Mitigating Human-Black Bear Conflicts by Understanding Spatial Patterns and Associated Site Characteristics

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ABSTRACT

Conflict with humans poses a serious risk to the viability of carnivore populations worldwide. Identifying effective non-lethal management strategies demands an understanding of the interplay among multiple drivers of conflict at the scale of conflict situations. I quantified the spatial patterns of human-bear conflict in Whistler, Canada with utilization distributions of conflict incidents. I examined the strength of evidence for the effects of landscape and habitat variables associated with conflict using Resource Utilization Functions, Generalized Least Squares, and model selection. Seasonality emerged as a determinant of spatial variability of conflict with bears using more concentrated attractants in the fall than in the summer or spring. No covariates could be identified as drivers of conflict at a local scale despite the pressing need to design management interventions at this scale. This lack of predictability underscores the necessity for responsive adaptive management policies to reduce human-carnivore conflict in increasingly human-dominated landscapes.

Key words: conflict, scale, black bear, *Ursus americanus*, carnivore conservation, generalized least squares, resource utilization function, spatial analysis

DEDICATION

To the wild animals that continue to survive in increasingly human dominated landscapes, your efforts are appreciated.

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Introduction

Geographical Information Systems (GIS) are becoming an increasingly important tool in quantitative wildlife ecology. Understanding spatial usage by animals is a necessary part of determining appropriate conservation and management strategies, and this is particularly important with respect to large mammals as human encroachment into wild landscapes increases (Apps et al. 2001; Bruggeman et al. 2007; Rode et al. 2007; Sangay & Vernes 2008; Zielinski et al. 2006). GIS technology has been used to quantify spatial use by wild populations of black bears (*Ursus americanus*), but its application to conflict black bears remains largely unexplored (Baruch-Mordo et al. 2008; Wilson et al. 2005; Wilson et al. 2006). This study is a first step in assessing and quantifying the spatial use patterns of black bears and the landscape and habitat features that may predispose sites to human-bear conflict.

Due to the point nature of the spatial data collected on large mammals such as bears, point pattern analyses are often employed to identify patterns and clustering within animal space use. Kernel density estimation is the established method used in wildlife ecology to extrapolate point data to an entire study area allowing home ranges and habitat selection to be examined across a landscape (Worton 1987, 1989). Specifically, this method extrapolates a random sample of point location data into a utilization distribution, or probability density function, across space.

When performing kernel density estimation, the bandwidth of the kernel used is important because it determines the smoothing factor of the utilization distribution (Gitzen et al. 2006; Worton 1989). Using different bandwidths may yield different analytical results. Thus, it is necessary to choose a bandwidth based on existing point data, the question being asked and the animal being studied. Similarly, using kernel analysis on different data sets can yield different results for the same species. This study addresses the sensitivity of kernel analysis to bandwidth inputs, the discrepancies between human-bear conflict data collection methods, and examines seasonal fluctuations in the location of human-black bear conflicts.

Methods

Data Collection

All data was collected in the Resort Municipality of Whistler (RMOW), British Columbia (Fig.1) during 2006 (1 year of 3 the year study). Nineteen individual black bears were equipped with collars and monitored using radio telemetry. Animals were located approximately once per day by researchers, and their Universal Transverse Mercator (UTM) coordinate location was recorded using a handheld global positioning system (GPS) within ±10m accuracy. Each time a study animal was located, the bear's behavior was observed and classified. An incident was classified as a 'conflict' when a bear was obtaining an unnatural food reward, causing property damage, exhibiting defensive behaviour towards the public, or when bears were sighted in urban areas in close proximity to people. Data points obtained during these conflict events are used in this analysis and labeled as "study animal data" (*n*=464) herein.

The second data set was obtained from Problem Wildlife Occurrence Reports (PWORs) submitted to the Conservation Officer Service (COS) during 2006. These were complaints made by the public when they witnessed a bear in conflict or in an inappropriate location. PWORs were categorized by researchers according to event type and address location. All events (*n*=1066) are referred to as "PWOR data" herein.

Spatial Projection

GPS locations from study animal data were imported into ArcMap GIS software (ESRI 2009) and projected using North American Datum 1983 (zone 10N). PWOR data were geocoded with a Municipal address layer within ArcMap (RMOW 2007) and then spatialized using the center point coordinates of each address polygon. Maps were projected onto a 5m orthographic photo (RMOW 2007).

Kernel Density Estimation

Kernel density estimation is the established method for delineating spatial intensities of use for free ranging animals (Worton 1989). It is a non-parametric smoothing technique that determines densities based on a grid formation across the landscape. Each data point is given a respective probability density, and the intersection between these points and the rectangular grid are averaged across the landscape by equation (1) (adapted from Seaman & Powell 1996).

$$\hat{f}(x) = [1/(nh^2)] \sum_{i=1}^{n} K\left\{\frac{(x - X_i)}{h}\right\} \quad (1)$$

Where *x* is a vector of x,y coordinates, *n* is the number of points, *h* is a smoothing parameter also known as the bandwidth, and the location of each observation *i* is represented by a vector *X* of the coordinates within the *K* kernel, a Gaussian function. The size of the neighbourhood analyzed by *K* is controlled through the bandwidth *h*. The *h* value is important because it determines how smooth the utilization distribution will be, thus determining the surface's probability density estimates; if *h* is chosen incorrectly one can over-smooth or under-smooth the data. Objective methods for choosing *h* exist, including h_{ref} which calculates the optimal bandwidth for a standard bivariate normal distribution of points and Least Squares Cross Validation (LSCV) which finds the *h* that minimizes the integrated square error between the estimated density and true unknown density of points (Seaman & Powell 1996). The bandwidth can also be subjectively determined based an analyzer's knowledge of the animal's movement and the ecological question at hand. Many studies have examined the consequences of using various bandwidth selection methodologies; with LSCV being the most recommended option for fine scale analysis of home range point data (Gitzen et al. 2006; Horne & Garton 2006; Millspaugh et al. 2006). For the data exploration purposes of this particular analysis, I subjectively define bandwidth values to examine the effects on resulting utilization distributions of local scale human-bear conflict data. I created all kernel outputs using a fixed kernel density estimator in Hawth's Tools for ArcGIS (Beyer, H. L. 2004).

Sensitivity Analysis

Six different values for the bandwidth parameter *h* were examined with the study animal dataset (500m, 200m, 200m, 75m, 50m, and 10m). The *h* values chosen were based on the estimated range of local scale bear foraging patterns. Raster cell size was also tested using 10m, 50m, and 100m. All outputs were compared visually within ArcMap. My recommended subjective choice of bandwidth was based on further requirements for data analysis and interpretation as well as the scale at which conflict was occurring. I created a final output kernel with *h*=100 m using a combined version of the data sets, and probabilities across a 3-dimensional landscape were explored using the ArcScene function in the Geostatistical Analyst extension of ArcMap (Willems & Hill 2009).

Congruence of datasets

To explore dataset congruency, I created kernel density outputs for both data sets independently using an *h* value of 100 m and raster cell size of 10 m. Conflict activity hotspots for each dataset were established using 50% volume contours created in Hawth's Tools, a methodology used previously as an indicator of high spatial bear use (Wilson et al. 2006; Clevenger et al. 2002). An overlap layer was created using the ArcMap intersection tool in Arc Toolbox. Volume contours were compared visually. Kernels were independently intersected with the address layer to yield an output list of all the addresses involved. Address layers of the hotspots of each dataset were numerically compared for congruency through the join function in ArcMap.

Seasonal differences

Both the PWOR and Study Animal datasets were separated into spring, summer, and fall. The conflict events that occurred in the winter were excluded because they are exceptional events as bears are usually hibernating during this season. Kernels (*h*=100 m, cell size=10 m) were created for each season and for each dataset. Datasets were combined to examine seasonal effects rather than difference between reporting types. This was done by summing the 2 kernels created for each season using the raster calculator in the Spatial Analyst extension of ArcMap. The top 50% volume isopleth contours of the resulting seasonal kernels were again created to represent conflict hotspots. I visually compared outputs for differences in location.

Results

Sensitivity Analysis

Based on visually observed qualitative differences, the ideal bandwidth size for representing a utilization distribution of local scale bear conflict may be 100 m, with a raster cell size of 10 m. The visual differences between the kernel outputs are shown in Fig. 2, and corresponding comments on all specific images are listed in Table 1. Image f was chosen as the ideal kernel for further exploration of the data because it represents local scale smoothing without under-smoothing to a point layer.

Both datasets (*n*=1530) were combined into a kernel (*h*=100 m, cell size=10 m) to give the output shown in Fig. 3. The transition from point layer (Fig. 3a) to kernel (Fig.

3b) is explicitly demonstrated, along with the 3D version (Fig. 3 c) showing the relative probability of conflict across the landscape. Note the gradients in relative probabilities (heights in 3D image) are small, and that there is one large, contiguous hotspot in the center right of the study area, in addition to numerous other peaks.

Congruence of Data sets

Both data sets demonstrate the highest degree of conflict over in the same central area, which corresponds to the town center (Fig. 4). This area has the highest density of people, which may result in a higher frequency of reports. There are other hotspots for both datasets that occur throughout town in similar locations. The address layer intersection with PWOR data and the study animal data indicates 432 and 259 addresses are conflict hotspots respectively. These outputs have 167 addresses in common. Two major errors are apparent (highlighted in red, Fig. 4), where the kernel is different than the site of conflict. These are the result of geocoding errors within large parcels of land with one address, where the center of the polygon is different than the site of the conflict.

Seasonal differences

The conflict hotspots for spring, summer and fall show differences in location across the landscape (Fig. 5). There is a strong 3-way overlap for all seasons in the town center however, indicating that conflict occurs here year round (Fig. 5 inset). The spring hotspots occur within close proximity to golf courses and ski hills. Summer hotspots are distributed throughout residential areas with no clear pattern while fall conflicts occur primarily in the town center.

Discussion

Choosing the correct inputs when doing kernel estimation is important, as it will affect interpretation of results. The bandwidth value is especially important. There is no exact procedure for choosing h, because one must consider the scale of the study area, distribution pattern of the point layer, as well as the question being asked. This study indicated that h~100 m may work for examining human-bear conflict hotspots in Whistler (Fig. 2), which is an h smaller than other studies (Clevenger et al. 2002) and not based on an objective calculation (Seaman & Powell 1996). I suggest that this smaller h of 100 m may be appropriate because of the high density of points in urban areas, and an h value >100 m resulted in the entire town being a hotspot (Fig. 2a&b). This will leave little room for interpretation of habitat parameters within. Conversely, a very small h (<100 m) essentially yields a point layer, which may over contrast the data potentially making interpretation covariate importance difficult in future analyses.

Exploring the effects of different h values on the kernel outputs was an important exercise in understanding the potential bias created by this user-defined input. However, when going beyond the data exploration purposes of this analysis to quantifying drivers of human-bear conflict, the use of objective methods must be considered. Objective methods, such as LSCV or h_{ref}, are specifically designed for home range and resource selection analysis of individual study animals, and may be more useful by providing an unbiased h. These calculations, however, do not always yield an 'ideally' smoothed surface where the kernel output reflects the scale of the animal's movement and the ecological question being posed, and high variance levels can outweigh the gain of unbiased results (Horne & Garton 2006). Nevertheless, future analyses may employ LSCV objective bandwidth selection as it is widely accepted in ecology, works well for fine scale data, and it yields an *h* similar to what is chosen here (Millspaugh et al. 2006). Finally, raster cell size should be smaller than the *h* value to allow for proper interpretation (Fig.2 e & f). A raster cell size of 10m is ideal because it reflects the micro scale of conflict occurrences within addresses as well as the accuracy of the GPS coordinates taken. As long as covariate resolution can be defined at this small scale of 10m, this raster cell size can be used in future analyses (Marzluff et al. 2004). In sum, the input values chosen were based on expert opinion and were biologically appropriate for the scale of bear conflict patterns, as well as adequate to create a visually interpretable utilization distribution across an address segregated landscape.

Since the final kernel output has a small gradient in probabilities (represented as heights in Fig. 3c) taking the 50% volume contour was effective for focusing in on a general pattern of conflict hotspots. Both the PWOR, study animal data and their 50% volume overlap indicate that the town center is a major conflict hub. It also suggests that human detection ability within the town center is high, and it remains possible that conflict hotspots outside of town could be larger, but were harder to detect. When using public reporting as a proxy for animal space use, the element of human detection ability needs to be accounted for because more observations will inherently occur where there are more people (Horne et al. 2007). Other studies did not identify this as a problem when examining public reports, because detection ability was likely more uniform across their primarily rural landscape (Baruch-Mordo et al. 2008; Wilson et al. 2005; Wilson et al. 2006).

When comparing the two datasets outside the town center, there is congruency where the addresses are small in area, but some significant errors occur when the addresses represent a large area (Fig. 4). This is because the geocoding method results in a point value at the center of the polygon, which may be far from the conflict site. Therefore, caution must be used when combining these datasets, especially when using such a micro scale kernel. The addresses that do overlap successfully can be confirmed as hotspots, and can be used for further habitat analysis through multivariate regression (Wilson et al. 2005; Wilson et al. 2006). Taking a smaller volume to represent hotspots may have been more advantageous as it would have highlighted more extreme hotspots rather than a general spatial trend in the data (Nelson & Boots 2008).

Creating separate kernels for the different seasons was the first step towards landscape and habitat attribute analysis of conflict site locations. Seasonal variation is an accepted variable within the bear conflict literature, but it cannot simply be added as a testable parameter within one mathematical model, but separate models for each season must be created (Baruch-Mordo et al. 2008; Wilson et al. 2006). The results of this study indicate that in every season, the town center will be a conflict hotspot, likely due to the high density of garbage as well as the high detection ability of people in this area. Conflicts in residential areas show spatial patterns that may be consistent with the hypothesis that bears vary their use of feeding sites based on shifting spatial and temporal resource availability (Davis et al. 2006). Large spring conflict hotspots occur near golf courses and ski hills, where bears typically feed on new grass shoots. This indicates that conflict could be occurring in close proximity to natural forage sites or at ‘spatial convenience’ to where bears are already present. In other words, bears may get into conflict opportunistically as they exploit other natural food resources. Summer hotspots become more distributed within the study area, possibly reflecting re-allocation of natural foods. Conversely, fall conflicts likely occur primarily within the town center because there is little natural food available, and bears generally seek high caloric, protein rich anthropogenic foods prior to hibernation. This seasonal variation in hotspot locations suggests that seasonal bear foraging patterns may exist not only for natural foods but also for foraging on anthropogenic attractants (Berland et al. 2008; Clark et al. 1993; Nams et al. 2006; Wilson et al. 2006).

Conclusions & Future Directions

Through this data exploration exercise, I have demonstrated that spatial analyses with GIS technology can be an effective tool in better understanding the spatial patterns of human-bear conflict. Choosing the correct inputs for spatial analysis is a critical first step in any ecological modelling of landscape use, and this study demonstrates the range of possible kernel outputs that one data set can yield. For my fine scale analysis, an *h* value of 100 m appeared ideal in refining hotspots without under smoothing the data. In addition to input sensitivity, this study illustrates aspects of my human-bear conflict data which are important considerations for future analysis; 1) that while public reports and study animal data differ in spatial accuracy and reporting consistency, they still provide the same general hotspots, and 2) seasonality may be a factor in driving spatial distribution of human-bear conflict. These findings are based on visual interpretation of hotspots and must still be confirmed through more robust statistical modelling of resource selection. This study provides the foundation of the model which aims to identify habitat and landscape factors that best predict human black-bear conflict at the small spatial scale at which conflict occurs (Chapter 2). This quantitative model described in Chapter 2 determines if the visual conclusions in this hotspot analysis are a function of mapping, or if they are reflected in the true biological and statistical reality of black bear conflict.

CHAPTER 2- SPATIAL PATTERNS OF HUMAN-BEAR CONFLICT UNPREDICTABLE AT LOCAL SCALES

Introduction

Elucidating the landscape-level features that govern spatial use patterns of a species is required to accurately design effective conservation strategies (e.g. Tilman and Karieva 1997). Non-migratory spatial use is typically driven by resources and risk (Johnson 1980; Wiens et al. 1993). Consequently, understanding the extent to which these factors mediate habitat use by animals, and the spatial scale at which they operate, is essential to ensuring that conservation policies match the scale at which ecological dynamics occur (Hilborn et al. 2005; Levin 1992). Conservation policy can occur at a variety of spatial scales, from international treaties (bio-regional scale) down to the municipal, park, or reserve by-law level (patch scale), with management occurring at the perceived scale of the issue (Hobbs 2003). Conservation policies must therefore be informed by a solid ecological understanding of spatial use by animals at the appropriate scales.

Human-carnivore conflict currently threatens the existence of species worldwide, making this conservation issue a high priority (Karanth & Chellam 2009). Carnivores are valuable both ecologically, in maintaining the resilience of ecosystems, and socially, as cultural icons (Carroll et al. 2001; Treves & Karanth 2003; Kellert et al. 1996). Lethal management is often employed because carnivores will directly compete with people for habitat and food, as well as present a human safety risk (Mattson et al. 1996; Packer et al. 2005; Rondinini & Boitani 2007; Sangay & Vernes 2008). The paradigm of lethal management can and has lead to the extirpation and/or extinction of species while simultaneously failing to solve conflict problems in the long term (Kellert et al. 1996; Treves & Karanth 2003). For populations with low numbers and low reproductive rates, each individual animal can have a significant influence on the population trajectory; therefore, dramatic perturbations in populations can be caused by lethal actions on individual animals (Maguire & Servheen 1992). As conservation concerns heighten and public attitudes toward wildlife change, citizens are demanding non-lethal approaches to dealing with problem carnivores (Treves & Karanth 2003).

For any animal that regularly uses human settlements, understanding the factors driving the spatial use of habitat can inform wise management policies. Such policy should increasingly be sought at a local scale within the context of regional level management plans focused on habitat protection. While daily management policy within towns/settlements needs to be tailored to local scales, studies are not necessarily geared toward the local context (Theobald et al. 2000). This is true for research identifying spatial drivers of human-carnivore conflict, which has primarily been conducted at the regional level (Baruch-Mordo et al. 2008; Sangay & Vernes 2008; Treves et al. 2004; Wilson et al. 2006). While bears use habitat and resources at multiple scales concurrently, conflict incidents are typically managed at the local scale. Carnivore managers still need scientific advice on this ground level conservation informed by ecological evidence to successfully prevent and mitigate conflict. This should include a thorough understanding of animal space use within human dominated landscapes where conflict is most likely to occur.

Black bears can offer insight into the management of other more vulnerable carnivores that face similar conservation challenges (Powell et al. 1996). Black bears are often drawn to human-dominated landscapes to forage on anthropogenic food sources. This pervasive use of human settlements challenges managers to minimize cost and risk to human safety, yield to public pressure for humane treatment of wildlife, and ensure the viability of carnivores and the ecological functions they provide. This trade-off motivates the study of carnivore conflict management in a non-lethal context, in particular, how to prevent it from occurring. To inform local management on how to prevent human-bear conflict within a town site, I examined the factors that best predict spatial patterns of conflict at that scale.

Methods

Location and Study Species

The Resort Municipality of Whistler is situated 135 km north of Vancouver, within the Coastal Mountain range of southwest British Columbia, Canada (Fig. 1). Tourism is the primary industry and is centered on ski operations. The vegetation of this valley is dominated by Western Hemlock (*Tsuga heterophylla)* and provides nutritious bear food resources, including blueberries and huckleberries (*Vaccinium sp.*).

This community shares the land with a dense population of black bears, which are omnivorous carnivores that feed opportunistically. Bears choose their home range on the basis of food resource distribution (Mitchell & Powell 2007) and vary their use of feeding sites with shifting spatial and temporal resource availability, as well as human-activity (Davis et al. 2006). Appleton (2006) estimated bear densities in Whistler to be approximately one bear per 1km^2.

Data Collection and Classification

I collected data on conflict bears from 2005-2007 as part of a broader collaborative non-lethal management study. Bears were primarily caught in steel culvert traps that were set within urban areas and then equipped with Telonics Very High Frequency (VHF) or Lotek Global Position System (GPS) collars. Of the bears trapped, collared and monitored, 5 females and 27 males were included in this study. I grouped study animals into one of four categories relevant to bear biology: adult male, sub-adult male, female without cubs, and female with cubs (Alt et al. 1980; Davis et al. 2006; Lyons 2005). Gender and reproductive status were determined through visual observation, known life history, and monitoring.

Researchers located the animals approximately once per day to obtain their *Universal Transverse Mercator* (UTM) coordinate location and to observe and record the bear's behavior. In addition, researchers also responded to bear complaints from the public as they were reported. An incident was classified as a 'conflict' when a bear was obtaining an unnatural food reward, causing property damage, exhibiting defensive behaviour towards the public, or when bears were sighted in urban areas in close proximity to people.

Conflict locations were pooled for all years (2005-2007) and then separated into seasons determined by known vegetation cycles in the Whistler Valley (McCrory & Appleton 2007) (Spring=April 1-June 30, Summer=July 1-Aug 31, Fall=Sept 1-Dec 15, and Winter=Dec 16-March 31). Conflict events that occurred in the winter were excluded as exceptional events as bears are usually denning during this time period. I imported GPS locations from study animal data into a Geographical Information System (GIS, ArcInfo 9.3.1, (ESRI 2009)) and projected them with North American Datum 1983 (zone 10N).

Utilization Distribution

The Utilization Distribution (UD) is a spatial surface derived from a sample of point locations, and it provides a continuous measure of the intensity of animal space use. I used kernel density estimation outputs to describe a UD for the conflict activity of each black bear reproductive class (Millspaugh et al. 2006; Worton 1989). All UDs were 99% volume isopleths of fixed kernels made with Least Square Cross Validation bandwidths (Beyer, H. L. 2004; Gitzen et al. 2006; Horne & Garton 2006; Marzluff et al. 2004). Raster cell size was 30 m to reflect the micro scale of conflict occurrences and habitat resolution. UDs were created with datasets containing $\geq$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) and 2 UDs for female bears, one for each reproductive class in the fall, for 8 UDs in total. UDs were examined for spatial congruency between classes using a volume of intersection analysis and results show <20% overlap between every combination of the 8 UDs, justifying their separation

(Appendix A). I obtained UD density values from the center of each grid cell to represent the relative probability of conflict (response variable). I log transformed UD density values to ensure that the assumption of normality in the residuals would be met for regression.

Explanatory variables and the* a priori *model set

To determine which landscape and habitat covariates drive human-bear conflict, I first extracted covariate features from GIS layers. Covariate polygons were created from the Terrestrial Ecosystem Maps (Green 2004), bear habitat maps (McCrory & Appleton 2007), and by spatializing information from orthophotographs and ground work. I identified candidate covariates based on researchers' experience in the field and previous studies of human-bear conflict (Table 2; Baruch-Mordo et al. 2008; Wilson et al. 2006). Further details on the attractants involved in each bear class' conflict can be found in Appendix B. Every point was given a value of in/out of a possible bear attractant zones (e.g. landfill) and the distance from that point to each landscape covariate (e.g. wetland) was calculated based on Euclidean distances (Spatial Analyst, ESRI 2009; see Fig. 6). I 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).

I built a set of *a priori* candidate models to examine the underlying causes of conflict distribution by grouping independent variables into 5 base models (Table 2, Fig. 6 & Appendix C). 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 and 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. I fit all possible combination of the 5 base models to my probability of conflict data set, for a total candidate set of 31 models (Table 2). Certain UDs were not located within a given covariate field, so that covariate was omitted from the particular data sets' analysis (for details, see Table 3).

Conflict Utilization Function and Statistical Analysis

The flexibility of resource selection methodologies allows researchers to examine currencies other than basic use (Buskirk & Millspaugh 2006). I used Resource Utilization Functions to analyse which candidate models best predict spatial distribution of conflict. This methodology approaches resource selection 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 regression to analyze relationships with explanatory variables. More commonly-used binary (used/unused or available) resource selection models were not employed because there are a high number of unreported conflicts that would contaminate the sample, violating the allowable 20% contamination between available and used, potentially biasing my result (Manly et al. 2002). I herein call my approach Conflict

Utilization Function (CUF) as my currency is not general resource use, but conflict occurrences specifically.

To create CUFs, I assigned each point an explanatory covariate value from polygons and Euclidean distances rasters. I exported the final resulting CUF attribute tables populated with log transformed relative use values (ln(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, I reanalyzed using generalized least squares (GLS) because it accounts for spatial autocorrelation in the error term (Beale et al. 2010). I derived the spatial correlation structure by modelling the semi-variogram of each dataset. In all cases semi-variograms indicated Gaussian structure, therefore I 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 on split data sets (Beale et al. 2010). The coefficient of determination was computed from the global model for each data set. I tested the normalized residuals for model assumptions of normality and homogeneity of variance, which was met in every case (Crawley 2007). I conducted all statistical analyses in R 2.10.1 (R Development Core Team 2009) using the 'nlme' package (Pinheiro et al 2009).

To determine the strength of evidence among alternative variables driving human-black bear conflict I took an information-theoretic model selection approach (Burnham & Anderson 2002). I used Akaike's Information Criterion (AIC) which accounts for model fit and parsimony. I normalized the model likelihoods to a set of Akaike weights (w_i) representing the strength of evidence in favour of a given model.

Results

Utilization Distribution and Spatial Distributions of Conflict

The 3D depictions show that while all UDs were generally even and flat across the study area, the relative probability of conflict did vary slightly among bear classes (Fig. 7; heights are amplified for visualization). Females with cubs in the fall show the most peaked pattern indicating zones of high conflict near the landfill and town center. Adult males in the summer and fall, and sub-adult males in the spring and fall all show moderate peaks scattered throughout the landscape. Both adult males in the spring and sub-adult males in the summer show a distinctly non-peaked pattern with seemingly equal probability of conflict across the landscape.

Conflict Utilization Function Modelling Results

My CUF models were unable to explain a significant proportion of the variation in the spatial distribution of human-black bear conflict within this semi-urban landscape (Table 4). However, in some cases, the strength of evidence for alternative candidate models indicates spatial patterns that can inform locally-based conservation policy. Results of the AIC averaged models for each class can be found in Appendix D.

Seasonal Variation:

There is evidence that the Human Use and Attractant Source models are driving 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 influence conflict with adult and sub-adult male black bears in the summer and spring.

Model support by bear class:

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 (ΔAIC = 1.475 and 2.511 respectively). Support is driven by a positive association to being within parks. Adult males did not use the town center nor go near the ski hill in this season.

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 (ΔAIC = 3.146) and the Spring Green up & Attractant Source model (ΔAIC = 3.219).

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. Female study animals (both with and without cubs) never used the paintball course.

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. In addition to not using the Paintball course, this class did not get into conflict near the rail-line corridor.

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) and 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. This class used neither the Landfill nor the Paintball area in this season.

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.

Discussion

Although I found some spatial patterns in the probability of human-bear conflict throughout the study area (Fig. 7), the set of candidate models could not adequately predict this variation (Table 4). This lack of explanatory power has important conservation implications for carnivorous species found within semi-urban landscapes. It illuminates the challenges of managing human-carnivore conflict non-lethally as well as modelling at the local scale at which it commonly occurs.

Model Interpretation

Seasonality emerged as a factor in the spatial distribution of human-black bear conflict. In the fall, all bear classes used more concentrated attractant sources and human-dominated areas. Consumption of concentrated protein rich food is common in bears during hyperphagia and is important to their reproductive health and survival, therefore bears may be seeking high caloric human foods during this time (Hilderbrand et al. 1999). The opposite pattern was evident in spring and summer where bears were in conflict with humans around natural forage patches, which may be the consequence of the close proximity of natural forage to attractants (Table 4, Fig. 7). However, datasets in these seasons have similar support for the same models despite the hypothesized importance of different vegetation in the spring. The lack of support for any explanatory model for adult males in the spring may be driven by mating season dictating movement rather than foraging. The one candidate model that never had any support 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). Weak strength of evidence for these features in driving conflict could be the result of either scale, in that these features are not important at the local level, or the result of AIC favouring parsimonious models given poor model fit.

The CUF model results do not illustrate any clear differences in the drivers of conflict between bear classes. The kernel shapes, however, suggest that there may be non-random differences in use patterns between classes (Fig. 7), but the quantitative models do not identify covariates that can predict these conflict patterns or differences (Table 4). Conservation planning centered on a particular gender or reproductive class may need to be informed by further research such as a full volume of intersection analysis of many individual animal UDs to extrapolate any true differences between classes (see Appendix A for further details on volume of intersection analysis).

Overall, my model of the spatial patterns of human-bear conflict suggests that there is a near equal probability of conflict occurring throughout Whistler in relation to tested explanatory covariates. The visually observed peaks in the UDs demonstrate that there are likely important zones of conflict but, after taking into account spatial autocorrelation, are not reflected in the quantitative CUF model. These results for local scale conflict run counter to other studies which found evidence of conflict patterns at a regional scale (Treves et al. 2004; Wilson et al. 2006) as well as studies showing black bear foraging selection and preferences (Davis et al. 2006; Lyons 2005). It has been suggested that 'small scale' (albeit larger than my scale at 10 km^2) conflict for wolves is a result of the interplay of many factors (Treves et al. 2004) but my results cannot confirm that. I argue that these results reflect the conflict activity in Whistler, and I herein present 4 hypotheses to explain the lack of fit.

First, other covariates may exist that predict conflict better than the ones I used. The primary driver of conflict may be the unquantified fine scale availability of attractants throughout the study site, such as a pie cooling in the window, or an unlocked garbage shed. For Grizzly bears (*Ursus arctos*), conflict intensity has been assumed to be driven by one or a few attractant(s), for example sheep (Rondinini & Boitani 2007), calving grounds, bone yards, and/or beehives (Wilson et al. 2006). In this case, the primary driver of conflict may have been garbage/food availability at fine scales which was not an explicit factor in my analysis. Such attractants are likely fluctuating in availability and randomly distributed across the town when averaged over years.

Second, spatial patterns of conflict may have more to do with the individual choices and learned behaviours of the study animals than with the landscape itself. Breck (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 food type. Due to my opportunistic sampling design, I was unable to account for individual variation, and repeated measures of individuals within generalized bear classes may have confused overall conflict with individual conflict. A discrete choice model for individual bears may be necessary to predict small scale conflict patterns (Carter et al. 2010; Cooper & Millspaugh 1999). Such studies may be costly and their benefit debatable given that conflicts tend to reoccur in the same location because of attractant availability, regardless of the individual animal present (Treves et al. 2004).

Third, the town is effectively one homogenous conflict hotspot within this local scale of selection by the bears. Carter (2010) found that black bears select at a resolution of >1 km^2, whereas my resolution was 30 m^2. Conflict site covariates may thus be equal, or equally unimportant, in value at this scale. This could be the result of the town’s inherent small size and the integration of natural habitat patches within developed areas. Modelling a range of conflict probabilities is challenging when the covariates have equal values. For example, when examining the peaks stemming from the town center for the sub-adult males in the fall, they do not uniformly radiate from the town center as the covariate’s Euclidean raster does, but rather have some peaks nearby as well as no conflict at all (Fig. 7). This lack of consistency in conflict probabilities across covariates would result in models not fitting as well as would be expected from visual observation.

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. Study animals may be sufficiently habituated such that the use of any area within the town is perceived as low risk to them. It may be hard to parse out patterns under this management regime which tolerates many food-conditioned bears and prevalent attractants, and where conflict incidents are simply too numerous and wide spread. This is a presence-only model, so the absence of a recorded conflict is not evidence that there was no conflict. Application of this model to a study site with fewer conflicts may have lead to more explicit patterns.

Implications for Conservation

My results indicate one important concept; conflict is unpredictable at local scales. Although conflict prevention remains crucial to non-lethal bear management, such unpredictability means that there remains no single solution to preventing conflict through strategic spatial planning at the local scale. I therefore suggest that adaptive management, including constant maintenance of attractants and mitigation of separate incidents, must drive everyday ground level conservation policy. Conservationists should consider these findings when advocating for non-lethal carnivore management. Carnivore preservation is an important goal and is legislated in many cases, but understanding the challenges that will inherently arrive with increasingly human-dominated landscapes is ecologically, economically and socially essential (Treves & Karanth 2003).

The consequences of expanding human settlements as well as the maintenance of habitat fragments can have variable effects on different species (Markovchick-Nicholls et al. 2008). For bears, conflict and human-caused mortality has been correlated temporally and spatially with increasing development especially when in high quality bear habitat (Baruch-Mordo et al. 2008). Conservation planning for carnivores can be challenging because areas of good habitat for bears are often ideal for human settlements and thus are rarely found absent of human impacts (Apps et al. 2004; Carroll et al. 2001). Along with habitat quality, proximity to humans and the activities associated with those humans are the key factors dictating their survival (Apps et al. 2004). My results are indicative of the challenge of coexisting with carnivores, and I advocate that the difficulty of local scale non-lethal conflict management must be considered prior to development or community expansion.

Tackling zones of high human-carnivore conflict can be a costly management strategy and the effectiveness of conservation may be negatively correlated with increasing levels of conflict (Rondinini & Boitani 2007). For species and populations of carnivores facing critical levels of habitat destruction and human expansion, there is little option but to mitigate conflict (Rondinini & Boitani 2007). It is not only important for their own survival but for the protection of other species. Carnivores are used as a proxy, or umbrella species, for conservation where maintenance of their habitat is a guise for the protections of others (Carroll et al. 2001). They are also a keystone species for certain ecosystems and may dictate the quality and resilience of that system (Carroll et al. 2001; Treves & Karanth 2003). In the face of threats to economic livelihood and even human life, preserving carnivore populations remains an immense, but important, challenge.

Conservation policies, like any management decision, can be applied at many scales but the scale chosen must answer the question at hand (Boyce 2006; Hobbs 2003; Nams et al. 2006). My study indicates that within semi-urban settings, conservation policies must reflect a lack of local scale conflict predictably. While managers should continue to focus on prevention as the key to non-lethal conflict management, there is no single approach to strategic attractant control based on local scale landscape attributes. Further, conflicts that do inevitably happen need to be mitigated on an individual basis throughout townships. Conflict prevention and non-lethal mitigation will therefore require adaptive management of everyday attractants and individual animals, obtained through hard work by management and enforcement agencies, wildlife education programs, and the public. In other words, management must occur on the 'pie-in-the-window' scale highlighting that maintenance of high numbers of people and carnivores together in close proximity will require ongoing and likely pricey adaptive management.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Conservation policy must be informed by an ecological understanding at the scale of the issue. For carnivores in conflict with humans within semi-urban areas, this means an understanding of patterns at the local scale, where managers are working every day. My study examining the spatial patterns of human-bear conflict in Whistler, B.C. shows that conflict may not be predictable at this small scale.

My conclusions are based in rigorous spatial and statistical modelling. This was done by applying black bear conflict data to a Conflict Utilization Function, which analyses relative probability of conflict across space in relation to landscape and habitat variables. Results indicate that seasonality may drive spatial distribution of conflict. Bears utilize more human-dominated areas and concentrated attractant sources in the fall, and conversely demonstrate a more dispersed pattern in the summer and spring. Different bear reproductive classes and gender groups did not show quantifiably different patterns in conflict. Finally landscape and habitat covariates were unable to predict the spatial location of conflict, and I hypothesize four explanations: 1) the primary driver was unquantified availability of garbage and attractants, 2) individual choices and learned behaviours of bears are driving small scale spatial patterning, 3) landscape and habitat attributes are essentially homogenous at this scale of study in the town of Whistler, and/or 4) conflict is simply too prevalent in Whistler to extrapolate any pattern.

My findings speak to the importance of all attractants- both concentrated and dispersed- throughout the Municipality; all likely play a proportionally equal role in driving conflict. Further, bears of any gender or reproductive class are capable of getting into conflict anywhere within Whistler. Given these results, I suggest that there is no single way to prevent human-bear conflict through spatial planning at the local scale. To mitigate conflict at this level, managers must adopt a policy of adaptive management of everyday attractants and individual bears that contribute to conflict. This will be at the pie-in-the-window scale, from house to house and bear to bear. This is a highly costly and intensive management strategy and speaks to the challenges of carnivores and people coexisting within semi-urban landscapes.

TABLES

Table 1. Evaluative comments on the kernel outputs shown in Figure 2 and desirability for local scale human-bear conflict point data analysis.

	Bandwidth size (m)	*Cell size (m)*	*Comments*
a)	500	10	Bandwidth too large for the close proximity of points resulting in an over smoothed surface.
b)	200	10	Bandwidth remains too large for the study site; more refined distribution occurring.
c)	50	50	Bandwidth size too small, creating a distribution refined almost to a point layer. Change in raster size ineffective and too fuzzy for bandwidth size.
d)	75	10	Bandwidth shows clear defining points, but too refined for desired hotspot analysis.
e)	100	100	Bandwidth size creates desired smoothing where hotspots are apparent, but smoothed beyond a point layer. Cell size too large for point distribution; must be smaller than *h*.
f)	100	10	Bandwidth size as desired. Raster cell size show better definition.

Table 2. Model categories, corresponding variables and biological meaning used to base Conflict Utilization Function a priori *model set to explain human-bear conflict.*

Model	*Covariate*	*Definition*	*Relevance to bears*
1. Attractant Source	a) Village Center	Commercial center 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	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	2m 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 and landscaped vegetation
	b) Grassy Area	Area vegetated with grass, generally golf courses or sports field	Provision of natural food and landscaped vegetation
4. Green Areas with Attractants	a) Parks	Recreational park with mixed vegetation	Natural and human foods as well as potential cover
	b) Valley Trail	2m wide trail that transects study site	Natural and human foods as well as cover and travel corridor
5. Human Usage	a) Density of people	Spatial index of human density	Humans as a 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

Table 3. Omitted covariates from candidate models because no conflicts occur in those covariates.

Dataset	*Omitted Covariates*
Adult males (Spring)	None
Adult males (Summer)	Town Center & Ski hill
Adult males (Fall)	Landfill
Solo females (Fall)	Paintball course
Females with cubs (Fall)	Paintball course & Rail-line
Sub-adult males (Spring)	None
Sub-adult males (Summer)	None
Sub-adult males (Fall)	Paintball, landfill

Table 4. Top 3 models from AIC a priori *model selection for conflict utilization function generalized least square regression for each bear class/season.*

Dataset	*Top models*	*ΔAIC*	*AIC w_i*	*Global R^2*
Adult males (spring) (*n*=7986)	No strength of evidence for any model			0.04%
Adult males (summer) (*n*=1253)	1. Green Areas with Attractants 2. Spring Green-up 3. Attractant Source	0 1.475 2.511	0.407 0.195 0.166	0.81%
Adult males (fall) (*n*=1596)	1. Human Use 2. Human Use & Spring Green-up 3. Spring Green-up & Attractant Source	0 2.071 3.337	0.534 0.190 0.101	4.4%
Solo females (fall) (*n*=2030)	1. Attractant Source 2. Human Use & Attractant Source 3. Spring Green-up & Attractant Source	0 3.146 3.219	0.569 0.118 0.114	1.9%
Females with cubs (fall) (*n*=292)	1. Human Use 2. Attractant Source 3. Spring Green up	0 0.617 0.644	0.249 0.183 0.180	3.6%
Sub-adult males (spring) (*n*=1257)	1.Spring green-up 2. Attractant Source 3. Green Areas with Attractants	0 0.42 0.44	0.210 0.163 0.161	5.6%
Sub-adult males (summer) (*n*=5460)	1. Spring Green up 2. Human Use & Spring Green up 3. Spring Green up & Green Areas with Attractants	0 4.417 4.789	0.700 0.077 0.064	4.3%
Sub-adult males (fall) (*n*=663)	1. Human Use & Attractant Source 2. Human Use 3. Attractant Source	0 0.168 0.394	0.168 0.155 0.138	4.2%

FIGURES

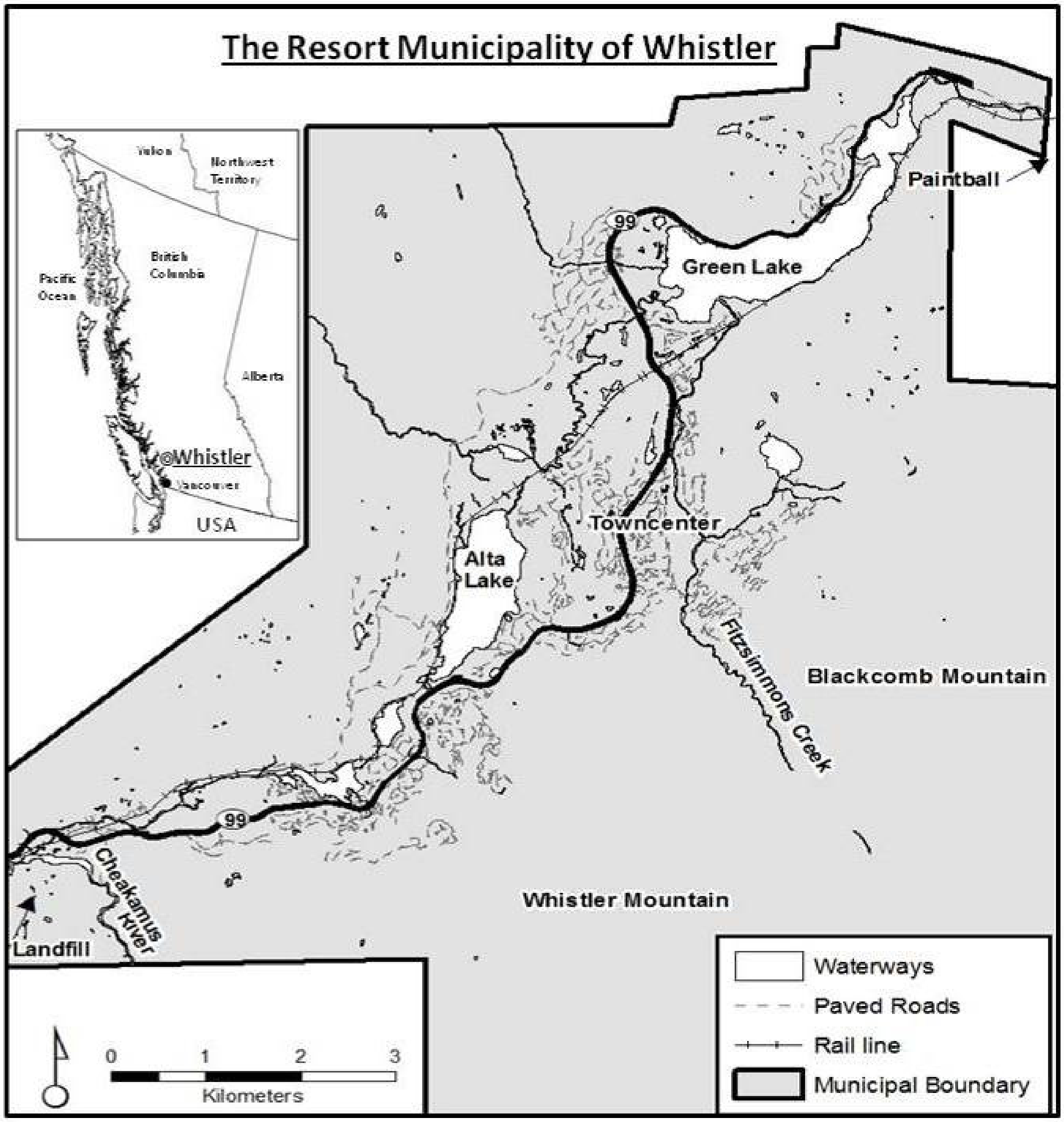


Figure 1. The Resort Municipality of Whistler, with its location in North-western Canada.

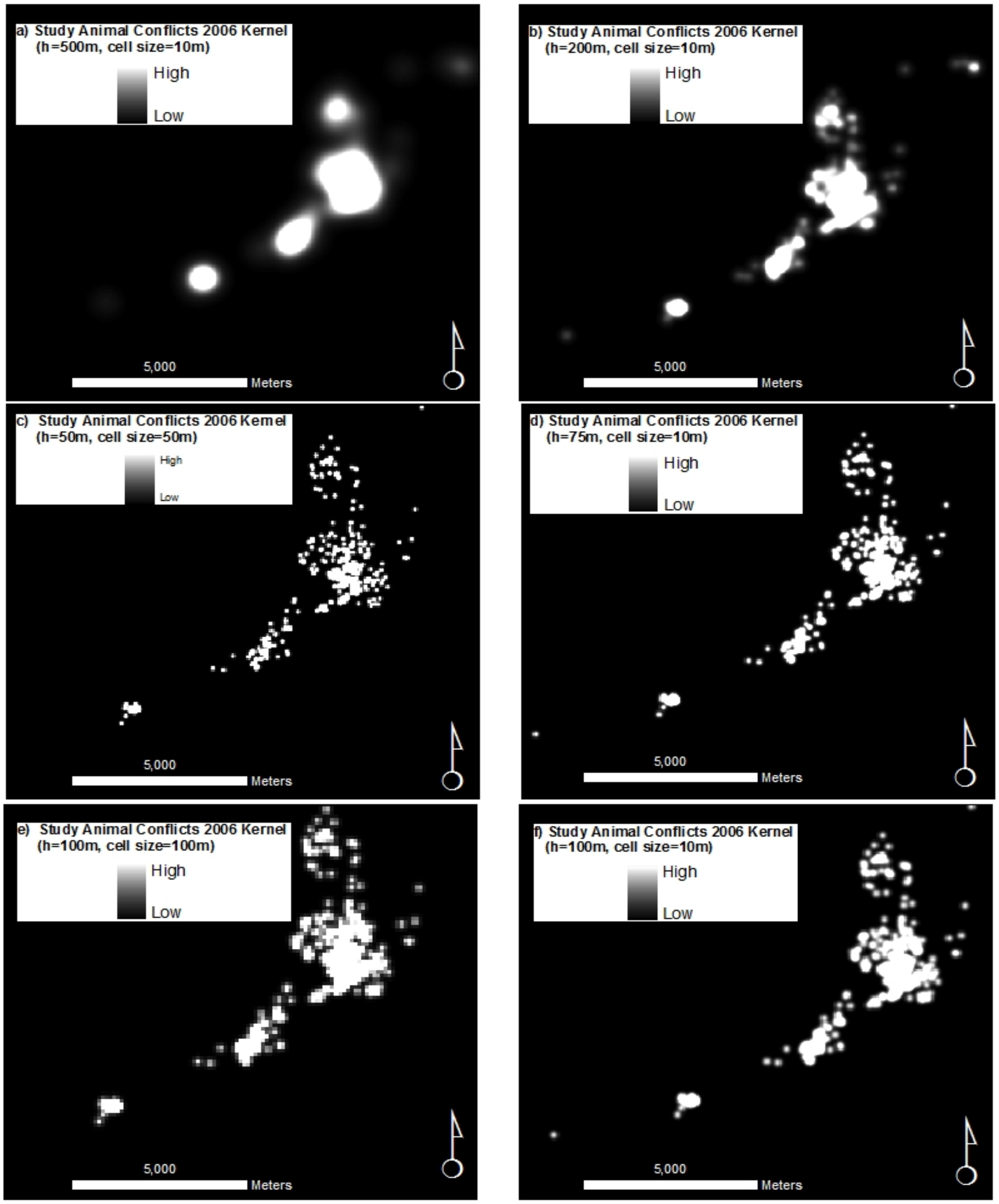


Figure 2. Kernel density outputs for human-bear conflicts locations obtained from study animals during 2006 using different kernel and raster cell size settings.

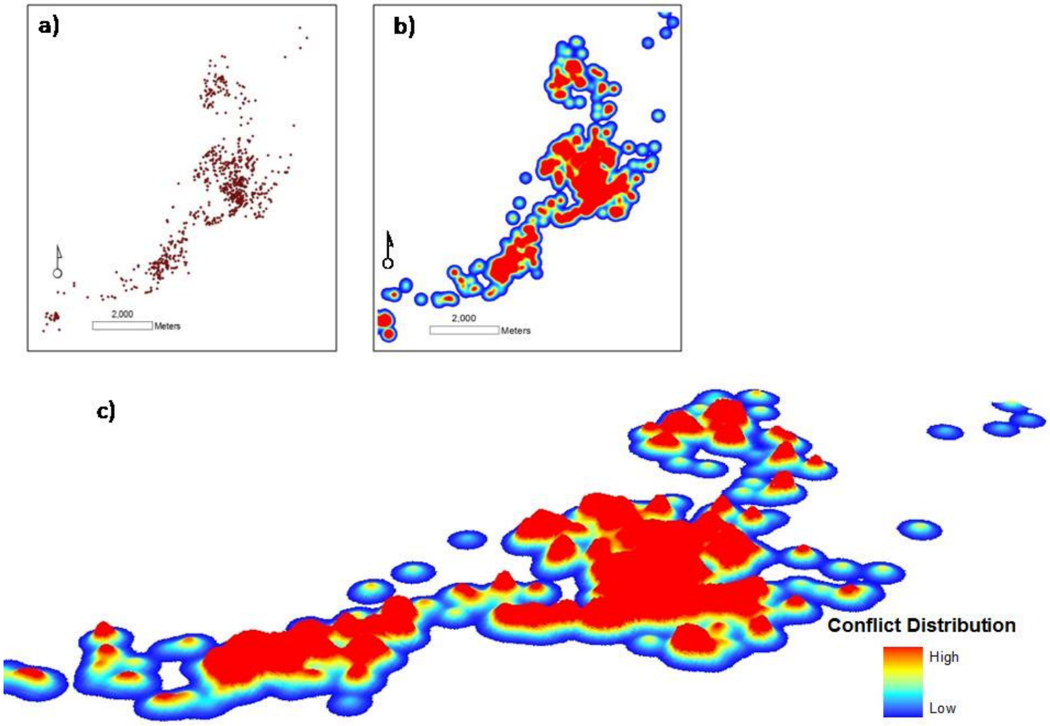


Figure 3. (a) Combined human-bear conflict data for Whistler displayed as point data,(b) kernel density output, and (c) 3D image of kernel density illustrating probability of conflict.

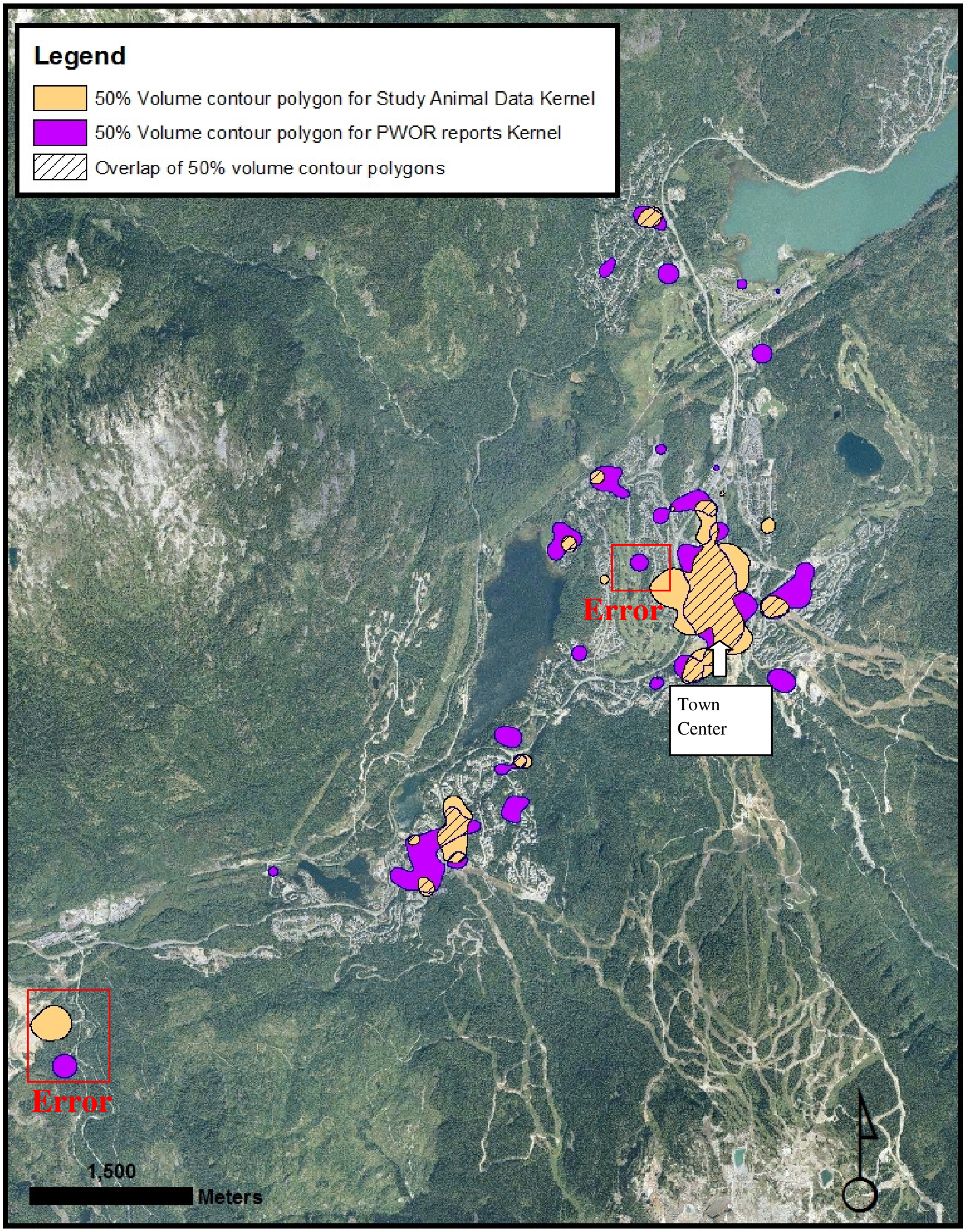


Figure 4. Fifty percent volume contour polygons created from kernel density estimations for two different human-bear conflict datasets. Coloured regions represent conflict hotspots, and red squares highlight spatialization errors.

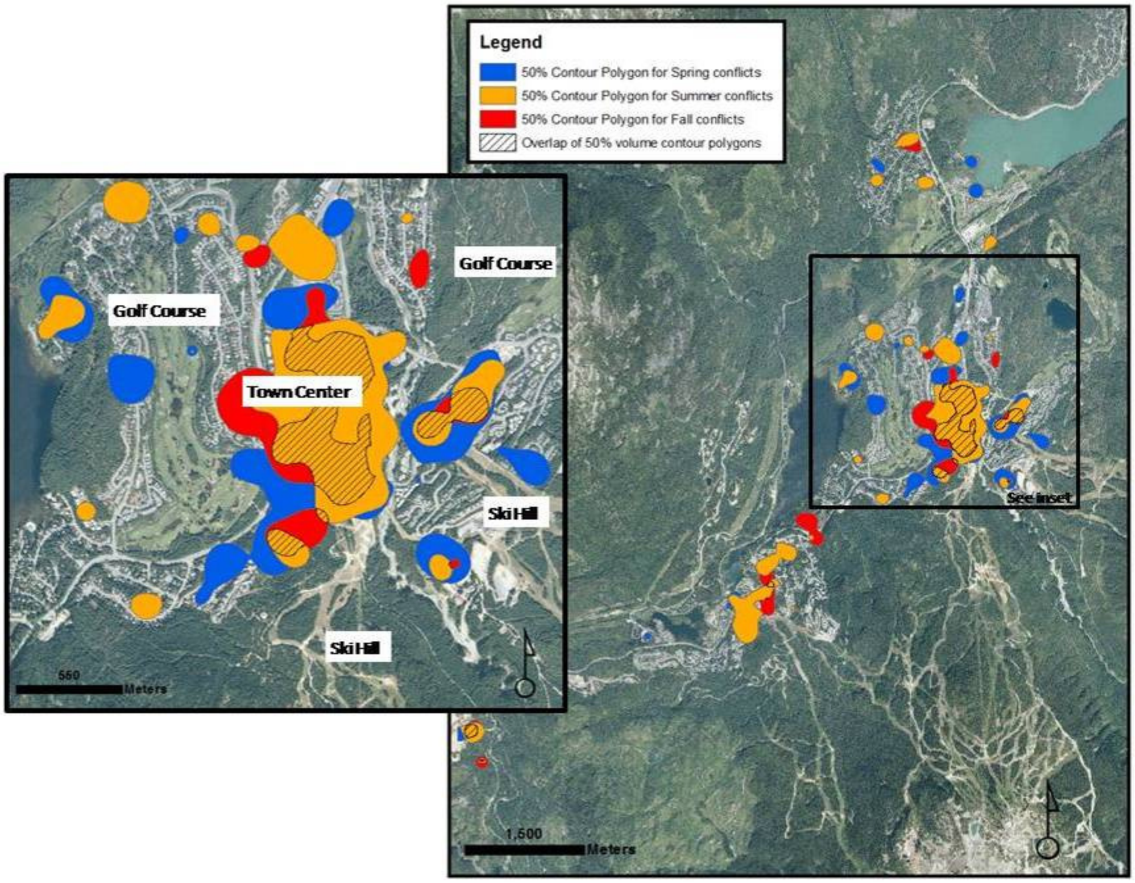


Figure 5. Seasonal differences in kernel generated human-bear conflict hotspots. Inset focuses on town center and adjacent golf courses and ski hills.

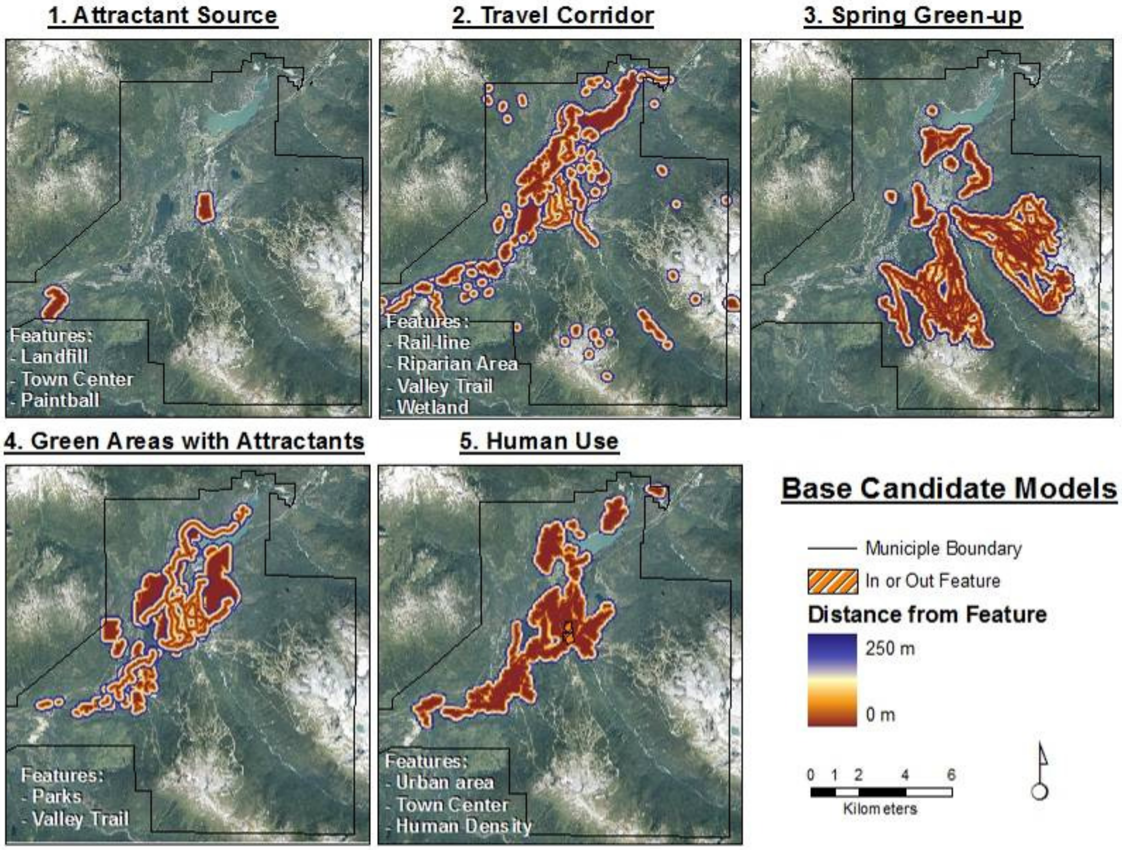


Figure 6. Geographical illustration of the 5 base candidate models where each model is comprised of multiple landscape features (independent variables).

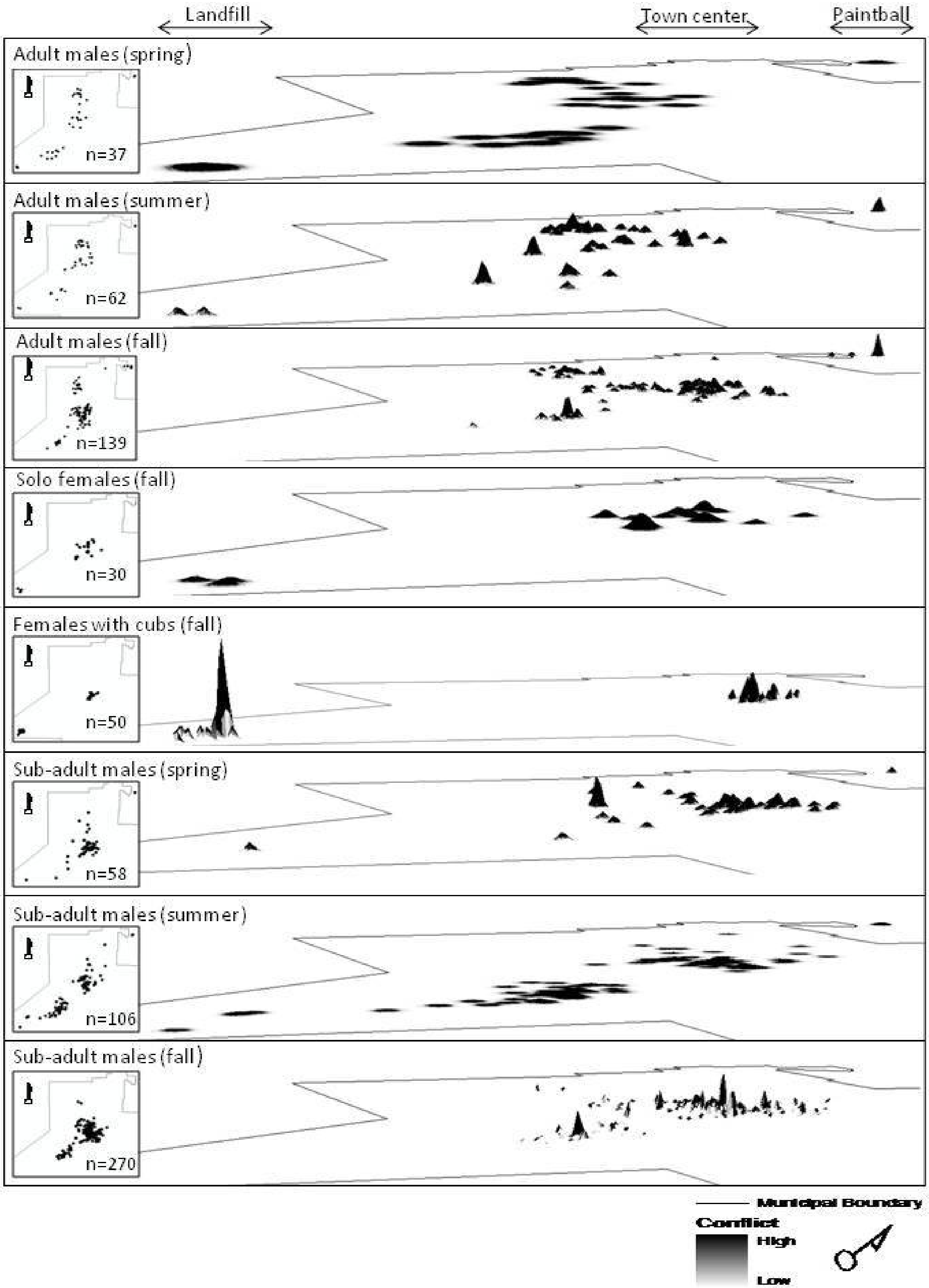

Landfill
Town center
Paintball
Adult males (spring)
n=37
Adult males (summer)
n=62
Adult males (fall)
n=139
Solo females (fall)
n=30
Females with cubs (fall)
n=50
Sub-adult males (spring)
n=58
Sub-adult males (summer)
n=106
Sub-adult males (fall)
n=270
Municipal Boundary
Conflict
High
Low

Figure 7.Three-dimensional kernel density derived Utilization Distributions illustrating the relative probability of human-black bear conflict by sex, season and reproductive class within the study area. Insets illustrate the corresponding raw data point patterns within the study area. Approximate geographic location of main attractant sources (paintball, town center, and landfill) identified above top panel.

APPENDICES

APPENDIX A

Volume of Intersection Analysis

Overview

I explored each Utilization Distribution (UD) shape and location to examine spatial overlap between the 8 different bear classes. This was done using the volume of intersection (VI) methodology, which is a technique used to examine spatial usage overlap between two individuals (Millspaugh et al. 2000; Millspaugh et al. 2004). Since all UDs are 3-dimensional, volume must be examined because of variation in spatial location as well as relative use (height). This gives an estimate of UD overlap between 0 and 1, where a VI overlap of 1(or 100%) indicates the exact same UD and 0 (0%) indicates no overlap. All 8 UDs were tested and compared for VI overlap. Results indicate that my analysis should remain separated by reproductive class and season, as no UDs exceed a 20% overlap (Tables A1&A2). Lowest VI values occurred between classes, whereas highest degree of overlap occurred between classes for different seasons. Adult and sub-adult males seem to overlap the most in the fall (12.2%). A visual representation of VI is shown in Fig. A1.

Corresponding Tables and Figures:

Table A1. Volume of intersection comparison between female bear conflict Utilization Distributions in the fall and other bear classes.

Solo Females (Fall)	*VI Value*	*Females with Cubs (Fall)*	*VI Value*
Females with cubs	3.43%	Solo females	3.43%
Sub-adult males	6.22%	Sub-adult males	9.65%
Adult males	8.79%	Adult males	4.21%

Table A2. Volume of intersection comparison for sub-adult and adult male bear conflict Utilization Distributions for all seasons.

Male reproductive class overlap (all seasons)	*VI Value*	*Adult Males Between Seasons*	*VI Value*	*Sub-adult Males Between Seasons*	*VI Value*
Spring	2.81%	Summer:Spring	16.38%	Summer:Spring	16.57%
Summer	6.19%	Spring:Fall	14.97%	Spring:Fall	16.76%
Fall	12.24%	Fall:Summer	17.79%	Fall:Summer	11.41%

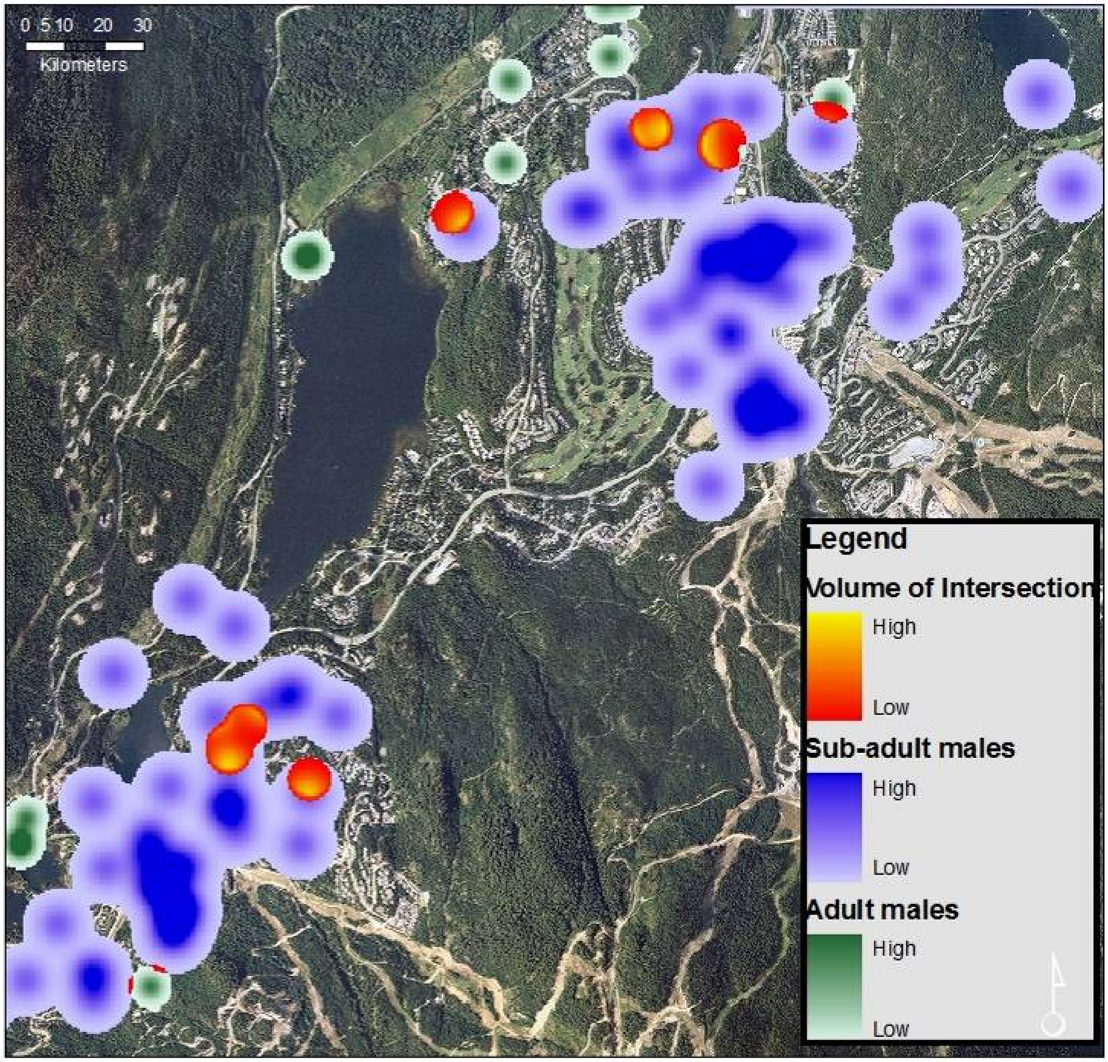


Figure A1. Map output visually illustrating part of the volume of intersection (red) between Sub-adult males and Adult male utilization distributions of conflict.

APPENDIX B

Summary of Bear Attractants Involved in Conflict Incidents

Overview

I examined the attractant sources involved in conflict incidents used in the CUF study (Chapter 2) to determine which attractants may be causing conflict for each season and class of bear. This was done for every incident where the attractant source could be directly attributed to the incident (*n*=361). The most used attractant sources (other than unsecured garbage) for both adult and sub-adult males in all seasons are sheds with dumpsters and pedestrian garbage bins (a.k.a. hid-a-bags) (Photos B1&B2 and Figs. B1&B2). Females tend to utilize landfill structures and garden vegetation as well as sheds with dumpsters (Figs. B3&B4). The distribution of conflict throughout the many attractant types in every season suggests that there is little patterning in what bears will utilize and it is likely more a symptom of what is available (Fig. B5). This indicates that management effort must go into securing sheds and hid-a-bags, but more importantly all attractants including unsecured garbage.

Corresponding Photos & Figures:

Photo B1. Example of a shed with dumpster structure that has been involved in a human-bear conflict.

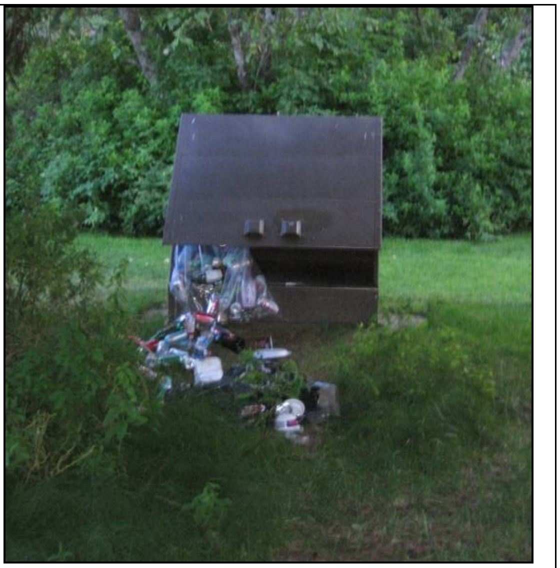


Photo B2. Example of a pedestrian garbage bin hid-a-bag structure that has been involved in a human-bear conflict.

Figures B1-3. Types of structures involved in human-bear conflicts in Whistler between 2005-2007 separated by reproductive class and gender.

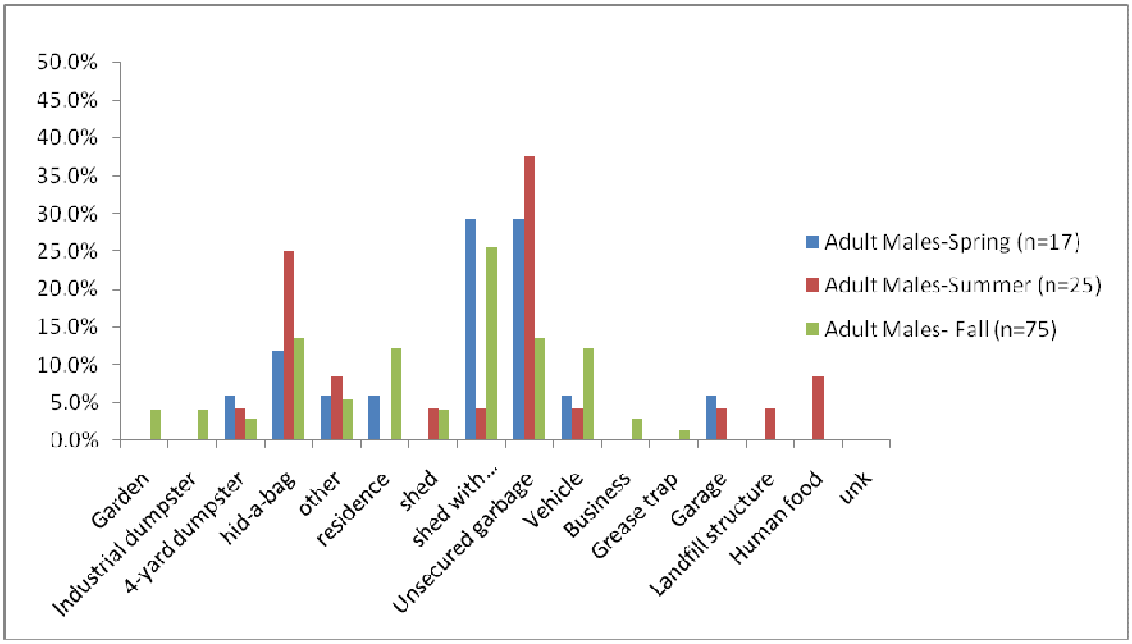


Figure B1. Adult male conflict types by season

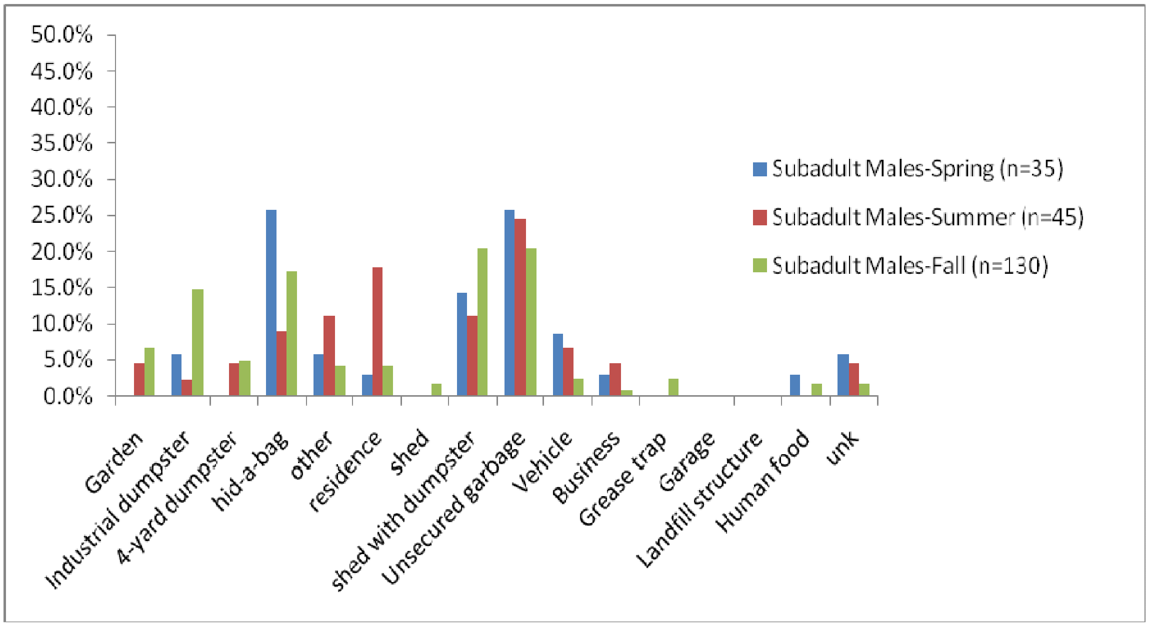


Figure B2. Sub-adult male conflicts by season

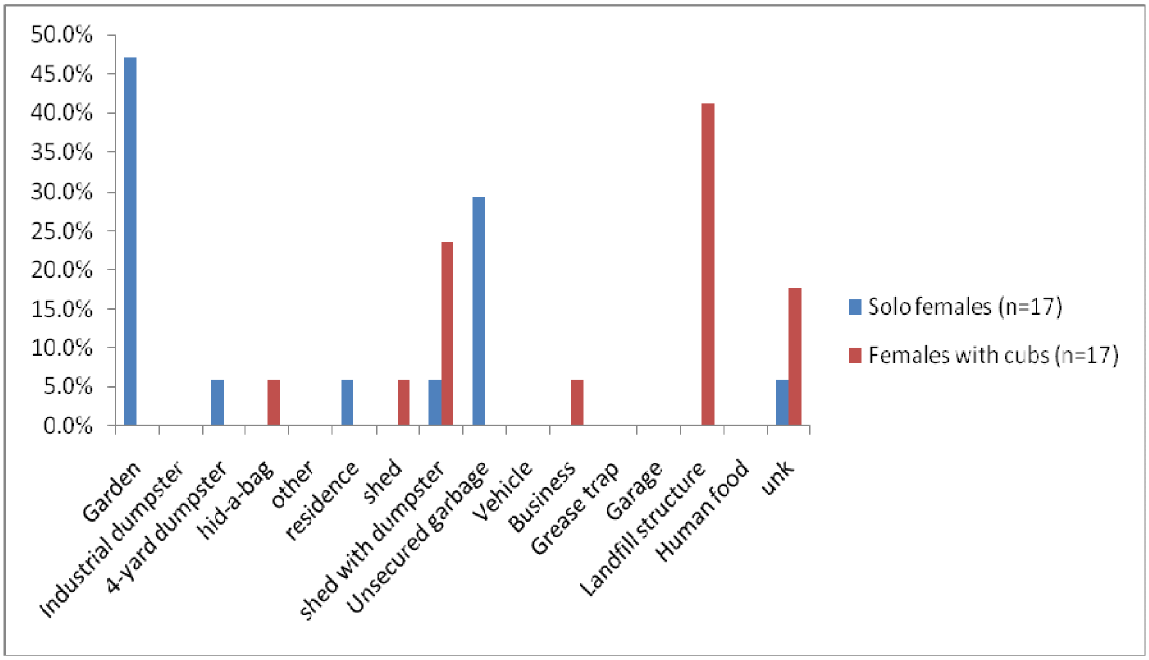
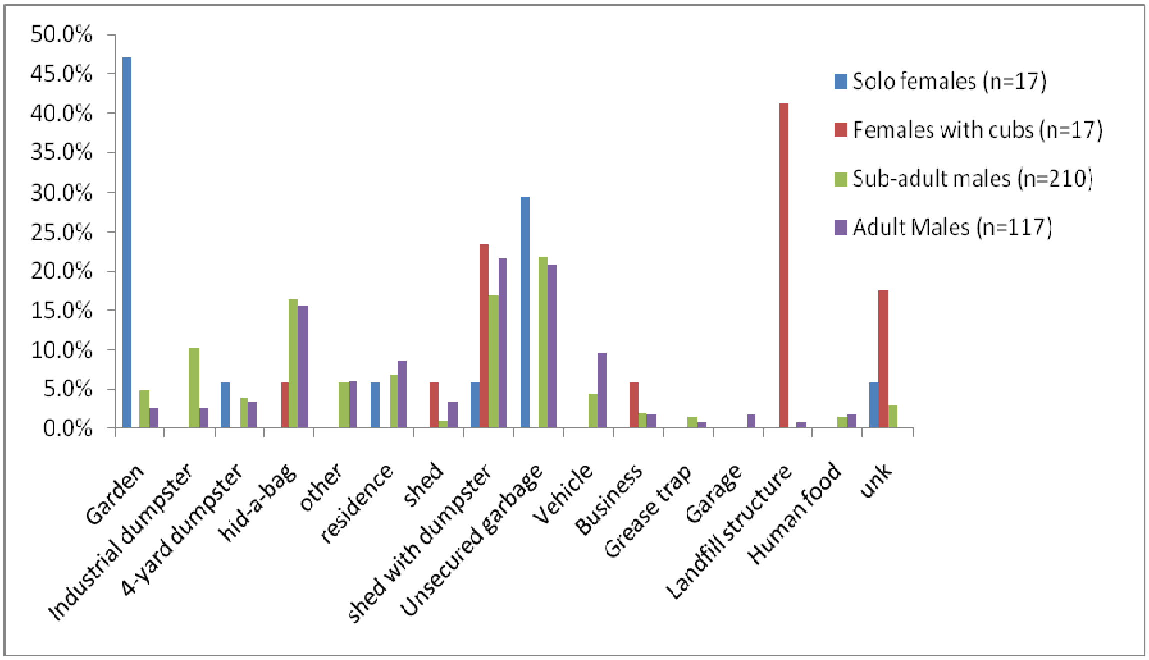


Figure B3. Female conflict in the fall



Figures B4. Types of structures involved in human-bear conflicts totalled for years 2005-2007 and then separated by gender and reproductive class.

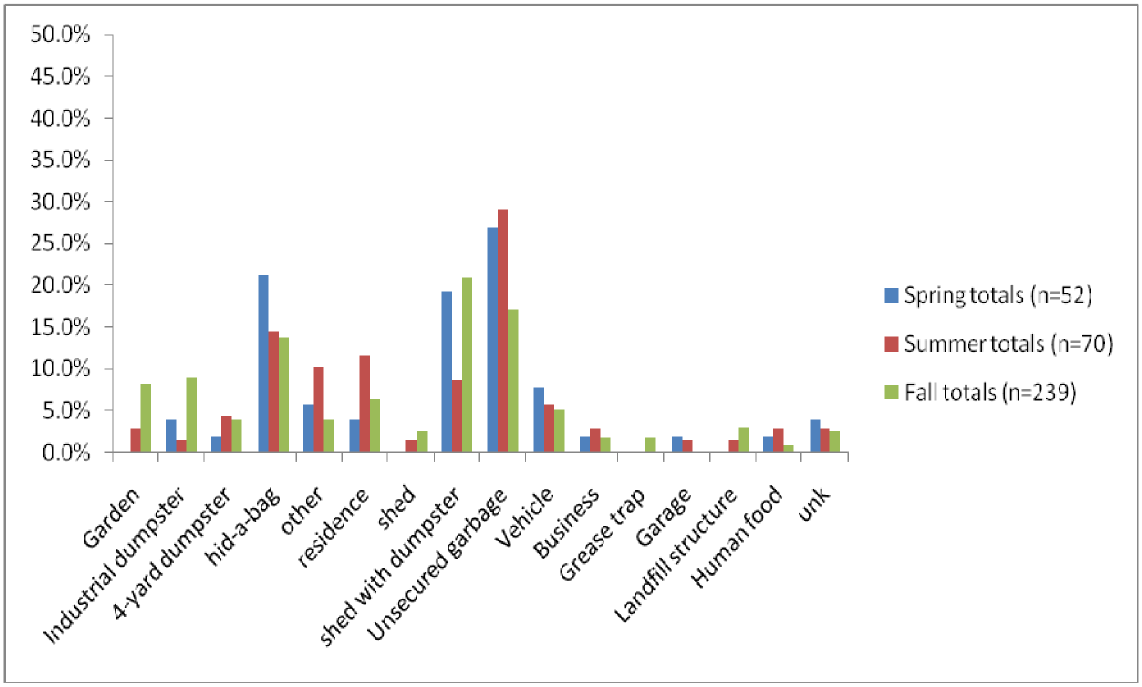


Figure B5. Types of structure involved in human-bear conflicts for years 2005-2007 separated by season.

APPENDIX C
Landscape Usage

Overview

To elucidate possible space use patterns prior to statistical analysis, I examined the 8 Utilization Distributions (UD) for their overlap with landscape and habitat attributes. I used a ‘percent cover’ way to examine the attributes that comprise each UD. The landscape type (i.e. type of attribute, such as golf course) of the center point location of each raster grid was determined by joining GIS covariate layers to the UDs. I assigned each point a categorical value for its location within a landscape type, and then summed the entire dataset to give a percentage of use of each type. I did this for the following variables; wetland, urban, power line, paintball, landfill, golf course, town center, park, rail line, valley trail, ski hill, riparian area/shoreline. I compared results and examined them graphically for 1) Sub-adult males; comparing seasons 2) Adult males; comparing seasons 3) Females in the fall; comparing solo to those with cubs. Results indicate high but potentially different use of urban areas by all bear classes with usage occurring most during fall (Figs. C1-C3). Sub-adult males and females with cubs appear in conflict in the main village more than solo females or adult males (Fig. C2). Both groups of females used the landfill more than the males (Fig. C3). Parks and the valley trail are the only green spaces that have notable conflict for all classes of bears. No other obvious patterns of conflict occurring in natural habitat areas can be observed. These results support the model conclusions in Chapter 2, showing the importance of attractant sources such as the main village during the fall. In addition, they support the inclusion of parks and valley trail as a site with attractants in the candidate base models.

Corresponding Figures

Figures C1-3: The relative percent usage of habitats and landscape attributes for Utilization Distribution of human-bear conflict in Whistler from 2005-2007, separated by bear classes.

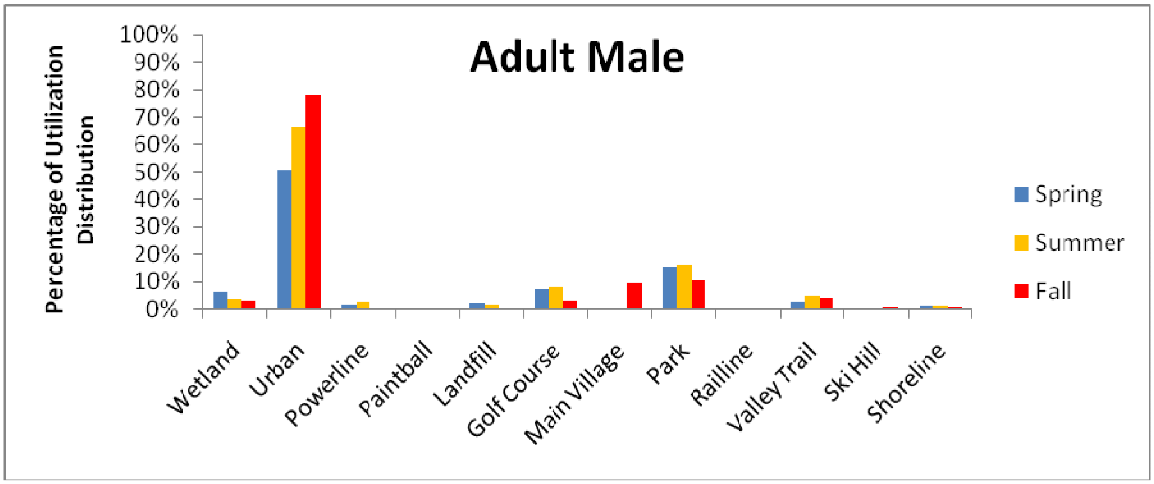


Figure C1. Sub-adult males in the fall for the spring, summer and fall seasons.

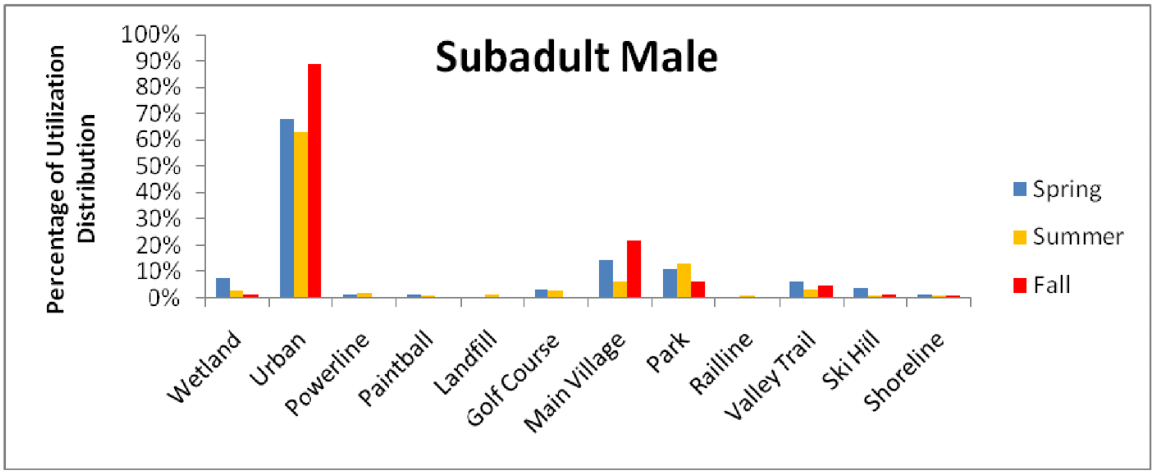


Figure C2. Adult males in the fall for the spring, summer and fall seasons.

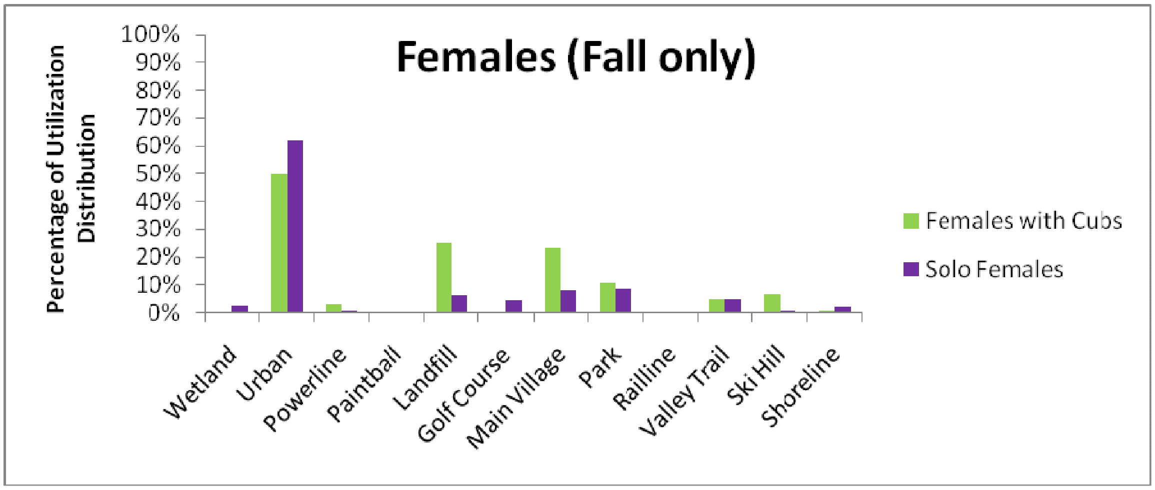


Figure C3. Females in the fall; comparing solo to those with cubs-fall

APPENDIX D

AIC Averaged Models

Tables D1-D7. The resulting model coefficients for AIC weighted average models for top models summing to an AIC weight (w_i) of 0.95 from Generalized Least Squares regression on the conflict utilization function for each dataset of bear reproductive classes in three seasons. This average model incorporates the relative importance of each covariate as per its likelihood into an overall model.

Table D1. Adult Males (summer)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-4.66	0.38	0.0095		
Park (In or Out)	2.28E-02	1.05E-02	1.02	1.00	1.04
Park (distance to)	9.86E-06	2.93E-05	1.00	1.00	1.00
Valley Trail (In or Out)	-4.06E-03	1.23E-02	1.00	0.97	1.02
Valley Trail (distance to)	-7.92E-06	2.26E-05	1.00	1.00	1.00
Golf course/Turf (distance to)	1.91E-06	1.37E-05	1.00	1.00	1.00
Paintball (In or Out)	6.81E-02	2.83E-02	1.07	1.01	1.13
Landfill (In or Out)	-5.10E-02	5.92E-02	0.95	0.85	1.07
Landfill (distance to)	-2.06E-04	2.44E-04	1.00	1.00	1.00
Rail line (distance to)	-2.07E-06	2.51E-06	1.00	1.00	1.00
Wetland (distance to)	-2.81E-06	2.30E-06	1.00	1.00	1.00
Riparian area (distance to)	2.23E-06	1.77E-06	1.00	1.00	1.00
Urban area (distance to)	1.20E-05	6.65E-05	1.00	1.00	1.00
Human Density	1.26E-05	4.88E-05	1.00	1.00	1.00

Table D2. Adult Males (fall)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-5.71	1.89	0.0033		
Park (In or Out)	5.95E-03	7.31E-03	1.01	0.99	1.02
Park (distance to)	1.29E-05	1.44E-05	1.00	1.00	1.00
Valley Trail (In or Out)	1.01E-02	5.96E-03	1.01	1.02	1.00
Valley Trail (distance to)	6.24E-06	2.06E-05	1.00	1.00	1.00
Golf course/Turf (distance to)	4.96E-05	4.96E-05	1.00	1.00	1.00
Ski hill (distance to)	6.78E-05	6.93E-05	1.00	1.00	1.00
Paintball (In or Out)	1.51E-03	1.54E-02	1.00	0.97	1.03
Town Center (In or Out)	1.45E-01	1.16E-01	1.16	0.92	1.45
Town Center (distance to)	2.86E-06	2.00E-05	1.00	1.00	1.00
Urban area (distance to)	1.23E-04	3.07E-04	1.00	1.00	1.00
Human Density	-3.45E-04	3.23E-04	1.00	1.00	1.00

Table D3. Solo Females (fall)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-4.89	0.22	0.0075		
Park (In or Out)	9.65E-06	1.09E-04	1.00	1.00	1.00
Park (distance to)	-2.63E-07	3.16E-07	1.00	1.00	1.00
Valley Trail (In or Out)	2.46E-04	1.63E-04	1.00	1.00	1.00
Valley Trail (distance to)	-2.76E-07	5.99E-07	1.00	1.00	1.00
Golf course/Turf (distance to)	2.88E-07	5.47E-07	1.00	1.00	1.00
Ski hill (distance to)	2.91E-05	4.69E-05	1.00	1.00	1.00
Rail line (distance to)	1.04E-06	1.10E-06	1.00	1.00	1.00
Wetland (distance to)	-4.49E-07	2.70E-07	1.00	1.00	1.00
Riparian area (distance to)	8.97E-08	2.69E-07	1.00	1.00	1.00
Town Center (In or Out)	8.24E-04	3.87E-03	1.00	0.99	1.01
Town Center (distance to)	3.40E-05	6.84E-06	1.00	1.00	1.00
Urban area (distance to)	-5.93E-07	8.49E-07	1.00	1.00	1.00
Human Density	1.19E-06	1.76E-06	1.00	1.00	1.00
Landfill (In or Out)	5.06E-03	3.41E-03	1.01	1.00	1.01
Landfill (distance to)	9.27E-05	1.93E-04	1.00	1.00	1.00

Table D4. Females with cubs (fall)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-4.37	0.67	0.013		
Park (In or Out)	9.37E-04	1.29E-02	1.00	0.98	1.03
Park (distance to)	8.80E-06	1.44E-05	1.00	1.00	1.00
Valley Trail (In or Out)	1.07E-02	4.27E-02	1.01	0.93	1.10
Valley Trail (distance to)	-5.38E-04	1.16E-04	1.00	1.00	1.00
Golf course/Turf (distance to)	-1.22E-04	3.23E-04	1.00	1.00	1.00
Ski hill (distance to)	-4.30E-05	1.00E-04	1.00	1.00	1.00
Wetland (distance to)	5.08E-05	7.16E-05	1.00	1.00	1.00
Riparian area (distance to)	-7.23E-05	5.18E-05	1.00	1.00	1.00
Town Center (In or Out)	3.22E-01	1.79E-01	1.38	0.97	1.96
Town Center (distance to)	2.07E-04	1.74E-04	1.00	1.00	1.00
Urban area (distance to)	-1.07E-05	1.06E-04	1.00	1.00	1.00
Human Density	-1.13E-04	1.78E-04	1.00	1.00	1.00
Landfill (In or Out)	-1.45E-02	6.78E-02	0.99	0.86	1.13
Landfill (distance to)	2.03E-04	2.01E-04	1.00	1.00	1.00

Table D5. Sub-adult males (spring)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-6.08	0.18	0.0023		
Park (In or Out)	2.14E-02	1.07E-02	1.02	1.00	1.04
Park (distance to)	6.26E-06	2.43E-05	1.00	1.00	1.00
Valley Trail (In or Out)	3.32E-03	8.81E-03	1.00	0.99	1.02
Valley Trail (distance to)	-9.02E-06	3.09E-05	1.00	1.00	1.00
Golf course/Turf (distance to)	-5.46E-06	2.18E-05	1.00	1.00	1.00
Ski hill (distance to)	-2.57E-05	2.36E-05	1.00	1.00	1.00
Rail line (distance to)	-4.52E-06	2.52E-05	1.00	1.00	1.00
Wetland (distance to)	-2.39E-05	1.18E-05	1.00	1.00	1.00
Riparian area (distance to)	-1.04E-05	1.09E-05	1.00	1.00	1.00
Town Center (In or Out)	-9.60E-04	1.62E-02	1.00	0.97	1.03
Town Center (distance to)	3.31E-05	2.05E-05	1.00	1.00	1.00
Urban area (distance to)	-5.08E-05	9.35E-05	1.00	1.00	1.00
Human Density	6.37E-06	1.17E-05	1.00	1.00	1.00
Paintball (In or Out)	5.32E-03	2.96E-02	1.01	0.95	1.07

Table D6. Sub-adults (summer)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-4.80	0.09	0.0083		
Park (In or Out)	3.76E-04	3.41E-04	1.00	1.00	1.00
Park (distance to)	-1.29E-06	9.63E-07	1.00	1.00	1.00
Valley Trail (In or Out)	1.65E-04	3.30E-04	1.00	1.00	1.00
Valley Trail (distance to)	-1.87E-07	6.83E-07	1.00	1.00	1.00
Golf course/Turf (distance to)	3.24E-05	1.23E-05	1.00	1.00	1.00
Ski hill (distance to)	-2.01E-06	1.27E-05	1.00	1.00	1.00
Town Center (In or Out)	-7.14E-04	1.47E-03	1.00	1.00	1.00
Town Center (distance to)	-1.10E-06	1.56E-06	1.00	1.00	1.00
Urban area (distance to)	1.13E-07	2.42E-06	1.00	1.00	1.00
Human Density	-2.25E-06	2.02E-06	1.00	1.00	1.00
Paintball (In or Out)	-5.69E-04	2.29E-03	1.00	1.00	0.99

Table A7. Sub-adults (fall)

Variable	β-mean	Standard Error	Exp(β)	95% CI for Exp(β)	
				Lower	Upper
Intercept	-3.61	0.17	0.027		
Park (In or Out)	-1.53E-01	7.28E-02	0.86	0.74	0.99
Park (distance to)	-7.66E-05	5.31E-05	1.00	1.00	1.00
Valley Trail (In or Out)	6.14E-02	1.02E-01	1.06	0.87	1.30
Valley Trail (distance to)	-2.04E-05	7.50E-05	1.00	1.00	1.00
Golf course/Turf (distance to)	3.61E-06	1.45E-05	1.00	1.00	1.00
Ski hill (distance to)	1.60E-06	1.19E-05	1.00	1.00	1.00
Rail line (distance to)	1.04E-04	9.40E-05	1.00	1.00	1.00
Wetland (distance to)	3.38E-05	4.47E-05	1.00	1.00	1.00
Riparian area (distance to)	6.94E-05	4.10E-05	1.00	1.00	1.00
Town Center (In or Out)	2.67E-01	1.33E-01	1.31	1.01	1.70
Town Center (distance to)	-1.06E-04	7.78E-05	1.00	1.00	1.00
Urban area (distance to)	-5.06E-04	2.14E-03	1.00	1.00	1.00
Human Density	-9.33E-04	4.37E-04	1.00	1.00	1.00

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