

Original Research

Quantifying the Spatial Ecology of Human-Bear Conflict in a Wildland-Urban Landscape

Mary W. von der PORTEN¹, Andrew B. COOPER¹, Nicola A. BICKERTON², and Anne K. SALOMON¹

¹ School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, V5A 1S5, Canada.

² Ministry of Forests, Lands and Natural Resource Operations, Province of British Columbia.

Abstract

Human-carnivore conflict poses a serious conservation challenge worldwide. While non-lethal management strategies are increasingly sought, identifying effective management and conservation tools demands an understanding of the interplay among multiple drivers of conflict and the behavioral ecology of the species in question. We quantified the spatial patterns of human-Black Bear (*Ursus americanus*) conflict in Whistler, Canada using utilization distributions of incidents grouped by bear reproductive class, gender, and season. We examined the strength of evidence for the effects of landscape and habitat covariates associated with conflict at a local scale (30m²) using a resource utilization function and model selection approach. Results indicate that spatial patterns of conflict differed among bear reproductive classes and genders, and between seasons, reflecting bear ecology and behaviour. However, landscape attributes were unable to predict the relative probability of conflict. This demonstrates that bear behaviour is flexible such that individual animals will forage opportunistically to gain food rewards around human activity, and that the spatial patterns of conflict at a local scale may be a result of attractant availability and learned behaviour rather than habitat quality. Our study suggests that wildland-urban landscapes can provide relatively unconstrained access to bears, and thus conflict with humans. Furthermore, landscape attributes are unable to predict the location of conflict at the local scale. Therefore, the manipulation of landscape features may not prevent or reduce conflict within the wildland-urban interface. Rather, multiple non-lethal measures, fine scale attractant reduction, and highly responsive adaptive management are required to reduce human-bear conflict.

Key Words: Black Bear, Carnivore Management, Human-Wildlife Conflict, Spatial Model, *Ursus americanus*, Wildlife-Urban Interface.

INTRODUCTION

Human-carnivore conflict threatens the survival of some carnivorous species worldwide, making it a significant conservation concern (Karanth and Chellam 2009). The lethal management of carnivores is commonly employed because carnivores can directly compete with people for habitat and food as well as pose a risk to human safety (Rondinini and Boitani 2007; Sangay and Vernes 2008). The lethal management paradigm has led to the extirpation and extinction of some species while ultimately failing to solve conflict in the long term (Kellert *et al.* 1996; Treves and Karanth 2003). As residential, industrial, and agricultural development into natural landscapes increases, there is a growing need to find innovative solutions and mitigation measures to reduce human-carnivore conflict while conserving populations. These solutions should minimize cost and risk to public safety, promote the humane treatment of wildlife, and ensure the persistence of carnivore populations and the ecological functions they provide (Treves and Karanth 2003). Undoubtedly, the best solutions would prevent conflict from occurring in the first place.

For any animal that regularly uses human settlements, elucidating the landscape and habitat features that govern the spatial use of habitat can inform wise management and conservation policies. Such non-migratory spatial use by wildlife is typically driven by trade-offs between resources and risk (Johnson 1980; Wiens *et al.* 1993; Linke *et al.* 2013). For carnivores in developed landscapes, resources come in the form of food and space, and risks are often driven by conspecifics and human activity (Carroll *et al.* 2001; Valeix *et al.* 2012). While trade-offs between these factors occur at multiple spatial scales simultaneously for each animal, to be effective, management tactics must match the scale at which the dominant ecological dynamics occur (Levin 1992; Hilborn *et al.* 2005). To date, research identifying spatial covariates of human-carnivore conflict has primarily been conducted at regional spatial scales (Theobald *et al.* 2000; Treves *et al.* 2004; Wilson *et al.* 2006; Baruch-Mordo *et al.* 2008; Sangay and Vernes 2008), but conflict incidents are often managed, and animals destroyed, at the 'local' scale from bear to bear and house to house. As human developments are increasingly intermeshed into natural habitats, regional scale policies may not be effective measures if they fail to address local scale, everyday management and the site specific ecology of the species in question. Local scale information on carnivore spatial ecology is therefore needed to inform daily management policies within human settlements. Here, we quantify the spatial ecology of human-Black Bear (*Ursus americanus*) conflict in Whistler, British Columbia, Canada at a local scale (30x30 m) to better understand how carnivores navigate the risks and food rewards provided by humans within the wildland-urban interface.

North American Black Bears are often drawn to human-dominated landscapes to forage on anthropogenic food sources.

In British Columbia, over 90% of the province is inhabited by Black Bears, creating frequent instances of human-bear conflict (Demarchi and Hamilton 2000). These conflicts generate thousands of complaints yearly and result in the average annual destruction of 950 Black Bears and 50 Grizzly Bears (*Ursus arctos*) (Province of British Columbia 1999; Davis *et al.* 2002). Consequences of this conflict for bears include disruptions in their reproductive cycle, spatial displacement (i.e., population sinks), and elevated mortality rates (Treves and Karanth 2003; Treves *et al.* 2004). Possible consequences for people include safety risks, property damage, management costs, as well as the degradation of natural environments and biodiversity. This profusion of human-Black Bear conflict creates an opportunity to gain insight into how bears navigate human-dominated landscapes to inform more effective non-lethal management strategies. Results can be extended to the conservation of other more vulnerable carnivores that face similar challenges (Powell *et al.* 1996).

Here, we addressed two primary questions regarding conflict at the local scale; 1) what landscape attributes are correlated with the location of human-bear conflict, and 2) do reproductive status and season affect the spatial distribution of conflict? Our study examines human-bear conflict incidents at the wildland-urban interface. Our results contribute to the scientific understanding of bear ecology and inform non-lethal carnivore management at local spatial scales.

MATERIALS AND METHODS

Location and study species

This research was conducted within the wildland-urban interface of the Resort Municipality of Whistler, 135 km north of Vancouver, within the Coastal Mountain range of southwest British Columbia, Canada (Figure 1). Whistler is a resort centered on mountain tourism. The natural habitat of Whistler provides nutritious food resources including blueberries and huckleberries (*Vaccinium sp.*) and the natural surroundings are integrated with human developments (Appleton 2006).

As a result of this wildland-urban environment, an interface zone for wildlife and human activity exists throughout the entire town. Many species of carnivores, including Bobcats (*Lynx rufus*) and Cougars (*Puma concolor*), have been in conflict in Whistler. Black Bears, however, are most commonly involved in human-wildlife conflicts because population numbers are high with an estimate at 1 bear /km², the town is accessible, and the rewards from human foods and naturally landscaped foods are abundant (Conservation Officer Service 2008; Appleton 2006).

Data Collection and classification

We collected data on conflict bears from 2005-2007 as part of a broader collaborative non-lethal management study. Bears were caught in steel culvert traps set within urban areas and then equipped with Telonics (Mesa, AZ, USA) Very High

Frequency (VHF) or Lotek (Newmarket, Ontario, Canada) Global Position System (GPS) collars. Of the 51 bears trapped, collared and monitored, five females and 27 males were included for analysis in this study because they met two critical criteria: 1) they were located in conflict, and 2) their conflict locations were not taken during a parallel aversive conditioning study. We then grouped study animals into one of four categories relevant to bear reproductive biology: adult male, sub-adult male, female without cubs, and female with cubs (Alt *et al.* 1980; Lyons 2005; Davis *et al.* 2006). Gender and reproductive status were determined through capture, visual observation, known life history, and monitoring.

Researchers actively tracked and monitored study animals on

foot to observe and record the bear behaviour and obtain their *Universal Transverse Mercator* (UTM) coordinate location with an accuracy of 10m. Monitoring occurred as part of 24h surveillance programs and opportunistically as incidents were reported. Every bear observations were classified as either a conflict or non-conflict situation. An incident was considered a 'conflict' when researchers witnessed a bear was obtaining an unnatural food reward, causing property damage, inside a structure (e.g., shed, house, etc.), or when bears were sighted in urban areas in close proximity to people. Non-conflict records were when a bear was sighted in a natural habitat not exhibiting conflict. Only conflict data were analyzed in this study ($n = 752$); non-conflict data was omitted.

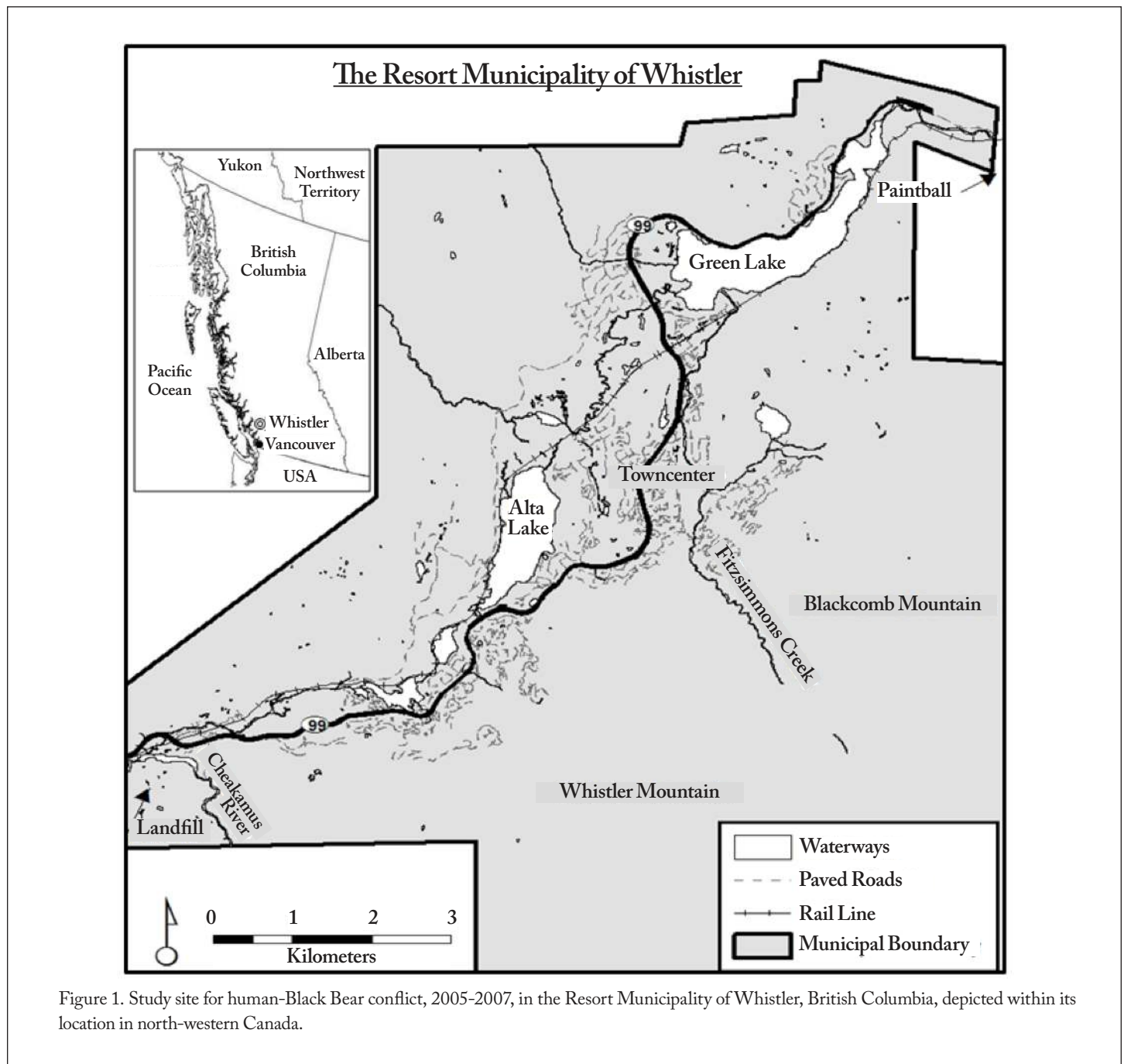


Figure 1. Study site for human-Black Bear conflict, 2005-2007, in the Resort Municipality of Whistler, British Columbia, depicted within its location in north-western Canada.

We uploaded GPS locations with corresponding behaviour data from monitoring activities into a Geographical Information System (GIS, ArcInfo 9.3.1, ESRI, California, USA) and used a North American Datum 1983 (zone 10N) projection. Data was separated into seasons determined by known vegetation cycles and phenology in the Whistler Valley (McCrorry and Appleton 2007) (Spring = April 1-June 30, Summer = July 1-August 31, Fall = September 1-December 15, and Winter = December 16-March 31). Conflict events that occurred in the winter were excluded as exceptional events because bears are usually denning during this time period. Habitat and landscape covariates were treated as constant during the study allowing the pooling of data for years 2005-2007 to yield large enough sample sizes for further analysis. Little change in the study area's attributes occurred during these years.

Utilization distributions

The Utilization Distribution (UD) is a spatial surface derived from a sample of point locations and provides a continuous measure of the intensity of animal space use. We used kernel density estimation outputs to describe a UD for the conflict activity of each Black Bear class (Worton 1989; Millspaugh *et al.* 2006). All UD's were 99% volume isopleths of fixed kernels made with Least Square Cross Validation derived bandwidths (Beyer 2004; Marzluff *et al.* 2004; Gitzen, Millspaugh and Kernohan 2006; Horne and Garton 2006). Raster cell size was 30x30 m to reflect the micro scale of conflict occurrences and habitat data resolution. UD's were created with datasets containing ≥ 30 points after separating for reproductive class and season (Marzluff *et al.* 2004; Millspaugh *et al.* 2006). This yielded 6 UD surfaces for male bears (3 seasons x 2 reproductive classes from 27 individual bears) and 2 UD's for female bears (from 5 individual bears), one for each reproductive class in the fall. Therefore, a total of 8 UD's were created from 32 study animals. We obtained UD density values from the center of each grid cell to represent the relative probability of conflict which we later used as our primary response variable in our regression models. We log transformed UD density values to ensure that the assumption of normality in the residuals would be met for regression.

In a preliminary analysis we explored each UD shape and spatial location to examine overlap between the 8 different bear classes. This was done using the volume of intersection (VI) method, which is a technique used to examine spatial usage overlap between two individuals (Millspaugh *et al.* 2000; Millspaugh *et al.* 2004). Results from testing UD overlap suggest that the analysis could remain separated by reproductive class and season, as no UD's exceed a 20% overlap (von der Porten 2010). Given the low overlap, UD's were treated as individual datasets.

Explanatory variables and the a priori model set

To determine which landscape and habitat covariates drive human-bear conflict, we first extracted covariate features from GIS

layers. Polygons of habitat and landscape characteristics important to bears were delineated based on detailed mapping already available from Terrestrial Ecosystem Maps (Green 2004 - common site specific mapping used in British Columbia), bear habitat maps (McCrorry and Appleton 2007), and by spatializing information from orthophotographs and ground work during the study. While this previously collected data set limited the explanatory variables we could examine, it provided a unique opportunity to quantify the processes driving human-bear conflict at this spatial scale. Based on this data set, we identified candidate covariates from our set of spatial polygons based on researchers' experience in the field and previous studies of human-bear conflict (Wilson *et al.* 2006; Baruch-Mordo *et al.* 2008). A list of all features and their relevance to bear ecology can be found in Table 1.

The UD surface raster cells (30x30 m resolution) were converted to a point layer in ArcMap, and each point given a value of either in or out of a possible bear attractant polygons and the distance from that point to each landscape polygon was calculated based on Euclidean distances using ArcInfo Spatial Analyst (Figure 2). We used raster cells of 30x30 m for this to match the resolution of the kernels and prevent nullifying the resolution of the UD (Marzluff *et al.* 2004).

We built a set of a *priori* candidate models to examine the underlying causes of conflict distribution by grouping independent variables into five base models (Table 1, see Figure 2). The first model, 'Attractant Source', includes land use types with concentrated anthropogenic food sources. The second model, 'Travel Corridor/Natural Forage', includes land use types that may allow for travel and forage into human-use areas where edible vegetation persists in spring, summer and fall. The third model, 'Spring Green-up', consists of the zones which typically produce nutritious vegetative shoots in spring. The fourth model, 'Green Areas with Attractants' includes green spaces that contain natural bear foods and dispersed attractants such as garbage bins and human foods. The final model, 'Human Usage', represents areas with high human traffic. We fit all possible combination of the five base models to our probability of conflict data set, for a total candidate set of 31 models.

Conflict utilization function and statistical analysis

The flexibility of resource selection methodologies allows researchers to examine currencies other than basic use such as feeding or reproductive activities (Buskirk and Millspaugh 2006). We used Resource Utilization Functions to analyse which candidate models best predict spatial distribution of human-bear conflict. This methodology approaches resource use analysis in a presence-only manner, analyzing relative use across the landscape (Marzluff *et al.* 2004). It involves taking the probability densities across the surface of the UD as a continuous dependent variable and using multiple regression to analyze relationships with explanatory

variables. More commonly-used binary (used/unused or available) resource selection methods were not employed because there were a high number of unreported conflicts that would contaminate the sample, violating the allowable 20% contamination between available and used, potentially biasing our result (Manly *et al.* 2002). We herein call our approach Conflict Utilization Function (CUF) as our currency is not general resource use, but conflict occurrences specifically.

We conducted all statistical analyses in R 2.10.1 (R Development Core Team, Vienna, Austria. <http://www.R-project.org>) using the 'nlme' package (Pinheiro *et al.* 2009). We assigned each point an explanatory covariate value from the polygons and Euclidean distances rasters to create CUFs. We exported the final resulting CUF attribute tables populated with log-transformed relative use values ($\ln(\text{UD density})$), X Y coordinates, and explanatory covariate values from ArcMap into R. All CUFs were originally regressed with Ordinary Least Squares but residuals were found to be spatially autocorrelated when tested with Moran's I; therefore,

we reanalyzed using generalized least squares (GLS) because it accounts for spatial autocorrelation in the error term (Beale *et al.* 2010). We derived the spatial correlation structure by modelling the semi-variogram of each dataset. In all cases semi-variograms indicated Gaussian structure, therefore we used a Gaussian correlation structure for each GLS model (Crawley 2007). Due to the size of the sub-adult male summer and the adult male spring data sets, computational constraints were such that the model was run and verified by splitting these data sets in two and running analyses separately (Beale *et al.* 2010). The coefficient of determination was computed from the global model for each data set. We tested the normalized residuals for model assumptions of normality and homogeneity of variance, which was met in every case (Crawley 2007).

To determine the strength of evidence among alternative variables driving human-Black Bear conflict, we took an information-theoretic model selection approach (Burnham and Anderson 2002). We used Akaike's Information Criterion (AIC)

Table 1. Model categories, corresponding variables and biological meaning used to base Conflict Utilization Function *a priori* model set to explain human-bear conflict in Whistler, British Columbia, Canada, 2005-2007.

Model	Covariate	Definition	Relevance to bears
1. Attractant Source	a) Village Centre	Commercial centre of town	Humans as a risk; human foods available
	b) Landfill	Garbage stored and/or transferred to another location	Provision of human foods
	c) Paintball course	Recreational area for paintball fights	Petroleum oil content of paintballs attractive
2. Travel Corridor/ Natural Forage	a) Rail-line	Train thoroughfare	Provision of natural food and travel corridor
	b) Riparian Area	Near stream habitat	Provision of natural food, travel corridor and cover
	c) Wetland	Marshy or bog like habitat	Provision of natural food, travel corridor and cover
	d) Valley Trail	2-m-wide trail that transects study site	Natural and human foods as well as cover and travel corridor
3. Spring Green-Up	a) Ski hill	Resort ski area	Provision of natural food
	b) Grassy Area	Area vegetated with grass, generally golf courses or sports field	Provision of natural food
4. Green Areas with Attractants	a) Parks	Recreational park with mixed vegetation	Natural and human foods as well as potential cover
	b) Valley Trail	Trail that transects study site	Natural and human foods as well as cover and travel corridor
5. Human Usage	a) Density of people	Spacial index of human density	Humans at risk
	b) Urban	Area developed for human use	Humans as a risk; human foods available
	c) Village Center	Commercial center of town	Humans as a risk; human foods available

which accounts for model fit and parsimony. We normalized the model likelihoods to a set of Akaike weights (w_i) representing the strength of evidence in favour of a given model.

RESULTS

Spatial distribution of conflict

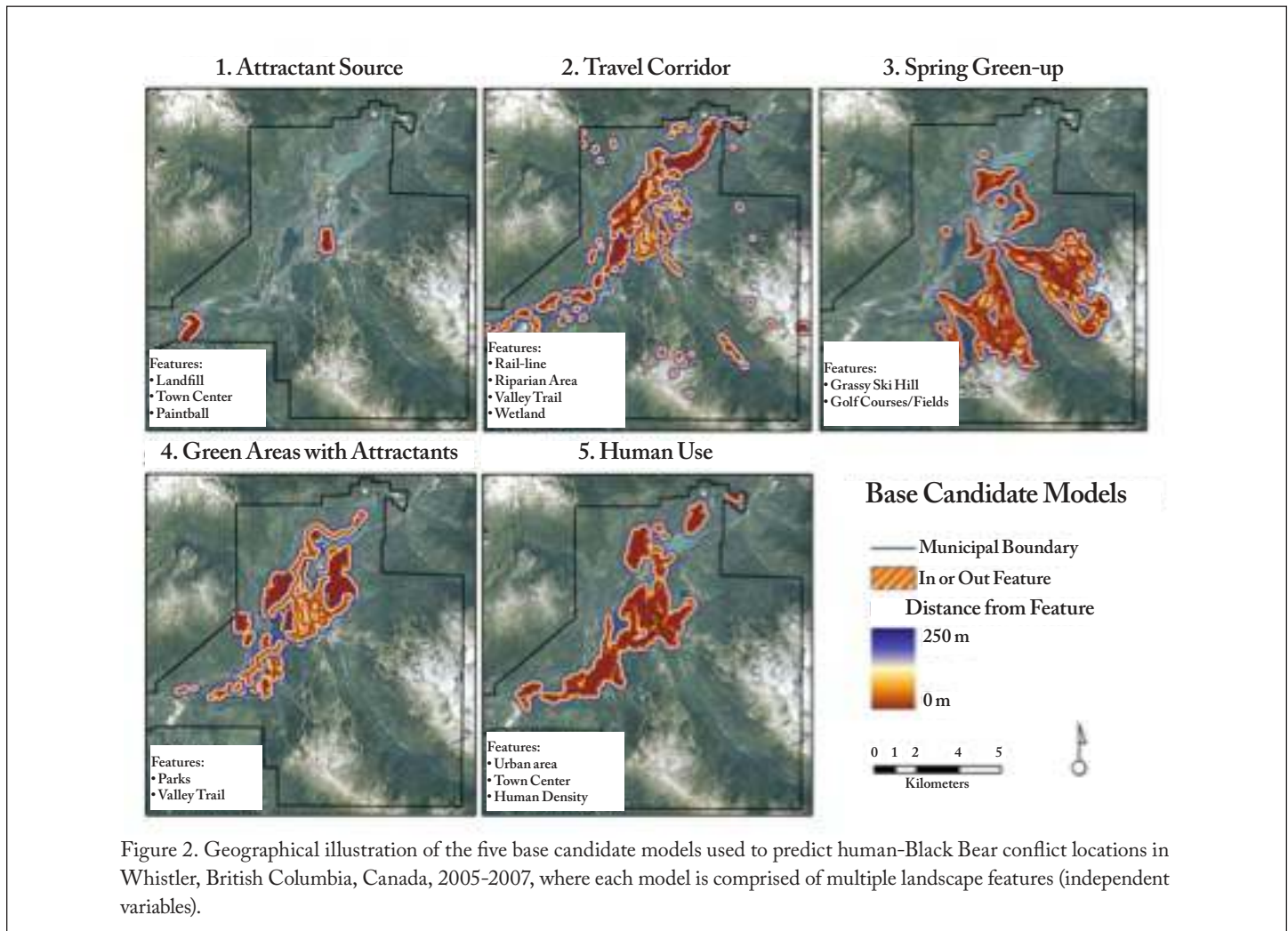
Results indicate that spatial conflict probability is not uniform across the landscape and that the relative probability of conflict did vary spatially and among bear classes (Figures 3 and 4). Females with cubs in the fall show the most aggregative pattern indicating zones of high conflict near the landfill and town center; 25% of the Females with Cubs UD overlaps with the landfill and 23% overlaps with the town center; 6% of the Solo Female UD overlap occurs at the landfill and 8% in the town center. The remaining female conflict was dispersed throughout the study area (see Figure 4). Conflicts with adult males in the summer and fall, and sub-adult males in the spring and fall show moderate aggregations with peaks scattered throughout the landscape (see Figure 3). Adult males in the spring and sub-adult males in the summer show a distinctly uniform, non-peaked pattern with seemingly equal probability of conflict across the landscape. Less than 3% of the Adult Male

Conflict UD spatially overlaps with the concentrated attractant sources (concentrated attractant source layer includes the landfill, town-center, and paintball field where bears were attracted in high numbers to consume paintballs containing oil), except in the town center in the fall where there is 9% overlap (see Figure 4). Each bear class used more concentrated attractant sources in the fall; however, the majority of each of the 8 UD does not overlap with the concentrated attractant sources (see Figure 4).

Conflict Utilization Function modelling results

Our CUF models were unable to explain a significant proportion of the variation in the spatial distribution of human-Black Bear conflict within this wildland-urban landscape (Table 2). However, this result in itself and the strength of evidence for alternative candidate models of human-bear conflict indicate spatial patterns that are highly relevant to wildlife management policy.

Seasonal Variation- There is evidence that the Human Use and Attractant Source models are driving a proportion of human-bear conflict for all bear classes in the fall, relative to other landscape features. In contrast, there is evidence that the Spring Green Up and Green Areas with Attractants models describe a proportion of conflict with adult and sub-adult male Black Bears in the summer



and spring.

Model support by bear class (see Table 2 for all results listed in this section)

Solo females (fall) – The Attractant Source model has relatively strong support ($w_i = 0.569$) driven by a high probability of conflict in the town center and landfill.

Females with cubs (fall) – The Human Use model is best supported by the data ($w_i = 0.249$), models ranking second and onwards have similar weight; all include the town center as a driving feature.

Sub-adult males (spring) – Spring Green-up narrowly has the highest relative support ($w_i = 0.210$), but there is little strength of evidence for this model over the other candidate models due to the

diffuse support across all models.

Sub-adult males (summer) – Spring Green-up has the most support ($w_i = 0.700$) relative to the other candidate models. The separate test dataset, created because of the large sample size, confirmed this result.

Sub-adult males (fall) – No single model has clear support, but the town center stands out as a positive driver of conflict for the top 95% of models.

Adult males (spring) – This data set was split for analysis due to the large sample size and all results were diffuse and inconclusive. There is no strength of evidence for any model, and no covariates appear to drive the relative probability of conflict.

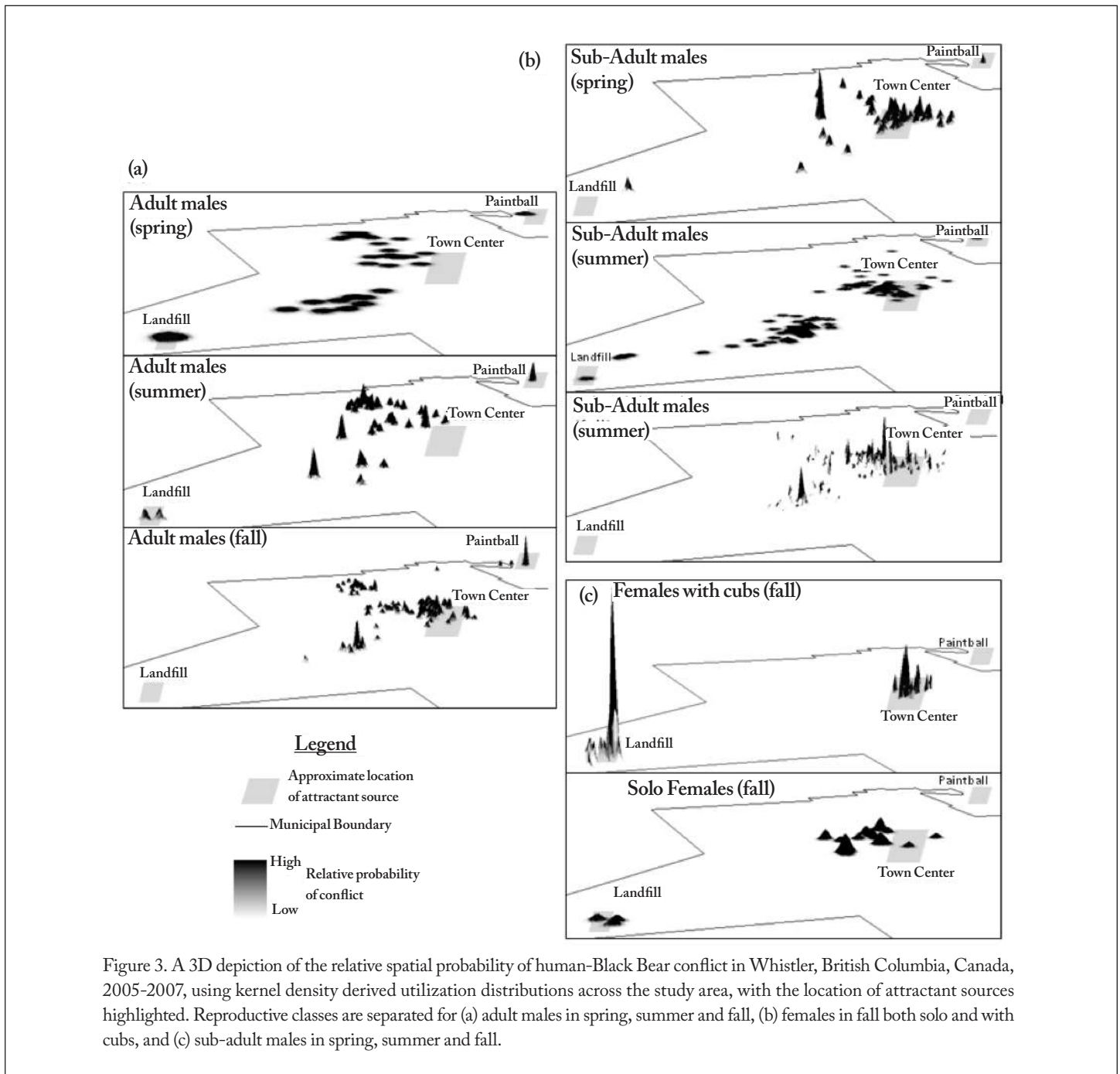


Figure 3. A 3D depiction of the relative spatial probability of human-Black Bear conflict in Whistler, British Columbia, Canada, 2005-2007, using kernel density derived utilization distributions across the study area, with the location of attractant sources highlighted. Reproductive classes are separated for (a) adult males in spring, summer and fall, (b) females in fall both solo and with cubs, and (c) sub-adult males in spring, summer and fall.

Adult males (summer) – The Green Areas with Attractants model is best supported by the data ($w_i = 0.407$) although evidence for the alternative candidate models, Spring Green-up and Attractant Sources, exists ($\Delta AIC = 1.475$ and 2.511 respectively). Support is driven by a positive association to being within parks.

Adult males (fall) – The Human Use model has the greatest relative support ($w_i = 0.534$) and is driven by conflict within the town center. It is better supported by the data relative to the combined Human Use and Spring Green-up model ($\Delta AIC = 3.146$) and the Spring Green-up and Attractant Source model ($\Delta AIC = 3.219$).

DISCUSSION

Spatial Distribution of Conflict

We observed distinct spatial patterns in the probability of human-bear conflict throughout the study area (see Figures 3 and 4), yet the combination of landscape and habitat features we identified as explanatory variables, at a resolution of 30 x 30m, do not appear to be driving spatial patterns in human-Black Bear conflict (Table 2). Rather, conflicts tend to occur at spatially concentrated attractant sources (landfill, town center, paintball) and at unquantified, fine scale ephemeral attractants dispersed

throughout the study area (open garbage bins, unsecured sheds, etc.). The magnitude of conflict and its spatial variation then differs as a function of season, bear gender, and reproductive status (see Figures 3 and 4). These results illuminate the challenges of predicting human-wildlife conflict at the local scale at which it commonly occurs, and consequently, has important implications for bear management at the wildland-urban interface.

Seasonality emerged as a factor driving the spatial distribution of human-Black Bear conflict. In the fall, all bear classes used concentrated attractant sources and human-dominated areas (see Figure 3). Consumption of concentrated protein-rich food is common in bears during hyperphagia and it is important for their reproductive health and survival (Hilderbrand *et al.* 1999). Therefore, bears may be seeking calorically rich foods during this time prior to denning, when natural food sources have become relatively scarce, and rich anthropogenic food sources are available. The opposite pattern was evident in spring and summer when bears were in conflict with humans away from human-dominated areas, which may be due to bears foraging naturally and arriving opportunistically at attractants dispersed throughout neighbourhoods (see Table 2, Figure 3). The Spring Green-up

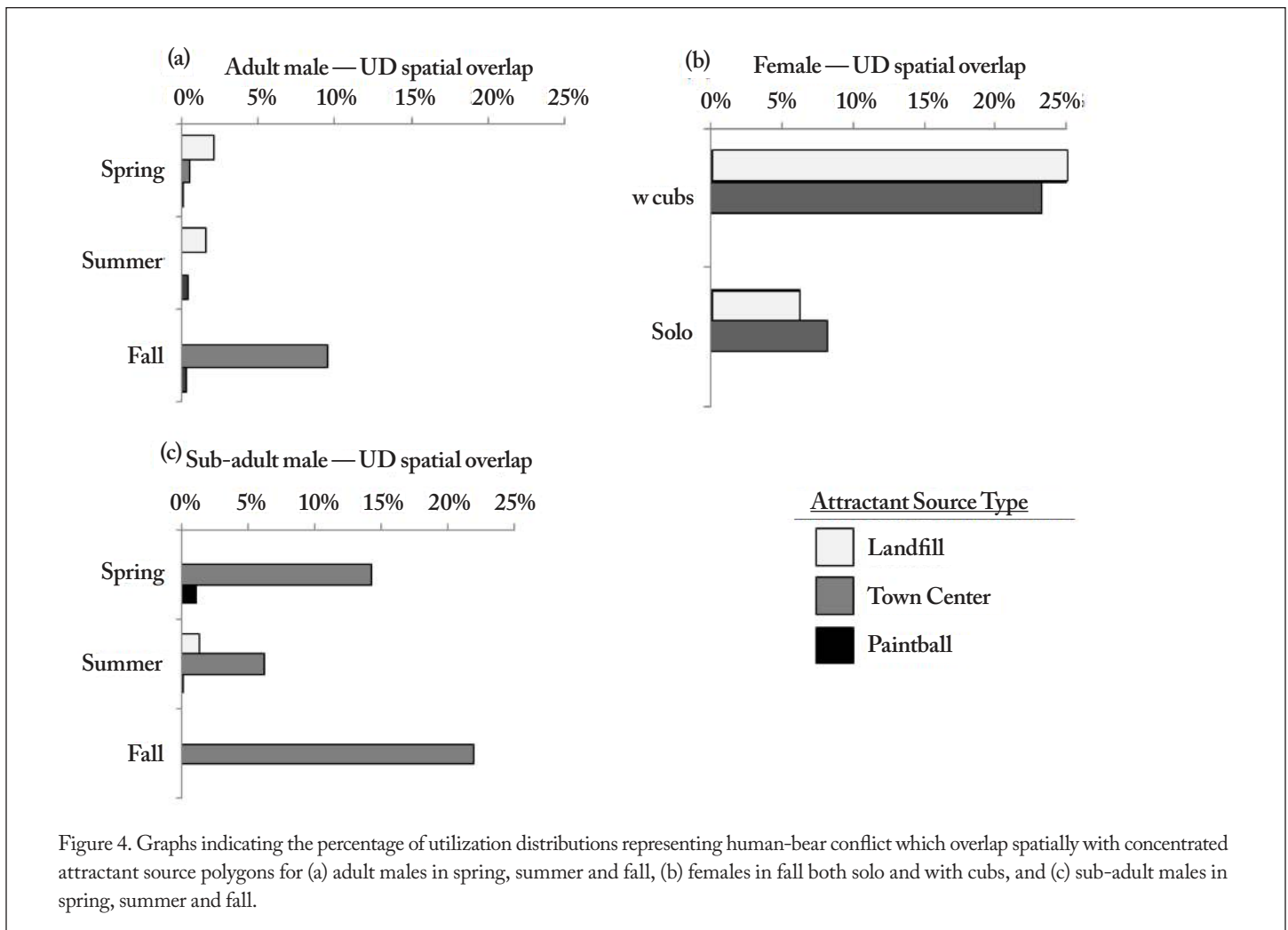


Figure 4. Graphs indicating the percentage of utilization distributions representing human-bear conflict which overlap spatially with concentrated attractant source polygons for (a) adult males in spring, summer and fall, (b) females in fall both solo and with cubs, and (c) sub-adult males in spring, summer and fall.

model, for example, best predicts conflict with sub-adult males during the summer relative to the alternative candidate models (Table 2). However, this is not the case with adult males during the summer where there is similar support for our alternative models of human-bear conflict. The lack of support for any explanatory model for conflict with adult males in the spring may be due to mating season behaviour influencing movement more so than foraging opportunities.

The one candidate model that received little relative support from our conflict data set in any season or within a bear class was the ‘Travel Corridor with Natural Forage’ model, which runs counter to studies that highlight the importance of riparian areas in

driving bear movement and conflict (Clevenger *et al.* 2002; Wilson *et al.* 2006; Roever *et al.* 2010). Weak evidence for these features in driving conflict could be the result of either AIC favouring parsimonious models despite poor model fit, or scale, in that these features are not important at the local level. Considering that there is good quality interface habitat present throughout the most of the study area, specific travel corridors may not be important at this scale because natural landscaping provides numerous small scale travel opportunities for bears.

While the UD shapes across our study area suggest that there may be non-random differences in the spatial probability of human-bear conflict among bear class and season, the quantitative

Table 2. Top three models from AIC *a priori* model selection for Conflict Utilization Function generalized least square regression for each bear class/season for human-Black Bear conflict in Whistler, British Columbia, Canada, 2005-2007.

Dataset	Top models	ΔAIC	AIC w_i	Global R^2
Solo females (fall) (<i>n</i> = 2,030)	1. Attractant Source	0	0.569	0.019
	2. Human Use and Attractant Source	3.146	0.118	
	3. Spring Green-up and Attractant Source	3.219	0.114	
Females with cubs (fall) (<i>n</i> = 292)	1. Human Use	0	0.249	0.036
	2. Attractant Source	0.617	0.183	
	3. Spring Green-up	0.644	0.180	
Sub-adult males (spring) (<i>n</i> = 1,257)	1. Spring Green-up	0	0.210	0.056
	2. Attractant Source	0.42	0.163	
	3. Green Areas with Attractants	0.44	0.161	
Sub-adult males (summer) (<i>n</i> = 5,460)	1. Spring Green-up	0	0.700	0.043
	2. Human Use and Spring Green-up	4.417	0.077	
	3. Spring Green-up and Green Acres with Attractants	4.789	0.064	
Sub-adult males (fall) (<i>n</i> = 663)	1. Human Use and Attractant Source	0	0.168	0.042
	2. Human Use	0.618	0.155	
	3. Attractant Source	0.394	0.138	
Adult males (spring) (<i>n</i> = 7,986)	No strength of evidence for any model			0.0004
Adult males (summer) (<i>n</i> = 1,253)	1. Green Areas with Attractants	0	0.407	0.0081
	2. Spring Green-up	1.475	0.195	
	3. Attractant Source	2.511	0.166	
Adult males (fall) (<i>n</i> = 1,596)	1. Human Use	0	0.534	0.044
	2. Human Use and Spring Green-up	2.071	0.190	
	3. Spring Green-up and Attractant Source	3.337	0.101	

¹ Interpretation note: A model with a ΔAIC value within 1-2 of the best model has substantial support in the data and should be considered along with the best model. A ΔAIC value within only 4-7 units of the best model has considerably less support. A ΔAIC value > 10 indicates that the worse model has virtually no support and can be omitted from further consideration (Burham and Anderson 2002).

explanatory models we identified *a priori* do not reveal covariates which drive these patterns at local scales. This runs counter to the findings of regional scale studies which found evidence of multiple factors driving human-bear conflict patterns (Stahl *et al.* 2002; Treves *et al.* 2004; Wilson *et al.* 2006) as well as evidence of Black Bear foraging selection and preferences (Lyons 2005; Davis *et al.* 2006). We postulate that these results reflect the conflict activity in Whistler and the ecology of the bears studied, and herein present four hypotheses to explain the lack of model fit.

First, other covariates may exist that predict conflict better than the ones we used in our quantitative models or that were available from our previously collected landscape attribute data set. We suspect that the primary driver of conflict may be the unquantified fine scale availability of ephemeral attractants throughout the study site, such as the quintessential freshly baked pie cooling in the window, which was reported as a conflict during our study, or the unlocked garbage shed. For Grizzly Bears, conflict intensity has been assumed to be driven by one or a few attractant(s) in a matrix of suitable habitat features, for example sheep (Rondinini and Boitani 2007), calving grounds, bone yards, and/or beehives (Wilson *et al.* 2006). In our study, the primary driver of conflict may have been garbage/food availability distributed ephemerally at fine spatial scales. Such attractants are more numerous at the concentrated attractant hotspots identified in our model were distinct spatial patterns in the conflict UD were detected (see Figures 3 and 4), but fine scale attractants also exist distributed throughout the study site and may fluctuate unpredictably in availability and distribution in areas of human activity. Fine scale attractant availability was not quantified in this study and therefore could not be used as an explicit factor in our analysis. Further studies should target this approach in an area in which fine scale attractants can be quantified or controlled; elucidating human activities and demographics that contribute to attractant availability may play a role in predicting their presence.

Second, spatial patterns of conflict may be driven more by individual bears' choices, learned behaviours, and level of habituation rather than by the specific landscape features themselves. Individual bears can show dramatic variation and flexibility in their foraging habits eliciting unique patterns. Breck *et al.* (2009) highlighted the refined ability of bears to forage in human landscapes, showing that they will select for a certain 'car style' in Yosemite, demonstrating extreme selection on the scale of anthropogenic food type. Anecdotally, one non-collared bear in our study area arrived daily, on-time, for the local bakery delivery, foraging from the truck on repeated incident. Due to our opportunistic sampling design, we were unable to account for individual variation and learned behaviour, and repeated measures of individuals within our generalized bear classes may have confused overall conflict with individual conflict in our results. A discrete choice model for individual bears may be necessary to

predict small scale conflict patterns (Cooper and Millspaugh 1999; Carter *et al.* 2010) as well as the use of individual activity budgets (Aebischer *et al.* 1994).

Third, Whistler, with its wildland-urban landscape, is effectively one large conflict hotspot within this local scale of use by the bears and our polygons were not able to decipher differences as a result. Carter *et al.* (2010) found that Black Bears select at a resolution of >1 km², whereas our resolution was 30 m². With the exception of the concentrated attractant sources, covariates describing adjacent habitat quality may be equally important, or equally unimportant, in value at the local scale. This could be the result of the town's inherent small size and the integration of natural habitat patches within developed areas, and speaks to the ubiquity of Whistler's wildland-urban interface habitat and the accessibility of fine scale ephemeral attractants during the years of the study.

Fourth, conflict throughout the town may be so pervasive, numerous, and spatially dispersed as to prevent a single factor or set of factors to emerge as the main driver(s) of conflict location. Study animals may be sufficiently habituated such that the use of any area within this wildland-urban interface is perceived as a manageable risk. It may be hard for any spatial model to parse out patterns under this management regime which tolerates many food-conditioned habituated bears and prevalent fine scale attractants, and where conflict incidents are simply too numerous and wide spread.

MANAGEMENT IMPLICATIONS

This study of Black Bear conflict at the local scale reveals an important and broadly relevant concept regarding human-carnivore conflict within the wildland-urban interface; although conflict incidents may be prevalent at attractant hotspots, they may be difficult to predict at local spatial scale based on landscape attributes alone. Further, the quality of the wildland-urban interface habitat and bear habituation levels may both be so high that some bears are willing to use almost any area at certain times of year regardless of human activity. This suggests that local scale management must be driven by fine scale attractant prevention (both concentrated sources and dispersed) and the mitigation of each separate conflict incident, rather than landscape and habitat maintenance. We herein consider the known importance of matching management policies to the scale of the problem at hand, and our conclusions suggest that there may be different solutions at different scales for managing bear conflict in the wildland-urban interface (Hobbs 2003; Boyce 2006; Nams, Mowat and Panian 2006).

The regional scale conflict management approach should continue to involve habitat conservation planning for bear populations and potential restriction of human activities in certain areas (Treves and Karanth 2003; Nams *et al.* 2006; Roever *et al.* 2010; Linke *et al.* 2013). Nested within regional habitat maintenance, local-scale management of conflicts which do inevitably happen should

involve the day-to-day mitigation of incidents where landscape attributes may not be a dominant factor driving conflict location. This small scale of spatially and temporally shifting availability of ephemeral attractants may be driving conflict and thus it is at this scale where attractants need to be controlled to yield an effective conflict mitigation strategy. In other words, within a wildland-urban interface such as Whistler, where quality habitat prevails in the developed landscape, bears will likely eat garbage wherever there is garbage available. As such, mitigation will require adaptive management of attractants and individual animals by management and enforcement agencies, wildlife education programs, and the public. Local management must occur at the scale of each arising attractant. Without strict attractant control, conflicts will remain numerous and successful conflict prevention will remain difficult to achieve.

Human-caused bear mortality in high quality habitat has been correlated temporally and spatially with increasing development and proximity to humans, and the human activities associated with these habitats are key factors dictating bear survival (Apps *et al.* 2004; Baruch-Mordo *et al.* 2008). Non-lethal management is touted as the modern solution to reducing bear mortality and achieving conservation through co-existence, but the challenge remains how to do so effectively, without continually shooting bears. Our results suggest that when deriving non-lethal management solutions, we should invoke different approaches at different management scales, where local-scale management focuses on the fine scale availability of attractants both concentrated and dispersed. Our results and our experience researching these bears continually for years reiterate that no management strategy beats conflict prevention thorough attractant control. Clark *et al.* (2005) termed the study of carnivore management as a “transscience” because of the multiple dimensions involved in the process of successful carnivore management. Therefore, the maintenance of people and carnivores together in close proximity in a wildland-urban interface habitat will require ongoing and likely pricey adaptive management at the local scale if a non-lethal approach is to be achieved.

LITERATURE CITED

- Appleton, R. 2006. Black bear Abundance and seasonal forage habitat value in Whistler, BC. MRM thesis. Simon Fraser University, Burnaby, British Columbia, Canada.
- Alt, G. L., G. J. J., Matula, F. W. Alt, and J. S. Lindzey. 1980. Dynamics of home range and movements of adult Black Bears in North-eastern Pennsylvania. *International Conference on Bear Research and Management* 4: 131-136.
- Apps, C. D., B. N. McLellan, J. G. Woods, and M. F. Proctor. 2004. Estimating grizzly bear distribution and abundance relative to habitat and human influence. *Journal of Wildlife Management* 68: 138-152.
- Baruch-Mordo, S., S. W. Breck, K. R. Wilson, and D. M. Theobald. 2008. Spatiotemporal distribution of black bear-human conflicts in Colorado, USA. *Journal of Wildlife Management* 72: 1853-1862.
- Beale, C.M., J. J. Lennon, J. M. Yearsley, M. J. Brewer, and D. A. Elston. 2010. Regression analysis of spatial data. *Ecology Letters* 13: 246-264.
- Beyer, H. L. 2004. Hawth's analysis tools for ArcGIS. <http://www.spatialecology.com/htools> . Accessed 1 December, 2009.
- Boyce, M. S. 2006. Scale for resource selection functions. *Diversity and Distributions* 12: 269-276.
- Breck, S. W., N. Lance, and V. Seher. 2009. Selective foraging for anthropogenic resources by black bears: Minivans in Yosemite National Park. *Journal of Mammalogy* 90: 1041-1044.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Springer-Verlag, New York, New York, USA.
- Buskirk, S. W., and J. J. Millspaugh. 2006. Metrics for studies of resource selection. *Journal of Wildlife Management* 70: 358-366.
- Carroll, C., R. F. Noss, and P. C. Paquet. 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. *Ecological Applications* 11: 961-980.
- Carter, N. H., D. G. Brown, D. R. Etter, and L. G. Visser. 2010. American black bear habitat selection in northern Lower Peninsula, Michigan, USA, using discrete-choice modeling. *Ursus* 21: 57-71.
- Clark, T. W., M. B. Rutherford, and D. Casey. Editors. 2005. Coexisting with large carnivores: Lessons from Greater Yellowstone. Island Press, Washington, D.C. USA..
- Clevenger, A. P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. *Conservation Biology* 16: 503-514.
- Conservation Officer Service. 2008. Problem Wildlife Occurrence Reports. Province of British Columbia public complaint records. Reviewed by M.von der Porten and N. Bickerton.
- Cooper, A. B., and J. J. Millspaugh. 1999. The application of discrete choice models to wildlife resource selection studies. *Ecology* 80: 566-575.
- Crawley, M. J. 2007. The R book. John Wiley and Sons Ltd., Chichester, West Sussex, England.
- Davis, H., R. D. Weir, A. N. Hamilton, and J. A. Deal. 2006. Influence of phenology on site selection by female American black bears in coastal British Columbia. *Ursus* 17: 41-51.
- Davis, H., D. W. Wellwood, and L. M. Ciarniello. 2002. “Bear Smart” community program: background report. British Columbia Ministry of Water, Land and Air Protection. Victoria, British Columbia, Canada.
- Demarchi, D. N., and A. N. Hamilton. 2000. Black bear capability in British Columbia map. Data from B.C. Ministry

- of Environment, Lands and Parks, Victoria, British Columbia, Canada.
- Gitzen, R. A., J. J. Millspaugh, and B. J. Kernohan. 2006.** Bandwidth selection for fixed-kernel analysis of animal utilization distributions. *Wildlife Society Bulletin* 70: 1334-1344.
- Green, R. N. 2004.** *Terrestrial Ecosystem Mapping of the Resort Municipality of Whistler*. B.A. Blackwell and Associates Ltd. www.balackwell.com. Accessed 20 January, 2012.
- Hilborn, R., J. M. Orensanz, and A. M. Parma. 2005.** Institutions, incentives and the future of fisheries. *Philosophical Transactions of the Royal Society - Biological Sciences* 360: 47-57.
- Hilderbrand, G. V., C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. A. Hanley, S. M. Arthur, and C. Servheen. 1999.** The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. *Canadian Journal of Zoology* 77: 132-138.
- Hobbs, N. T. 2003.** Challenges and opportunities in integrating ecological knowledge across scales. *Forest Ecology and Management* 181: 223-238.
- Horne, J. S. and E. O. Garton. 2006.** Likelihood cross-validation versus least squares cross-validation for choosing the smoothing parameter in kernel home-range analysis. *Journal of Wildlife Management* 70: 641-648.
- Johnson, D. H. 1980.** The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61: 65-71.
- Karanth, K. U., and R. Chellam. 2009.** Carnivore conservation at the crossroads. *Oryx* 43: 1-2.
- Kellert, S. R., M. Black, C. R. Rush, and A. J. Bath. 1996.** Human culture and large carnivore conservation in North America. *Conservation Biology* 10: 977-990.
- Levin, S. A. 1992.** The problem of pattern and scale in ecology. *Ecology* 73: 1943-1967.
- Linke, J., G. J. McDermid, M. J. Fortin, and G. B. Stenhouse 2013.** Relationships between grizzly bear and human disturbances in a rapidly changing multi-use forest landscape. *Biological Conservation* 166: 54-63.
- Lyons, A. J. 2005.** Activity patterns of urban American black bears in the San Gabriel Mountains of southern California. *Ursus* 16: 255-262.
- Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and E. P. Erickson. 2002.** *Resource selection by animals: Statistical design and analysis of field studies*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Marzluff, J. M., J. J. Millspaugh, P. Hurvitz, and M. S. Handcock. 2004.** Relating resources to a probabilistic measure of space use: Forest fragments and Steller's Jays. *Ecology* 85: 1411-1427.
- McCroly, W., and R. Appleton. 2007.** Black bear habitat and corridor map project. commissioned by the Resort Municipality of Whistler. Whistler, British Columbia, Canada.
- Millspaugh, J. J., G. C. Brundige, R. A. Gitzen, and K. J. Raedeke. 2000.** Elk and hunter space-use sharing in South Dakota. *Journal of Wildlife Management* 64: 994-1003.
- Millspaugh, J. J., R. A. Gitzen, B. J. Kernohan, J. A. Larson, and C. L. Clay. 2004.** Comparability of three analytical techniques to assess joint space use. *Wildlife Society Bulletin* 32: 148-157.
- Millspaugh, J. J., R. M. Nielson, L. McDonald, J. M. Marzluff, R. A. Gitzen, C. D. Rittenhouse, M. W. Hubbard, and S. L. Sheriff. 2006.** Analysis of resource selection using utilization distributions. *Journal of Wildlife Management* 70: 384-395.
- Nams, V. O., G. Mowat, and M. A. Panian. 2006.** Determining the spatial scale for conservation purposes - an example with grizzly bears. *Biological Conservation* 128: 109-119.
- Pinheiro, J., D. Bates, S. DebRoy, D. Sarkar, and the R Core Team 2009.** nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-96.
- Powell, R. A., J. W. Zimmerman, D. E. Seaman, and J. F. Gilliam. 1996.** Demographic analyses of a hunted Black Bear population with access to a refuge. *Conservation Biology* 10: 224-234.
- Province of British Columbia. 1999.** Don't attract bears to garbage. BC Ministry of Environment Stewardship Branch Publication. http://www.env.gov.bc.ca/wld/beargarbage/garbg_br2.htm. Accessed 4 February, 2012.
- Roever, C. L., M. S. Boyce, and G. B. Stenhouse. 2010.** Grizzly bear movements relative to roads: application of step selection functions. *Ecography* 33: 1113-1122.
- Rondinini, C., and L. Boitani. 2007.** Systematic conservation planning and the cost of tackling conservation conflicts with large carnivores in Italy. *Conservation Biology* 21: 1455-1462.
- Sangay, T., and K. Vernes. 2008.** Human-wildlife conflict in the Kingdom of Bhutan: Patterns of livestock predation by large mammalian carnivores. *Biological Conservation* 141: 1272-1282.
- Stahl, P., J. M. Vandel, S. Ruetter, L. Coat, Y. Coat, and L. Balestra. 2002.** Factors affecting lynx predation on sheep in the French Jura. *Journal of Applied Ecology* 39: 204-216.
- Theobald, D. M., N. T. Hobbs, T. Bearly, J. A. Zack, T. Shenk, and W. E. Riebsame. 2000.** Incorporating biological information in local land-use decision making: designing a system for conservation planning. *Landscape Ecology* 15: 35-45.
- Treves, A., and K. U. Karanth. 2003.** Human-carnivore conflict and perspectives on carnivore management worldwide. *Conservation Biology* 17: 1491-1499.
- Treves, A., L. Naughton-Treves, E. K. Harper, D. J. Mladenoff, R. A. Rose, T. A. Sickley, and A. P. Wydeven. 2004.** Predicting human-carnivore conflict: A spatial model derived from 25 years of data on wolf predation on livestock. *Conservation Biology* 18:

114-125.

- Valeix, M., G. Hemson, A. J. Loveridge, G. Mills, and D. W. Macdonald. 2012. Behavioural adjustments of a large carnivore to access secondary prey in a human-dominated landscape. *Journal of Applied Ecology* 49: 73–81.
- von der Porten, M. 2010. Mitigating human-Black Bear conflict by understanding spatial patterns and associated site characteristics. MSc thesis. Simon Fraser University, Burnaby, British Columbia, Canada.
- Wiens, J. A., N. C. Stenseth, B. Vanhorne, and R. A. Ims. 1993. Ecological mechanisms and landscape ecology. *Oikos* 66: 369-380.
- Wilson, S. M., M. J. Madel, D. J. Mattson, J. M. Graham, and T. Merrill. 2006. Landscape conditions predisposing grizzly bears to conflicts on private agricultural lands in the western USA. *Biological Conservation* 130: 47-59.
- Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* 70: 164-168.

ABOUT THE AUTHORS

Mary von der Porten holds a Master of Resource Management from Simon Fraser University and a Bachelor of Science with Distinction in Biology from the University of Victoria. She is a Registered Professional



Biologist with the College of Applied Biology of British Columbia. Her interests in wildlife biology range from animal movement patterns and habitat use to the management of wildlife disease and other population level risks. Mary is currently undertaking her Doctor of Veterinary Medicine at the Western College of Veterinary Medicine, where she is conducting research on assisted reproductive technology for the conservation of Wood Bison (*Bison bison athabasca*) threatened by endemic disease.

Andy Cooper is a quantitative ecologist specializing in the application of statistical and mathematical tools to questions rooted in marine ecology and resource management. His research focuses on such topics as population dynamics and stock assessment, decision-making under uncertainty, historical ecology, biodiversity, animal movement, and resource selection. Dr. Cooper is currently working on projects examining: (1) the temporal and spatial patterns of multispecies fishery landings in the Gulf of Maine in the early 1900s, (2) an epidemiological approach to the analysis of indicators and reference points of ecosystem and population health, (3) hierarchical models to aid in the analysis of monitoring data, and (4) the impact of uncertainty in stock structure on the management of herring in the western Atlantic. Dr. Cooper has worked extensively with federal and regional fisheries management

agencies as well as marine conservation groups in the USA, and is currently working with REM students and faculty, Fisheries and Oceans Canada, and others to tackle questions focusing on the North Pacific marine ecosystem.

Nicola Bickerton is a registered professional wildlife biologist living in Squamish, British Columbia. She has spent her career working on various wildlife projects researching Black Bear conflict behaviour, Grizzly Bear habitat conversation, and Killer Whale (*Orcinus orca*) monitoring. Her most recent employment was with the BC provincial government reviewing project proposals ensuring wildlife species and values were conserved. Nicola holds an Honours BSc in Zoology and a Post-Baccalaureate in Environmental Science.



Anne Salomon is an assistant professor of applied ecology at Simon Fraser University. Her research is motivated by a deep interest in understanding how human activities alter the productivity, biodiversity, and resilience of coastal food webs to inform ecosystem approaches to marine conservation. Salomon and her students study the cascading effects of predator depletion, marine spatial planning and ecosystem-based management, and the dynamics of linked human-ocean ecosystems. Ultimately, she strives to engage coastal communities and government agencies in collaborative research and encourage constructive dialogue among stakeholders to design effective conservation policies that balance the needs of people and nature.



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