predictive spatial models in Chapter 2 represent a visualization of the combined effects of modelled predictor variables effects on relative conflict probability. It is therefore important to interpret them with care. The "hotspots" on the maps show which areas on the landscape have a convergence of variables conducive to conflict. When considering management action, these models and maps should be used in conjunction with other available information. For example, there is a hotspot of conflict within urban Victoria that has a low number of actual reported conflicts for both black bears and cougars, potentially due to low carnivore occurrence from blocked accessibility into patches of forest surrounded by roads and urban development. In that case, the basic map with conflict reports shown as circles (Fig. 2.1) is a better representation of conflict locations and abundance. But, the importance of the model is showing which variables are responsible for that pattern. For land managers and conservation officers, true hotspots of conflict may already be known, but as development changes land usage, it is important to understand if conditions associated with conflict are being created to plan mitigation before conflicts can occur.

Outputs from the conflict models are also subject to uncertainty due to methodological decisions made during modelling. I chose to apply a use-availability modelling framework because true conflict absences are hard to obtain. This framework can be sensitive to how availability is defined, i.e. how the available points are chosen. To characterize the area of

potential human-carnivore overlap, I used 10,000 random points selected from a polygon that encompassed all observed conflicts plus a buffer corresponding to an estimate of the smallest home range for both species and sexes (i.e. female black bears). Using such a large number of availability samples was recommended by Northrup et al (2013) to adequately represent the range of variables range within the study area. And using a small home range buffer was conservative, but some other studies have used even smaller buffers, e.g. 100 m around edges of urban areas (Merkle et al. 2011). Future work could explore the sensitivity of results by testing different ways of selecting availability points. To avoid the issue of including sites with low occurrence of conflict or animals in the availability sample, it could be possible to first develop habitat models for black bears and cougars, and then select availability only from areas where relatively high habitat suitability occurs within some proximity of human settlement . This makes sense as conflict likely occurs more often in habitats used more frequently by carnivores. For example, human-cougar conflict at the provincial scale was associated with proximity to roads and intermediate elevation (Teichman, Cristescu, and Nielsen 2013), which is also where cougars predominantly kill natural prey such as deer (Gladders 2003).

There are also other methods to model and map conflict probability. A similar study in Alberta, Canada, used a presence-absence modelling framework, where absence points were locations of reported sightings of carnivores where no conflict occurred (Emily Sunter, *unpublished data*). Given that the conflict database I had access to was specifically for conflict reports rather than any type of human-carnivore interaction, I did not have confidence that the sightings reported were unbiased in space, unlike the conflict reports which have been previously found to not be affected by human demographics (Wilbur et al. 2018). It would be useful for future research to use social science methods (e.g. interviews, questionnaires) to assess the

degree of bias (or lack thereof) in public reporting of carnivore sightings. Additionally, since land managers and conservation officers work directly in their communities over long time-spans, expert elicitation methods could be used to understand what variables they think are associated with conflict probability (e.g. Martin et al. 2012). It would be especially beneficial to test a variety of different methods and compare results to what was found using my models. If the results are similar, other communities could choose the method that suits their budget, data, and timeframe. If the results significantly diverge, further research would be needed to ground-truth and determine which approach is the most accurate. This comparison of methods would also serve as a further test of the sensitivity of my modelling decisions on the output predictions.

Finally, it is important to continue validating models with new information. The k-fold cross validation technique I employed allowed me to see if the known conflict locations were being accurately predicted as conflict (Boyce et al. 2002). A similar approach could be used with new conflict reports to see if they occur within high-conflict probability areas. It would be especially interesting to see if the current model is able to predict conflict in new places where I did not have conflicts reported initially.

4.3 Future research

This thesis represents an important first step in examining human-carnivore conflict from the perspectives of both humans and wildlife – from reports of conflicts with bears and cougars, to detections of bear habitat use across the urban-wildland gradient. It may be desirable to follow this study with integrated modelling that explicitly combines these two data sources, i.e. the calculation of an initial probability of carnivore occurrence in an area followed by the subsequent probability of conflict given the carnivore is present. This hierarchical modelling framework could further hone the conflict maps to allow for specifically targeting areas for mitigation.

Going further, if the methods used to calculate the probability of carnivore occurrence included tracking individual carnivores using techniques such as GPS collars, that would allow for an understanding of their home range and habitat preferences, whether they are being drawn into human areas and consequently at risk of higher mortality, and if there are areas of overlap with people that do not result in conflict due to mitigation or other adaptation.

Using GPS collars or other methods such as DNA mark-recapture (e.g. Lamb et al. 2017) that can estimate carnivore population parameters (e.g. survival, population growth rate) should be a future step in explicitly testing for human-carnivore coexistence. Another piece that would be required is an understanding of risk tolerance on the part of humans in areas with a high conflict probability, as coexistence in the human-wildlife conflict framework includes costs to humans that do not cause changes to fitness (Nyhus 2016). This research could add to a previous study on Vancouver Island that found that public attitudes towards black bears are more positive than for cougars (Campbell and Lancaster 2010), potentially testing if those positive attitudes lead to a reduction in reactive lethal control.

It is also important to understand how human disturbance is influencing inter- and intra-specific interactions. Some camera trap sites in urban areas had many black-tailed deer detections but no carnivores, which may suggest that deer using human-dominated areas as a refuge from predators (Muhly et al. 2011). Scaling up the camera network from Sooke to the CRD would allow for a better test of this idea by expanding the area sampled. Large-scale monitoring would also allow for broader management questions for carnivores, such as assessing and protecting corridors as they are of interest to local conservation organizations. There may also be competition over human food resources between carnivores. Therefore, I suggest performing diet analysis on carnivores across the gradient of human disturbance to see if black

bears and cougars are accessing the same resources, and if there are intra-specific diet specialists for human foods.

This research has provided more evidence suggestive of the major role food attractants play in conflict occurrence and habitat use, but further studies need to devote attention to measuring the availability of natural and anthropogenic foods over multiple seasons and years. This should include ungulate prey availability for cougars, berries and salmon for black bears, and the full spectrum of human food resources from livestock to garbage. Studying these variables could provide information on how plastic conflict behaviours are to natural food abundance, and the degree to which anthropogenic foods distract from natural foraging behaviours.

Finally, given the importance of mitigation methods to reduce conflict and create coexistence, continued tests of mitigation efficiency are needed. There is a bias within peer-reviewed literature about the effectiveness of mitigation techniques, including a lack of replication with different species and across ranges, a focus on Canid species, and a skew towards positive effects (Miller et al. 2016). This has led some researchers to be concerned that recommended mitigations may waste money or even cause ecological degradation (Treves, Krofel, and McManus 2016). Given that that the CRD (and Vancouver Island in general) is a conflict hotspot but does not currently have a widespread conflict management plan, it represents a great opportunity to test mitigations across multiple carnivore species and families.

Overall, future research is needed to further our understanding of the effects of human development on carnivores, as well as of the best mitigation methods for different species in different areas. However, given limited funding, it must be remembered that current best practices exist and have been shown in many areas to reduce human-carnivore conflict (Davis, Wellwood, and Ciarniello 2002). There is potentially an opportunity cost if implementation of

mitigations is delayed while waiting for new data to be collected and new analyses completed. Therefore, if conflict is at an intolerable level for local residents, impacting their attitudes and safety, or leading to reactive lethal control for carnivores, using a prescriptive program followed by monitoring to assess effectiveness may be advisable. If conflict is low but potentially increasing, or tolerance levels of residents have led to the attitude that lethal control is not socially acceptable, then spending time and money on research to target mitigation with greater local context and potentially wide-ranging applicability may be appropriate.

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Appendices

Appendix 1: Chapter 2 summaries of human-carnivore conflict

Table A1.1: Number of human-black bear conflicts reported in the Capital Regional District (CRD), BC, Canada between 2011-2017 in four seasons. Spring: February-April, summer: May-July, autumn: August-October, winter: November-January. Data from British Columbia Conservation Officer Service Human-wildlife Conflict Reporting Database.

	Spring	Summer	Autumn	Winter	Total
2011	5	111	24	34	174
2012	10	84	58	33	185
2013	10	70	128	15	223
2014	21	43	38	26	128
2015	1	40	150	39	230
2016	9	13	56	45	123
2017	19	156	12	11	198
Total	75	517	466	203	**1261**

Table A1.2: Number of human-cougar conflicts reported in the Capital Regional District (CRD), BC, Canada between 2011-2017. Data from British Columbia Conservation Officer Service Human-wildlife Conflict Reporting Database.

	Number of Conflicts
2011	26
2012	34
2013	32
2014	14
2015	16
2016	10
2017	8
Total	**140**

Appendix 2: Chapter 2 predictor variables for predictive spatial models

Table A2.1: Predictor variables used to model human-carnivore conflict probability for black bears and cougars in the Capital Regional District (CRD) between 2011-2017. Variables all extracted with buffers at 150 and 500 m radius around conflict points. Weighted buffers reduce the contribution of buffer cells not fully within the circular buffer by the percent excluded.

Predictor Variable	Source	Description
Human Density	Gridded Population of the World	Average number of people per square kilometre within weighted buffer
Road Density	Digital Road Atlas	Total length of roads in buffer around point in km / area in km^2 of buffer
Trail Density	CRD Regional Parks	Total length of trails in buffer around point in km / area in km^2 of buffer
Elevation	ASTER Global Digital Elevation	Average height above sea level within weighted buffer
Distance to Agriculture	CRD Regional Parks	Average distance to agriculture land cover cell within weighted buffer
Distance to Urban	CRD Regional Parks	Average distance to urban land cover cell within weighted buffer
Distance to Forest Patch	CRD Regional Parks	Average distance to <300m^2 contiguous forest land cover cell within weighted buffer
Distance to Intact Forest	CRD Regional Parks	Average distance to >300m^2 contiguous forest land cover cell within weighted buffer

Appendix 3: Chapter 2 extended candidate models

Table A3.1: Candidate models for probability of human-carnivore conflict with black bears (seasonally and non-seasonally) and cougars. Top models indicate which predictor variables best explain location of conflicts for each species/season. HD = human density, RD = road density, DAg = distance to agriculture, DUrb = distance to urban, DFP = distance to forest patch, DFI = distance to intact forest, Ele = elevation, TD = trail density. Values following variable names represent the buffer radius used to measure the variables. Df is the degrees of freedom of the model, ΔAIC is the difference in AIC scores from the top model.

Species/Season	Predictor Variables	df	ΔAIC
	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150	12	0.0
Black Bear	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150	10	13.6
	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150	11	14.7
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele1500 + TD150 + TD150*HD150	10	108.2
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150	9	126.5
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150	10	127.6
	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150	10	0.0
	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150	11	1.7
Black Bear - Spring	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150	12	2.9
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150	9	21.4
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele1500 + TD150 + TD150*HD150	10	22.3
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150	10	23.0

Species/Season	Predictor Variables	df	ΔAIC
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Black Bear - Summer	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	10	0.3
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	11	2.3
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele1500 + TD150 + TD150*HD150$	10	91.3
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	9	94.7
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	10	96.6
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Black Bear - Autumn	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	11	11.2
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele1500 + TD150 + TD150*HD150$	10	17.2
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	10	18.7
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	10	19.9
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	9	27.5
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150 + TD150*HD150$	12	0.0
Black Bear - Winter	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	10	4.5
	$HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	11	5.9
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele1500 + TD150 + TD150*HD150$	10	52.1
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150$	9	58.0
	$HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + Ele150^2 + TD150$	10	58.9

Species/Season	Predictor Variables	df	ΔAIC
	HD500 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + Ele150^2 + TD150	10	0.0
	HD500 + HD500^2 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + Ele150^2 + TD150	11	2.0
	HD500 + HD500^2 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + Ele150^2 + TD150 +	12	3.9
Cougar	TD150*HD500	9	5.6
	HD500 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + TD150	10	7.5
	HD500 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele1500 + TD150 + TD150*HD500	10	7.5
	HD500 + HD500^2 + RD150 + DAg150 + DUrb150 + DFP500 + DFI150 + Ele150 + TD150		

Appendix 4: Chapter 2 seasonal black bear model coefficient estimates
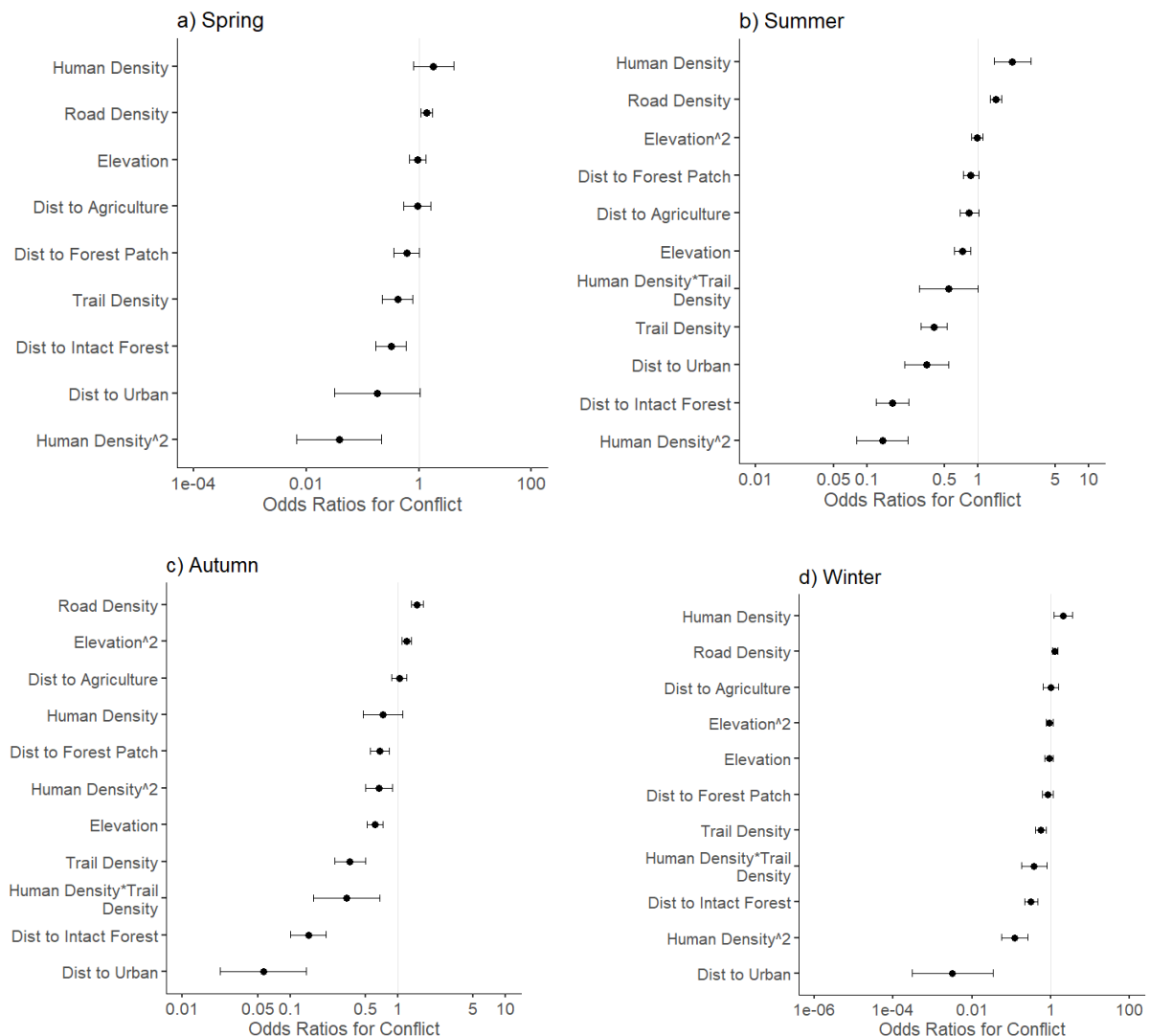
Figure A4.1: Estimated effects of human and environmental variables on human-black bear conflict in the Capital Regional District (CRD), BC, Canada in four seasons. Coefficient estimates from best-supported logistic regression models of conflict locations between 2011-2017 back transformed from the logit scale to odds ratios. Confidence intervals are mean and 95% confidence intervals. Predictor variables have been standardized to a mean of zero and standard deviation of one to allow for direct comparison. a) spring: February-April, b) summer: May-July, c) autumn: August-October, d) winter: November-January.

Appendix 5: Chapter 3 predictor variables for black bear habitat use models

Table A5.1: Explanatory variables used to model variation in independent black bear detections, monthly, measured from 54 camera traps sampled in and around Sooke, BC, Canada from July 2018 – July 2019. Weighted buffers reduce the contribution of buffer cells not fully within the circular buffer by the percent excluded. All buffers were a radius of 150m around each camera trap unless otherwise noted.

Predictor Variable	Source	Description
Human Density	Gridded Population of the World	Average number of people per square kilometre within weighted buffer
Road Density	Digital Road Atlas	Total length of roads in buffer around point in km / area in km^2 of buffer
Trail Density	CRD Regional Parks	Total length of trails in buffer around point in km / area in km^2 of buffer
Elevation	ASTER Global Digital Elevation	Average height above sea level within weighted buffer
Distance to Agriculture	CRD Regional Parks	Average distance to agriculture land cover cell within weighted buffer
Distance to Urban	CRD Regional Parks	Average distance to urban land cover cell within weighted buffer
Distance to Forest Patch	CRD Regional Parks	Average distance to <300 m^2 contiguous forest land cover cell within weighted buffer

Predictor Variable	Source	Description
Distance to Intact Forest	CRD Regional Parks	Average distance to >300 m^2 contiguous forest land cover cell within weighted buffer
Conflict	HWCRD	Number of conflicts in 500m buffer around camera site/month
Distance to Water	Sooke Municipality	Euclidean distance to lotic or lentic water
Salmon	Charters Creek	Presence/absence for cameras near lotic water/month
Proportion Developed	CRD Regional Parks	Number of land cover cells within weighted buffer that are urban, agriculture, or grass compared to total
Enhanced Vegetation Index (EVI)	USGS/NASA, MOD13Q1	Weighted average based on number of days the 16-day MODIS satellite window had within a month and the amount each raster cell fell into a 150m buffer around each site
Active Days (Sampling effort)	Camera traps	Number of days camera was active / total days per month

Appendix 6: Chapter 3 extended candidate models

Table A6.1: All candidate models for relative abundance of black bears measured from 54 camera traps sampled in and around Sooke, BC, Canada from July 2018 – July 2019 using zero-inflated GLMMs. Evaluated covariates include HD = human density, RD = road density, TD = trail density, EVI = enhanced vegetation index, DUrb, = distance to urban, DAg = distance to agriculture, Con = conflict, DW = distance to water, Sal = salmon, Ele = elevation, and AD = active days. Values following variable names represent the buffer radius used to measure the variables. Df is the degrees of freedom of the model, within ΔAIC is the difference in AIC scores from the top model within a hypothesis, between AIC is the difference in top models between two hypotheses. All models also have a random intercept for camera trap site.

	Predictor Variables	df	Within ΔAIC	Between ΔAIC
Conflict (EVI)	HD150 + HD150^2 + RD150 + EVI150 + DAg150 + DUrb150 + Ele150 + TD150 + TD150*HD150 + AD	14	0.0	0.0
	HD150 + HD150^2 + RD150 + EVI150 + DAg150 + DUrb150 + Ele150 + TD150 + AD	13	0.7	
	HD150 + RD150 + EVI150 + DAg150 + DUrb150 + Ele150 + TD150 + TD150*HD150 + AD	13	2.6	
	HD150 + RD150 + EVI150 + DAg150 + DUrb150 + Ele150 + TD150 + AD	12	2.8	
Conflict (distance-to-forest)	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150 + TD150*HD150 + AD	15	0.0	6.5
	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150 + AD	14	1.6	
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150 + TD150*HD150 + AD	14	4.2	
	HD150 + RD150 + DAg150 + DUrb150 + DFP150 + DFI150 + Ele150 + TD150 + AD	13	4.9	

	Predictor Variables	df	Within ΔAIC	Between ΔAIC
Full Model	HD150 + HD150^2 + RD150 + EVI150 + DAg150 + DUrb150 + Con500 + DW150 + Sal + Ele150 + TD150 + TD150*HD150 + AD	17	0.0	
	HD150 + HD150^2 + RD150 + EVI150 + DAg150 + DUrb150 + Con500 + DW150 + Sal + Ele150 + TD150 + AD	16	0.9	
	HD150 + RD150 + EVI150 + DAg150 + DUrb150 + Con500 + DW150 + Sal + Ele150 + TD150 + TD150*HD150 + AD	16	3.0	
	HD150 + RD150 + EVI150 + DAg150 + DUrb150 + Con500 + DW150 + Sal + Ele150 + TD150 + AD	15	3.4	
Human Disturbance	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + Con500 + TD150 + TD150*HD150 + AD	13	0.0	
	HD150 + HD150^2 + RD150 + DAg150 + DUrb150 + Con500 + TD150 + AD	12	0.9	
	HD150 + RD150 + DAg150 + DUrb150 + Con500 + TD150 + TD150*HD150 + AD	12	3.9	
	HD150 + RD150 + DAg150 + DUrb150 + Con500 + TD150 + AD	11	4.1	
Environmental	EVI150 + DW150 + Sal + Ele150 + AD	9		

Appendix 7: Chapter 3 correlation matrix

Table A7.1: Correlation matrix for predictor variables used to model variation in independent black bear detections, monthly, measured from 54 camera traps sampled in and around Sooke, BC, Canada from July 2018 – July 2019.

	Human Density	Road Density	Trail Density	Elevation	Distance to Urban	Distance to Agriculture	Conflict	Distance to Water	Salmon	Enhanced Vegetation Index (EVI)
Human Density	1.000	0.480	-0.409	-0.304	-0.337	-0.435	0.262	-0.126	-0.090	-0.204
Road Density		1.000	0.091	-0.120	-0.404	-0.196	0.176	-0.124	-0.016	-0.123
Trail Density			1.000	0.495	0.183	0.557	-0.146	-0.113	0.077	0.034
Elevation				1.000	0.365	0.664	-0.137	0.183	-0.057	0.088
Distance to Urban					1.000	0.468	-0.143	0.286	-0.018	0.158
Distance to Agriculture						1.000	-0.167	0.015	0.065	-0.056
Conflict							1.000	-0.040	-0.036	-0.038
Distance to Water								1.000	-0.093	0.179
Salmon									1.000	-0.071
Enhanced Vegetation Index (EVI)										1.000

Appendix 8: Chapter 3 map of black bear detections and conflict probability
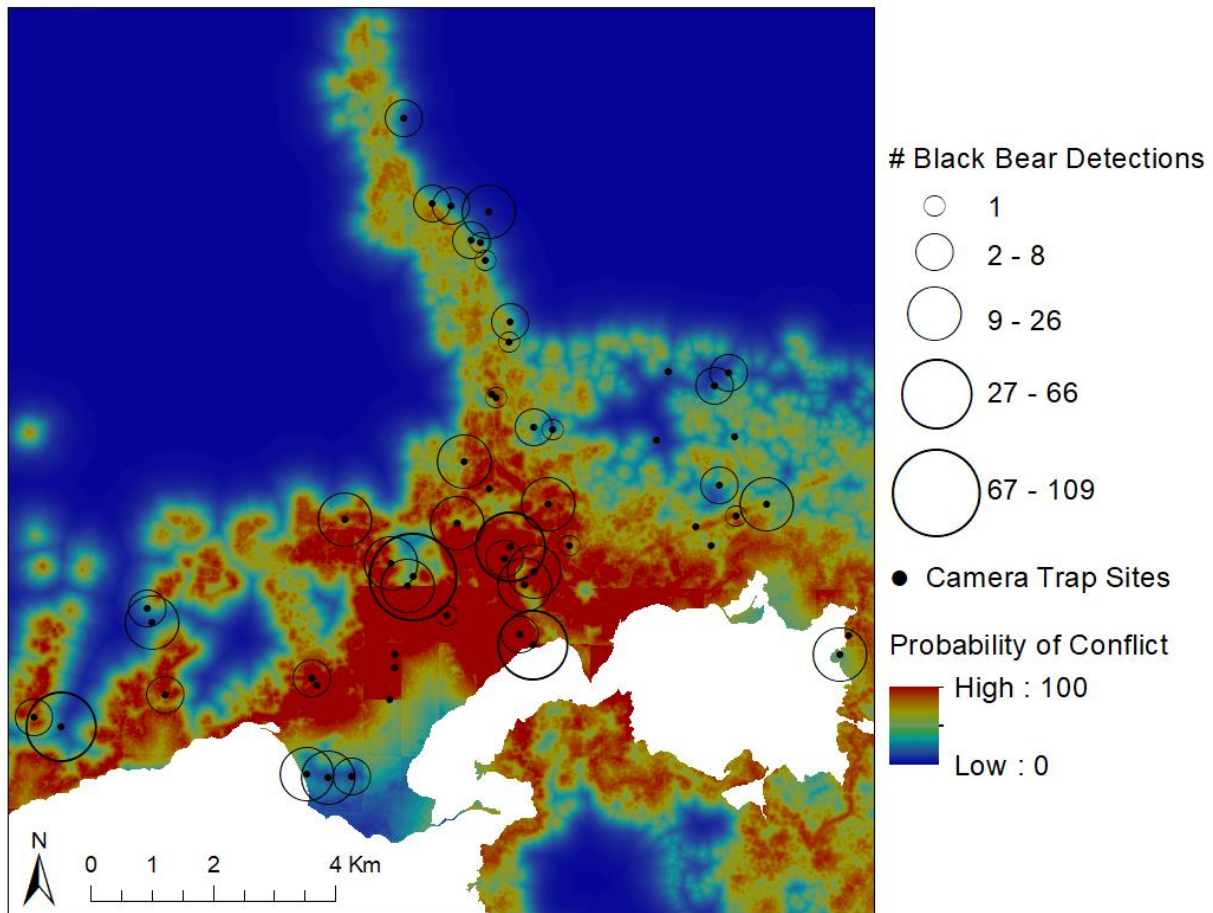

Figure A8.1: Independent detections of black bears in Sooke, BC, Canada from 54 camera traps sampled from July 2018-2019 shown as size of circles on raster layer of model-predicted seasonal conflict probability.

Appendix 9: Camera trap photos of human-black bear conflict

Figure A9.1: Example camera trap detections of human-black bear conflicts from 54 camera traps in Sooke, BC, Canada deployed from July 2018 – July 2019. Clockwise from top: bear with garbage bag accessed after damaging a shed; bear looking into pig pen (potential conflict avoided by electric fence); bear eating plastic outside den in January during typical hibernation period.

Appendix 10: Chapter 3 properties of black bear relative abundance by season and conflict probability

Table A10.1: Mean, range, and standard deviation (SD) for the relative abundance of black bears in areas of low, medium, or high conflict probability in four seasons (spring: February-April, summer: May-July, autumn: August-October, and winter: November-January). Relative abundance from independent detections on 54 camera traps sampled from July 2018-2019 in Sooke, BC, Canada.

Conflict Probability	Season	Mean	Range	SD
Low	Spring	0.189	0-7	0.805
	Summer	0.524	0-10	1.430
	Autumn	2.250	0-46	6.330
	Winter	0.367	0-12	1.430
Medium	Spring	0	0	0
	Summer	0.944	0-13	2.350
	Autumn	0.867	0-8	1.800
	Winter	1.330	1-2	0.577
High	Spring	0	0	0
	Summer	0	0	0
	Autumn	3.070	0-27	5.640
	Winter	0	0	0

Appendix 11: Chapter 3 black bear nocturnality risk ratio table

Table A11.1: Number of independent black bear detections in the day versus night at urban, rural, and wild camera trap sites. Nighttime activity is the proportion of detections between sunset and sunrise, and the risk ratio compares nighttime activity for areas of high human disturbance (Xh, urban and rural) with wild, low disturbance (Xl) areas using the equation Risk Ratio = ln(Xh/Xl).

	Day	**Night**	**Nighttime Activity (X)**	**Risk Ratio**
Urban	36	40	0.526	0.823
Rural	195	173	0.470	0.712
Wild	80	24	0.231	NA

Appendix 12: Chapter 3 black bear seasonal nocturnality risk ratio table

Table A12.1: Number of independent black bear detections in the day versus night at urban, rural, and wild camera trap sites in four seasons (spring: February-April, summer: May-July, autumn: August-October, winter: November-January). Nighttime activity is the proportion of detections between sunset and sunrise, and the risk ratio compares nighttime activity for areas of high human disturbance (Xh, urban and rural) with wild, low disturbance (Xl) areas using the equation Risk Ratio (RR) = ln(Xh/Xl).

Season	Strata	Day	Night	Nighttime Activity (X)	Rural RR	Urban RR
Spring	Rural	9	4	0.308	-0.668	
Spring	Urban	2	0	0		NA
Spring	Wild	6	9	0.600		
Summer	Rural	62	13	0.173	0.786	
Summer	Urban	9	1	0.100		0.236
Summer	Wild	35	3	0.079		
Autumn	Rural	113	122	0.519	1.018	
Autumn	Urban	24	30	0.556		1.086
Autumn	Wild	39	9	0.188		
Winter	Rural	11	34	0.756	-0.280	
Winter	Urban	2	9	0.818		-0.201
Winter	Wild	0	3	1.000		