

**Ecology of the Badger (*Taxidea taxus jeffersonii*) in the Thompson Region of British Columbia: Implications for Conservation**

by

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We accept this thesis as conforming  
to the required standard

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### **ABSTRACT**

My objective in this thesis was to fill knowledge gaps in badger (*Taxidea taxus jeffersonii*) ecology in British Columbia, in order to address conservation initiatives for the subspecies. I found that badgers used large home ranges (95% fixed kernel,  $\bar{x} = 28.6$  km<sup>2</sup>, n = 7), and this was related to long-distance movements made during the breeding season. Badgers burrowed in habitats that were dominated by grass and supported abundant prey, but individuals exhibited plasticity of habitat use that depended on available resources. Within home ranges, badgers used certain areas more intensively (core areas) than others, particularly sites that reliably had prey and patches of suitable burrowing habitat. Badgers were relatively tolerant of humans, and used anthropogenically altered landscapes where there was sufficient prey. Conservation of badgers in British Columbia will depend on reversing the negative impacts of humans, and on raising awareness of the ecological role of badgers in grasslands.

Examiners:

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Dr. K.W. Larsen, Supervisor (Adjunct, Department of Biology)

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## ***Table of Contents***

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Title Page .....	i
Abstract .....	ii
Table of Contents .....	iv
List of Tables .....	vii
List of Figures .....	ix
Acknowledgements .....	xi

### **Chapter One**

<b>Introduction.....</b>	<b>1</b>
1.1 BACKGROUND .....	1
1.2 BADGER ECOLOGY .....	4
1.3 STUDY AREA .....	11
1.4 REFERENCES CITED.....	14

### **Chapter Two**

<b>Patterns of Spatial Use by Badgers (<i>Taxidea taxus jeffersonii</i>) in South-Central British Columbia, Canada.....</b>	<b>20</b>
2.1 INTRODUCTION .....	20
2.2 METHODS .....	22
2.3 RESULTS .....	28
2.4 DISCUSSION .....	33
2.5 CONCLUSIONS.....	38
2.6 REFERENCES CITED.....	39

### **Chapter Three**

<b>Habitat Selection and Characteristics of Badger (<i>Taxidea taxus jeffersonii</i>) Burrows in South-Central British Columbia, Canada.....</b>	<b>45</b>
3.1 INTRODUCTION .....	45
3.2 METHODS .....	47
3.3 RESULTS .....	52
3.4 DISCUSSION .....	60
3.5 CONCLUSIONS.....	64
3.6 REFERENCES CITED.....	65

### **Chapter Four**

<b>Conclusions and Conservation Issues .....</b>	<b>69</b>
4.1 CONCLUSIONS.....	69
4.2 LIMITATIONS OF THIS STUDY .....	71
4.3 CONSERVATION CONCERNS .....	73
4.4 RECOMMENDATIONS FOR FUTURE RESEARCH.....	81
4.5 REFERENCES CITED.....	83

### **Appendix I**

<b>A Two-Step Process to Determine Accurate Core Areas .....</b>	<b>86</b>
I.1 INTRODUCTION .....	86
I.2 METHODS .....	88
I.3 DISCUSSION .....	95
I.4 REFERENCES CITED.....	98

### **Appendix II**

<b>S Code to Calculate Index of Aggregation.....</b>	<b>102</b>
II.1 STEP 1: Generating simulated datasets using Monte Carlo methods.....	103
II.2 STEP 2: Calculating the Index of Aggregation and Probability Values.....	104
II.3 REFERENCES CITED.....	105

**Appendix III**

<b>Food Habits of Badgers in the Thompson and Okanagan Regions of British Columbia.....</b>	<b>106</b>
III.1 INTRODUCTION .....	106
III.2 METHODS .....	107
III.3 RESULTS .....	109
III.4 DISCUSSION .....	112
III.5 REFERENCES CITED.....	114

## *List of Tables*

---

<b>Table 2.1</b> Age-class and sex of badgers captured, and telemetry monitoring data for each animal. Both 100% minimum convex polygons (100% MCP), and 95% fixed kernel estimates (95% FK) were calculated from the independent locations (n) collected for each animal. An * in the Animal ID column indicates those badgers included in both fixed kernel and core area analysis. ....	29
<b>Table 2.2</b> Index of aggregation results for all seasons (1999 – 2002), and for the summer (Apr 1–Aug 31). The index value (R) indicates the degree of aggregation of telemetry locations collected and the probability of the modeled index (p). The number of locations used in the analysis is represented by n. Index values for B06 and B14 were calculated during the summer only because there were no locations collected during other seasons. ....	32
<b>Table 2.3</b> Summary of core areas used by badgers. The number of core area patches, size of core areas (km <sup>2</sup> ), probability contours that delineate core area boundaries, and percent of home range in core areas (km <sup>2</sup> ) are reported. ....	32
<b>Table 2.4</b> Average estimated home range size (km <sup>2</sup> ) of badgers in various parts of their range in North America. Home ranges are 100% minimum convex polygon (100% MCP) and 95% fixed kernel (95% FK). ....	35
<b>Table 3.1</b> Variables and description of categories or counts that were collected at burrow and random locations within each badger’s home range. ....	49
<b>Table 3.2</b> Total number of habitat plots surveyed at burrows within each home range (100% minimum convex polygon), and within core areas. These were compared to random sites that were field surveyed, or where habitat class was assessed from maps. ....	54
<b>Table 3.3</b> Soil variables and G-test results, with degrees of freedom and probabilities (p), comparing burrow sites to random locations within each animal’s home range. Significant results indicated in bold. ....	56
<b>Table 3.4</b> Soil variables and G-test results, with degrees freedom and probabilities (p), comparing habitat characteristics at burrow locations within core areas to burrows within each animal’s home range. Significant results indicated in bold. ....	56
<b>Table 3.5</b> Sign tests comparing the differences between average prey counts at burrows and random locations (+/–) within each home range, and the binomial probabilities (p) of finding these patterns (Zar 1999). NP indicates species not detected. ....	59

<b>Table 3.6</b> Sign tests comparing the differences between average prey counts at burrows inside core areas to other burrows within home ranges (+/-), and the binomial probabilities (p) of finding these patterns (Zar 1999). NP indicates species not detected. ....	59
<b>Table 3.7</b> Relationships of habitat variables, shown through probability values from G-tests (categorical variables), Kruskal-Wallis tests (categorical and continuous variables) and Spearman's rho tests (continuous variables).....	60
<b>Table 3.8</b> Best model equation from forward stepwise probit analysis, $\chi^2$ , and probability (p) values, with degrees of freedom (df).....	60
<b>Table 4.1</b> Badger mortality documented on the Thompson/Okanagan Badger Project...	73
<b>Table III.1</b> Percentage of scats and GITs in which food items were detected. Samples were collected from the Thompson Region (n = 23) and the Okanagan Region (n = 5). ....	110
<b>Table III.2</b> Percentage of scats and GITs in which food items were detected. Samples (n) were collected from the Thompson Sub-regions.....	111
<b>Table III.3</b> Summary of GIT contents and scat collected at maternal burrows of 5 female badgers in the Thompson and Okanagan Regions, and percentage of samples in which food items were detected. Three of the badgers were confirmed to have had kits at the time of collection.....	111



## List of Figures

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- Figure 1.1** Distribution of the four subspecies of North American badger, in the USA and Canada, and the *jeffersonii* subspecies in British Columbia (inset). (Source: Newhouse & Kinley 1999). ..... 5
- Figure 1.2** Annual number of badger pelts traded in British Columbia, from 1919/20 to 1976/77. Note that the number of pelts traded increased after 1967 despite the closure of commercial trapping. (Source: Adams et al. 2003). ..... 9
- Figure 1.3** The study area boundary encompassed dry ecosystems located in the valley bottoms along the Thompson Rivers, and included the city of Kamloops, British Columbia, Canada (50° 40' N, 120° 20' W). ..... 12
- Figure 1.4** Sightings (n = 306) of badgers from 1995-2001, as reported to the Thompson-Okanagan Badger Project (source: Weir & Hoodicoff 2002). ..... 14
- Figure 2.1** Average movement rates of badgers (n = 7), from March 2000 to March 2002. .... 30
- Figure 2.2** Home range areas illustrated using 100% minimum convex polygons (100% MCP) and 95% fixed kernel areas (95% FK) for badgers in the Thompson region of British Columbia, Canada. Note that an animal may have multiple fixed kernel polygons representing its home range. .... 31
- Figure 2.3** Badger home ranges (95% FK), core areas, and telemetry locations for: (A) adult male B05; (B) adult male B10 and juvenile male B08, along the South Thompson River; and (C) adult male B03, along the North Thompson River. .... 33
- Figure 3.1** Location of burrows that were surveyed within each badger's home range (100% minimum convex polygons), and within core areas delineating areas of more intensive use. .... 53
- Figure 3.2** Selection indices illustrating each badger's burrowing location selection (positive) and avoidance (negative) of habitat classes (Manly et al. 1993). Selection index is scaled so 1/number of habitat classes used by each badger is equal to zero. While there was no consistent selection for habitat classes, badgers tended to use open habitats dominated by grasses. .... 55
- Figure 3.3** Average prey sign counted (+/- 1SD) at burrows (white) and at random (black) locations within each badger's home range, illustrating that there was more prey sign counted at burrows than at random locations for each animal in the study area. .... 58

- Figure I.1** Theoretical three-dimensional kernel diagram of a single home range. The peaks illustrate areas where there is a higher probability of an animal being located. .... 89
- Figure I.2** Cross-section of a kernel calculation illustrating the different effects of smoothing, and the relationship of bandwidth to smoothing function..... 90
- Figure I.3** Diagram illustrating contour probability plotted against contour area divided the home range area (95% Fixed Kernel). In this example, area (Y-axis) is slower to accumulate than volume (X-axis) when compared to uniform use (Reference slope = 1). Graphically, the result is a concave line. The core area is determined where the slope of the tangent line is equal to 1. In this example, core areas are determined using the 60% probability contour..... 95

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# *Chapter One*

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## **Introduction**

### **1.1 BACKGROUND**

The global decline of the mammalian carnivores (Order Carnivora) is directly attributed to human activity. Habitat loss, degradation, fragmentation, and systematic exterminations have diminished their populations over the last century, as world population growth and use of natural resources have altered the landscape (Woodroffe 2001, Pimm & Raven 2000). Because society's attitude towards large carnivores is often negative, these animals particularly have been affected by these factors. People fear predators such as wolves, bears, and cougars, and view them as threats to livestock and competition for game species (Kellert et al. 1996). These attitudes, in addition to biological characteristics such as low reproductive rates and large range requirements, have helped drive many large carnivores to near extinction (McKinney 1997, Purvis et al. 2000). More recently, carnivore conservation has been helped by lobby groups that improve the status of "charismatic mega-fauna" in the eyes of the public. As a result, persecution has declined somewhat, and research has been expanded to respond to conservation issues (Kellert et al. 1996).

There is less public support for the so-called "meso-carnivores," due to their smaller size, and their reputation as pests, e.g. Minta & Marsh (1988). These members of the Carnivora have been heavily persecuted, especially on private lands, to the point where there is a conservation concern for many species (Johnson et al. 2001). Unfortunately, these same species have not been studied as extensively as larger

predators, partially due to the fact that these are “pest” species, and because they are smaller and harder to inventory. Thus, many meso-carnivores such as wolverines (*Gulo gulo*), fishers (*Martes pennanti*), bobcats (*Lynx rufus*), and North American badgers (*Taxidea taxus*) remain poorly understood despite their ecological importance, and conservation concerns for them (Kucera & Zielinski 1995, Ruggiero et al. 1994).

The North American badger provides a clear example of a meso-carnivore that is considered a pest by some landowners, and consequently has experienced significant population declines in parts of its range (Rahme et al. 1995). Badgers are fossorial carnivores that dig and live in burrows. These burrows often are viewed as a risk to livestock and farm machinery, and consequently badgers are exterminated (Minta & Marsh 1988). In the past, badgers also were commonly trapped for their pelts to make shaving brushes: in Canada and the United States, over 43,000 badgers were trapped between 1982 and 1983 (Shieff & Baker 1987). More recently, habitat loss and prey declines have been identified as the primary concern for badger populations (Rahme et al. 1995). In addition to habitat loss, extensive prey extermination programs have reduced prey species. Together, these factors have contributed to population declines of badgers across North America, but most noticeably in the northwest portion of their range.

In British Columbia, badgers are at the north-western limit of their geographic range, and populations are smaller than historically reported (Rahme et al. 1995). The subspecies that occurs in British Columbia (*jeffersonii*) is considered endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, Newhouse & Kinley 1999). Despite this concern, the ecology of this animal is poorly understood

across its range, particularly in British Columbia. Until recently, research on North American badgers has been conducted in six American states, where ecological conditions are unlike those in British Columbia: badger densities are high, and badger conservation is not a concern (Lindzey 1971, Sargeant & Warner 1972, Todd 1980, Messick & Hornocker 1981, Minta 1990, Warner & Ver Steeg 1995, Goodrich & Buskirk 1998). To date, only two research projects have focused on badgers in British Columbia, one located in the East Kootenays (Newhouse & Kinley 2001), and the other in the Thompson/Okanagan (Weir & Hoodicoff 2002). These studies have identified a number of critical knowledge gaps for badgers in the northwest, including spatial ecology and habitat selection.

The purpose of this thesis is to broaden our knowledge of the ecology of badgers in south-central British Columbia and, in doing so, aid in the conservation of these animals. Specifically, my objectives are to determine the patterns of spatial use, and burrow site selection by badgers. In Chapter Two, I investigate how badgers use the landscape, by using data gathered through radio-telemetry. In connection with this work, Appendices I and II discuss spatial analysis techniques, and outline an improved method of quantifying high-use ('core') areas within the home range of individual animals. In Chapter Three, I examine how habitat attributes such as soil and prey sign are correlated with the presence of badger burrows, and in Appendix III, I provide a cursory examination of the diet of badgers in the study region. I conclude my thesis in Chapter Four with a discussion of how my results relate to observations of mortality in the badger populations, and how this information may be used to address badger conservation. As a precursor to the rest of the thesis, I provide here a more detailed review of the natural

history and conservation status of the badger, with a focus on those populations living in the Pacific Northwest. I conclude this chapter with a description of the study area more detailed than that found in the introductions of the following chapters.

## **1.2 BADGER ECOLOGY**

The North American badger is a member of the Family Mustelidae, occurring over most of southern North America, from central Mexico, through the United States and into southern Canada. There are four subspecies of badger in North America (Long 1972), and the *jeffersonii* subspecies occurs in the north-western United States and southern British Columbia (Figure 1.1). In British Columbia, badgers occur in the dry interior of the Thompson and Okanagan regions, north to the southern Chilcotin, and east to the Rocky Mountain trench. These animals prefer grasslands and open forests where there is sufficient prey to eat, and friable soils for burrows (Rahme et al. 1995). While most badger habitat occurs in the valley bottoms, badgers have been reported at elevations ranging up to 2400m (Rahme et al. 1995).

North American badgers are solitary animals that maintain individual home ranges, but overlap occurs between neighbouring animals (Lindzey 1978, Messick & Hornocker 1981, Minta 1993). The ranges of adult males generally are larger than those of females, and are larger in the breeding season than the winter (Lindzey 1978, Lampe & Sovada 1981). Correlations among home range use, prey density and habitat are not fully understood (Messick 1987). However, in Wyoming, access to mating females during the breeding season determines the size and orientation of males' home



ranges. Conversely, access to food and burrowing sites determines the size and orientation of females' home ranges (Minta 1993).



**Figure 0.1** Distribution of the four subspecies of North American badger, in the USA and Canada, and the *jeffersonii* subspecies in British Columbia (inset). (Source: Newhouse & Kinley 1999).

Badgers are opportunistic carnivores that specialize in hunting fossorial prey (Messick 1987). During hunting and foraging, badgers avoid digging out entire burrow systems by using olfactory cues to locate prey and penetrate the soil at targeted areas (Messick 1987). Badger diets include a number of small mammal species, mainly ground squirrels (*Spermophilus* spp.), marmots (*Marmota* spp.), and pocket gophers (*Thomomys* spp.). Various species of birds (and their eggs), reptiles, insects, fish, and even a small component of vegetation also are eaten (Errington 1937, Snead & Hendrickson 1942, Messick & Hornocker 1981, Lampe 1982, Lindzey 1982, Goodrich & Buskirk 1998). Diet varies widely according to local prey availability, abundance, and season, and diet diversity is greatest during the summer (Lampe 1982). As one prey type becomes less available, badgers will switch to an alternative source to compensate (Messick & Hornocker 1981). Juvenile diets contain more arthropods and birds, and fewer mammals and reptiles than adults, probably due to undeveloped predatory skills (Messick & Hornocker 1981).

The breeding season for female badgers generally is in July or August when they enter estrous (Lindzey 1982). Although rare, female badgers can reproduce during their first summer. Males are capable of breeding from May to August in their second year (Messick 1987). Females may be induced ovulators requiring multiple copulations before estrous occurs, and this could be the reason males are reproductive for an extended time (Messick 1987). Induced ovulation also could restrict reproduction of badgers living in low densities where breeding partners are more difficult to locate. Badgers, as with other mustelids, delay implantation of the blastocyst in the uterine wall until January or February (Messick 1987). Delayed implantation is thought to synchronize birth dates

with the availability of maximum food resources, in order to off-set the metabolic demands associated with reproduction (Long & Killingley 1983).

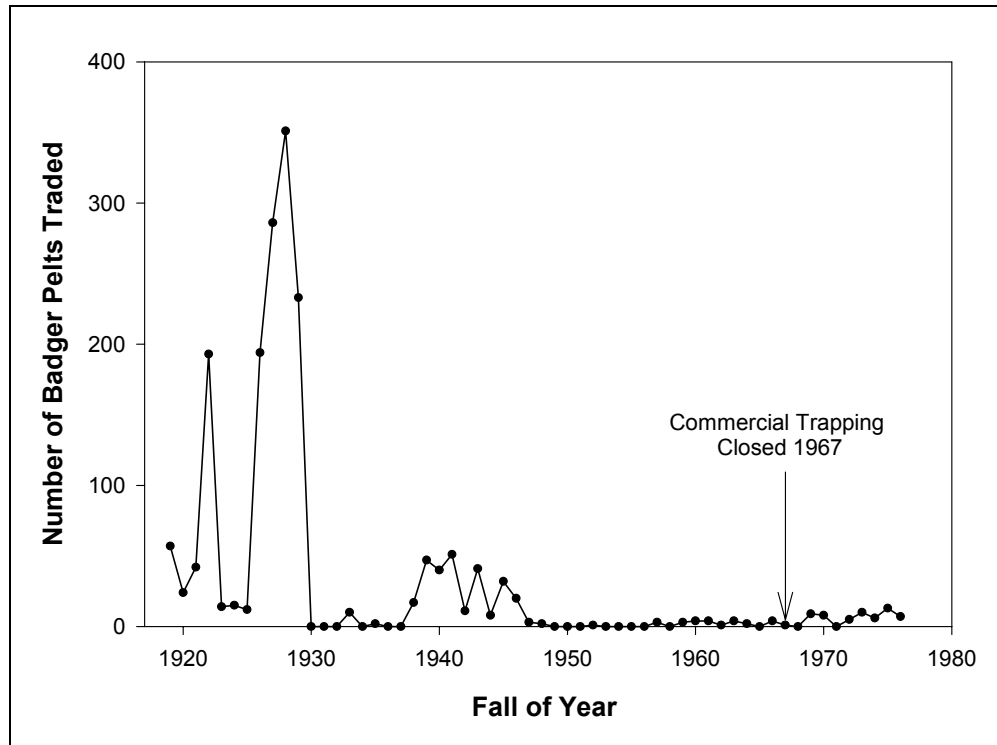
Badger kits (1 to 4) are born in late March to early April. In British Columbia, average litter size is estimated at 1.4 kits, based on observed litters of study animals and reported sightings (Newhouse & Kinley 2001, Weir & Hoodicoff 2002). The natal burrow is used until the family moves to another maternal burrow, presumably due to accumulation of feces in the initial den, and to allow the mother to hunt in new areas (Lindzey 1978, Messick & Hornocker 1981). The female remains with the kits until late May when she begins to forage on her own, returning to the maternal burrow to tend to her kits. Family groups can hunt together between late May and July, until the young disperse (Messick 1987). Natal dispersal in Idaho coincides with the estivation of Townsend and Belding's ground squirrels (Messick et al. 1981). Potential high energy costs involved in securing food for family groups versus individuals may prompt this behaviour (Messick et al. 1981).

Badgers are one of the few species of grassland carnivores in western North America, and are important members of a naturally functioning grassland ecosystem. In these ecosystems, badgers play a role in regulating fossorial and semi-fossorial prey (Messick 1987). Digging by badgers also may help with soil conditions such as aeration and nutrient mixing (Reynolds & Laundre 1988). Badger burrows are used for refuge by a number of species including black widow spiders (*Latrodectus Hesperus*), snakes, tiger salamanders (*Ambystoma tigrinum*), and many of the badger's prey species (Snead & Hendrickson 1942, Lindzey 1971, Messick & Hornocker 1981, personal observation).

Badger burrows also provide nesting sites for burrowing owls (*Athene cunicularia*), (Todd 1980, Gleason & Johnson 1985, Rich 1986, Desmond & Savidge 1996, Desmond et al. 2000), another endangered species in British Columbia.

### ***Issues in Badger Conservation***

Initial declines in the badger population were attributed to historical trapping and extermination practices (Rahme et al. 1995, Newhouse & Kinley 1999). In British Columbia, the number of badger pelts traded each year during the mid 1920s exceeded the estimated number of badgers in British Columbia today (Figure 1.2, Adams et al. 2003). In 1967, commercial trapping for badgers was stopped in British Columbia, but extermination of badgers and their prey on private lands continued to have an additional impact on population sizes (Rahme et al. 1995). In 1978, the provincial badger population was estimated between 100 and 1000 badgers based on subjective estimates by regional wildlife biologists (Munro & Jackson 1979). By 1995, Rahme et al. (1995) estimated the population of badgers in British Columbia at less than 600 individuals. In 1999, population estimates sat at less than 350 individuals, and as a result, COSEWIC uplisted the national status of badgers in British Columbia (*jeffersonii* subspecies) to endangered (Newhouse & Kinley 1999). Provincially, badgers are assigned “threatened” status (Cannings et al. 1999), and today it is estimated that less than 250 adult badgers are left in British Columbia (Adams et al. 2003).



**Figure 0.2** Annual number of badger pelts traded in British Columbia, from 1919/20 to 1976/77. Note that the number of pelts traded increased after 1967 despite the closure of commercial trapping. (Source: Adams et al. 2003).

More recently, habitat loss has been identified as a major concern for badger populations in British Columbia (Rahme et al. 1995). In the south of the province, grasslands are patchily distributed, and occur at lower elevations in valley bottoms. The Thompson/Okanagan region in south-central British Columbia is experiencing rapid growth, and new developments, golf courses, and highways continually encroach onto natural habitats. Agricultural activity has converted much of the natural grassland into fields, orchards, and vineyards. Of all the grassland in this region, 42.2% is privately owned, 9.9% is Indian Reservation, while only 7.4% is preserved in protected areas (Grasslands Conservation Council of British Columbia 2002). Grassland habitat also has been degraded due to fire suppression, resulting in forest in-growth of 10-50% of the

grassland in the region (Kirby & Campbell 1999). Consequently, badgers appear to be confined to smaller, more isolated pockets of habitat amid a human-dominated landscape.

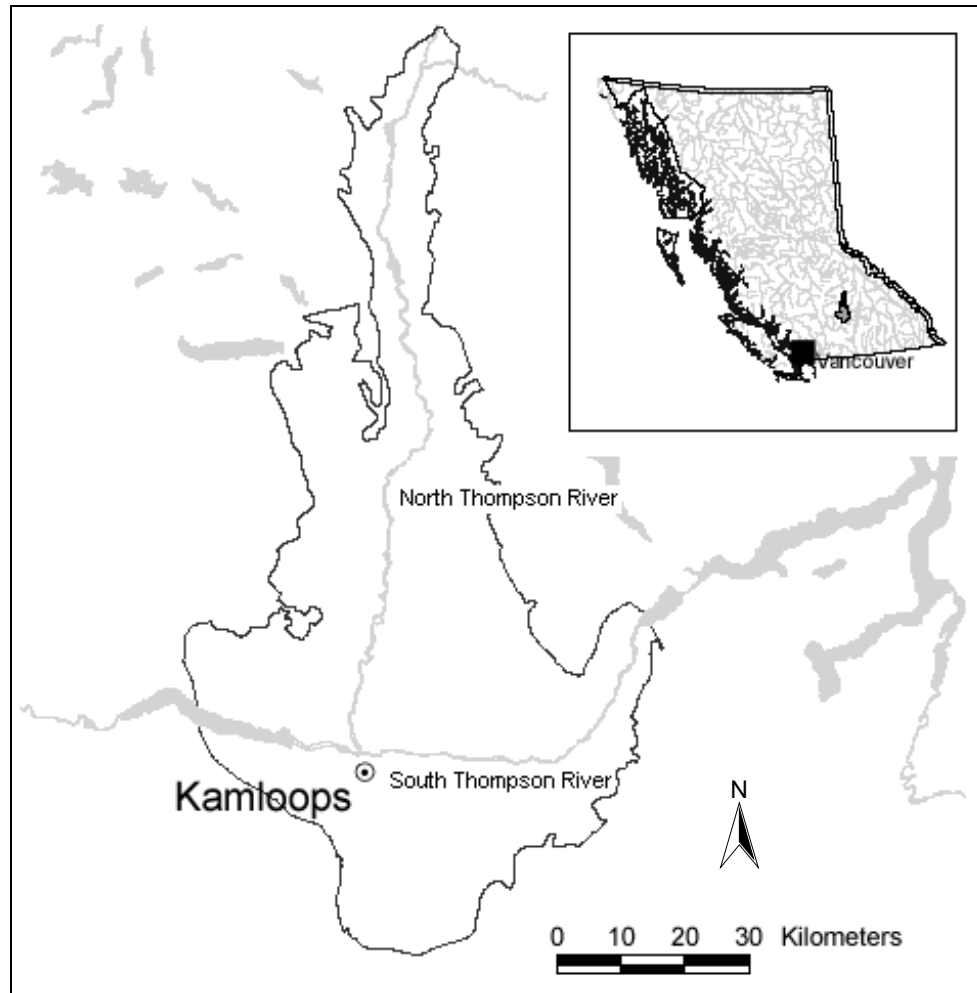
Highways have been shown to be a major cause of badger mortality in many areas of the animals' range. Highways and railways are built along valley bottoms through the most productive badger habitat. The berms formed along these linear corridors are favourable to badgers, as soils are soft and easily excavated, and small mammals are attracted to grasses planted to stabilize banks (Meunier et al. 1999). In Idaho, Messick et al. (1981) reported 59% of 157 mortalities recorded were due to roadkills. In Nebraska, Case (1978) reported roadkilled badgers comprised 2.5% of the 24,244 mortalities recorded for 10 vertebrate species along Interstate-80 from 1969 to 1975. Badger road mortality is significantly correlated with season: most occur during the breeding season when badgers are making long-distance movements (Case 1978). Unfortunately, the badger breeding season also corresponds with the peak tourist season and increased traffic volumes on highways. Because most movements made by badgers are nocturnal, animals are less visible to motorists. The issue of roadkill mortality for badgers in British Columbia is discussed more specifically in Chapter Four.

Anthropogenic changes in prey populations also affect badgers. Small mammal abundance and diversity is greater in undisturbed grasslands than in agricultural fields (Navo & Fleharty 1983). Habitat quality for small mammals has likely been reduced due to overgrazing and fire suppression (Snyder & Best 1988, Sherman & Runge 2002). Ground squirrels and pocket gophers have been significantly reduced as a result of extermination programs, and the use of pesticides is of particular concern. Badgers may

also suffer from secondary poisoning, especially if the stomach contents of poisoned prey are ingested (Rahme et al. 1995). In British Columbia, use of pesticides for eradicating ground squirrels and pocket gophers on crown land is prohibited, yet is more commonly used on private lands (Rahme et al. 1995). Strychnine may not be widely used in the province, but zinc phosphide and chlorophacinone are two rodenticides that are recommended by the British Columbian Ministry of Agriculture, Fisheries and Food (Rahme et al. 1995). The extent of pesticide use and secondary poisoning of badgers still is unknown in the province.

### **1.3 STUDY AREA**

My study area covered approximately 4,390 km<sup>2</sup> in the vicinity of Kamloops, British Columbia, Canada (50° 40' N, 120° 20' W; Figure 1.3). Typical badger habitat was located primarily in the dry valley bottoms, and I used these ecosystems to delineate the study area. The landscape is dominated by the North and South Thompson river valleys that meet in Kamloops. This region represents the northern extent of the Great Basin of the western United States. Erosion from rivers has resulted in the formation of basins and steep valley walls and gullies. The arid basins of the Thompson once were large glacial lakes that have deposited glaciofluvial and glaciolacustrine soils over the landscape. Eolian action has formed sand dunes, and “hoodoos” across the landscape. The climate typically is semi-arid, with average annual precipitation in the lower elevations ranging from 285 – 476mm (Lloyd et al. 1990).



**Figure 0.3** The study area boundary encompassed dry ecosystems located in the valley bottoms along the Thompson Rivers, and included the city of Kamloops, British Columbia, Canada ( $50^{\circ} 40' N$ ,  $120^{\circ} 20' W$ ).

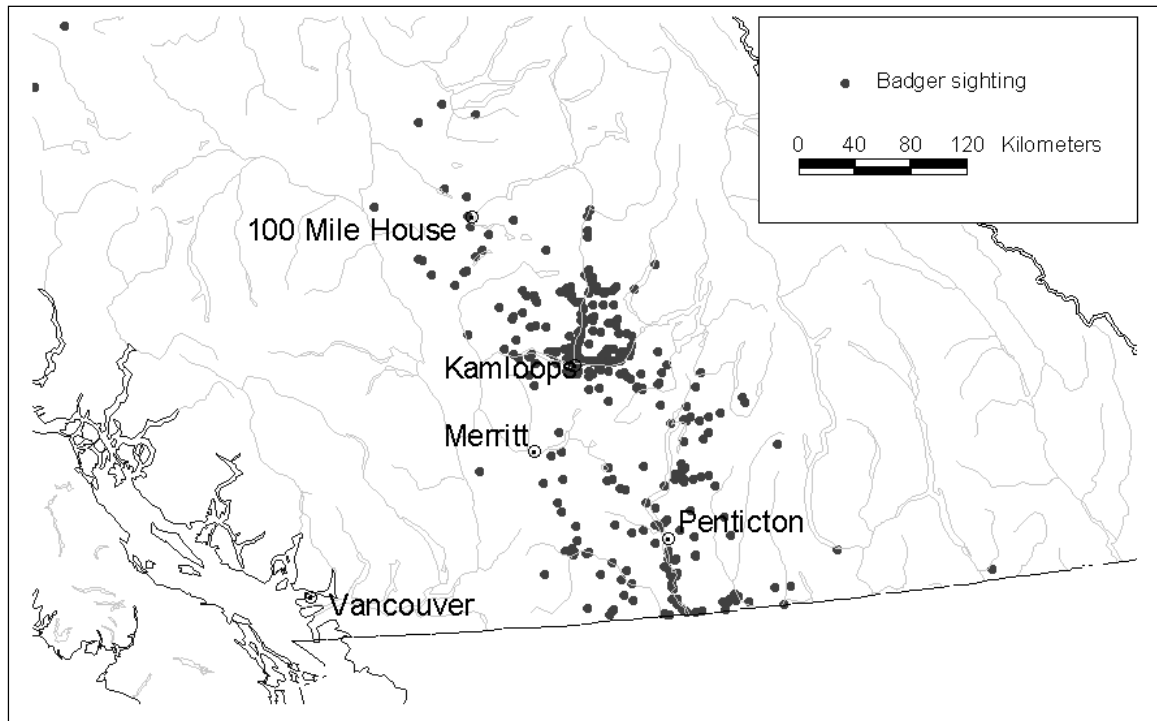
The lower elevations (250 to 1000m) of the Thompson River valleys are dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*), big sagebrush (*Artemisia tridentata*), and rabbit brush (*Chrysothamnus nauseosus*). Ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) trees occur in moist pockets at low- to mid-elevations. The understory of these open forests is dominated by pinegrass (*Calamagrostis rubescens*) and shrub species such as saskatoon (*Amalanchier alnifolia*), birch-leaved spirea (*Spirea betulifolia*), soopolallie (*Shepherdia canadensis*),



common snowberry (*Symphiocarpus albus*), and roses (*Rosa* spp.). Closed canopy ecosystems in the higher elevations are used less by badgers in British Columbia (Apps et al. 2002). However, badgers in other parts of their distribution have been observed in high elevation and alpine areas, particularly where there is sufficient prey to eat (Messick 1987).

Anthropogenic disturbance in the Thompson Region is widespread. Grasslands have rich soils and high agricultural capability and are irrigated and converted to hay and alfalfa fields, orchards, and vineyards. Cattle ranches also are active in most of this area, and grazing permits are issued on public land. Trees are harvested on forested public and private lands. Urban developments, including golf courses and transportation corridors, encroach onto natural habitat. Four major transportation routes intersect in Kamloops: the Yellowhead Highway (#5), the TransCanada Highway (#1), and the Canadian Pacific and Canadian National Railways.

The Kamloops area was chosen as a study area because of the relatively large number of badger sightings recorded there. Prior to, and throughout my study, the Thompson/Okanagan Badger Project collected badger sightings reported by the public (Weir & Hoodicoff 2002). Sightings were concentrated in the Thompson and Okanagan regions, and extended north to the Chilcotin (Figure 0.4). Of 403 sightings reported, 306 were estimated to have occurred between 1995 and 2000. Sightings ranged in elevation from 340m to 2,200m.



**Figure 0.4** Sightings (n = 306) of badgers from 1995-2001, as reported to the Thompson-Okanagan Badger Project (source: Weir & Hoodicoff 2002).

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## *Chapter Two*

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### **Patterns of Spatial Use by Badgers (*Taxidea taxus jeffersonii*) in South-Central British Columbia, Canada**

#### **2.1 INTRODUCTION**

The size, shape and location of animal home ranges are some of the measurements most frequently used to study the ecology of an individual and of populations. These measurements are well justified, as home ranges generally encompass the resources that animals need for feeding, mating, and rearing offspring (Burt 1943). However, animals that maintain home ranges do not use them uniformly because of the heterogeneity of resource distribution. Sites with resources are important to an animal, and therefore, visited more often than other parts of a home range (Hayne 1949). For example, denning or nesting sites, patches of dependable food resources, and mating grounds are focal features within a home range that may be frequented (Springer 1982, Litvaitis et al. 1986, Samuel & Green 1988, Marzluff et al. 1997, Pechacek et al. 2000). Simply estimating home range area remains valuable; however, some knowledge of the relative intensity of use of a home range can help to identify the source and location of resources important for an animal (Hayne 1949).

Areas within home ranges that are used relatively more by animals have been described as *core areas* (Burt 1943, Ford 1983). These areas should be defined using two major criteria (Powell 2000). First, core areas must be used more often than expected from a random pattern of locations. Second, core areas should not be defined arbitrarily, but with relevance to the organism in question. Delineating core areas for animals that



occupy home ranges may help to identify important areas. Once a core area is identified for an animal, this area may be used to assess habitat selection, or used to establish priorities for conservation.

Within Canada, the badger subspecies *Taxidea taxus jeffersonii* is restricted to a small area of the western-most province of British Columbia, and is considered endangered within Canada (Newhouse & Kinley 1999). The ecology of these animals is poorly understood, although loss of grassland habitat generally is considered a leading cause in the decline of populations (Rahme et al. 1995). Habitat conservation for these animals lacks direction because their use of the landscape, including critical habitats remains unknown. Research in the United States has shown that home range size varies throughout badger distribution, and is correlated with prey density, female availability, and habitat attributes (Lindzey 1978, Messick & Hornocker 1981, Minta 1993). Badgers also are known to show restricted movement patterns in winter (Messick 1987). For all these reasons, one would predict that home ranges will contain one or more core areas. By improving our knowledge of the spatial ecology of badgers, and identifying areas and/or resources that are used more frequently, will aid in the development of conservation strategies for the animal.

My objective in this chapter is to describe patterns of spatial use by badgers in the Thompson region of British Columbia. I identify the home ranges that badgers used in southern British Columbia, and isolate core areas using the criteria outlined by Powell (2000) based on the dispersion of telemetry locations. I then discuss the ecological significance of badger spatial use, and how the spatial ecology of badgers may direct

habitat conservation initiatives. In Appendix I, I have included a more thorough discussion of my methods, and a critique of other methods currently used to delineate core areas within the home ranges of animals.

## **2.2 METHODS**

### ***Study Area***

The study area extended over approximately 4,390 km<sup>2</sup> near Kamloops, British Columbia, Canada (50° 40' N, 120° 20' W). At this site, the North and South Thompson Rivers ran through deep, arid valleys that converged at Kamloops. Typical badger habitat was located primarily in dry valley bottoms where bunchgrass (*Pseudoroegneria spicata*), sagebrush (*Artemisia tridentata*) and ponderosa pine (*Pinus ponderosa*) dominated the landscape (Lloyd et al. 1990). Soil primarily was loamy textured, originating from glaciolacustrine, and glaciofluvial parent materials (Lloyd et al. 1990). Urban and golf course development, agriculture, transportation corridors and forest encroachment onto the grasslands had substantially fragmented the natural habitat. In addition, cattle grazed on both private and public rangeland, and forest harvesting occurred in the upper-elevation forests of the North and South Thompson River valleys.

### ***Field Methods***

Badgers were live-trapped in the spring and summer of 1999, 2000 and 2001. Because badgers are found at low densities in the region, I relied on public sightings of fresh sign in addition to my own observations to identify trap sites. I set traps at active burrow sites overnight for a maximum of 14 hours. I used Victor, 1 ½ coil spring leg-hold traps that were padded and off-set to prevent injury. These were secured in the

ground with a 45 cm long, 3 mm diameter cable attached to a flared anchor. I baited each set with approximately 200g of deer (*Odocoileus hemionus*), red squirrel (*Tamiasciurus hudsonicus*), or ground squirrel (*Spermophilus columbianus*) carrion and scented each trap site with commercial canine lure.

I immobilized captured badgers, and transported each animal to the veterinary clinic where a veterinarian surgically fitted each badger with an intraperitoneal radiotransmitter. In the field, I immobilized captured badgers using a 1:1 mixture of tiletamine hydrochloride and zolazepam hydrochloride (Telazol®). Animals were given up to 5mg/kg Telazol, depending on the duration of sedation needed to transport each from the capture site to the veterinary clinic at the University College of the Cariboo, in Kamloops (up to 1 hour). At the clinic, the veterinarian implanted Telonics (IMP400/L with high power option) radiotransmitters into each badger. Using transmitter implants significantly compromised the strength of the signal being emitted, but this approach was necessary because badgers lack distinct necks and can readily remove traditional wildlife radio-collars. During each surgery, the veterinarian administered approximately 1.5 ml penicillin, and 35 ml saline hydration. After the surgery, the veterinarian administered up to 100ml saline hydration subcutaneously to rehydrate the animal. Badgers were placed in a recovery barrel made from a 200 L opaque plastic barrel with cutout airholes, and fitted with a removable lid that could be clamped securely. When the badgers were fully conscious, I released each animal at its capture location in front of a burrow. In order to minimize undue trauma for these animals, transmitters were not retrieved after the study was completed. Protocols for working with the badgers were approved by the University College of the Cariboo Research Ethics Committee (Animal Subjects), and the University

of Victoria Animal Care Committee. Both committees are recognized by the Canada Council on Animal Care.

I conducted radio-telemetry from the ground using a truck-mounted omni antenna, and handheld 2- and 3-element Yagi antennas. During the summer months, I targeted a minimum of 1 location per week, per animal. During the winter, telemetry was attempted once every 2 weeks. After detecting the signal for an animal, I walked to the badger's location or its burrow entrance, and recorded each location in universal transverse mercator (UTM) coordinates with a handheld global positioning unit (GPS). This eliminated telemetry location error. Most locations were collected during the day; however, I also conducted 7 overnight focal monitoring sessions to determine nocturnal activities and movements. During the summers, if an animal was not located during the week, an intensive search was conducted on the ground, and periodically from a fixed-wing airplane.

I considered telemetry locations as independent if they were separated by at least 12 hours over-night (Litvaitis et al. 1986). I used this criterion since badgers were most active at night, and were capable of travelling long distances. Coordinates used for home range analysis were telemetry locations where the animals were active, or found in burrows. I calculated distances between telemetry locations (per 12 hrs) to determine minimum distance travelled during the summer and winter seasons. I considered the summer season from April 1 to August 31, when animal movement rates were greatest, and the winter season from September 1 to March 31, when animals decreased their movements.

I calculated 100% minimum convex polygon (100% MCP) areas to approximate home range for individuals, and to compare to those reported in other studies (Mohr 1947). I used the ANIMAL MOVEMENT extension for ARCVIEW (Hooge & Eichenlaub 2000) to calculate MCP areas. I did not use MCPs for any other analyses because fixed kernels measure home ranges more accurately and precisely (Worton 1989).

### ***Determining Home Range using Fixed Kernels***

To describe use within the home range, I used fixed kernel (FK) density estimates (Worton 1989). Home range area was interpreted as the 95% probability contour. This contour's value is arbitrary but standard, and can be compared to other studies using fixed kernel analysis. I used the fixed kernel method because it has lower bias, and better surface fit for a given bandwidth than the adaptive kernel method (Seaman & Powell 1996, Seaman et al. 1999). It also is the recommended method when describing relative use in the interior of a home range (Powell 2000). Although a minimum of 30 locations is suggested for kernel analysis (Seaman & Powell 1996), I used a minimum of 20 locations as this allowed me to include a reasonable number of animals in my analysis. I calculated fixed kernel areas using the program HOME RANGER (Hovey 1999).

Because many of the telemetry points were collected at the same location (e.g. same burrow), fixed kernel methods produced disjunct polygons in areas where telemetry points were densest. To create a smoother kernel estimate, that is, a more continuous home range, I adjusted the smoothing parameters used in my home range analysis. I first calculated each home range using only unique locations, i.e. used a location only once even if the animal was located at the same location on multiple occasions (Weir &

Hoodicoff 2002). I calculated the bandwidth ( $h$ ) by least squares cross validation with no *ad hoc* adjustment (Worton 1989). I then used the same bandwidth to calculate the kernel areas using all telemetry locations. If this still generated discontinuous home range areas, I increased the smoothing parameter further (*ad hoc* = 3.0).

### ***Identifying Core Areas within Home Ranges***

I identified core areas within home ranges of each badger using a method that tests for non-random use of the home range, and delineates core areas with respect to home range size (Appendix I). First, I tested each animal's telemetry locations for randomness across its home range. I used an index of aggregation ( $R$ ) based on mean distances to each point's nearest-neighbour (Clark & Evans 1954, Krebs 1999).

Locations at the edge of an area tend to have larger nearest-neighbour distances, so I used a modified formula that takes this bias into account (Sinclair 1985).  $R$  was calculated using the equation:  $R = r_{\text{mean}} / r_{\text{expected}}$

*where:*

$r$  = distance to nearest neighbour

$r_{\text{mean}} = \sum (r) / n$

$r_{\text{expected}} = 0.5 * \text{sqrt}[A/n] + [0.051 + 0.041/\text{sqrt}(n)] L / n$

$A$  = 100% MCP home range area

$L$  = length of perimeter of  $A$

$n$  = number of locations

Index values ( $R$ ) can be interpreted as a continuum where a value of 1 indicates that the locations are in a completely random pattern. A value approaching 0 indicates aggregation, and a uniform pattern is indicated as  $R$  approaches an upper limit of 2.15.

I was unable to use a standard normal deviate ( $z$ ) to test the significance of  $R$  values, as suggested by Krebs (1999). The number of telemetry locations I collected was

small, and home ranges tended to be linear, so the use of the  $z$  statistic was inappropriate (Sinclair 1985 after Donnelly 1978). Therefore, I used an alternative method for testing the significance of  $R$  using Monte Carlo simulations, which are not affected by boundary effects (Manly 2001).

Monte Carlo simulations involve generating random samples from a population of observed values. For each animal, I generated a random walk model that produced a set of simulated locations that could be compared to its telemetry data. To do this, I first calculated successive distances between locations collected. I then generated a random walk by choosing a random distance from the distances between observed values, and a random bearing (0-359 degrees). I created a simulated path with as many locations (coordinates) as were contained in the empirical data set. For each animal, I created 999 simulated random walks, and calculated an index of aggregation for each simulation to compare to the observed value. The probability ( $p$ ) of the observed index was assigned in relation to these simulated values, where  $p$  represented the probability of a simulated dataset being more aggregated than the observed value. The programming for this was done using MATHSOFT S-PLUS® (1999, Appendix II).

Finally, I delineated core areas boundaries for those animals with significantly aggregated locations. I used a method described by Powell (2000) and Bingham and Noon (1997) for determining a biologically relevant boundary. I plotted the probability contour (0-95%) along the X-axis, against the area of each probability contour divided by the home range area (95% FK) along the Y-axis. If the distribution of locations within the 95% probability contour were perfectly uniform, the slope of the regression line

would equal 1, indicating that the contour area accrued evenly with contour volume. If the regression line sagged below this reference line, contour area accrued disproportionately to contour volume. The line sags to the extent that locations are concentrated because area will be accumulated less rapidly than expected under uniformity. Core areas for each animal are defined at the contour probability (%) where the slope of the tangent to the sagging line is 1. The methods I used to estimate home range and core areas are discussed further in Appendix II.

After I confirmed aggregation of locations and core area contours, I used the program HOME RANGER (Hovey 1999) to calculate contour boundaries and areas, and imported them into ARCVIEW 3.1 Geographical Information Systems (ESRI 1998) coverage for mapping and further analysis.

## **2.3 RESULTS**

### ***Field Results***

A total of 14 badgers were trapped and radio-tracked from March 1999 to September 2002 (Table 2.1). All badgers trapped were males, except one adult female (B06) and her female kit (B07). This male-bias occurred despite efforts to trap both male and female badgers. I collected between 2 and 51 locations from each badger, for a total of 322 independent telemetry locations over 3791 telemetry days (1 telemetry day for every badger that had an operational transmitter for 24 hrs). On occasion, telemetry signals from badgers could not be detected from the ground or air. This I attributed to topographical constraints, long-distance movements by badgers, and strength of transmitter especially when the animal was under ground. For individuals from which I



had collected 7 or more locations, MCP areas ranged from 9.0 km<sup>2</sup> to 258.4 km<sup>2</sup> ( $\bar{x}$  = 78.6 km<sup>2</sup>, SD = 89.4, n = 9, Table 2.1). Only seven animals (6 males, 1 female) with >20 telemetry locations were used in the remaining analysis.

**Table 2.1** Age-class and sex of badgers captured, and telemetry monitoring data for each animal. Both 100% minimum convex polygons (100% MCP), and 95% fixed kernel estimates (95% FK) were calculated from the independent locations (n) collected for each animal. An \* in the Animal ID column indicates those badgers included in both fixed kernel and core area analysis.

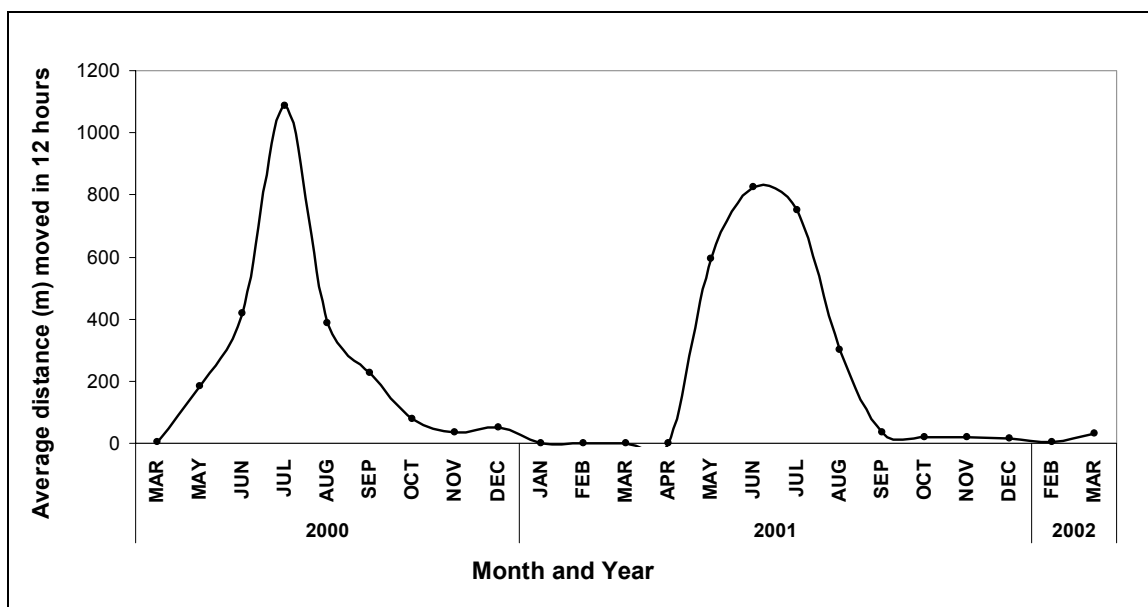
Animal ID	Age class	Sex	Year captured	No. days monitored	Locations (n) 2000-2001	100% MCP (km <sup>2</sup> )	95% FK (km <sup>2</sup> ) <sup>a</sup>
B01	Adult	M	1999	391	7	258.4	—
B02	Adult	M	1999	299	4	—	—
B03*	Adult	M	1999	806	51	197.0	80.4
B04	Juvenile	M	1999	56	2	—	—
B05*	Adult	M	1999	937	65	55.1	36.7
B06*	Adult	F	2000	86	51	9.0	12.3
B07	Juvenile	F	2000	10	10	—	—
B08*	Juvenile	M	2000	303	31	87.9	20.6
B09*	Adult	M	2001	294	30	45.1	24.2
B10*	Adult	M	2001	205	26	11.3	13.3
B11	Adult	M	2001	148	2	—	—
B12	Adult	M	2001	137	12	21.8	—
B13	Juvenile	M	2001	56	2	—	—
B14*	Adult	M	2001	63	21	21.8	12.8
			<b>Sum</b>	3791	314		
			$\bar{x}$	271	22	78.6	28.6
			(SD)	(280.4)	(20.9)	(89.4)	(24.4)

<sup>a</sup> locations collected in 1999 were omitted from fixed kernel home range analysis because monitoring was conducted infrequently, and telemetry locations may have been biased to areas familiar to researchers.

### *Seasonal Movements of Badgers*

I collected 207 locations during the summer (Apr 1 – Aug 31), and 61 locations during the winter. During the summer, the average time and distance between locations of each animal was 6.4 days (SD = 18.05) and 3.0 km (SD = 3.40). During the winter, the average time and distance between locations of each animal was 18.3 days (SD = 31.25) and 0.5 km (SD = 0.86).

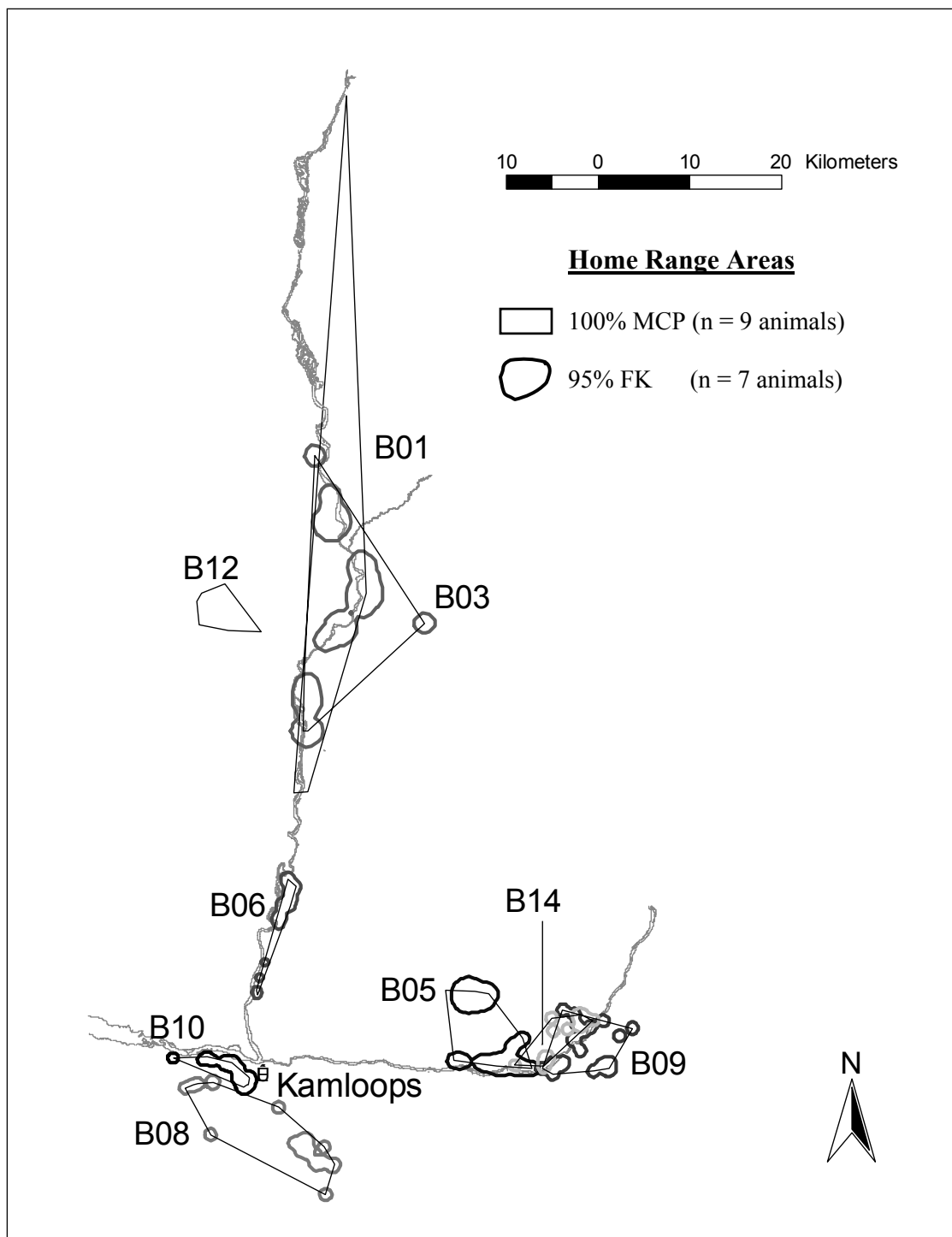
Badgers moved more during the summer than the winter. Average movement rates were 645 m in 12 hours (SD = 985.3) during the summer, and 48 m in 12 hours (SD = 126.8) during the winter. Long-distance movements started in mid-April, peaked in July, and continued until the end of September (Figure 2.1). This corresponded to the badger breeding season, and periods of high prey activity. The female (B06) travelled over 6 km in 12 hours on 2 occasions, July 18 and 24, 2000. On July 24, 2000, I observed a male traveling over 14 km during 4 hours of night-time monitoring.



**Figure 2.1** Average movement rates of badgers (n = 7), from March 2000 to March 2002.

### *Home Ranges*

Ninety-five percent fixed kernel (95% FK) areas for 7 badgers varied between 12.3 km<sup>2</sup> and 80.4 km<sup>2</sup> ( $\bar{x}$  = 28.6 km<sup>2</sup>, SD = 24.4, Table 2.1). The female (B06) had the smallest home range (100% MCP and 95% FK), and male badgers in the northern part of the study area used the largest home ranges (B01, B03, B05). Home ranges of some male badgers overlapped (B01, B05; and, B09, B14, B05; Figure 2.2).



**Figure 2.2** Home range areas illustrated using 100% minimum convex polygons (100% MCP) and 95% fixed kernel areas (95% FK) for badgers in the Thompson region of British Columbia, Canada. Note that an animal may have multiple fixed kernel polygons representing its home range.

### *Use of Core Areas*

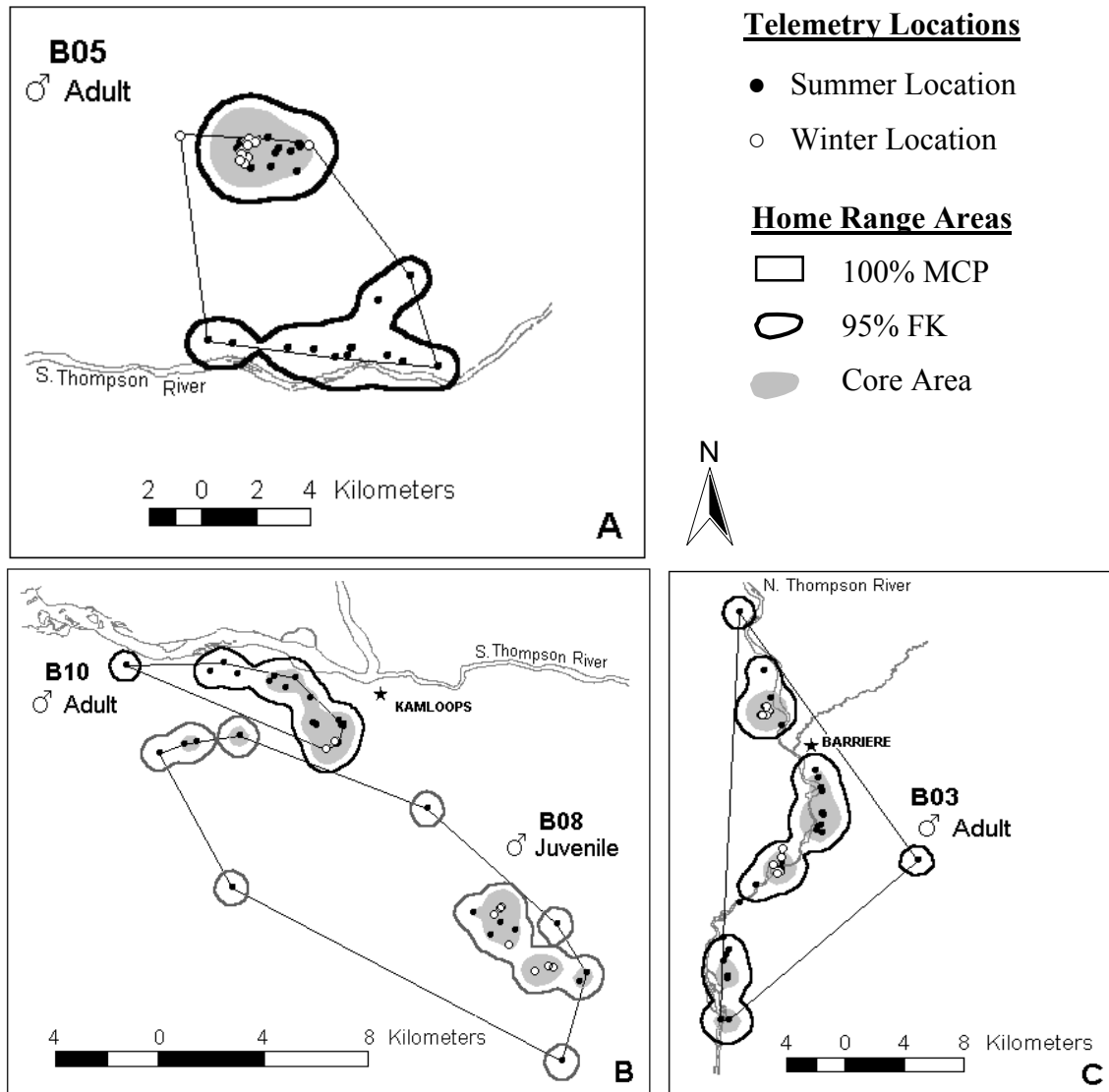
All animals, except B09, showed some degree of aggregation across their home ranges during the year (Table 2.2). Four animals (B03, B05, B08, and B10) used core areas year round ( $p < 0.05$ ). These animals maintained 1 to 5 core areas within their home ranges that were delineated by 60% - 67% probability contours (Table 2.3, Figure 2.3). Core areas accounted for 21% - 34% of badgers' home range areas (95% FK) and encompassed an average of 82% of each animal's telemetry locations. Badgers were located within core areas during the fall and winter months (Sept 1 – March 31). Only two animals also used core areas during the summer months (B03, B05, Table 2.2).

**Table 2.2** Index of aggregation results for all seasons (1999 – 2002), and for the summer (Apr 1–Aug 31). The index value (R) indicates the degree of aggregation of telemetry locations collected and the probability of the modeled index (p). The number of locations used in the analysis is represented by n. Index values for B06 and B14 were calculated during the summer only because there were no locations collected during other seasons.

Animal ID	All Seasons (1999 – 2002)			Summer (Apr 1 – Aug 31)		
	R	p	n	R	p	n
B03	0.44	0.014	51	0.49	0.007	38
B05	0.52	0.034	65	0.63	0.018	36
B06	—	—	—	0.50	0.774	51
B08	0.21	0.037	31	0.98	0.467	15
B09	0.90	0.216	30	1.02	0.064	22
B10	0.73	0.045	26	0.72	0.077	24
B14	—	—	—	0.78	0.106	21

**Table 2.3** Summary of core areas used by badgers. The number of core area patches, size of core areas ( $\text{km}^2$ ), probability contours that delineate core area boundaries, and percent of home range in core areas ( $\text{km}^2$ ) are reported.

Animal ID	No. of Core areas	Area ( $\text{km}^2$ )	Probability contour	% of HR area ( $\text{km}^2$ )
B03	5	23.7	64%	29%
B05	1	7.6	67%	21%
B08	5	5.4	60%	26%
B10	1	4.5	63%	34%
	$\bar{x}$	10.3	63%	28%
	(SD)	(9.03)	(3%)	(6%)



**Figure 2.3** Badger home ranges (95% FK), core areas, and telemetry locations for: (A) adult male B05; (B) adult male B10 and juvenile male B08, along the South Thompson River; and (C) adult male B03, along the North Thompson River.

## 2.4 DISCUSSION

This research shows that individual badgers used space differently in the Thompson region of British Columbia. Generally, badgers maintained large home ranges across the study area, and were capable of moving greater distances than has been reported outside the province. Also, badgers did not use their home ranges uniformly.

There was considerable variation in the patterns of use between individuals even within my small sample size. Some badgers concentrated their activities in core areas within their home ranges, while others appeared to use their home ranges randomly, especially in summer. This may be related to dispersion of limited resources within each badger's home range. Therefore, understanding and acknowledging individual variation in the patterns of landscape use could be a valuable asset in setting management strategies, especially for keying into resources within an animal's home range that are critical to protect.

### ***Home Range Size and Movements***

Badgers in my study area used larger home ranges compared to those reported by other studies (Lindzey 1978, Messick & Hornocker 1981, Minta 1993, Warner & Ver Steeg 1995, Goodrich & Buskirk 1998). In the Thompson region, male badger home ranges averaged 87 km<sup>2</sup> (100% MCP). This is twice the size of the largest home range reported in the United States (Table 2.4, Warner & Ver Steeg 1995). In the East Kootenay region of British Columbia, male home ranges are even larger (average of 450 km<sup>2</sup>, Newhouse & Kinley 2001). This is over 100 times the average home range area reported in the United States.

**Table 2.4** Average estimated home range size (km<sup>2</sup>) of badgers in various parts of their range in North America. Home ranges are 100% minimum convex polygon (100% MCP) and 95% fixed kernel (95% FK).

Source	Study Location	Sample Size		100% MCP (km <sup>2</sup> )		95% FK (km <sup>2</sup> )	
		Male	Female	Male	Female	Male	Female
Warner and Ver Steeg (1995)	Illinois	6	7	44 <sup>a</sup>	13 <sup>a</sup>	—	—
Lindzey (1978)	NW Utah	2	5	5.8	2.4	—	—
Minta (1993)	Wyoming	18	15	3	8	—	—
Goodrich and Buskirk (1998)	Wyoming	8	6	—	—	12 <sup>b</sup>	3.4 <sup>b</sup>
Messick and Hornocker (1981)	SW Idaho	2	3	2.4	1.6	—	—
Newhouse & Kinley (2001)	BC - Kootenay	4	3	450	51	70	30
This Study (2003)	BC - Thompson	8	1	87.3	9	42.6	12.3

<sup>a</sup> 95% minimum convex polygon estimate

<sup>b</sup> 95% adaptive kernel estimate

The large home range sizes I observed were related to the long distance movements that badgers made during the summer. Badgers may have made long-distance movements to search for mates. For male badgers, home range size is determined by access to breeding females (Minta 1993). While the lack of females in my study limits the conclusions I can make, the large home ranges of males may have been at least partially influenced by a low female density. As a result, males likely had to travel longer distances in search of females to breed with and therefore, used larger home range areas (Minta 1993, Powell 1994).

The availability of food resources also may have contributed to the large home range sizes of these badgers. Reduced food availability is thought to increase the size of home ranges of North American badgers (*Taxidea taxus*, Lindzey 1982, Minta 1993). For female badgers in particular, home range size and orientation is influenced by food dispersion (Minta 1993). This, in turn, would influence the home range size of male badgers as they search for mates across the landscape. Relationships between home

range size and food availability have been widely reported in the literature for other mammalian carnivores (Ward & Krebs 1985, Litvaitis et al. 1986). For example, the territories of European badgers (*Meles meles*) increased in size when prey availability was reduced (Kruuk & Parish 1982, DaSilva et al. 1993). Prey biomass also was linked to home range size of bobcats (*Lynx rufus*), whereby animals expanded their home ranges in response to land-use patterns that caused declines in prey populations (Litvaitis et al. 1986, Rolley 1987, Knick 1990). Red foxes (*Vulpes vulpes*) also expanded their home ranges during mating seasons due in part to increased movements, and decreased abundance of prey (Chamberlain & Leopold 2000). Because there is a correlation between the size of home ranges for badgers, and the availability of resources (Minta 1993), there also may be a correlation between dispersion of resources and use of core areas within the home range. This will be explored further in Chapter Three.

### ***Patterns of Spatial Use within the Home Range***

Badgers in my study did not use their home ranges uniformly, and there was considerable variation in the patterns of use between individuals. This may reflect the patchiness of resources on the landscape. Aggregation of locations varied from badgers that used their home ranges randomly (B09), to badgers that used core areas within their home ranges (B03 and B05). Badgers that used core areas also had the largest home ranges of all the study animals (B03 = 80.4 km<sup>2</sup>, B05 = 36.7 km<sup>2</sup>, 95% FK). Because the study area was large, and spanned a diverse landscape of natural and human-altered habitat, variability in badger spatial ecology probably reflected the variability of the resources available to each badger.



Badgers may have been keying into core areas within their home ranges where resources were concentrated. For example, use of core areas may have been related to burrowing sites, mate proximity, or areas of concentrated prey. Badgers specialize in hunting fossorial prey such as ground squirrels and marmots (Messick 1987). Both species live in colonies that would be dependable patches of food for badgers, and therefore, returned to more often. The use of food patches as core areas also has been described for bobcats. Knick (1990) found that extra-territorial forays and patch use was more pronounced for bobcats during winters when they fed on lagomorphs that were found in clumped distributions. This contrasted with the summers, when bobcats foraged on mice that were more uniformly distributed. I also observed badgers that did not use core areas, suggesting the landscape, and perhaps prey resources, were different for these badgers. More uniform use of their home ranges may indicate more evenly dispersed prey resources such as voles, mice and arthropods. While there is evidence to suggest badger spatial ecology is dependent upon prey dispersion, this relationship should be tested more rigorously before definitive conclusions are drawn.

Sex may have influenced the spatial ecology of these badgers; however, I was not able to fully explore these differences due to the lack of females that were captured. The lone adult female of my sample (B06) did not use core areas during the breeding season. She had two kits during the months she was monitored, and I expected that her movements would be restricted to the vicinity of maternal burrows. However, she had the highest movement rates of all the study animals during the breeding season. In mid-July, she made two long-distance movements in 24 hours from one end of her home range to the other. She may have been searching for males, or she may have been moving to more

productive hunting grounds (Lampe & Sovada 1981). It also is possible that the relatively short duration of monitoring of this female prevented me from observing use of core areas around maternal burrows.

Use within home ranges varied seasonally, which is consistent with other studies (Sargeant & Warner 1972, Messick & Hornocker 1981). Badgers in this study reduced their movements during the winter and used smaller home ranges. In fact, 4 of 5 badgers used core areas within their home ranges during the winter. As badgers decrease their movements in the autumn, they increase food consumption and their fat levels for the winter months (Harlow 1981, Michener 2000). Therefore, there should be some correlation between prey availability and over-wintering locations of badgers.

## **2.5 CONCLUSIONS**

The small number of animals, the male sex-bias, and the low number of locations per animal limited my capacity to draw conclusions about spatial use by badgers. Unfortunately, these problems would be exceptionally difficult to overcome: the extremely low densities of the animals in British Columbia, coupled with their large home range areas, made low sample sizes virtually unavoidable. It was difficult to relocate animals using radio-telemetry, especially when radio signals are reduced when the animal was under ground, and also prevented me from using a more structured trapping regime, such as a grid. Capture of badgers was not random as animals were targeted where researchers saw fresh sign. This could have contributed to the large proportion of males captured as they move longer distances, and were more likely to be

observed. Capture effort was probably biased for animals closer to roads and highways than may be represented by the entire population.

Despite these limitations, my results suggested that individual badgers were capable of using larger portions of the landscape than reported in studies outside of the province, and I was also able to identify core areas within home ranges that may be sources of key resources and therefore critical for conservation for the population. Understanding the spatial patterns of badgers will have an impact on how habitat should be defined for the species. This is especially true for large-ranging carnivores whose home range areas are not used evenly. Animals maintain cognitive maps of the landscape, and they use these maps to remember where resources are located (Stamps 1995). Therefore, core areas may be used for many years as long as resources are available. Thus preservation of these areas is justified. Understanding the scale at which animals operate on the landscape will enable conservation initiatives to be set relative to the needs of the animals, rather than those of the researcher or policy maker. This likely will produce more effective, long-term management plans.

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## ***Chapter Three***

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### **Habitat Selection and Characteristics of Badger (*Taxidea taxus jeffersonii*) Burrows in South-Central British Columbia, Canada**

#### **3.1 INTRODUCTION**

Habitat is defined as the place where an animal normally lives, or the collection of resources and conditions necessary for its occupancy (Garshelis 2000). There are basic questions that researchers studying habitat seek to answer (Erickson et al. 2001, Marzluff et al. 2001). The first set of questions is: how do animals perceive their landscape, and do they regard resources encountered on a recent travel trajectory, or remember particular resource areas? Researchers can address some of these questions by studying spatial ecology, use of home range area, and the differential use of space within home ranges as a way of assessing important sites (Chapter Two). The second set of questions is: do animals consider availability of different resources in the same way? That is, do animals living in different environments still tend to select the same resources, and does this suggest that the animals in different environments can make adjustments to meet the same resource needs?

Habitat selection often is described as an “average behaviour” that is easier to interpret and translate into management policies (Marzluff et al. 1997). However, Bowers (1995) suggests that habitat selection occurs at the level of an individual animal, and therefore, at individual scales. This is perhaps most relevant when describing habitat selection within individual home ranges. Describing and reporting individual variation is

beneficial because it may reflect the heterogeneity of landscapes, and illustrate the plasticity of resource use for a species.

Species that live in both natural and human-altered habitats require the same resources, yet can illustrate individual selection for habitat characteristics. For example, badgers (*Taxidea taxus jeffersonii*) in British Columbia, Canada appear to be declining primarily due to habitat loss, yet habitat selection is poorly understood for the species (Newhouse & Kinley 1999, Rahme et al. 1995). Although generally associated with grasslands, badgers have been observed in a variety of habitat types, from urban to the alpine (Weir & Hoodicoff 2002, Messick 1987). However, badgers do have two basic life requisites: suitable soils to dig burrows into, and sufficient ground-dwelling prey to eat (Rahme et al. 1995). Because badgers live in a variety of habitats, their needs can theoretically be met in a number of ways. Since burrows are unique features in badger ecology, these may be linked to resources that are consistently selected for by badgers in any landscape. However, origin of these resources would differ for an animal living in natural grassland compared to one living in a more anthropogenic environment, and this may shed some light on the abilities of badgers to adapt to meet their needs in different habitats.

My objective in this chapter is to assess the habitat selection of badgers in south-central British Columbia, by looking at the location of burrows and resources in the vicinity. In Chapter Two, I illustrated that badgers use larger home ranges than reported in southern populations of the United States. My data revealed that some badgers use core areas within their home ranges, suggesting there are areas that are more important to

these individuals. In this chapter, I describe burrowing habitat to determine resource availability for badgers. I compare habitat, soil characteristics, and prey availability at burrow sites and at random locations to determine if there are common features of selection for badgers living in different habitats. I also describe the role of resources in spatial ecology, particularly the use of core areas, and the implications of my results on the management of badger habitat in British Columbia.

## 3.2 METHODS

### *Study Area*

I studied badgers in an area that covered approximately 4,390 km<sup>2</sup> in the vicinity of Kamloops, British Columbia, Canada (50° 40' N, 120° 20' W). Two large rivers, the North Thompson and South Thompson, meet in Kamloops. The valley bottoms are dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*), big sagebrush (*Artemisia tridentata*), and rabbit brush (*Chrysothamnus nauseosus*). Ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) trees occur in moist pockets at low- to mid-elevations. The arid basins of the Thompson were once large glacial lakes that have deposited glaciofluvial and glaciolacustrine soils over the landscape. Eolian action has formed sand dunes and hoodoos across the landscape.

Disturbance in the Thompson Region is widespread, mostly due to agriculture and ranching. Urban developments and transportation corridors are encroaching onto natural habitat, as Kamloops is a growing city where four major highways and two railways intersect. The forested public lands and some private lands are harvested for timber.

Seasonal grazing permits also are issued to ranchers in the area, and many of the clearcuts and roadsides are extensively seeded to enhance grazing.

### ***Habitat Data Collection***

Badgers were live-trapped in the spring and summer of 1999, 2000 and 2001. Each animal was fitted with an intraperitoneal radiotransmitter (Telonics IMP400/L with high power option) by a veterinarian. I conducted radio-telemetry using a truck-mounted omni antenna, and handheld 2- and 3-element Yagi antennas. Animals were located a minimum of once per week during the summer months, and once every two weeks during the winter. Active burrows were identified when an animal was located inside, or near a burrow. Burrow locations were recorded in universal transverse mercator (UTM) coordinates with a handheld global positioning unit (GPS). Most locations were collected during the day when badgers were the least active. I did not include data for individuals with fewer than 20 radio-telemetry locations, or fewer than 12 identified burrows.

I collected data on general habitat features, soil characteristics, and prey availability at burrows and at random locations to assess burrow habitat selection (Table 3.1). Habitat selection was tested for each badger individually because home ranges were in ecologically distinct areas (Design III, Thomas & Taylor 1990). I stratified data collected at each individual's burrows by the intensity of use (core area and non-core area), and I pooled data across season and year of use due to low sample sizes. I also surveyed a minimum of 5 random locations within each home range. Random locations were chosen by laying a numbered grid pattern over each home range, and randomly

selecting grids where there were no known burrows within that area. Data were collected at the UTM location represented by the southwest grid intersection. I also compared habitat classes at random locations from maps to burrows surveyed. Map locations were selected using a grid of 20 locations that were evenly dispersed within each home range. Habitat class at each location was assessed using biogeoclimatic classification maps (Meidinger and Pojar 1991), and 1:20 000 orthographic photos. In order to assess the accuracy of my map classification, I also classified all burrow and random plot locations in the same manner. I was consistent with the ground classification 75% of the time.

**Table 3.1** Variables and description of categories or counts that were collected at burrow and random locations within each badger's home range.

<b>Variable</b>	<b>Description</b>	<b>Categories or Counts</b>
HABITAT	General habitat classification	Grassland/Shrub, Forest ( $\geq 2\%$ canopy), Cutblock, Fields and Pastures, Powerline right-of ways, Road/Railroad, Urban, River
SOILS	Soil coarse fragment content	<20%, 20-35%, 35-70%, >70%
	Soil texture	Sand, Loam, Silt, Clay
	Soil parent material	Anthropogenic, Colluvium, Fluvial, Glaciofluvial, Glaciolacustrine, Morainal, Organic
PREY	Mice/Voles: Small holes (~5cm)	All prey variables were counts of holes/mounds along 4-50m long transects that were at right angles to a random bearing, originating from a burrow or plot centre.
	Ground Squirrels: Medium-sized holes (6-12cm)	
	Pocket Gophers: Soil mounds or diggings	
	Marmots: Larger holes (12+cm)	

### *Habitat Class*

General habitat was divided into eight classes to reflect the degree of heterogeneity of the landscape. For each individual, I compared habitat classes at burrows with random and mapped locations. I also compared habitat at burrows in core areas to burrows outside core areas. I used a standardized selection index to represent

selection or avoidance of habitats (Manly et al. 1993). The selection index is preferred to a  $\chi^2$  goodness-of-fit test when availability of resources is estimated because there is less probability of a Type I error (Manly et al. 1993, Thomas & Taylor 1990). The selection

index is calculated using the equation:

$$B_i = \frac{\hat{w}_i}{\sum_{i=1}^n \hat{w}_i}$$

where:

$B_i$  = Standardized selection index for species  $i$

$w_i$  = Selection ratio for habitat  $i$  where  $w_i = o_i / p_i$

$o_i$  = Proportion or percentage of habitat  $i$  used

$p_i$  = Proportion or percentage of habitat  $i$  available in the environment

### ***Soils Characteristics***

Soil characteristics were chosen to reflect factors that would affect the digging ability of badgers. These included coarse fragment content of the soil represented by the percentage of particles >2mm in a soil sample, soil texture description, and soil parent material. For each badger, I compared each soil variable between burrow sites and random locations using G-tests. I also compared each soil variable at burrows located within core areas to other burrows located within that home range to determine if badgers select soil characteristics in areas of intense use.

### ***Prey Availability***

To assess the role of prey availability in burrow site selection, I quantified prey sign at burrows and at random sites. First, I identified potential food items from diet reported in the literature (Errington 1937, Snead & Hendrickson 1942, Salt 1976, Todd 1980, Lampe 1982, Sovada et al. 1999), and from evidence of badger diet in the Thompson (Appendix II). Then, I recorded potential availability of four of the main prey species identified: northern pocket gophers (*Thomomys talpoides*), mice and voles,

Columbian ground squirrels (*Spermophilus columbianus*), and yellow-bellied marmots (*Marmota flaviventris*). I counted prey tunnel openings that were located within four, 1m by 50m transects that radiated from the burrow, or plot centre. A random bearing was chosen for the first transect, and each transect was at right angles to that random bearing. While prey diggings do not necessarily indicate actual numbers of prey (Van Horne et al. 1997), I justified this approach since this was the best available index to measure prey availability within the constraints of my study, and is at least a relatively quick and simple way to assess prey presence.

To compare the occurrence of prey sign around burrows to that of the random locations, I calculated simple binomial probability (sign tests, Zar 1999). For example, there was a 6% probability that more sign of all four prey species was counted around burrows, as compared to random points. Similarly, there was a 6% probability that more mice/vole sign was counted around burrows, than at random points. While this test has relatively low power, a more elaborate test (e.g. parametric) was not possible, as there was a large disparity between average prey burrow numbers (e.g. there were far more pocket gopher mounds than ground squirrel burrows). One other factor to consider was the disparity between the caloric values of a marmot compared to a vole. Therefore, the numbers of sign counted for each prey species was considered separately.

### ***Relationships between Habitat Variables***

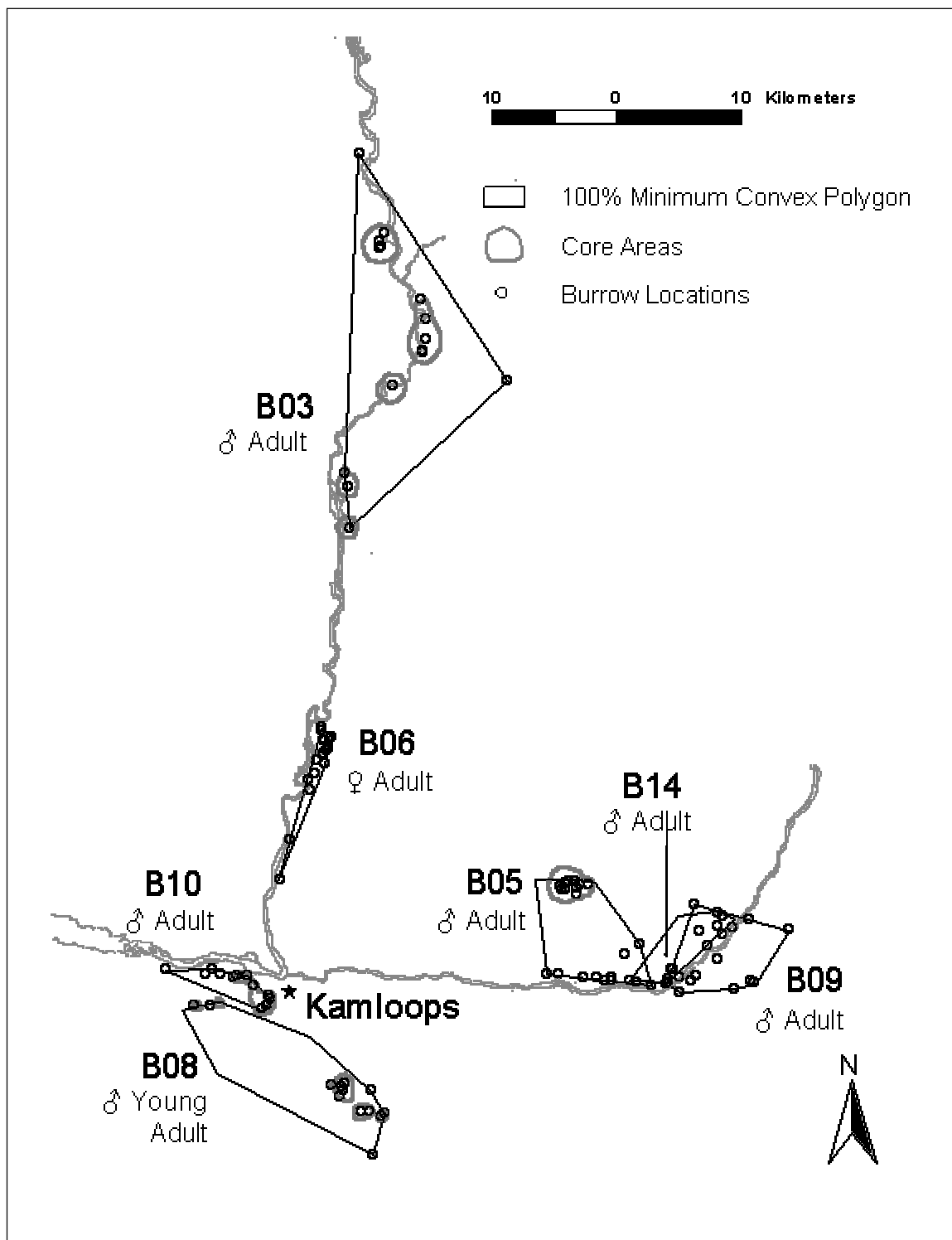
To test for differences in the habitat variables between “burrow” and “random” data points, I constructed models for each individual that predicted burrow habitat selection. Because habitats and soils that benefit badgers also would benefit their

fossorial prey, I tested for correlations between the variables I quantified. Only independent variables ( $p > 0.10$ ) were included in the models. Correlation of habitat variables was assessed using G-tests, habitat and prey variables using Kruskal-Wallis test statistics, and prey variables by using Spearman's Rho test statistics (Zar 1998). I used forward step-wise probit analysis to find the most parsimonious model for each individual. All analyses were performed using SPSS (1999) software.

### **3.3 RESULTS**

I collected habitat data at 104 burrows used by seven different badgers (Figure 3.1). One badger was a female (B06) that had 2 kits in 2000, and the remaining 6 badgers were male. Each badger's habitat selection was calculated independently, except for badgers B09 and B14. Data for these animals were pooled because these animals were trapped towards the end of my final field season, and I was not able to collect enough locations to analyze them individually. There was biological justification for combining the habitat data collected for these animals since their home ranges overlapped considerably, and they used the same burrows at different times. I compared each variable between these two animals with a  $\chi^2$  test for heterogeneity before data were pooled. Of 104 burrows, 80 burrows were used heavily (inside core areas), and 24 burrows were used less often (outside core areas). I also surveyed a total of 32 random locations, and classified habitat at 140 mapped locations within all of the seven home ranges (100% Minimum Convex Polygon, Table 3.2).





**Figure 3.1** Location of burrows that were surveyed within each badger's home range (100% minimum convex polygons), and within core areas delineating areas of more intensive use.

**Table 3.2** Total number of habitat plots surveyed at burrows within each home range (100% minimum convex polygon), and within core areas. These were compared to random sites that were field surveyed, or where habitat class was assessed from maps.

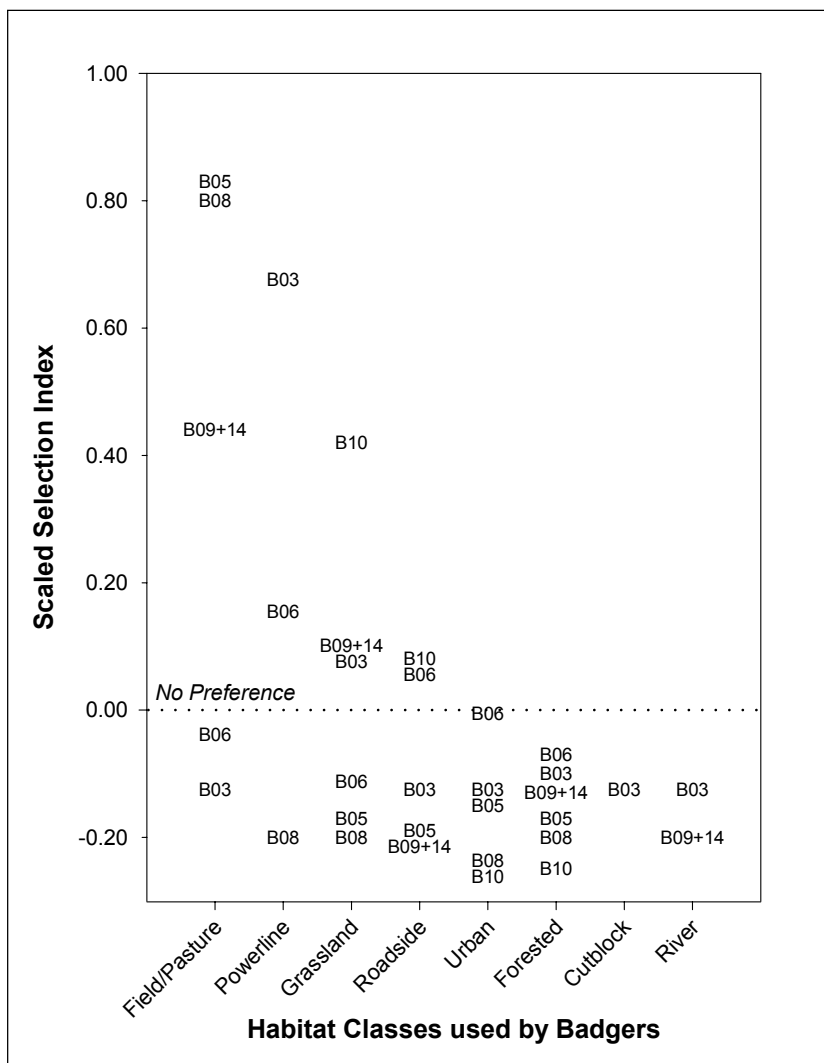
Animal ID	100% MCP (km <sup>2</sup> )	NUMBER OF LOCATIONS USED IN ANALYSIS			
		Total Burrows Surveyed	Burrows in Core Area	Random Sites Surveyed	Random Sites Mapped
B03	258.4	15	12	5	20
B05	197.0	22	11	7	20
B06	55.1	18	–	5	20
B08	87.9	13	9	5	11
B09+ B14	45.1 + 21.8	24	–	5	34
B10	11.3	12	8	5	10
<b>TOTAL</b>		<b>104</b>	<b>40</b>	<b>32</b>	<b>115</b>

Burrows were located at elevations that ranged from 344 m to 1480 m above sea level, and 63% of burrows were located below 500 m in elevation. More often, burrows were located on mid to lower slopes than on crests or lower slopes and depressions. Slope gradients ranged from 0 to 43 degrees, and burrows were found, on average, on slopes of 17 degrees (mode = 0 degrees). Burrow openings generally faced the same aspect as the slope they were situated on; however, no aspect was favoured. Burrows usually were dug where there was some micro-topographic relief (e.g. ditches or berms at edges of fields) along the upper edges rather than in the depressions of these features. Most burrows were located in habitat types dominated by graminoids (44%) and low shrubs (32%).

### *Habitat Class*

Badgers in my study situated their burrows in both natural and anthropogenically-altered habitats, including cultivated fields and pastures, powerline right-of ways, natural grasslands, and seeded roadsides (Figure 3.2). Habitat selection was consistent for burrows located in core areas, except grasslands and roadsides may have been used more

often by badgers B03 and B10 respectively. Badgers avoided burrowing in forested areas, harvested sites near canopy cover, and riparian areas; however, I have documented the use of all of these habitat types by badgers that were burrowing and travelling. Habitat classes were not consistently selected or avoided for all individuals. For example, badger B08 selected fields and pastures, and avoided natural grassland habitats, whereas, badger B03 avoided fields and pastures, yet selected powerline right-of-ways.



**Figure 3.2** Selection indices illustrating each badger's burrowing location selection (positive) and avoidance (negative) of habitat classes (Manly et al. 1993). Selection index is scaled so  $1/\text{number of habitat classes used by each badger}$  is equal to zero. While there was no consistent selection for habitat classes, badgers tended to use open habitats dominated by grasses.

### *Soil Characteristics*

Soil variables explained only some selection for burrow locations (Table 3.3). Generally, burrows were located in glaciolacustrine and glaciofluvial soils, of finer textures (silt and loam), with low coarse fragment content (<35%). Soil parent material differed between burrow and random sites for 2 of 6 animals (B05, B08), as did soil texture (B05, B09+B14). Soil coarse fragment content was significantly lower at burrows than random sites for only 1 animal (B08). There was even less of a trend in soils selection within core areas. Only soil parent material and soil texture differed at burrows in core areas compared to other sites within each home range (see B05, B10, Table 3.4).

**Table 3.3** Soil variables and G-test results, with degrees of freedom and probabilities (p), comparing burrow sites to random locations within each animal's home range. Significant results are indicated in bold.

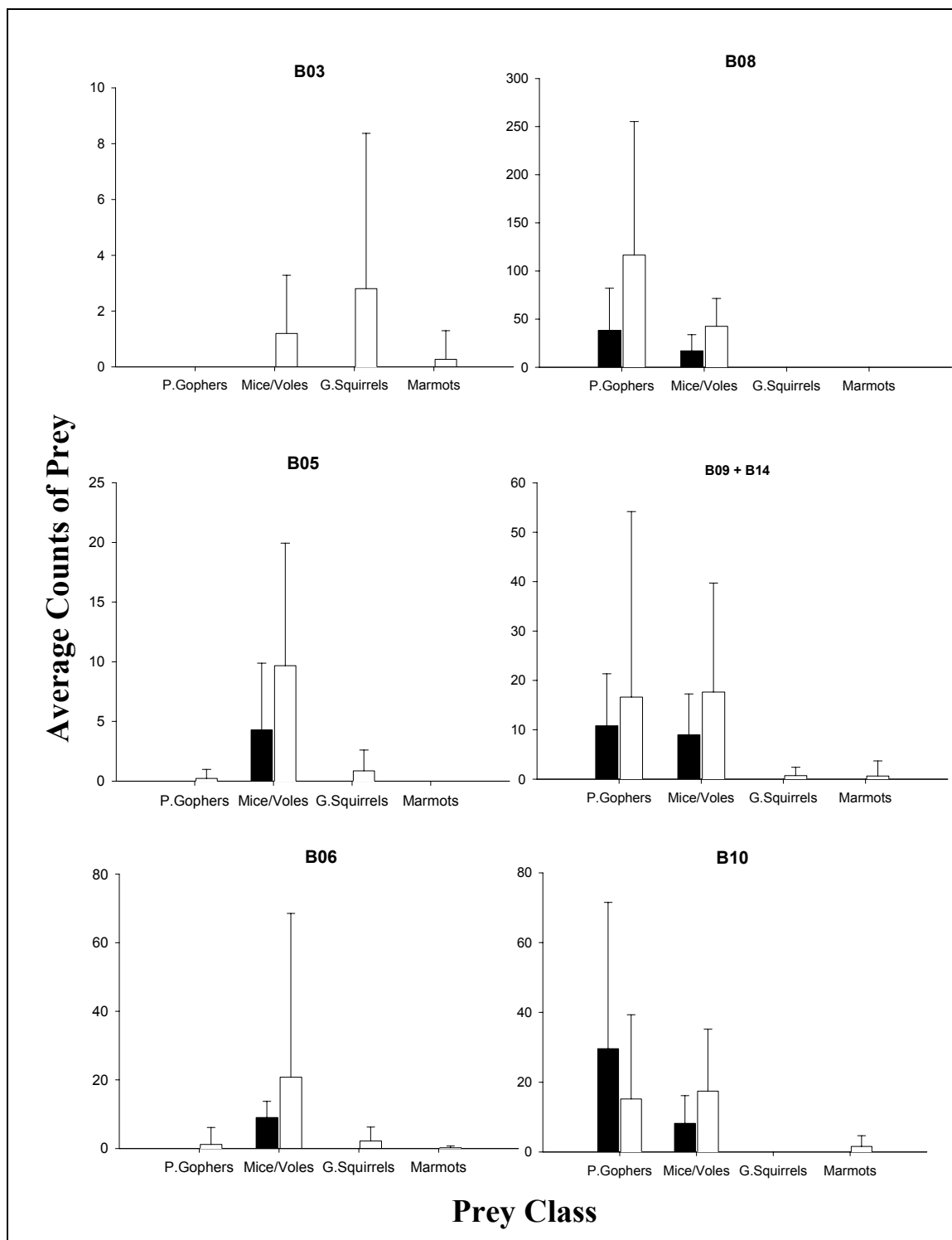
Animal ID	SOIL VARIABLES					
	Parent Material		Soil Texture		Coarse Fragment	
B03	4.31	3 df (0.230)	5.82	3 df (0.120)	2.51	2 df (0.285)
B05	<b>15.35</b>	<b>2 df (&lt;0.001)</b>	<b>9.89</b>	<b>3 df (0.020)</b>	5.89	3 df (0.117)
B06	2.00	3 df (0.573)	2.56	4 df (0.634)	2.45	3 df (0.485)
B08	<b>7.67</b>	<b>3 df (0.053)</b>	2.87	4 df (0.579)	<b>4.40</b>	<b>1 df (0.036)</b>
B10	4.22	3 df (0.239)	2.60	2 df (0.273)	3.93	3 df (0.140)
B09+B14	2.34	2 df (0.310)	<b>8.61</b>	<b>3 df (0.035)</b>	2.47	2 df (0.290)

**Table 3.4** Soil variables and G-test results, with degrees freedom and probabilities (p), comparing habitat characteristics at burrow locations within core areas to burrows within each animal's home range. Significant results are indicated in bold.

Animal ID	SOIL VARIABLES					
	Parent Material		Soil Texture		Coarse Fragment	
B03	2.87	2 df (0.238)	1.18	2 df (0.553)	0.25	1 df (0.619)
B05	<b>9.02</b>	<b>1 df (0.003)</b>	<b>11.16</b>	<b>3 df (0.011)</b>	3.78	2 df (0.151)
B08	1.50	2 df (0.472)	0.90	3 df (0.825)	0.95	1 df (0.331)
B10	<b>3.79</b>	<b>1 df (0.051)</b>	1.40	1 df (0.237)	0.54	1 df (0.463)

### ***Prey Availability***

There was more prey sign at burrows than at random locations within home ranges, although overall trends were relatively weak (Figure 3.3). For 5 of 6 badgers, the predominance of prey sign at burrows was higher than that expected by chance ( $p < 0.5$ , Table 3.5). For 3 of 4 badgers, there was a greater chance of more prey sign occurring at burrows inside core areas than outside core areas (Table 3.6). Not all prey types were detected within each animal's home range. In the northern portion of the study area, ground squirrels were more abundant (B03, B05, B06). Pocket gophers were present in greater numbers in the southern and eastern portion of the study area (B08, B09+14, B10), although did occur incidentally north of the South Thompson River. Mice and voles were distributed consistently across the study area, and found at burrows in all badgers' home ranges.



**Figure 3.3** Average prey sign counted ( $\pm 1$ SD) at burrows (white) and at random (black) locations within each badger's home range, illustrating that there was more prey sign counted at burrows than at random locations for each animal in the study area.

**Table 3.5** Sign tests comparing the differences between average prey counts at burrows and random locations (+/-) within each home range, and the binomial probabilities (p) of finding these patterns (Zar 1999). NP indicates species not detected.

Animal ID	DIFFERENCE IN AVG. PREY SIGN COUNTS				p
	Mice/Voles	Ground Squirrels	Marmots	Pocket Gophers	
B03	+	+	+	NP	0.13
B05	+	+	NP	+	0.13
B06	+	+	+	+	0.06
B08	+	NP	NP	+	0.25
B10	+	NP	+	-	0.50
B09 + B14	+	+	+	+	0.06
p	0.01	0.06	0.06	0.19	

**Table 3.6** Sign tests comparing the differences between average prey counts at burrows inside core areas to other burrows within home ranges (+/-), and the binomial probabilities (p) of finding these patterns (Zar 1999). NP indicates species not detected.

Animal ID	DIFFERENCE IN AVG. PREY SIGN COUNTS				p
	Mice/Voles	Ground Squirrels	Marmots	Pocket Gophers	
B03	+	+	+	NP	0.13
B05	-	+	NP	+	0.50
B08	+	NP	NP	+	0.25
B10	+	NP	+	+	0.13
p	0.31	0.25	0.25	0.13	

### *Relationships between Habitat Variables*

Table 3.7 summarizes the relationships among the habitat, soils, and prey variables. Prey sign counts (mice/voles, ground squirrels and pocket gophers) were correlated with habitat class. Soil coarse fragment content was correlated with soil parent material, and soil texture. Probit models were poor predictors of burrowing habitat selection, and only two had p-values < 0.10 (Table 3.8). In both cases (B05, B10), habitat class was the only variable used in the model.

**Table 3.7** Relationships of habitat variables, shown through probability values from G-tests (categorical variables), Kruskal-Wallis tests (categorical and continuous variables) and Spearman's rho tests (continuous variables).

Habitat Variable	Habitat Class	Coarse Fragment	Soil Texture	Parent Material	Mice/Vole Sign	Ground Squirrel Sign	Marmot Sign
Coarse Frag	0.182						
Soil Texture	0.880	<b>0.058</b>					
Parent Material	0.998	<b>0.058</b>	0.592				
Mice/Vole Sign	<b>&lt;0.001</b>	0.273	0.325	0.527			
G. Squirrel Sign	<b>&lt;0.001</b>	0.230	0.554	0.938	<b>0.081</b>		
Marmot Sign	0.485	0.594	0.340	0.952	0.751	0.830	
P. Gopher Sign	<b>0.003</b>	<b>0.018</b>	0.114	0.403	0.441	0.186	0.240

**Table 3.8** Best model equation from forward stepwise probit analysis,  $\chi^2$ , degrees of freedom (df), and probability (p) values.

Animal ID	Probit Model Equation	$\chi^2$	df	p
B03	0.50 Parent Material + 0.003 Habitat	22.58	17	0.163
B05	0.24 Habitat	38.54	27	0.070
B06	0.46 Parent Material + 0.18 Soil Texture	23.53	20	0.264
B08	0.10 Parent Material – 0.07 Soil Texture + 0.09 Habitat	16.78	13	0.209
B09+B14	-0.47 Parent Material + 0.15 Habitat	32.94	26	0.164
B10	0.310 Habitat	26.06	15	0.037

### 3.4 DISCUSSION

Badgers used both natural and anthropogenically altered habitats, and were relatively tolerant of human activities. Similar to the results of Apps et al. (2002), badgers in my study favoured grasslands and moderately altered habitats, especially those that were dominated by grasses such as fields, pastures, powerline rights-of-way, and roadsides. Badgers in my study also generally avoided forested areas, harvested sites near canopy cover, and riverbank areas. In British Columbia, roadsides and fields often are seeded with grasses that attract some prey species (Meunier et al. 1999), and this



situation may help explain why these would be attractive to predators (Warner & Ver Steeg 1995).

I found no strong selection for any of the soils variables I tested, and this may be a result of the wide availability of suitable soils. Because the Thompson valley is dominated by glaciolacustrine soils, most sites are easily excavated by badgers. Where soils may be limiting, roadsides, railway berms, and agricultural fields also may provide suitable sites because the soils already have been loosened and mounded by humans. At the landscape level, Apps et al. (2002) found badgers in British Columbia selected glaciofluvial and glaciolacustrine soils, and at finer scales, fine sandy-loams with low coarse fragment content and good drainage. In addition to being easier to dig, these soil types may provide extra stability for burrows (Apps et al. 2002). Soil conditions that are favourable for burrowing would be advantageous to both badgers and their fossorial prey species such as ground squirrels, prairie dogs and pocket gophers (Messick 1987).

Badgers appear to burrow in areas where there is abundant prey, and badger burrows have been correlated with prey activity elsewhere. In the southern United States, badger activity was positively correlated with colony size and number of burrow openings on colonies for Gunnison (*Cynomys gunnisoni*) and white-tailed (*C. leucurus*) prairie dogs (Clark et al. 1982). In Idaho, badger burrows were positively correlated with the number of ground squirrel (*Spermophilus beldingi*) burrows (Todd 1980). Also in Wyoming, female badgers were located within white-tailed prairie dog colonies more often than predicted (Goodrich & Buskirk 1998). These studies were conducted in relatively ecologically homogeneous areas where prey was abundant, and one female

badger could situate her home range in the midst of a large ground squirrel colony (Goodrich & Buskirk 1998). In my study area, the landscape was a patchwork of grassland, agricultural fields, forests, and urban developments, each providing habitat for different prey species. Badgers presumably had to adjust their use of the landscape within their home ranges to use suitable habitats that would provide them with sufficient and stable food resources.

I combined variables to predict burrow site selection for badgers, but the degree of individual variation precluded a consistent model at the scale I examined. While habitat was the single best predictor, it did not sufficiently explain badger site selection within the home range. This may have been due to correlation between prey (mice/voles, ground squirrels, and pocket gophers) and habitat class. The four prey species surveyed were not equally available to each badger, and each prey species has relatively distinct ecological requirements. Badgers, on the other hand, do not appear to have these same constraints. Badgers have a number of potential food items (Errington 1937, Snead & Hendrickson 1942, Sovada et al. 1999), are capable of living in a variety of habitat types, and do not seem to be limited by unsuitable soils. As wide-ranging animals, badgers also have the advantage of being able to move long distances in short periods of time to maximize their use of resources. Therefore, at the scale I examined, I suspect that the suitability of badger burrowing sites may be dictated by more complex combinations of prey and habitat factors than those tested in my study.

### *The Role of Habitat in Spatial Use*

Habitat availability and the ecology of prey influenced patterns of spatial use by badgers in the study area. Northern pocket gophers occur south of the South Thompson River (Johnstone 1954) and thus were available only to badgers that ranged in that area (mainly B08, B09+B14, and B10). At these sites, the dispersion of pocket gophers appeared relatively even, and since the habitat was more homogeneous, this would affect habitat use by badgers in these areas. Of the five badgers that had access to pocket gophers, two badgers used core areas (B08, B10). Badger B08 was a younger badger, and may have used areas where there were established burrows, rather than selecting patches of prey. Pocket gophers were abundant within his home range so prey was not likely limited. The home range of badger B10 was located in a very urban area, and he used patches of suitable habitat between parking lots and buildings that comprised core areas. Conversely, badgers that were located in the north (B03, B05 and B06) had access to Columbian ground squirrel colonies as prey. As colonial animals, ground squirrels were a stable resource for badgers, and may be one reason badgers returned to core areas. For example, B03 used core areas that were ground squirrel colonies during the two years of research. Badger B05 used a core area of hay fields and pastures where there were abundant mice and vole sign.

Other members of the Carnivora are known to adjust their use of the landscape to take advantage of prey. In Idaho, Knick (1990) found that bobcats used patches during the winter when they fed primarily on lagomorphs that were found in clumped distributions. During the summers, bobcats used more of their ranges when they foraged on mice that were more uniformly distributed. In Mississippi, Chamberlain and Leopold

(2000) found that gray foxes consistently selected habitats and placed core areas where small mammals were abundant. Yet, in Illinois, Nielsen and Woolf (2001) found that habitat use by bobcats did not differ between core areas and home ranges, and that core areas benefited bobcats by reducing competition for resources (e.g. denning sites for females, breeding sites for males).

### **3.5 CONCLUSIONS**

There were limitations to the conclusions I could make from this study, suggesting further research is needed to know whether a predictive habitat model for badger burrows is possible. There were few study animals in my analysis, and large variation between individuals, precluding a consistent predictive model. I collected data from few habitat locations, and differences in proportions may mistakenly indicate selection or avoidance of rare habitats because of small absolute differences in use (Johnson 1980). Also, because I had only one female in my sample, the difference in habitat use between sexes still is unexplored. Because habitat preference is related to animal fitness, further research needs to include population dynamics such as female availability, natality and juvenile survivorship before badger habitat can be properly defined. In British Columbia, further research must be conducted to determine the distribution of prey species, and the relationships between habitat-specific prey densities, home range size, and habitat preference of badgers.

Badgers were capable of adjusting to the environment around them, and there appeared to be no distinct trends in my study to suggest the badgers were constrained to any particular resource or habitat. Badgers in my study area occupied large home ranges,

and appeared to concentrate burrows in areas of dense prey sign within my study area. Predictable prey sources may have been particularly important for badgers, especially when they made long distance movements during the breeding season. Land managers need to ensure badgers have a sufficient habitat and enough prey sources on both public and private lands within the fragmented landscape. Maintaining pocket gophers and ground squirrels on private lands may be critical as these often are exterminated as pest species (Rahme et al. 1995). The high degree of individual variation precluded development of a single habitat model to generalize badger habitat selection. In a heterogeneous landscape, badgers exhibit great individual variation and this has direct application to the conservation of badgers, and habitat management for the species.

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## *Chapter Four*

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### **Conclusions and Conservation Issues**

#### **4.1 CONCLUSIONS**

My overall objective in this thesis was to address knowledge gaps in badger (*Taxidea taxus jeffersonii*) ecology in British Columbia, in order to address conservation initiatives for the subspecies. The focus of my research was on the spatial ecology and habitat selection of badgers. The major results of this thesis are: (1) badgers used large home ranges, and this may have been related to the lack of breeding females in the study area; (2) badgers are not restricted to a particular habitat, and were relatively tolerant of human disturbance; and (3) spatial orientation of resources within each home range determined the patterns of spatial use by badgers, and explained the use of core areas by some individuals.

My observations of relatively large home ranges used by badgers, especially by males, suggested that breeding females may be limited in the Thompson region. Male home range area reportedly is determined by the availability of breeding females (Minta 1993). There may have been few females in the study area, as I only trapped one female and observed few family groups during the study. Also, the male badgers I monitored made their longest movements during the breeding season, presumably in search of rare mates. In some cases, badgers left abundant prey resources (i.e. colony of ground squirrels) to make these movements. If breeding females are limiting, this could result in inbreeding depression, and poor reproductive rates for the entire population.

I found no strong, single predictive model for burrow locations, which suggested that individuals were not restricted to a particular habitat, and were relatively tolerant of human disturbance. Burrows were found in loamy-textured soils with low coarse fragment content, but these soils were common in the lower valleys in both natural and disturbed sites. I found that badgers burrowed in many types of habitat, but tended to select open areas dominated by grass in natural and anthropogenically-altered habitat. These habitats consistently supported more prey. Badgers ate a number of different prey species, and not all species were available to each individual in the study area. This partially may have explained the inconsistency in habitat selection between individuals. For example, badgers in the northern portion of the study area selected powerline and grassland habitats where ground squirrels were most abundant, whereas, in the southern portion of the study area, badgers selected fields, pastures, and grasslands where pocket gophers were more abundant. It appeared that badgers were not restricted to natural grasslands in British Columbia. In fact, badger habitat may be best described by the availability of prey resources, rather than a vegetative classification. Because use of habitats across the landscape was not always consistent, policies should be set locally to take into consideration the habitat available to an individual.

The spatial orientation of resources within each home range determined the patterns of spatial use by badgers, and explained the use of core areas. Prey availability may have been a limiting factor for badgers in my study, particularly when badgers used large home ranges and required energy resources for long-distance movements. I found that some core areas were located at sites of predictable sources of prey. For example, one badger returned often to a colony of ground squirrels within his large home range.

Core areas for badgers were not limited to prey resources, but also consisted of islands of habitat within an urban landscape. Badgers were relatively tolerant of human presence, and in some cases used urban habitat almost exclusively, but required unpaved sites for burrows. In fact, one badger relied on core areas that were unpaved patches within an urban shopping area. This may mean that critical habitats should be identified as those that support prey and provide appropriate, safe burrowing locations, such as gullies and golf courses, depending on the local landscape.

In the following sections, I discuss the limitations of this study, and the challenges of researching a rare species. I consider both short- and long-term conservation issues, and suggest direct actions to mitigate negative impacts. I discuss mortality rates that resulted from highway roadkills in my study area, and the impacts this may have on the entire badger population. Because most badger habitat occurs on private lands, I explore the role landowners have in habitat conservation. I discuss how the persecution of badgers on private lands may be addressed by improving public awareness, and the perception of badgers as a pest species. Finally, I suggest that highlighting the role of badgers in naturally reducing small mammal populations will reduce extermination of prey by landowners. If these main issues can be addressed, badgers may be capable of co-existing with humans, and populations in British Columbia may have a chance to recover.

#### **4.2 LIMITATIONS OF THIS STUDY**

There were a number of limitations I experienced during my research. The few animals I used in my analyses limited my conclusions to the local population I studied.

Highway mortality also affected my sample size (this is discussed later in this chapter), and increased the time and effort put into trapping at the expense of monitoring animals. However, I still was able to concentrate my efforts on intensively monitoring individuals, and this would have been impossible to accomplish if sample sizes were much larger. Even though monitoring was hindered by poor signal strength, especially when animals were underground, I was able to collect sufficient locations to make solid conclusions about individual movements and habitat selection. The animals I captured mostly were male. This sex bias may indicate a lack of females in the population, and it limited my conclusions. In particular, I could not discuss the availability of breeding females or their role in spatial ecology because I captured only one adult female. However, many of these issues are inherent when studying a rare species, especially one that ranges over large tracts of land such as the badger.

Though there were limitations to this study, I have made a number of steps towards understanding badger autecology in British Columbia. Two years is a relatively short time frame, but I illustrated that individuals in the Thompson region were capable of a range of behaviour that was previously unreported. Among these were the use of large home ranges, long-distance movements, and plasticity in habitat use. I also have identified a number of conservation concerns for the population that stem from my research.

### 4.3 CONSERVATION CONCERNS

#### *Highway Mortality*

During the study period, highway mortality was significant. Of seven mortalities that I observed during the study, five were roadkills (Table 4.1). At least eight other badgers in the same area are reported to have been hit on highways during the same period. In the East Kootenay Region of British Columbia, at least seven badgers have been killed on highways since 1996 (Newhouse 2002). Using a provincial population estimate of 300 individuals, these figures represent deaths for 7% of the badgers in British Columbia.

**Table 4.1** Badger mortality documented on the Thompson/Okanagan Badger Project.

<b>Animal ID</b>	<b>Age Class</b>	<b>Sex</b>	<b>Year Trapped</b>	<b>Date of Mortality</b>	<b>No. Days Monitored</b>	<b>Cause of Mortality</b>
B01	Adult	M	1999	Aug 08/00	391	Roadkill
B04	Juvenile	M	1999	Sept 24/99	56	Predation
B06	Adult	F	2000	Aug 26/00	86	Roadkill
B07	Juvenile	F	2000	Jul 20/00	10	Roadkill
B09	Adult	M	2001	Aug /02	294	Presumed Roadkill
B11	Adult	M	2001	Oct 26/01	148	Predation
B13	Juvenile	M	2001	Jul 31/01	56	Roadkill

Because this is such a common occurrence, and represents a large percentage of the population in British Columbia, a more formal documentation of highway mortality should be done in the province, and in neighbouring provinces and states. Highway mortality of badgers commonly occurs in other areas as well. In Idaho, Messick et al. (1981) reported 59% of 157 mortalities recorded in Idaho were due to roadkills. In Nebraska, roadkilled badgers comprised 2.5% of the 24,244 road mortalities recorded for 10 vertebrate species along Interstate-80 from 1969 to 1975 (Case 1978). Similarly, in

Europe, badger (*Meles meles*) mortality due to roadkills also is widely documented (Jefferies 1969, Skinner et al. 1991, Van der Zee et al. 1992, Aarissorensen 1995, Clarke et al. 1998). In some regions, safe crossing zones have been established, and this has reduced some badger road mortality. However, European badgers use smaller territories, and their movements are more predictable than North American badgers, therefore, crossing zones may not be as effective here.

Badgers of both sexes have illustrated a propensity for burrowing into highway and railroad berms, and often this results in their death. In 2000, the adult female B06 was located with her 2 kits in a number of burrows on a highway-side bank. There were numerous reports of the family group crossing the highway, and stopping traffic even during the daytime. Eventually, a female kit was killed in July, and the mother was killed later in August along the same 10 km stretch of highway. In another instance, an untagged adult female burrowed into a highway-side bank with her month-old kit, and was in turn killed early one morning near her burrow.

Badgers may use roadsides for a number of reasons, and management practices that attract wildlife to these locations should be investigated further. For instance, disturbed soils along roadside berms are loose, and easier to dig. Females may be particularly attracted to these sites because of easier conditions for digging larger natal burrows. The management of roadsides also may attract small mammals that in turn would attract badgers. Many road rights-of-way in the study area are seeded with grasses to reduce erosion, and this attracts small mammals. Meunier et al. (1999) found that small mammal abundance was greater along unmown strips of roadsides and roads

adjacent to farmland, than in other portions of the landscape. Alternatives to seeding grass species to control erosion, such as placing large rocks along berms, may be an option.

Badgers that used large home ranges did not appear to view highways as a barrier to movements. In fact, they used highways and railways as movement corridors. Intensive monitoring revealed that badgers crossed highways many times during an evening, and used road-side ditches for movement. In one instance, a male badger (B03) travelled 14 km in only four hours at night along highway and railroad rights-of-way. Another male (B09) crossed the highway and a large river a minimum of 3 times in one evening.

Badgers are forced to cross or use highways because roads generally are located in valley bottoms, and often bisect a badger's home range. If it can be confirmed that badgers use consistent crossing sites, it may be possible to construct underground passes such as those in Europe for badgers (*Meles meles*) and hedgehogs (*Erinaceus europaeus*, U.S. Department of Transportation 2000). Badgers in the East Kootenay region of British Columbia use culverts to safely cross under highways (N. Newhouse pers. comm.). This was documented using remote cameras and tracking methods. Roadside abutments also block animal movement both onto, and off highways. These can trap animals especially when they are disoriented by traffic and cannot climb over the barrier. In my study area, one motorist reported a badger that was trapped on a highway and was running along the base of an abutment (Weir & Hoodicoff 2002). In some instances, abutments are continuous for kilometers along a highway, with no break or escape route.

Replacing some abutments with modified barriers that have escape exits may alleviate some mortality.

Each of the five highway mortalities on this project occurred in summer (April through August), during the breeding season when movement rates increase and when traffic volumes rise. In Nebraska, badger road mortality was significantly correlated with the month of year, with most roadkills occurring during the breeding season (Case 1978). Unfortunately, the badger breeding season also corresponds with the peak tourist season, and increased traffic volumes on highways, and wildlife mortality has been found to increase with traffic volumes (Trombulak & Frissell 2000). Because most movements are nocturnal, motorists likely do not see animals crossing roads and would not have enough time to respond. Badger mortality may be reduced by raising awareness of the impacts of traffic on wildlife populations, and by making motorists more aware of animals on the highways. This may be accomplished with speed reduction, and “badger crossing” signage. Because road mortality is not limited to badgers, implementing some of these practices may reduce overall wildlife mortality.

### ***Habitat Loss and the Role of Private Landowners***

The main concern for badgers in British Columbia is the continued loss of habitat (Rahme et al. 1995, Newhouse & Kinley 1999). Grassland in the province, even without human influence, is inherently linear and patchy because it is confined to dry valley bottoms. Natural fire regimes that maintain grasslands have been suppressed for decades, and as a result, forests are encroaching onto grasslands. In the Kamloops Forest Region, forest encroachment is occurring on nearly 19,000 hectares of previously grassland-



dominated habitat (Kirby & Campbell 1999). Agricultural conversion and urban development in the valleys is substantial. Grasslands have rich soil and a warm climate for growing agricultural crops such as hay, ginseng, and grapes. Viniculture, in particular, is a rapidly growing industry in the Okanagan Valley and hectares of grassland are converted to grow grapes. These environmental conditions also are favoured by people, and both the Okanagan and Thompson valleys are popular areas to live and vacation in.

The critical role landowners play in grassland preservation and species conservation should not be underestimated. Most of my research was conducted on private lands, and badgers commonly used agricultural fields, rangelands, and even unpaved urban sites. In fact, only 7% of the province's grasslands are in protected areas, and the rest is on crown or private lands (Grasslands Conservation Council of British Columbia 2002). Apps et al. (2002) reported that private lands dominated by ponderosa pine and Douglas-fir ecosystems represented 9% of their study area, but 35% of suitable badger habitat. In contrast, 15% of those ecosystems occurred in protected areas, but only 3% was estimated as suitable badger habitat. Seabloom et al. (2002) suggested that most of the protected habitat in the United States is restricted to high elevations where less than 10% of the biological diversity found. They continued by stating, "The biggest challenge now facing conservation biology is to conserve the 90% of biodiversity residing on low-lying lands that are often privately owned. It is here that rates of habitat loss are increasing most rapidly."

Apps et al. (2002) suggested that while existing protected areas in East Kootenay had limited value, private land stewardship was very important to badger habitat

conservation. Yet, there are few incentives offered to encourage ranchers and land developers to maintain natural habitats and wildlife species on their property. We rely on landowners' goodwill and values, despite potential financial losses due to wildlife damage, to maintain what they have historically viewed as "pest species," such as badgers, ground squirrels and pocket gophers. There should be motivation to encourage wildlife-friendly management practices for developments such as vineyards, orchards, and golf courses, since they may be able to provide habitat or travel corridors for badgers and other wildlife species.

### ***Persecution of Badgers***

Badgers have been portrayed in a negative context and are viewed as pests in aboriginal folklore, and by agriculturalists, landowners, and the general public. In interviews conducted recently by Tanner (2002), First Nations elders in the Kamloops area remembered badgers as competition for ground squirrels (*Spermophilus columbianus*) as a food source. Long and Killingley (1983) suggest that some American First Nations in the upper Midwest believed that badger blood foretells the future, and even death. Kellert et al. (1996) found that farmers and ranchers consistently expressed the most negative attitudes towards predators. Most of these perceptions are motivated by fear of economic loss. Badgers have a reputation for digging mounds, damaging property, harming livestock, and raiding poultry (Minta & Marsh 1988).

In British Columbia, private landowners still are legally able to kill badgers on private property if there is a perceived risk of damage. Although I suspect that this occurs on private lands, it was not possible to accurately estimate during my study

because not all landowners were willing to speak about their management techniques. Messick et al. (1981) reported that 61% (94/153) of badger mortality was caused by residents, and most of these badgers had damaged irrigation structures or burrowed in developed areas. In California, from 1978-1988, the U.S. Department of Agriculture Animal Damage Control service reported that losses due to badgers totalled over \$107,000, citing damage to crops, property, irrigation and water impoundment, and depredation of domestic fowl (Minta & Marsh 1988). During the same period, 1,456 badgers were destroyed for pest reasons. Formally documenting livestock injury and collateral damage due to badgers may help to estimate the costs associated with badgers, and offering alternatives to killing, such as relocating problem animals, may prevent many badger deaths.

There is evidence among the agricultural community of willingness to accommodate wildlife, and to tolerate some financial loss. In a study in the United States by Conover (1998), 80% of farmers surveyed with losses due to wildlife less than \$500 suggested this was acceptable, where only 31% of farmers with losses of greater than \$500 considered this was an acceptable cost. In fact, 51% of farmers surveyed (n = 647) purposely managed their farms for wildlife. Raising awareness of badgers and improving their reputations may mitigate some of the negative perceptions related to badgers. In my study area, badgers usually dug burrows in the periphery of fields, and tended to move often, so damage to land appeared minimal. In Conover's study (1998), farmers did not identify badgers as a source of wildlife problems. Most respondents cited deer (53%), raccoons (*Procyon lotor*, 25%), coyotes (*Canis latrans*, 24%) and groundhogs (*Marmota monax*, 21%) as pests. In fact, badgers may actually help to alleviate some of the

damage done to property by acting as a natural pest control, and hunting small mammals such as groundhogs.

### ***Prey Extermination***

In British Columbia, ground squirrels and pocket gophers often are seen as pests on private land, and eradicated (Rahme et al. 1995). This in turn, can have grave implications for predator species such as badgers (Rahme et al. 1995). In the United States, poisoning of prairie dogs (*Cynomys* spp.) reduced their historical range by as much as 98% (Miller et al. 1994). This contributed to the near extinction of black-footed ferrets (*Mustel nigripes*), and is cited as a factor in other candidates for the US Endangered Species, including mountain plovers (*Charadrius montanus*), ferruginous hawks (*Buteo regalis*), and swift foxes (*Vulpes velox*, Miller et al. 1994). A similar situation may be facing badgers in British Columbia.

Secondary effects of rodent control programs on badgers are unclear. Hegdal et al. (1981) reviewed the effects of rodenticides on mammalian predators and noted that secondary poisoning of badgers by sodium monofluoroacetate (1080), strychnine, anticoagulants, and zinc phosphide apparently caused only limited mortality. One badger death was reported after a badger ate a portion of a horse carcass that had been treated with sodium fluoroacetate (Lindzey 1971). It is likely that fossorial mortality goes undetected, and indirect effects of rodenticides are unknown. Secondary impacts of rodenticides on badgers are listed by Rahme et al. (1995) as an information gap, and researchers are no closer to understanding this relationship now. The poisons used (legally and illegally), the location, and the timing of their use must be identified.

Land managers may be encouraged to use badgers as a natural control for pest species. Badgers have long been considered as an effective and natural form of “pest control” for ground squirrels and pocket gophers (Silver 1928). Educational signs can be erected to inform other landowners and the public of wildlife-friendly practices. In fact, this approach has been successful in the East Kootenay where a golf course decided to tolerate squirrels burrowing in the rough, and only live-trap and relocate those digging in the fairway. The following year, a badger occupied the golf course (N. Newhouse pers. comm.). Collaboration with land managers may be key in stopping negative effects that humans have on badgers.

#### **4.4 RECOMMENDATIONS FOR FUTURE RESEARCH**

Based on the results of this study, and the issues I have discussed above, I make the following 3 recommendations for future research:

- 1. Role of Females in Badger Spatial Ecology:** The spatial orientation of males would be better understood with a measure of the number and location of females. Minta (1993) found that the size and orientation of home ranges of males is determined by the availability of females. This suggests that females are the resource that males key into when setting spatial boundaries, and may help explain the large home ranges of badgers in British Columbia.
- 2. Prey Availability:** The influence of prey on spatial ecology and habitat use needs to be investigated with an expanded experimental design. Badgers eat a variety of prey species; therefore, a more thorough study of badger diet and prey ecology should be

undertaken. In order to manage areas for prey species, we also need to understand how prey responds to land management activities such as grazing, cultivation and seeding, as well as the effects of extermination. Finally, the extent of use, and the level of toxicity of rodenticides used should be tested for small mammals and badgers.

**3. Habitat Selection:** A badger habitat capability model should be developed that incorporates finer-scale habitat requirements such as prey resources, and the impact of habitat losses within a home range, e.g. the effect of habitat loss due to paving a core area. Badger use of non-grassland habitats also should be explored, since this may expand the previous known range of badgers in British Columbia. The rates and extent of habitat loss due to urban growth and agricultural conversion must be monitored, and combined with the habitat capability model. This will provide managers with tools to consider badger habitat requirements in development plans, such as those made for forestry practices and urban growth, e.g. local Land and Resource Management Plans.

It appears that badgers are relatively tolerant of humans, and are able to adjust to altered landscapes as long as there are safe burrowing locations, and prey to eat. However, with the current rates of urban development, prey exterminations, highway mortality, and persecution, badgers still are at risk. The key to reversing these effects may be in raising public awareness of badgers, especially in more urban areas where they occur, and reversing badgers' reputation as a pest species by highlighting their ecological role in grasslands. Further research also is needed to identify the habitat requirements of badgers in order to give managers the information to support the recovery of badger populations across the province. Finally, collaboration between landowners, researchers,

and the government to provide incentives to maintain habitat and wildlife on privately owned lands may be the best approach to grassland conservation in the province.

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***Personal Communications:***

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## *Appendix I*

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### **A Two-Step Process to Determine Accurate Core Areas**

#### **I.1 INTRODUCTION**

Radio-telemetry can help answer questions regarding an animal's use of the landscape, such as habitat selection and home range. Some areas within a home range may be used relatively more by an animal due to unevenly distributed resources such as food, shelter, and mates (Adams & Davis 1967). In fact, the internal use of a home range may reveal more about an animal's ecology than the amount of area it uses. While there is a vast array of literature dedicated to the theory and calculation of home range sizes (Mohr 1947, Hayne 1949, Van Winkle 1975, Dixon & Chapman 1980, Worton 1989), few address the analysis of the internal use of a home range (Burt 1943, Ford & Krumme 1979, Don & Rennolls 1983, Samuel et al. 1985). As methods used to estimate home range areas are updated, methods to illustrate relative intensity of use in home ranges should be made more current to take advantage of newer models.

Sites that are used more by an animal are described as *core areas* (Burt 1943, Ford 1983). However, many methods used to describe the internal use of a home range often are subjective and arbitrary. Recently developed non-parametric estimators such as kernel analysis are useful tools for mapping the relative intensity of use within an animal's home range (Seaman & Powell 1996, Seaman et al. 1999, Dixon & Chapman 1980, Samuel & Garton 1987), but they alone are not sufficient to determine core areas. The definition of core area implies that some areas are used more than expected from

random movements. Some researchers arbitrarily have calculated core areas as those delineated by either a minimum area boundary (e.g. 50% minimum convex polygon), or a density of telemetry locations, e.g. 50% probability contour Naef-Daenzer (1993), Marzluff et al. (1997), Pechacek et al. (2000), Blundell et al. (2001). By doing this, researchers are assuming that movements are non-random. A 50% polygon can be drawn for any pattern of locations whether it is random, uniform or aggregated. Also, assigning an area in which there is a greater probability of finding that individual (based on telemetry locations collected) is independent of patterns of use. Neither of these methods distinguishes between areas that are heavily used or rarely used as the boundary is drawn arbitrarily. Because assigning core areas has biological implications, a more precise and consistent definition should be used to delineate important sites.

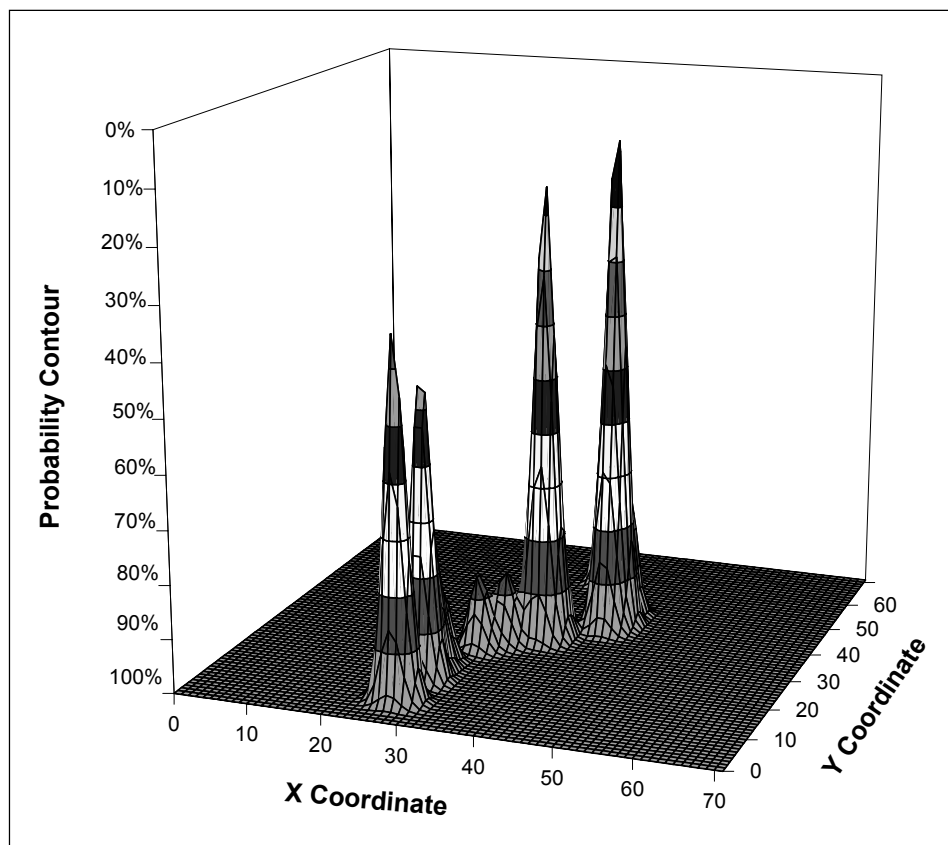
In this appendix, I consider a method to determine core areas within an animal's home range that is less arbitrary. According to Powell (2000), there are two criteria that must be met before core areas can be recognized within an animal's home range. First, a core area should be used more often than expected from random distribution of locations. To test for non-random dispersion of telemetry locations, I suggest using an index first proposed by Clark and Evans (1954) and later described by Sinclair (1985) and Krebs (1999). Second, a core area must be assigned that is biologically relevant. Specifically, the relationship between density of locations and the true size of a core area must be considered. I delineate core areas using a method outlined by Powell (2000), and Bingham and Noon (1997). This method uses kernel analysis to delineate appropriate core areas, so I begin by reviewing kernel analysis and its use to estimate home ranges, and how it is inappropriately used to calculate core areas. The method I use to determine

core areas mathematically addresses the concept less subjectively than reported in other studies. I use these processes in determining home ranges and core areas for badgers in Chapter Two.

## **I.2 METHODS**

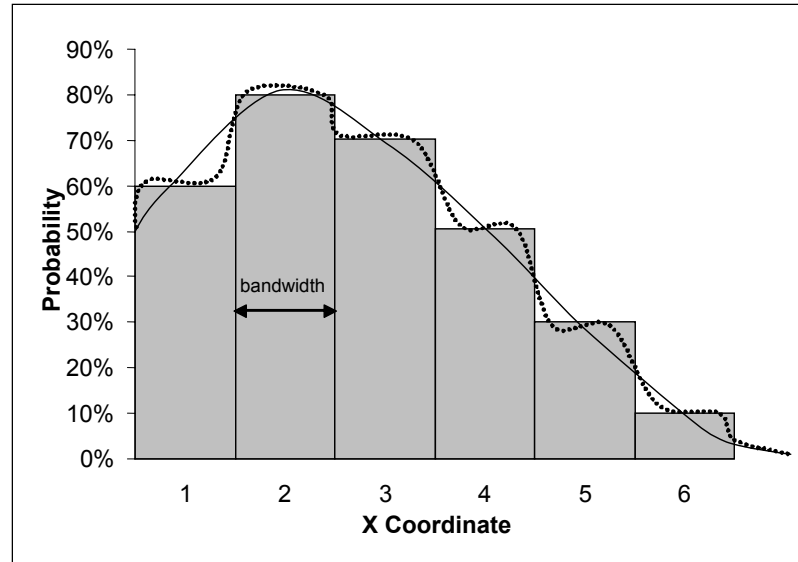
### ***Kernel Methods to Estimate Home Range***

Powell (2000) reported that kernel methods are probably the most accurate method to estimate home range areas. Telemetry location data are represented on the X-Y plane, and the density of locations is reflected in the height of the diagram. In theory, a grid of kernels is laid over the X-Y plane, and the density of locations within proximity of each intersection is calculated. The probability of an animal being located at X is calculated from the mean number of locations within a kernel divided by the area of the kernel. Thus, a utilization distribution of a home range is generated (Figure I.1, Van Winkle 1975). On the X-Y plane, contours (also called *isopleths*) are drawn around the area that represents the  $n\%$  probability of a location falling within that area. Typically, a 95% probability contour is used to represent a home range (Worton 1989), and 50% probability contours are used to estimate core area (Naef-Daenzer 1993, Marzluff et al. 1997, Pechacek et al. 2000, Blundell et al. 2001).



**Figure I.1** Theoretical three-dimensional kernel diagram of a single home range. The peaks illustrate areas where there is a higher probability of an animal being located.

A smoothing technique is used to give an even surface fit to the utilization distribution. If kernels are under-smoothed, the area will reflect too many small details, such as telemetry error. The resulting home range may be a number of smaller, disjunct polygons. If kernels are over-smoothed, the area will be overestimated and local details may be lost, and the home range may resemble a large, mononuclear ellipse. The researcher can control the degree of smoothing by setting the size and shape of each 3-dimensional kernel. The shape of each kernel has little effect on the kernel density output (Silverman 1986). However, the size of the kernel, called *bandwidth* (also represented by  $h$ ), has a significant effect on the kernel density output, and can optimize the smoothing effect (Figure I.2).



**Figure I.2** Cross-section of a kernel calculation illustrating the different effects of smoothing, and the relationship of bandwidth to smoothing function.

Bandwidth can be set in a number of different ways. Powell (2000) suggests that bandwidth can be set using telemetry location error, or an animal's radius of perception. Typically, bandwidth should be set greater than location error (Silverman 1986). *Least squares cross-validation* (LSCV) is the recommended process to choose the most appropriate bandwidth that minimizes smoothing error (Seaman & Powell 1996, Seaman *et al.* 1999). There are additional ways to refine the degree of smoothing before and after the bandwidth is set, and these vary between computer programs. Bandwidths can be constant for a dataset (*fixed kernel*), or varied (*adaptive kernel*) to adjust for different densities of locations and to achieve different smoothing effects (Worton 1989). Fixed kernel methods have lower bias, and better surface fit for a given bandwidth than the adaptive kernel method (Seaman & Powell 1996, Seaman *et al.* 1999). Fixed kernel methods are recommended when describing relative use in the interior of a home range, such as a core area (Powell 2000).

While kernels describe the relative intensity of use within a home range, they alone are not sufficient to describe core areas, for two reasons. The first reason is that probability contours can be assigned for all patterns of locations, whether aggregated, random, or uniform. That is, every pattern of locations will produce a 50% probability contour that may be artificially labelled as a core area. Moreover, the degree of aggregation will influence the total area considered to be a core area. Because kernels are based on density functions, the higher the density of locations within one area, the tighter the contour will be. This is the second reason kernel estimates are not sufficient to establish core areas. A boundary for the core area should be set where the appropriate level of concentration of locations is accounted for. So, if a core area is set arbitrarily at a 50% probability contour, the area of the contour may be larger than needed to encompass all of the aggregated locations. Conversely, the contour may not be large enough to encompass all of the aggregated locations. So, not only do locations have to be aggregated, but also the density of locations must be relative to the area considered as a core.

### *Assessing Aggregation of Telemetry Locations*

There are many methods that can be used to test for non-random use of space. Useful reviews of these have been provided by Hurlbert (1990), and Horne and Schneider (1995). In this example, I use a simple index of aggregation based on nearest-neighbour distances, first proposed by Clark and Evans (1954) and later outlined by Sinclair (1985) and Krebs (1999). A probability that the index of aggregation is non-random then can be modeled using Monte Carlo simulation (Solow 1989). The result is a measure of

aggregation within a pattern of telemetry locations, and a probability value to help interpret the degree to which the pattern exists.

An index of aggregation ( $R$ ) can be calculated for each animal using the radio-telemetry locations collected. Mean nearest-neighbour distances ( $r$ ) are determined for each observed location and compared to mean expected values using the following equation (Clark and Evans 1954, Krebs 1999):  $R = r_{\text{mean}} / r_{\text{expected}}$

*where:*

$$r_{\text{mean}} = \sum (r) / n$$

$$r_{\text{expected}} = 0.5 * \sqrt{A/n} + (0.051 + 0.041/\sqrt{n}) L/n$$

$r$  = distance to nearest neighbour

$n$  = number of locations per animal

$A$  = area of 100% MCP

$L$  = length of perimeter of  $A$

The index is sensitive to points nearest the boundary since these tend to have a larger nearest-neighbour distance than points well within the boundaries. This edge effect biases the index towards regularity (i.e. it increases the index value), because nearest-neighbour distances are overestimated. This is accounted for using the modified formula above for the expected nearest-neighbour distance (Sinclair 1985, after Donnelly 1978). An index value of 1 indicates that locations are completely random, while a value approaching 0 indicates clumping is occurring. In a regular, evenly dispersed pattern,  $R$  approaches an upper limit of 2.15.

Krebs (1999) suggests using the standard normal deviate ( $z$ ) to test the significance of  $R$ -values. However, this approach may be biased if sample sizes are small ( $n < 7$ ) and areas have smooth boundaries, e.g. a circle or square (Sinclair 1985 after Donnelly 1978). Edge effects caused by long and/or thin study areas also negate the use



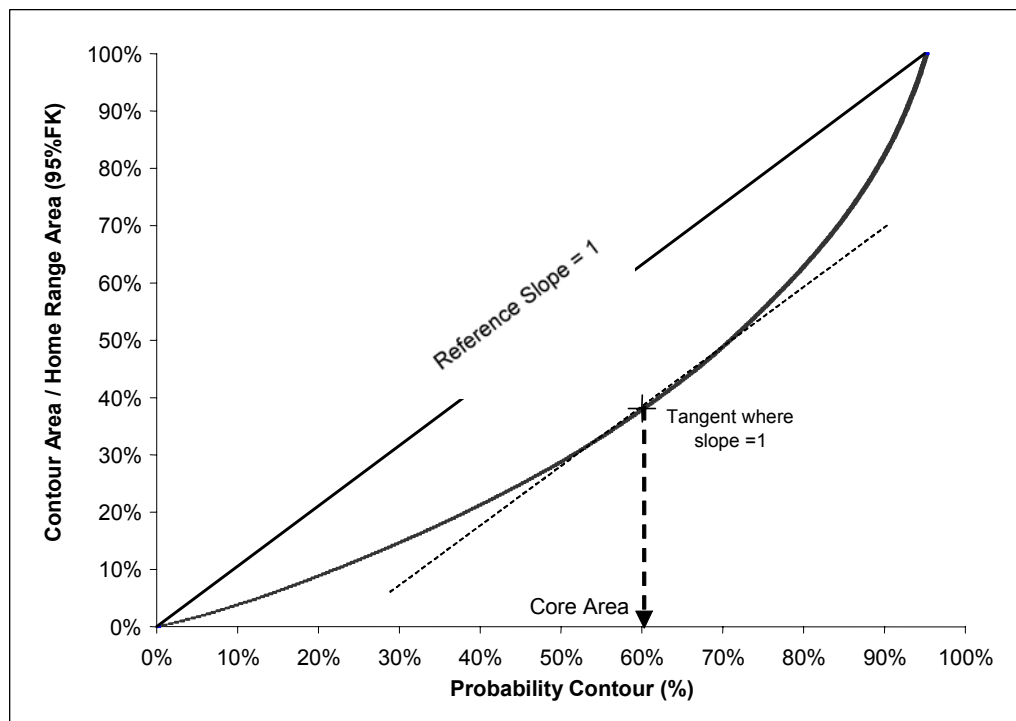
of  $z$  (Sinclair 1985). In many cases, the number of telemetry locations collected is limited, and home ranges may be linear, so the use of the  $z$  statistic is inappropriate. A Monte Carlo simulation is an alternative method for testing the significance of  $R$ . This is a non-parametric method and does not require *a priori* knowledge of an underlying frequency distribution, and is useful to estimate the sampling distribution of a sparsely sampled spatial point pattern (Solow 1989), such as radio-telemetry locations. These models are not as sensitive to sample size, or home range orientation (Manly 2001).

For a Monte Carlo simulation, a random walk model is generated from the original dataset to produce a new pattern of modeled locations, equal to the number of locations in the observed dataset. From an origin, a new dataset is generated by selecting random distances (from a normal distribution of the original successive distances), and random bearings (0-359 degrees). The aggregation index of the coordinates generated by these random walk models is replicated over 999 simulations. It is important to note that a random walk may produce an aggregated pattern of locations. That is, not all patterns produced by a random process will have a random index value. The 999 simulated index values are compared to the observed index to test for probability ( $p$ ) of the observed value. If the simulated  $R$  scored less than the observed  $R$ , the probability is increased by 1/1000. The percentage of simulated  $R$ -values less than that of an observed  $R$  value is used to assign a significance value to the latter. I have provided the programming code in S-language for use in the S-PLUS program by Mathsoft (1999, Appendix II).

### *Delineating Core Area Boundaries*

Once telemetry locations are determined to be aggregated, core area boundaries can be delineated. I have discussed the utility of kernel estimates in describing areas of relative intensity. The challenge is in selecting appropriate contours for core areas. The size and distribution of core areas will be influenced by the contour chosen.

Powell (2000) and Bingham and Noon (1997) suggest a method for delineating core areas that is based on a kernel density estimation of a home range. The rate that contour area accumulates (area divided by 95% FK home range area) is modeled with respect to the probability of an animal being located within its home range (Figure I.3). If the distribution of locations within 95% probability contour is perfectly uniform, the slope of the regression line equals 1 indicating that the contour area accrued evenly with contour volume. If the regression line sags below this reference line, the contour area accrues disproportionately to contour volume. As a result, the line sags to the extent that locations are concentrated because area will be accumulated less rapidly than expected under uniformity. Core areas are defined at the probability contour where the slope of the tangent to the sagging line is 1, or at the point where the vertical distance is farthest from the line of uniform use.



**Figure I.3** Diagram illustrating contour probability plotted against contour area divided the home range area (95% Fixed Kernel). In this example, area (Y-axis) is slower to accumulate than volume (X-axis) when compared to uniform use (Reference slope = 1). Graphically, the result is a concave line. The core area is determined where the slope of the tangent line is equal to 1. In this example, core areas are determined using the 60% probability contour.

### **I.3 DISCUSSION**

The use of an index to assess non-random patterns of animal locations is a more robust approach to delineating core areas, or other non-random patterns of use.

However, it is important to note that an aggregated index value does not disprove random use. For instance, an aggregated pattern of telemetry locations may result from sampling bias. Telemetry data are samples of actual animal locations and subject to bias when a site is over-sampled by a researcher, perhaps due to unequal familiarity with, or unequal access to, all parts of the study area. Therefore, aggregated patterns of use should be interpreted with caution. Apparent increased use of an area does not necessarily indicate

a true core area, nor does it prove biological importance of that site. Direct monitoring, and a sufficient number of telemetry locations collected will increase the accuracy and biological justification of core areas.

While the random walk model is used to assess the probability that the location data actually represent a random pattern, using the random walk model to consider a particular data set has many other advantages. It does not require the data to be normally distributed, and biological variables can be incorporated to represent the population under study. In the simulation, this preserves some of the biologically relevant information gathered in the sampling procedure, e.g. spatial movements over time. For example, the random walk may account for geographic constraints, maximum distances moved, and time between telemetry locations. Temporal autocorrelation of telemetry data is a contentious issue, and decisions must be made to include the amount of data that balance biological information and statistical robustness (Swihart & Slade 1985, Reynolds & Laundre 1990, Gautestad & Mysterud 1995, Hansteen et al. 1997, Roxburgh & Chesson 1998, De Solla et al. 1999). Instead of programming this index calculation in statistical software, there are programs that will calculate aggregation indices, e.g. ANIMAL MOVEMENT extension for ARCVIEW (Hooge & Eichenlaub 2000). However, there are no built-in tests for randomness in other software commonly used to determine home range areas, e.g. HOME RANGER, HOME RANGE, BIOTAS, JUMPIN, RANGES IV.

While there may be other ways to delineate core areas, there are advantages to using the method outlined by Powell (2000) and Bingham and Noon (1997). Setting boundaries that are relative to home range size, and more important, relative to the degree

of aggregation of telemetry locations will increase the accuracy of the placement of core areas. Also, probability contours will accurately estimate core areas when fewer locations are collected. The purpose of kernel estimators is that they create a probability function to delineate area around sparsely collected point data (Seaman & Powell 1996, Seaman *et al.* 1999). However, there is evidence that core areas may be falsely delineated with smaller samples, so caution should be used when interpreting the significance of core areas when too few locations are used in the model (Bingham & Noon 1997). If many telemetry locations are collected, there are other options available such as linkage estimators to establish core area boundaries (Kenward *et al.* 2001).

This method for delineating core area boundaries accounts for variation of the physical characteristics of individual home ranges. Because core areas are assessed for each individual, core areas are customized for the differences in home range size, orientation, and resource availability. For example, a home range that is confined due to geographic features may be used intensively, yet relatively evenly. If core areas were set at a 50% probability contour, there may be several tightly defined core areas that would underestimate the true area. Alternatively, home ranges may be situated in less topographically constrained habitat, where an animal may broadly forage and move back to several den sites within as many core areas. In this example, core area size may be overestimated, or appear as one large rather than several small core areas. Rather than delineating core areas as an arbitrary density of locations, such as 50%, core areas should be identified as those areas that are more heavily used relative to the home range size. This is a more objective measure of an animal's perception of the landscape, and

becomes important when assessing home range heterogeneity or habitat selection across spatial scales (Morris 1987, Levin 1992, Horne & Schneider 1995).

Finally, accurately establishing core areas is particularly important for conservation purposes, as there are biological implications to setting boundaries incorrectly. For wide-ranging species that are experiencing habitat losses, such as badgers (*Taxidea taxus*) in British Columbia, it is critical to identify areas used more than others within the home range. For this species, core areas may be colonies of ground squirrels, fields amidst an urban landscape, or perhaps less obviously, established burrows that have been used historically (see Chapter Three). Conservation plans can key into core areas that are identified as particularly important to badgers.

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## *Appendix II*

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### **S Code to Calculate Index of Aggregation**

I generated this S-language code to calculate Index of Aggregation (R) and probability (p) values using a Monte Carlo random walk simulation. I used the statistical program Mathsoft (1999) S-PLUS to complete the analysis. The following code follows a two-step process to calculate the index of aggregation, and the probability values.

First, I generated a dataset (simdata) of coordinates using the script **random.walk.model(data)**. The dataset consists of n simulations (i.e. 1000) each with an ID number. Each ID had a length of number of observations (nobs) of the original dataset. The first set is the original data, the next 999 are simulated using the **random.walk(data)** and **next.dist(data)** scripts. The dataset is saved as a .dbf file (e.g. b10simdata.dbf) and imported to another program to calculate minimum convex polygon area and perimeter for each ID. I used ANIMAL MOVEMENT EXTENSION (Hooge & Eichenlaub 2000) for ARCVIEW to do this. The .dbf file is exported into S-PLUS and is used where (mcps) is indicated in a script.

In the second step, I calculated the observed index value and probability value for each animal using the **return.p(simdata, mcps)** script. This script calculates each index value using the **calc.index (data, mcps)** script and returns the observed index value and the probability value.

## II.1 STEP 1: Generating simulated datasets using Monte Carlo methods

```

"next.dist"<=#calculates successive distances between xy coordinates
function(data)
{
  x <-data["X"]
  y <-data["Y"]
  xy <-cbind(x,y)
  nobs <-length(data[,1])

  #calculate distance between successive locations (nextdist)
  nextdist <- rep(0, (nobs-1))
  for(i in 1:nobs-1){
    nextdist[i]<-sqrt(((xy[i+1,1]-xy[i,1])^2)+
      ((xy[i+1,2]-xy[i,2])^2))
  }
  return(nextdist)
}

"random.walk" <=#returns the xy array of a random walk generated with observed data
function(data)
{
  x <-data["X"]
  y <-data["Y"]
  xy <-cbind(x,y)
  nobs <-length(data[,1])

  #creates a random walk given the next distances (next.dist) at a random bearing with
  replacement
  xmove <-rep(0, nobs-1)
  ymove <-rep(0, nobs-1)
  x <-rep(0, nobs)
  y <-rep(0, nobs)
  ranmove <- rnorm(nobs-1, next.dist(data))
  brg <-sample(0:359,nobs-1,T)
  ymove <-ranmove*(cos(brg/(180/pi)))
  xmove <-sqrt((ranmove^2) - (ymove^2))
  xmove[brg >= 180 & brg <= 359] <- -(xmove[brg >= 180 & brg <= 359])
  x[1] <- 0
  y[1] <- 0
  for (j in 2:nobs){
    x[j] <-xmove[j-1] + x[j-1]
    y[j] <-ymove[j-1] + y[j-1]
  }
  xy <-cbind(x, y)
}

```

```

"random.walk.model" <- #creates random walk xy-coordinates (n iterations) and
                          exports to a .dbf file
function(data)
{
  nobs <-length(data[,1])
  n <- 1000
  ID <- rep(1,nobs)
  x <-data[,"X"]
  y <-data[,"Y"]
  XY <-cbind(x,y)
  for (i in 1:n){
    ID <- i
    dataset <- random.walk(data)
    if(ID==1)
      {dataset <- XY}
    dataset <- cbind(ID, dataset)
    if(ID==1)
      write.table(dataset, "b10simdata.dbf", sep="\t", append=T)
    else
      write.table(dataset, "b10simdata.dbf", sep="\t", append=T,
                  dimnames.write=F)
  }
}

```

## **II.2 STEP 2: Calculating the Index of Aggregation and Probability Values**

```

"index.calc"<-#calculates Index of aggregation (R) as in Donnelly 1978 (Sinclair 1985)
function(data, mcps)
{
  x <-data[,"X"]
  y <-data[,"Y"]
  xy <-cbind(x,y)
  nobs <-length(data[,"ID"])
  group <- data[1,"ID"]
  mcp <- mcps[group, "AREA"]
  perim <- mcps[group, "PERIMETER"]

#calculate nearest neighbour distance (mindist)
mindist <-rep(0, nobs)
for(i in 1:nobs){
  bind <-rbind(xy[i,], xy)
  junk<-dist(bind)[1:nobs]
  if(sum(junk==0)>1){
    (mindist[i]<-0)}
}

```

```

else
    {mindist[i]<-min(junk[junk>0])}
}

#calculate mean nearest neighbour distance (meandist)
meandist <-mean(mindist[1:nobs])

#calculate expected nearest neighbour dist (expdist)
expdist <-0.5*(sqrt(mcp/nobs))+
(0.051 + 0.041/sqrt(nobs)) * (perim/nobs)

#calculate index value
index <-meandist/expdist
return(index)
}

"return.p" <- #runs index on model and true data returns true index and pvalue (data =
              b03model.sdd)
function(simdata, mcps)
{
  n <- length(levels(simdata[, "ID"]))
  counter <-1
#find simulated index values and return p-value
  for (i in 1:n) {
    #creates a subset of each ID to run index on
    temp <- simdata[simdata[, "ID"]==i,]
    sim.index <- index.calc(temp, mcps)
    if (i==1)
      true.index <- sim.index[i]
      if (sim.index <= true.index)
        counter <- counter + 1
  }
  p.value <- (counter/n)
  cat("true.index =", round (true.index, 4), fill=T)
  cat("p-value =", round (p.value, 4), fill=T)
}

```

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## ***Appendix III***

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### **Food Habits of Badgers in the Thompson and Okanagan Regions of British Columbia**

#### **III.1 INTRODUCTION**

Food is a basic requirement of life, and partially determines the way animals use landscapes (Ford 1983, Arditi & Dacorogna 1988). Carnivores are particularly influenced by the ecology of their prey species. One of the most common examples is the association between lynx and snowshoe hare (Poole 1995, Poole et al. 1996, O'Donoghue et al. 1998). Similarly, prey is an important component in mustelid ecology (Powell 1994, Johnson et al. 2000). Sometimes prey availability can describe habitat suitability for mustelids better than any vegetation association or ecological classification (Lofroth et al. 2000).

Badgers are opportunistic, and their diets include a number of small mammal species, including ground-dwelling squirrels (Sciuridae), pocket gophers (Geomyidae), mice (Cricetinae) and voles (Microtinae), as well as a variety of reptiles, amphibians, birds, insects, and even fish (Snead & Hendrickson 1942, Errington 1937, Salt 1976, Todd 1980, Messick & Hornocker 1981, Lampe 1982). Badger diets have been shown to vary geographically depending on local prey availability, abundance, and season (Lampe 1982). As one prey species becomes less available, badgers will switch to an alternative source to compensate. Therefore, even within one region, there may be a number of prey resources influencing badger ecology.

During a larger telemetry study looking at habitat selection by badgers in British Columbia, I had the opportunity to examine their diet through collected scats and gastro-intestinal tracts. I identified undigested species, and analyzed digested contents using hair identification techniques (Lofroth et al. 2000). Results of dietary analyses helped to determine the species that I quantified during habitat data collection, and habitat selection analysis in Chapter Three.

### **III.2 METHODS**

I collected 13 gastro-intestinal tracts (GITs) from roadkilled badgers, and those seized by conservation officers or government agents in the Thompson and Okanagan Regions of the province. Eight GITs were collected in the Thompson Region (3 males, 3 females, 2 unknown). Five GITs were collected from animals in the Okanagan (3 males, 2 females). I also collected 15 scat samples during monitoring and habitat data collection in the Thompson Region. Badgers tend to use underground latrines within their burrows, or bury their scat under soil near their burrow. As a result, badger scat samples are difficult to obtain without damaging burrows. Badger scat also can be difficult to distinguish from fox scat, so samples were identified as badger scat only if the animal was observed defecating, or if the sample was collected from inside a badger burrow or at a burrow entrance.

I washed the GIT contents out of the stomach and large and small intestine until all contents were extracted. Each scat and GIT sample was washed through a set of soil sieves (6.35, 5.6, 2.0 and 1.0 mm). I collected the remains off of the sieves, and transferred the material to aluminum pans that were left to dry under a fume hood (24 –

48 hours). Once dry, I separated all masses of hair so that no structure remained, and identified some food items such as partially digested prey, amphibian skins, feathers, seeds and various arthropods. Then, I transferred the sample material to a pan that was divided into a sampling grid of 100, 1.5 x 1.5 cm cells. I generated a random number using a calculator, and chose a single guard hair from that grid cell. I made an imprint of the hair into a piece of acetate (blue plastic report covers) by clamping the hair and acetate between two glass slides and heating in an oven at 300°F for approximately 10 minutes. I mounted the hair and acetate imprint onto glass slides and secured them using clear nail polish. Ten representative hairs were selected and processed from each sample.

Hairs were identified under a compound microscope with 10 and 40 power objectives and phase contrast filters. Identification was based on cortex and medulla characteristics of the hair, and cuticle features captured by the imprint. The hairs were identified using a Wyoming guide for mammal hair identification (Moore et al. 1974), as well as a collection of reference slides (Lofroth et al. 2000). There are limitations to using this procedure for identification of mammalian prey species (Foran et al. 1997); therefore, I identified species only to Family or Subfamily.

Separate analyses were done on the samples from the Thompson and Okanagan regions. Scats and GITs collected in the Thompson region also were stratified by sub-region: (1) the East sub-region encompassed the area East of the city of Kamloops and south of the South Thompson River; (2) the North sub-region included the area north of the South Thompson River; (3) the South sub-region included the area directly south of Kamloops towards the town of Merritt; and (4) the Falkland sub-region. I calculated the



frequency with which each food item occurred in the samples from each region. I assessed the differences between diet (GIT samples only), and between sexes using G-tests. I did not compare samples from each sex as I could not identify their origin with certainty. I also did not assess differences in diet across seasons due to few GITs collected, and uncertainty of some mortality dates.

### **III.3 RESULTS**

At least 11 different food items were identified from all of the samples collected, including small mammals, arthropods, berries, and amphibians and reptiles (Table III.1). Squirrels (*Spermophilus columbianus*, and *Marmota flaviventris*), and arviculids (*Microtus* spp. and *Clethrionomys* spp.) occurred most frequently in both the Thompson and Okanagan, appearing in 23.2% of all samples combined. Arthropods and Saskatoon berries (*Amelanchier alnifolia*) also were eaten by badgers. I assumed that the presence of badger (*Taxidea taxus*) hair was probably a result of grooming, and not a potential food source. Two juvenile badger GITs were empty; one was collected from the Thompson Region and one from the Okanagan Region. There was no statistical difference between the frequencies of food items detected in the Thompson compared to the Okanagan ( $G = 10.37$ , 12 df,  $p = 0.58$ ).

**Table III.1** Percentage of scats and GITs in which food items were detected. Samples were collected from the Thompson Region (n = 23) and the Okanagan Region (n = 5).

Food Items Detected	REGION		
	Thompson	Okanagan	Total
Sciuridae	45.5%	17.8%	23.2%
Microtinae	18.2%	24.4%	23.2%
Arthropods	9.1%	13.3%	12.5%
<i>Amelanchier alnifolia</i>	—	13.3%	10.7%
Feathers	—	4.4%	3.6%
Geomyidae	—	4.4%	3.6%
Cricetinae	—	4.4%	3.6%
<i>Bufo boreus</i>	9.1%	—	1.8%
Fish	9.1%	—	1.8%
Heteromyidae	—	2.2%	1.8%
<i>Thamnophis</i> spp.	—	2.2%	1.8%
<i>Taxidea taxus</i>	—	2.2%	1.8%
Unidentified	9.1%	11.1%	10.7%

Small mammals from five families dominated badger diets of the Thompson Sub-regions, but smaller components of arthropods, Saskatoon berries, birds, and a garter snake (*Thamnophis* sp.) also were eaten (Table III.2). Ground-dwelling squirrels and marmots (Sciuridae) were present in badger diets from all sub-regions of the Thompson, and voles (Microtinae) were present in diets from all sub-regions except Falkland. Pocket gophers (Geomyidae), mice (Cricetinae) and pocket mice (Heteromyidae) were recorded in fewer samples. Pocket gophers were detected only in the north, despite their distribution reportedly being limited to areas south of the Thompson River (Johnstone 1954). Pocket Mice were detected only in the eastern Sub-Region. This was most likely the Great Basin pocket mouse (*Perognathus parvus*) as it is the only heteromyid that extends as far north as the Thompson, and is limited to the extreme southeast of the region (Nagorsen 1990). Fewer food items were identified in the diets of the lone badger from Falkland, and in badgers from the northern portion of the Thompson Region.

**Table III.2** Percentage of scats and GITs in which food items were detected. Samples (n) were collected from the Thompson Sub-regions.

Food Items Detected	THOMPSON SUB-REGIONS				
	East n = 7	North n = 6	South n = 7	Falkland n = 1	Unknown n = 2
Sciuridae	12.5%	33.3%	20.0%	50.0%	—
Microtinae	25.0%	50.0%	13.3%	—	33%
Arthropods	25.0%	—	13.3%	—	—
<i>Amelanchier alnifolia</i>	18.8%	—	20.0%	—	—
Feathers	—	—	13.3%	—	—
Geomyidae	—	16.7%	—	—	17%
Cricetinae	6.3%	—	—	—	17%
Heteromyidae	—	—	6.7%	—	—
<i>Thamnophis</i> sp.	—	—	—	50.0%	—
<i>Taxidea taxus</i>	—	—	—	—	17%
Unidentified	12.5%	—	13.3%	—	17%

I did not detect any differences in the diets of females and males ( $G = 0.021$ , 13 df,  $p < 0.99$ ). Of the 5 identified females, 3 were confirmed to have kits when their samples were collected. Sciurid and microtine species were detected most commonly in these samples, but arthropods (mostly beetles and grasshoppers) and a toad also were eaten (Table III.3).

**Table III.3** Summary of GIT contents and scat collected at maternal burrows of 5 female badgers in the Thompson and Okanagan Regions, and percentage of samples in which food items were detected. Three of the badgers were confirmed to have had kits at the time of collection.

Badger Status	Mother of 2 kits	Mother & 1 kit	Lactating	Unknown	Juvenile
Region Collected	Thompson	Thompson	Okanagan	Thompson	Okanagan
Date Collected	Aug 26, 2000	May 22, 2000	Aug 31, 2001	Jun 11, 1999	Unknown
Sciuridae	50%	—	33%	—	<i>Empty</i>
Microtinae	50%	43%	—	33%	
Arthropods	—	43%	33%	—	
<i>Bufo boreus</i>	—	—	33%	—	
<i>Taxidea taxus</i>	—	—	—	33%	
Unidentified	—	14%	—	33%	

### **III.4 DISCUSSION**

Badgers in the Thompson and Okanagan Regions ate a wide variety of food items that were consistent with results from other studies in both the United States and in Canada. Badgers in this study ate mostly small mammals, most commonly ground-dwelling sciurids and voles, and a wide variety of minor prey items, including arthropods, amphibians, reptiles, and birds. Mice, pocket gophers and ground squirrels frequently were recorded in samples collected in Minnesota and North Dakota (Sovada et al. 1999). In Iowa, ground squirrels, mice, and scavenged cottontails were found most frequently in scat and intestinal samples (Snead & Hendrickson 1942). Ground squirrels were a main component of badger diets in Idaho (Messick & Hornocker 1981, Todd 1980). In Minnesota and in central Alberta, pocket gophers were eaten most frequently (Lampe 1982).

There were some unique items that I identified in badger diets. For example, no other study reported badgers eating Saskatoon berries. One badger scat that was collected during focal monitoring of an individual was composed almost completely of Saskatoon berry seeds. This suggested that badgers might be more omnivorous than was previously reported. Some prey species were not common in a region, but appeared in badger diets. Particularly, pocket mice were relatively uncommon in the Thompson Region (Nagorsen 1990), but if the identification was correct, they were detected in diets of badgers in the eastern sub-region. Similarly, pocket gophers were not known to extend north of the South Thompson River (Johnstone 1954), yet I found them in the diet of a badger living on the north shore.

I did not detect a significant difference between regional or sub-regional diets, but there was evidence that suggested badgers ate what was locally most available and convenient. It was not surprising that in the Thompson Region, ground squirrels and voles were the most abundant diet item, since these also were common in diets in other areas (Messick 1987). I suspect that badgers in the Thompson and Okanagan Regions preferred ground squirrels when and where they are available, but colonies were not abundant or evenly distributed in all regions. This could have prompted badgers to eat alternative species that did not provide the caloric advantages that ground squirrels might, such as voles and arthropods. For example, one full stomach contained a minimum of 1 pocket gopher, and 5 adult and 3 juvenile voles. It would take fewer ground squirrels and less energy to provide similar energy gains.

Female diets did not reflect the diversity found in all diets, and this might have been related to the fact that three of four females had kits the year the samples were collected. Female diets consisted mostly of sciurids, voles, and arthropods. When they females were nursing, they may have had to rely on abundant prey that were easily trapped, and may also have focused on these species when training their kits to hunt.

I was not able to test for distinction in diet composition between adults and juveniles, although the literature reported differences between these age groups. Because they are less skilled in hunting, younger badgers may have supplemented their diet with easily caught food on the surface, such as arthropods, voles and mice (Errington 1937, Messick & Hornocker 1981).

Badgers shift their diets seasonally according to prey availability (Lindzey 1982, Messick & Hornocker 1981); however, I was unable to determine a difference between seasons due to lack of data for some samples. According to other studies, badgers rely more on ground squirrels during the summer months, but diversify their diets in the spring and fall to rely more on other small mammals such as mice and voles (Errington 1937, Snead & Hendrickson 1942). In central Alberta, pocket gophers were common diet items until mid-summer when badgers ate more ground squirrels, and then shifted their diet to include more vole and insect species in the fall (Salt 1976).

The results presented here have limitations, and should be interpreted with caution. Sample sizes are low, and do not adequately represent the regions. The samples collected in the Okanagan were seized by government officers, and in some cases, date and location of original collection were not known. Also, the identification of hair using morphological features is relatively more subjective than the more accurate, but expensive genetic methods. Regardless, this study provides important information of the types of prey, and the variety of species badgers are eating in the Thompson/Okanagan region of British Columbia.

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Author \_\_\_\_\_

Corinna Sara Hoodicoff

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