ROAD ECOLOGY OF A NORTHERN POPULATION OF BADGERS (*TAXIDEA TAXUS*) IN BRITISH COLUMBIA, CANADA

BY

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“The last word in ignorance is the man who says of an animal or plant: 'What good is it?”

— *Aldo Leopold*

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ABSTRACT

The badger (*Taxidea taxus*) is one of British Columbia's (BC) most endangered mammals, with estimates placing the current provincial population at fewer than 340 adults. Previous research in the province has isolated two main factors contributing to the decline of badgers in BC: (1) a historical and current decline in habitat, and (2) road mortality caused by highways running through badger habitat. This intensive badger radio-telemetry study was initiated in 2007 to document badger ecology and movements in order to investigate why badgers are susceptible to vehicle collisions and possible mitigation methods.

From 2007-2009, a subset (11♀, 5♂) of the badger population in south-central BC were captured and outfitted with VHF radio-tags to track their location and movements. In addition, the systematic collection of hair to identify individuals using DNA was employed to assist in tracking movements, dispersal, and aid in identifying carcasses. Locations for study animals were used to determine fixed kernels (95% FK) for home range analysis. Mean home ranges for males were 253.1 km^2 while females had much smaller home ranges of 29.4 km^2. In addition to their extremely large home ranges, males displayed extensive movements during summer, while reproductive females maintained the smallest home ranges and restricted their movements during the kit rearing period. Movements of adult females with kits were influenced by time of kit emergence from the den, litter size, and period of time before natal den abandonment.

Newly emerging GPS technology was used to reveal extensive movements during summer that conventional radio-telemetry had underestimated. Movement rates were five times greater for GPS outfitted badgers versus conventional radio-telemetry estimates [GPS 4,801 m/day (n = 5): VHF radio 840 m/day (n = 16)] suggesting that badger movements and road crossings were underestimated by previous badger ecology studies.

In an attempt to document the frequency and ratio of above- and below-grade road crossings, remote motion cameras were placed at existing underpass structures to compare telemetry locations and GPS movements with camera data. Both marked and unmarked badgers were recorded using a variety of structures. Data revealed that both genders and family groups used culverts and livestock underpasses to pass under roads, with 500 mm culverts being used most frequently. Both above- and below-grade road crossings were detected, with frequency varying by individual, time of day, and seasonality.

Animals whose home ranges bisected highways were repeatedly observed crossing highways, with half of the study animals succumbing to collisions with vehicles (8 of 16). Due to their large home ranges, all five males in the study eventually crossed highway corridors with four of five males dying on these major roadways. Sites of badger road mortalities were spatially defined to identify areas of concentrated road mortality sites or 'hotspots' on major roadways in south-central BC.

Despite the high percentage of study animal road mortality, DNA data and population modeling suggests an increasing population of badgers in the regional study area. At the present time, the high incidence of road mortality in the study area seems to be negated to some extent by strong recruitment, hence the estimate of increasing population size.

Home range size and movement rate estimates for badgers in this study are some of the largest reported in BC. These phenomena may be explained by the patchy distribution of resources near the northern range limit of badgers in BC, such as suitable soils for burrowing and distribution of prey species. These limited resources often coincide with human populated areas where development of transportation corridors and agriculture often occur. These human-induced pressures on badger habitat often conflict with seasonal movement patterns of badgers (i.e., breeding season) leading to habitat fragmentation and direct mortality. The ability to increase our understanding of these movement patterns and provide mitigation measures (e.g., road underpasses, land conservation) that reduce direct mortality and increase productivity should allow for the continued existence of this species near their range limit in south-central BC, Canada.

In conclusion, I present a focused discussion on how an understanding of the ecology of badgers (particularly movements) may be integrated into habitat protection and restoration plans, including mitigation for current and future road infrastructure projects, thereby reducing impacts on this species.

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THE MESOCARNIVORE

A combination of rarity, anthropogenic impacts, and political factors has put roughly a quarter of all terrestrial mammal species at risk of extinction (Ceballos et al. 2005). The underlying cause of virtually all recent and ongoing declines of these animals is the growth of human populations and associated impacts such as habitat loss, over-exploitation, and the spread of invasive species (Cardillo et al. 2004). Nowhere has this decline been more precipitous than within the Order Carnivora.

Carnivores, particularly the larger species, are ecologically important because the loss or gain of a few individuals can cause strong predator-driven effects or indirect behavioural effects (e.g., fear-driven foraging) on communities and ecosystems (Ripple and Beschta 2004a, Ray 2005, Roemer et al. 2009). The loss of large carnivores also likely carries broader implications for the maintenance of biodiversity as a result of indirect effects at lower trophic levels (Crooks and Soule 1999, Henke and Bryant 1999). This phenomenon has been termed a 'trophic cascade', namely a predator/prey interaction that has effects throughout more than one level in a given food web (Hairston et al. 1960, Paine 1980). Although the classic trophic cascade is based on a three-tiered system consisting of predators, herbivores, and plants, cascades can in theory involve more than three trophic levels and may apply to any multilink linear food web interaction (Hairston et al. 1960, Polis et al. 2000).

The importance of large carnivores notwithstanding, most mammalian predators are neither large, nor at the apex of trophic food webs. A case in point is the so-called 'mesocarnivores' that often are limited by effects from higher up in the food web (i.e. "top-down effects"). Mesocarnivores may therefore have their ecological impact on the broader community mediated by the presence of other larger predators (Gittleman and Gompper 2005). But, given their smaller size and ability to thrive in diverse habitats, mesocarnivores are usually more abundant than large carnivores, yet their impact within communities has been generally assumed to be relatively minor (Roemer et al. 2009). Further, this group represents an ecologically diverse and influential guild of vertebrates that are capable of structuring the ecological community in which they occur (Buskirk and Zielinski 2003).

Recent arguments by Roemer et al. (2009) suggest the importance of mammalian mesocarnivores in ecosystems may be understated. Using theory and empirical data, they point out that the impact of these animals may be especially profound under three scenarios: (1) when larger carnivores are absent in an ecosystem, (2) on island or mainland ecosystems with relatively simple ecological communities, and (3) where they represent non-native introductions [e.g., foxes (*Vulpes vulpes*) in Australia (Banks 1999)]. All told, mesocarnivores may be fundamentally important drivers of ecosystem function, structure, or dynamics (Boitani 2001, Meserve et al. 2003, Donadio and Buskirk 2006, Maron et al. 2006, Jones et al. 2008).

Most often it is the large carnivores, such as wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), and mountain lions (*Puma concolor*) that are considered the most useful species for conservation planning (Carroll et al. 2001). More recently, conservation biologists have recognized that mesocarnivores can have the same role, not only because the home range sizes of some species [e.g. Wolverine (*Gulo gulo*), lynx (*Lynx canadensis*)] are similar to or greater than those of large carnivores, but because the extirpation of large carnivores in many regions has promoted mesocarnivores to the role of top predators (Buskirk and Zielinski 2003). Including a combination of focal carnivore species, especially mesocarnivores that specialize on habitats of concern, may ultimately be the best approach to large-scale monitoring and conservation of natural landscapes and ecosystem processes (Noss et al. 1996).

THE NORTH AMERICAN BADGER

The badger as a North American mesocarnivore

Most ecological research on badgers (*Taxidea taxus*) across North America has been limited to the western United States in the 1970s and 1980s (Sargeant and Warner 1972, Lindzey 1978, Messick and Hornocker 1981, Lampe 1982). Recently however, projects have been focused across their range where populations may be declining due to environmental and anthropogenic factors (Warner and VerSteeg 1995, Weir et al. 2003, Paulson 2007, Duquette 2008, Kinley and Newhouse 2008, Quinn 2008, Hoodicoff et al. 2009).

The North American badger is one of the largest members of the Family Mustelidae (the ‘weasel family’). A fossorial mesocarnivore, they are adapted for digging to obtain food and shelter. The well-developed forelimbs and claws are ideal for burrowing with a conical and wedge-shaped head for thrusting into small animal burrows. Adult badgers usually range in length from 72 to 91 cm, including the short bushy triangular tail, which is typically 10 to 14 cm long. Adult females weigh between 6 and 9 kg, while larger adult males weigh between 9 and 13 kg.

Many studies across the range of the badger in North America have been conducted and the ecological characteristics for the species have been described. The home ranges of both male and female badgers expand during the breeding season, indicating that both genders travel more extensively at that time to find mates (Sargeant and Warner 1972, Messick and Hornocker 1981). Males have larger home ranges and are likely to overlap with the home ranges of several females (Lindzey 1978, Minta 1993). Badgers generally mate in late summer between July and August. Young are born blind, furred, and helpless sometime in late March to early April. Their eyes open at four to six weeks of age. Weaning occurs around mid-May when the young are about half-grown. Juveniles are then taught to hunt around mid-June to early July when they are about two-thirds grown. The number of young reportedly ranges from one to seven; two to three young are most common (Kinley and Newhouse 2008). Badgers are polygamous forming loose pair bonds in late summer. They are territorial, particularly the females, and males likely fight over a female (Long and Killingley 1983). Dispersal and breakup of family units usually occurs in autumn when the female stops bringing food to the young badgers (Sargeant and Warner 1972, Messick and Hornocker 1981).

Activity patterns of badgers vary not only by time of day but are also influenced by seasons. Badgers are most active in summer, and least in winter. They are also most active at night, but reports of badgers being active in the day are common. They are not true hibernators, but spend much of the winter in cycles of torpor characterized by a reduction in heart rate and body temperature (Long and Killingley 1983). Badgers will accumulate stores of fat in the autumn and early winter when much of their prey hibernates and are thus easier to catch.

Badgers use multiple burrows within their home range and are capable of digging several in a single night. They will frequently reuse burrows and multiple badgers may use the same burrow in an area over several generations. While usually considered solitary animals, sociality among badgers has been observed, particularly family units in the summer (Messick and Hornocker 1981).

Badger diets in North America can vary depending on the geographic range where they occur. They have been described as an opportunistic predator, preying on various other species (Lampe 1982, Messick 1987, Sovada et al. 1999, Hoodicoff 2003, Michener 2004, Kinley and Newhouse 2008). Small mammals form the majority of their diet with an emphasis on fossorial colonial rodents such as ground squirrels (*Spermophilus* spp.) and marmots (*Marmota* spp.), species on which badgers have become specialists in exploiting as food resources (Michener 2004, Kinley and Newhouse 2008). Other common mammalian prey species include northern pocket gopher (*Thomomys talpoides*), muskrat (*Ondatra zibethicus*), leporids (rabbits and hares), and various microtine rodents (e.g., voles) (Newhouse and Kinley 2001, Hoodicoff 2003). Less common but other reported prey has included insects, birds (e.g., waterfowl, ground nesting), reptiles, amphibians, and fish.

Badgers are considered an important ecological driver for grassland and open forest ecosystems as they not only influence rodent prey populations but also geophysical processes (Eldridge and Whitford 2009). Both foraging and resting burrows dug by badgers form important habitat elements for other species that use vacant burrows for nesting sites or thermal cover, such as burrowing owls (*Speotyto cunicularia*) and several snake species (e.g., western rattlesnake, *Crotalus oreganus*) . Badger excavations and associated soil mounds are important features that alter the composition of grassland and open forest ecosystems by influencing a wide range of processes including water infiltration, soil aeration, organic decomposition rates, vascular plant diversity, and support for a variety of soil invertebrates (Eldridge 2004). Thus, this mesocarnivore shapes and influences specific habitats across its geographic range, and its presence is an excellent indicator for identifying properly functioning grassland / open forest ecosystems.

Badgers in British Columbia, Canada

Badgers (*Taxidea taxus*) occur at their northern range limit across southern Canada (Figure 1.1). Of the four subspecies of badgers occurring in North America, only *T.t. jeffersonii* occurs in British Columbia (BC) with an estimated population of less than 340

Figure 1.1. North American distribution of four subspecies of badger (*Taxidea taxus*) (from Newhouse and Kinley 2001).

adult individuals. The Rocky Mountains create the boundary between the *jeffersonii* subspecies of badgers (west of the Rockies) and *T. t. taxus* in the prairie provinces. Further south, the two races become intergraded on the Great Plains.

In BC, the range of the *jeffersonii* badger extends along the dry southern interior valleys, occurring west to the Coast Mountains, north to the Fraser Plateau and east to the Alberta border along the southern Rocky Mountain Trench (Figure 1.2).

Two major habitat features considered vital to badgers are suitable densities of prey and appropriate substrates in which to dig burrows (Rahme et al. 1995). Studies in BC supports this assumption, with the animals commonly being associated with grasslands and open forests that provides these resources (Apps et al. 2002, Weir et al. 2003).

Badgers are frequently found in low-elevation human-altered landscapes, such as gravel pits, golf courses, agricultural fields, forest-harvesting blocks, along highways, and ranchlands where disturbed soils offer ease of digging and rodent prey is plentiful. These habitats are also associated with linear features, such as roads and trails that offer the short-legged badger convenient travel corridors. Very few badger observations occur in the interior wetbelt with the Columbia Mountains posing as a substantial barrier to movement and dispersal. Thus, the biogeography of BC restricts badger distribution into disjunct regional sub-populations where maintaining genetic diversity becomes of critical importance in the face of declining populations across their range.

The conservation status and ecology of badgers in BC came to light during the late 1990s, when a sharp decline in their populations became apparent (Newhouse and Kinley 1999). While there is very little reliable historical data, it has been estimated that provincial populations have likely declined since the 1920s when the number of badgers trapped annually were greater than the current population estimate of 230-340 animals (*jeffersonii* Badger Recovery Team 2008). While the global status of the North American badger is considered secure (G5, NatureServe), in BC the *jeffersonii* subspecies is considered threatened by the BC Conservation Data Centre, and is federally ranked as ‘endangered’ by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Recent studies in BC have identified declining numbers of badgers in regional subpopulations of the Thompson-Okanagan and East Kootenay, including recent extirpation

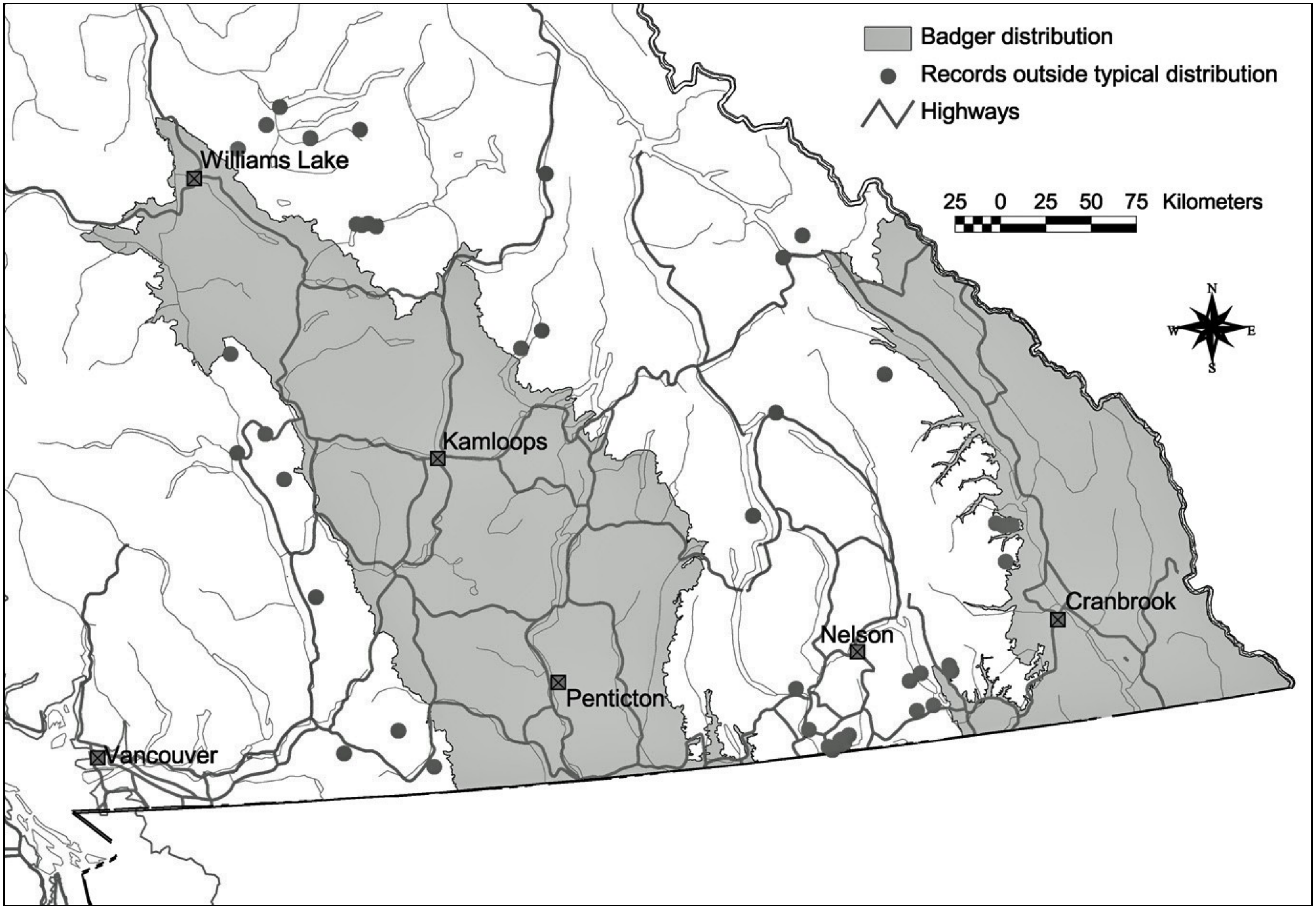

Figure 1.2. Map of badger (*Taxidea taxus*) distribution in British Columbia, Canada (Weir and Almuedo 2010).

from historical range in the Upper Columbia valley in the East Kootenay region (Weir et al. 2003, Kinley and Newhouse 2008, Hoodicoff et al. 2009). These finding in conjunction with genetic work conducted by Kyle et al. (2004) suggest that badger populations in BC occur in units that may have independent demographics. The primary factors limiting badger populations in BC are believed to be related to road mortality, habitat impacts, and prey constraints (Newhouse and Kinley 2001, Weir et al. 2003), although the exact effects of modification, alienation, and loss of habitat on badger populations in the province are largely unknown (*jeffersonii* Badger Recovery Team 2008).

Badgers in south-central BC (the 'Cariboo' region) have only recently been studied, in part because of the overall growing concern for badgers in the province. Prior to 2003, little was known about these animals other than the occasional sighting and vehicle collision mortality report. Fortunately, the fact that pressure on the population from human activities may be relatively recent suggests there may still be time to prevent the drastic decline of the animals seen in other regions. In 2003, the BC Ministry of Environment launched a project aimed at identifying the distribution and abundance of badgers in the region through burrow searches and solicitation of sightings of badgers and their burrows (Hoodicoff and Packham 2007). The project's objectives later evolved to include developing and testing non-invasive DNA hair-snagging techniques for estimating badger demographics in the region. A number of recovery activities in the Cariboo region resulted from this research, including refining hair-snagging protocols and creation of managed Wildlife Habitat Areas to maintain and improve habitat for badgers on public lands. In response to road mortality recorded during the project, badger road crossing signs to warn motorists were erected along Highway 97 in the central Interior.

It is well known that some carnivores have been severely affected by the expansion of transportation infrastructure (Ferreras et al. 1992, Proctor et al. 2005, Taylor 2005), however little is known about the response on populations due to mortality (Noss et al. 1996, Blanco et al. 2005). Roads can impede the movement of animals between resource patches, subdivide populations, and increase the risk of road mortality due to collisions (Forman et al. 2003). The leading cause of mortality for badgers in BC is badger-vehicle collisions on major highways (Weir et al. 2003, Kinley and Newhouse 2008). This pattern is not restricted to BC, as American wildlife biologists also have reported elevated mortality due to collisions with vehicles (Messick 1987), and the impacts of vehicles on the Eurasian badger (*Meles meles*) are well known (Clarke et al. 1998).

Badgers are vulnerable to highway mortality for several reasons: (1) highways are constructed in valley bottom habitats preferred by badgers, (2) badgers' large home ranges and peak movement rates (mating period) coincide with peak summer traffic volumes; (3) roadside right-of-ways are attractive to badger prey, and (4) badgers are most active at night, when drivers have greatest difficulty seeing smaller animals on the highway. In BC, proportion of mortality attributed to badger-vehicle collisions ranged from 13% in the East Kootenay to an astounding 86% in the Thompson region (Weir et al. 2003, Kinley and Newhouse 2008). Further habitat loss and degradation will likely cause further increases in road mortality.

Understanding the anthropogenic impacts of roads on badgers in the region is particularly pressing given that this population occurs at the extreme northern edge of their range. Peripheral populations are presumably encountering natural, limiting factors (e.g., soils, climatic factors), so the additive or synergistic effects of a factor like road mortality may be accentuated and lead to local extirpation (Kirkpatrick and Barton 1997, Fraser 2000, Vucetich and Waite 2003). Further, peripheral populations are likely to experience different regimes of natural selection than central populations, as geographically outlying populations are likely to occur in ecologically marginal or stressful conditions (Lesica and Allendorf 1995). Many species at the edge of their range occur in unusual or atypical habitats (van Woudenberg and Christie 1997). Thus, peripheral populations are expected to be genetically distinct because of divergent natural selection (Lesica and Allendorf 1995). This theory is supported by genetic sampling of badgers in BC, as Kyle et al. (2004) found genetically distinct units between populations separated by mountain ranges. Therefore, badgers in south-central BC have a high conservation value as distinct traits found in this population may be crucial for allowing the species to adapt in the face of environmental change.

THESIS GOALS AND STRUCTURE

As mentioned above, the monitoring of badgers in the Cariboo region of BC was initiated in 2003 by government biologists to determine burrow distribution and identify individuals. Using newly emerging DNA hair-snagging methods in 2007, I expanded the scope of the Cariboo region badger project to include live-capture and VHF radio-monitoring, in tandem with newly emerging micro-GPS technology. The overarching objective of my study was to investigate the complex relationship between badgers, their habitat, and roads within south-central BC. To my knowledge, few studies have attempted to summarize and interpret the patterns of mesocarnivores in relation to roads (Clarke et al. 1998, Grilo et al. 2009), with none relating to the North American badger. My intent was to use this information to provide natural resource and transportation planners and managers with insight and tools that may be used to mitigate road mortality for badgers in south-central BC, and ideally, elsewhere in the species' range.

The specific objectives of this thesis are presented in three main chapters. In the current chapter, I provide background and the historical context for my study, including a detailed description of the study area (see below). In Chapter 2, I report on the ecology of these animals in this region, mainly from the perspective of roads and sources of mortality and then examine the implications of this for the badger population. Finally, in Chapter 3, I present more focused discussion on how an understanding of the ecology of badgers (particularly movements) may be integrated into habitat protection and restoration plans, including mitigation for current and future road infrastructure projects, thereby reducing impacts on this species.

STUDY SITE DESCRIPTION

My field work was conducted in the Cariboo region surrounding the community of 100 Mile House in south-central BC (N51° 39′ 11″, W121° 17′ 29″). Non-invasive data collection coupled with an intensive radio-telemetry study occurred over an area encompassing approximately 7,200 km^2 (Figure 1.3). Due to the vast expanse and remoteness of this area the radio-telemetry component occurred within the core area (local study area) where highways bisected the regional study area.

The Cariboo region in BC is predominantly a broad, flat plateau between two mountain systems consisting of level to gently rolling landscapes, with incised river valleys and uplands locally rising above the general surface (Steen and Coupé 1997). The study area consists primarily of the physiographic subdivisions of the eastern Fraser Plateau, with a small amount of the Fraser Basin in the north, and very small areas of the Quesnel Highlands

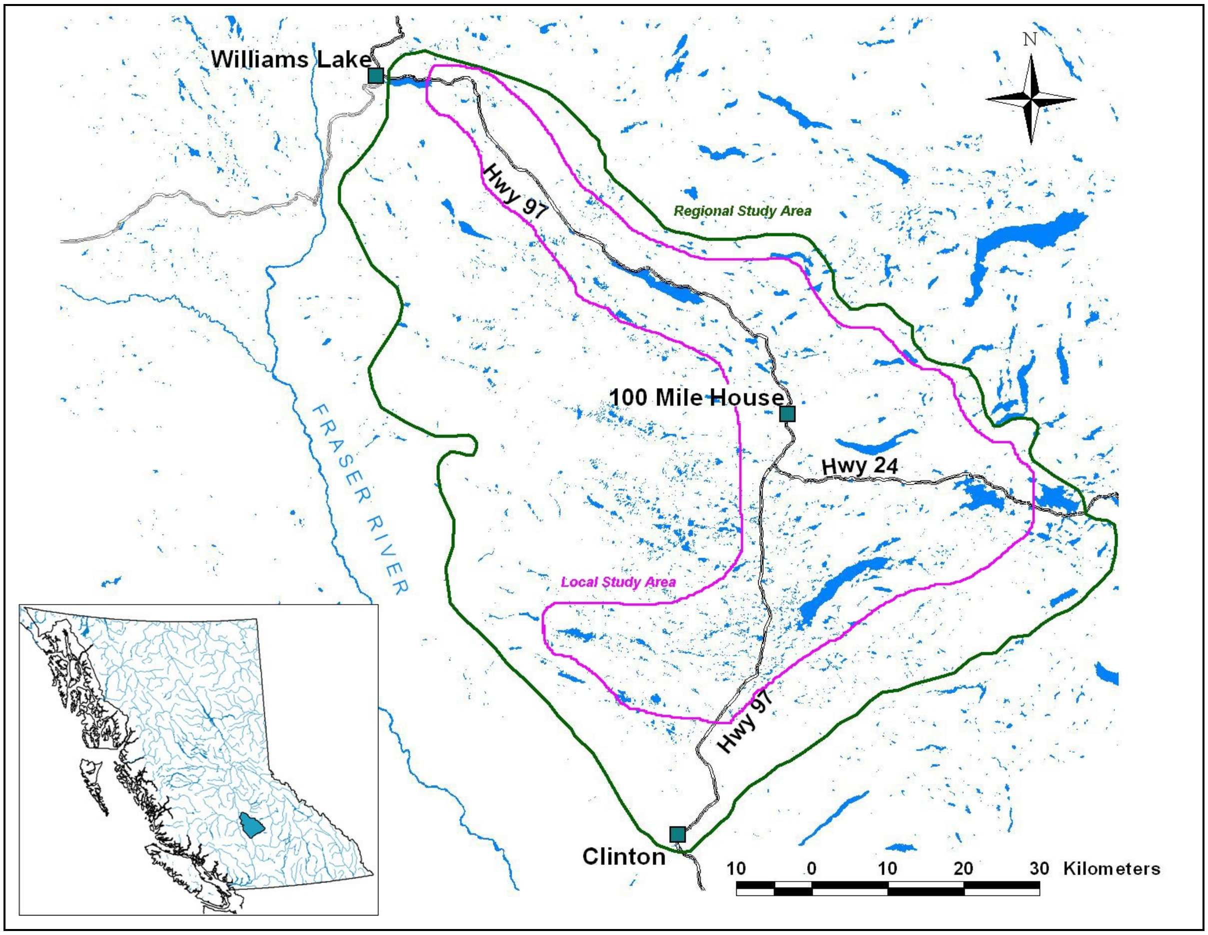

Figure 1.3. Regional badger study area (outer) and local study area (inner) with highway locations near the community of 100 Mile House (N51° 39′ 11″, W121° 17′ 29″) in south-central British Columbia, Canada.

to the east and Thompson Plateau to the south (Holland 1976). The Fraser Plateau, bounded by the Coast Mountains to the west and Columbia Mountains to the east, covers the majority of the study area with elevations of 900 – 1,500 m.

The area is underlain primarily by flat-lying to gently dipping olivine basalt bedrock, which in most areas is covered by a mantle of medium- to coarse-textured glacial till. In some areas the till is shaped by glaciers into drumlins and eskers (Holland 1976, Steen and Coupé 1997). A small portion of the study area is made up of the Fraser Basin where it extends north along valley bottoms from Lac La Hache to Williams Lake. This area is characterised by a low-relief, low-lying plain covered by glacial till and glacial lake deposits. The till frequently forms eskers and drumlins (Figures 1.4A and 1.4B).

The climate of the region is influenced by three principal air masses: warm, moist Pacific air form the west; cold, dry Arctic air from the north; and warm, dry Great Basin air from the south (Steen and Coupé 1997). Since the region is in the lee of the Coast Mountains, the moist westerly airflow is restricted resulting in a much drier continental climate. As Pacific air moves eastward across the Fraser Plateau, humidity and precipitation increase. Mean annual precipitation at 100 Mile House is 453.3 mm and at nearby Bridge Lake, approximately 44 km southeast, it is 599.3 mm (Environment Canada climate normals, unpub. data). The Arctic air mass lies north of the region during most of the summer but influences climate during the winter months, resulting in periods of very cold temperatures. However, the region is somewhat buffered by the full effects of the cold by mountain ranges to the northeast. High snowfall events often occur when the cold Arctic air invades the region and interacts with the moister Pacific air. Northern higher elevation parts of the region are more affected by Arctic air incursions than are southern portions and, as a result, the northern areas experience colder snowier winters and cooler summers. For example, mean annual temperature at Lillooet (elev. 198 m, approx. 115 km southwest) is 9.2° C, while at 100 Mile (elevation 1059 m) it is 4.2° C (Environment Canada climate normals, unpub. data). Warm Great Basin air has relatively little effect on the climate in this region, except in the Fraser River valley south of the Chilcotin River confluence, where hot, dry air in the summer can penetrate from the south, resulting in high daytime temperatures and clear skies. The relatively high elevations of the Fraser Plateau usually restrict the influence of this hotter air mass in the study area, resulting in cooler summer temperatures.

Figures 1.4A and 1.4B. Aerial photo of Highway 97 bisecting valley bottom habitat in northern portion of study area (above); and rolling hills with grassland/pasture habitat in central portion of study area (below) in south-central BC, Canada.

Vegetation patterns in the study area reflect the patterns of climate, topography and soils. The majority of the Fraser Plateau landscape is made up of climax stands of relatively open and slow growing lodgepole pine (*Pinus contorta*) . Higher precipitation areas and sites adjacent to wetlands often include hybrid white spruce (*Picea glauca var. engelmanii*). Where elevations become lower and summer temperatures are higher, Douglas-fir (*Pseudotsuga menziesii*) forests are well represented on the landscape often in mixtures with lodgepole pine. In these drier sites, Douglas-fir is the climax tree species. Pinegrass (*Calamagrostis rubescens*) is consistently present and often dominates the undergrowth of these forests. Further eastward, as precipitation increases, the Douglas-fir forests become seral to spruce forests, which become increasingly common. Small pockets of deciduous forests, dominated by aspen (*Populus tremuloides*), occur throughout most of the Fraser Plateau being more common and extensive in the northern Fraser Basin area towards Williams Lake. In the study area, native grasslands occur extensively on the slopes of the Fraser River valley south of the confluence of the Chilcotin River. These grasslands extend east into the Fraser Plateau before gradually transitioning to conifer dominated forests, with small grasslands occurring locally on dry, south-facing slopes. Grasslands are also common in open forest parklands in parts of the Interior Douglas-fir (IDF) zone further eastward. Wetlands are very common in the study area outside of the Fraser River valley, and are predominantly fens, marshes, and shrub-carr [(Steen and Coupé 1997) (Figures 1.5A and 1.5B)].

Soil parent materials in the Cariboo are predominantly glacial till of medium to coarse texture (Valentine and Dawson 1978). The till materials were generally transported only relatively short distances by Pleistocene glaciers and, as a result, the composition of the till often reflects the local bedrock. Coarse textured tills are common across the western Fraser Plateau where they were derived from granitic rocks of the Coast Mountains. Glaciofluvial and fluvial deposits occur locally, forming outwash plains, terraces, and eskers especially in valley bottoms. Lacustrine deposits occur locally and sporadically, particularly in the north portion of study area near Williams Lake. Deep organic deposits have a small extent and are much localized.

Figures 1.5A and 1.5B. Examples of badger habitat adjacent to wetlands. Field technician documenting a burrow in fine-textured soils upslope of a wetland, with grassland transitioning to Douglas fir dominated forests in background (top); Typical badger habitat adjacent to wetlands in the central portion of study area (below).

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CHAPTER 2 – ROAD ECOLOGY OF BADGERS (*TAXIDEA TAXUS*) IN SOUTH-CENTRAL BRITISH COLUMBIA, CANADA

INTRODUCTION

Over the past decades the density of transportation routes in North America has increased significantly, resulting in large numbers of wildlife being killed on roads (Stoner 1925, Lalo 1987). Understanding the factors that contribute to road mortality has emerged as one of the more critical issues facing wildlife conservation in many developed countries (Davies et al. 1987, Jones 2000, Mumme et al. 2000, Dique et al. 2003). Roads and their traffic have major impacts on animal populations and communities, and traffic mortality is a serious conservation concern worldwide for many species, especially those with declining or restricted distributions such as rare carnivores (Bennett 1991, Trombulak and Frissell 2000, Forman et al. 2003). The field of road ecology has emerged as a powerful tool for understanding the complex relationship between wildlife and the effects of roads on their populations.

Many carnivores have been seriously impacted by the expansion of transportation systems and networks; however we know little about carnivore response to the extent and magnitude of traffic mortality (Smith and C. K. Dodd 2003, Grilo et al. 2009). Carnivore populations exhibit several traits that can render them particularly vulnerable to habitat fragmentation and highway impacts. Because of their relatively large home-range sizes, carnivores often have to cross one or more highways to fulfill their food or water requirements, find mates, or disperse into unoccupied habitats (Ruediger 1998). Carnivore populations can be put at further risk when mortality rates rise because of their low population densities and reproductive rates (Ruediger 1998, Riley et al. 2006). Roads have been identified as a serious source of mortality for many medium-sized carnivores (or ‘mesocarnivores’) as their smaller size makes them more difficult to detect by motorists, and mortality rates of these animals from collisions often is underestimated (Ferreras et al. 1992, Clarke et al. 1998, Riley et al. 2006)

As mesocarnivores, North American badgers (*Taxidea taxus*) appear highly susceptible to road mortality. In particular, near the northwestern mountainous portions of their range a combination of factors predisposes the animal to road mortality: (1) highways in this region are constructed in valley bottom habitats preferred by badgers, (2) large home ranges are correlated with extensive movements, with peak movement periods (mating season) coinciding with peak summer traffic volumes; (3) roadside right-of-ways are attractive to badger prey, and (4) badgers are most active at night, when drivers have greater difficulty seeing a smaller animal on the highway. In BC, the leading cause of mortality for badgers has been identified as road mortality on major highways, with rates of ranging from 13% to an astounding 86% (Weir et al. 2003, Kinley and Newhouse 2008, Hoodicoff et al. 2009). This phenomenon is not restricted or new to BC, with American wildlife biologists in the northwest reporting elevated badger mortality due to collisions with vehicles (Messick 1987), and similar impacts are seen on populations of the European badger (*Meles meles*) (Clarke et al. 1998). Further habitat loss and degradation coupled with highway and traffic expansion will only serve to increase road mortality of these animals.

In south-central BC, the effects of road mortality on the North American badger become even more serious when viewed within the context of the animals being at the northern periphery of their range (see Figure 1.1 in Chapter 1). Indeed, the extreme northern limit for the badger subspecies *T.t. jeffersonii* is found within the central portion of BC, Canada (N51° 39′ 11″, W121° 17′ 29″). Peripheral populations such as this often represent strongholds for species undergoing declines, and may be important reservoirs of genetic diversity (Lesica and Allendorf 1995). In many cases, broad landscape approaches may be efficient in protecting peripheral populations (Noss 1987, Franklin 1993), but variations in life-history and demographics often make detailed information on these peripheral populations critical, especially for maintaining genetic variability (Millar and Marshall 1992, Soulé and Mills 1998, King and Burke 1999). Anthropogenic impacts on populations likely will work in an additive or synergistic manner with ecological constraints already occurring at the limit of a species' range.

As mentioned, the mountainous topography in central BC renders badgers prone to road mortality, partly because of the distribution of habitat. In this region, the open dry grasslands typically associated with these animals (Lindzey 1978, Messick and Hornocker 1981, Goodrich and Buskirk 1998, Paulson 2007) are predominantly found in valley bottoms where transportation corridors are typically placed. However, data collected during previous home range studies in BC have revealed a wider range of habitats used by badgers than expected. For example, the animals have been shown to use higher-elevation forests, including recent forest harvest blocks where prey (e.g., ground squirrels) were abundant (Apps et al. 2002, Weir et al. 2003). At the extreme northern range limit of the *jeffersonii* badger, there is a strong contrast in both topography and climate, suggesting different patterns of habitat use may be in effect. At this location, the topography is generally less rugged with patchy burrowing soils, and the climate is considerably harsher due in part to both increased elevation and latitude. Initial burrow searches and badger sighting records in this region indicate that badgers inhabit a diverse array of habitats, ranging from bunchgrass to sub-boreal pine and spruce zones. However, road mortality also occurs in the region, suggesting that the formulation of effective management plans for these animals will likely need to encompass a wider range of habitat types than previously thought, as well as address the incidence of road mortality. Given that traffic volume likely will increase in the face of northern development, a solid understanding of the ecology of these animals, including the impact and causes of road mortality, is needed to ensure their persistence at the northern periphery of their range.

I conducted a detailed ecological study of the northern-most badger population in BC. The overarching goal was to better understand the relationship of these animals to their extreme northern environment, and how that was potentially linked to road mortality on major highways bisecting the area. This complex relationship was investigated using conventional radio-telemetry in tandem with newly emerging GPS technology. The specific goals of my study were to:

- examine home range and movements of badgers, including dispersal of juveniles, particularly in the summer months when road mortality is highest;
- document reproductive success of adult females including seasonal timing of kit emergence and natal den abandonment and how roads may affect these patterns;
- quantify mortality factors of the studied population;
- document the distribution and abundance of animals in the region and the influence of roads on these parameters; and
- determine how existing highway infrastructure features may influence badger movements and connectivity.

Herein I use my data to examine the demographic parameters and the ecological effects of roads pertinent to the development of management plans for this extreme northern population, as well as badger populations elsewhere that may be facing similar challenges. Given the strong tie of my study to road ecology, my field work was focused towards the summer season (highest traffic volumes, breeding, etc.). A simultaneous study investigated the winter denning ecology of the animals (Symes 2013).

STUDY AREA

From 2007 to 2010, I conducted field work in the area surrounding the community of 100 Mile House, BC (N51° 39′ 11″, W121° 17′ 29″) (Figure 2.1). Non-invasive data collection coupled with an intensive radio-telemetry study occurred over an area encompassing approximately 7,200 km^2. Due to the vast expanse and remoteness of this area the radio-telemetry component occurred within the core area (local study area) where highways bisected the regional study area. The study area is comprised of a broad, flat plateau between two mountain systems, covered by glacial till and glacial lake deposits with elevations ranging from 900 – 1,500 m above sea level. The topography is level to gently rolling landscapes with incised river valleys and uplands locally rising above the general surface (Steen and Coupé 1997). The till frequently forms eskers and drumlins that provide badgers with friable soils suitable for burrowing.

Moisture regimes increase from west to east across the plateau. Summers are influenced by warm, moist Pacific air from the west and warm, dry Great Basin air from the south, resulting in a drier continental climate. Winters are influenced by Arctic air masses, leading to very cold winter temperatures with relatively low winter precipitation.

Much of the study area is dominated by Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine *(Pinus contorta*) trees that occur in open savannah-like stands on drier sites, with bluebunch wheatgrass (*Pseudoroegneria spicata*) and rough fescues (*Festuca* spp.) forming the understory. Wetter sites at higher elevations support dense conifer stands with pinegrass (*Calamagrostis rubescens*), and feathermoss (*Hylocomium splendens*) understory.

Soopolallie (*Shepherida canadensis)*, kinnikinnik (*Arctostaphylos uva-ursi*), rose (*Rosa* spp.), and twinflower (*Linnaea borealis*) are common understory shrubs. At lower elevations, the west and south of the study area is bordered by very dry warm bunchgrass-open forest communities, while at higher elevations to the north and east it is replaced by the

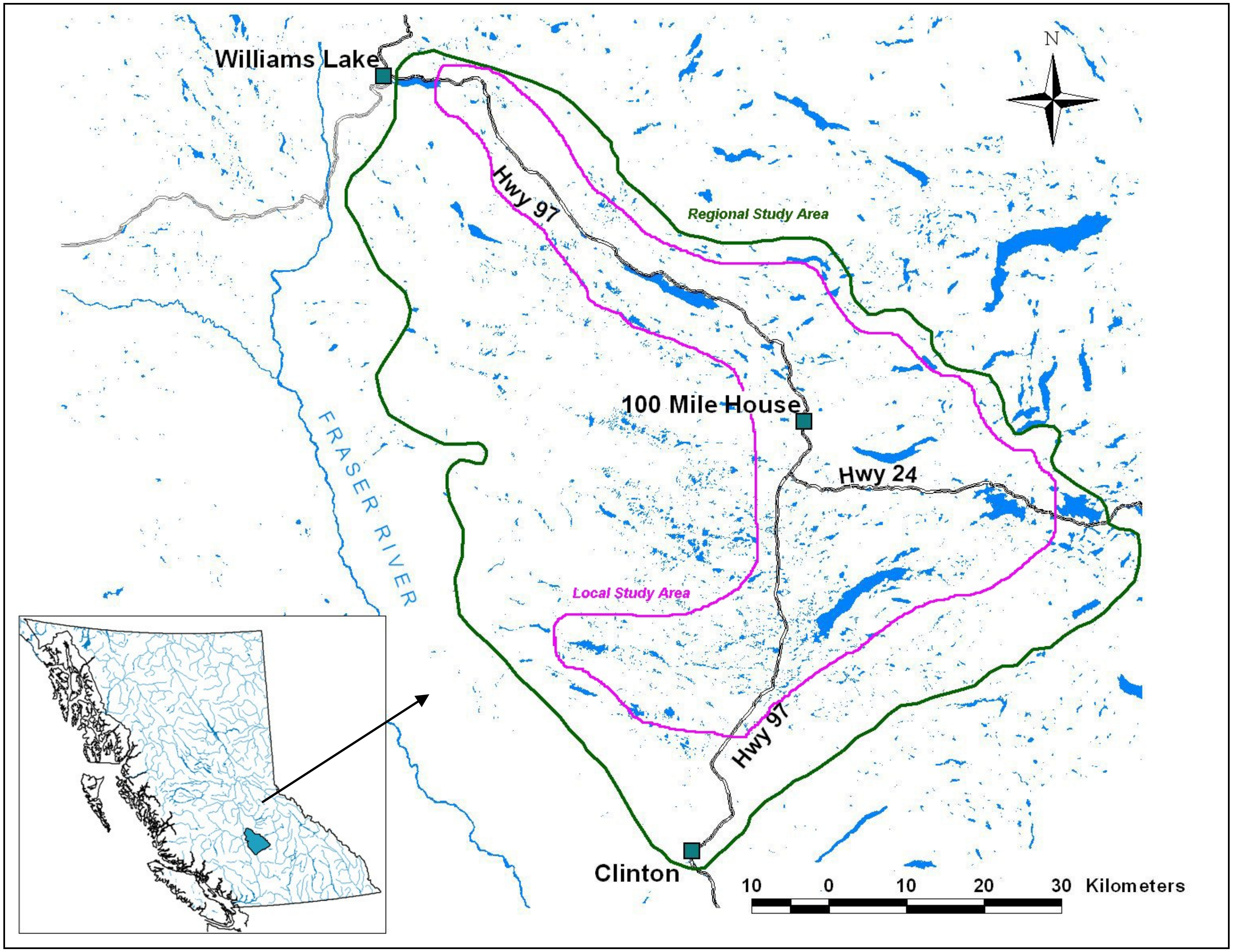

Figure 2.1. Regional study area (outer) and local study area (inner) boundaries with highway locations near the community of 100 Mile House (N51° 39′ 11″, W121° 17′ 29″) in south-central British Columbia, Canada.

cool, dry climates of lodgepole pine and spruce (*Picea glauca*) climax forests (Steen and Coupé 1997). Trembling aspen (*Populus tremuloides*) stands are common, and aspen is often scattered throughout the forest stands in the study area. Small pocket grasslands occur locally on south-facing slopes often bordering the many lakes and wetlands in the region. For a more detailed description of the study area refer to Chapter 1.

There are two major highways that pass through the study area: Highway 97 bisects the study area in a north-south direction, and Highway 24 runs on the eastern portion of the study area in an east-west direction (see Figure 2.1). Much of Highway 97 follows the historical wagon route along the valley bottom through native grasslands and open forests between the communities Cache Creek and Quesnel. With the growing need for an improved transportation system from the west coast to the economically-expanding north, Highway 97 will be upgraded to accommodate this growth. These upgrades are projected to include the widening of a 440 km portion through the central interior to four lanes of traffic. By 2022, almost 50 per cent of this segment will be either three or four lanes wide [(British Columbia Ministry of Transportation and Infrastructure [MoTI] 2009)]. Highway 24 currently serves primarily as a two-lane tourist highway linking many fishing lakes to smaller communities in the interior of the province.

Traffic volumes along Highway 97 range from 3,737 vehicles/day annually (AADT) to a peak of almost 7,000 vehicles/day during summer, while Highway 24 has much lower traffic volumes with an approximate average annual daily traffic volume of 911 vehicles/day, and a high of 2,000 vehicles/day in summer [(British Columbia Ministry of Transportation and Infrastructure [MoTI] 2010)].

METHODS

Live-capture and radio-telemetry

Active ground searches by vehicle and on foot were conducted within the local study area to determine recent badger activity (i.e. fresh burrows). Attempts were made to capture an equal number of badgers both within close proximity to highways (≤ 1 km) and distant from highways (≥ 4 km). Badgers were live-captured during May to August of 2007 – 2009 using Victor # 1 ½ padded soft-catch foot-hold traps (Victor-Oneida, Woodstream Inc., Lititz, Pa.), anchored with 40 – 45 centimeter cable T-anchor and set at active burrow entrances. Traps were set overnight and checked twice daily, at least every 12 hours. However, if traps were set at a burrow known to be occupied, the site was monitored continuously until capture or closing of the traps.

Captured badgers first had their weight visually estimated for drug volume and then were noosed using a restraint pole. Telazol® (tiletamine and zolazepam) was hand-injected in a large muscle mass at a dose of 5 – 10 mg/kg body weight, in a concentration of 100 mg/mL. Once immobilization had taken place, body condition was assessed, vital signs were monitored, and ophthalmic ointment was applied.

Immobilized badgers were either transported to a veterinary clinic or a mobile veterinary field unit for intraperitoneal implantation of VHF radio-transmitters using standard sterile surgical techniques. The animals were transported in a ventilated 200 L plastic barrel with a lid and secured in the back of an open-aired vehicle. An internal temperature sensor was used to remotely monitor temperature inside the barrel. Biological samples and morphometrics were conducted post-surgery while the animal was still under anaesthesia. Hair and tissue samples were collected for genetic analysis. No teeth were extracted for aging as we classified age by tooth wear (i.e., juvenile, young adult, mature adult, old adult). In order to distinguish individuals from public sightings (photo evidence), field observations, camera traps, and road mortality, we photographed the unique facial pelage and patterns of all individuals (including kits that we did not radio-tag).

Badgers were held for 1 – 2 hours after surgery until they were deemed sufficiently recovered from anaesthesia, demonstrating normal balance, posture, reflexes, and reactions. Once recovered, the animals were transported to the initial point of capture and released at their burrow. Monitoring then occurred regularly over the next 48 hours to ensure that the badgers returned to regular activity patterns.

Radio-telemetry locations were obtained by using a vehicle-mounted omni-directional antenna and an R-1000 receiver (Communication Specialist Inc., Orange, Calif.) to locate the general area the animal was using, and then following the signal on foot using a handheld radio-telemetry system. If precise locations of the animal (e.g. in a burrow, hunting in a pasture) could not be determined, I took several compass bearings and Universal Transverse Mercator (UTM) coordinates from a global positioning system (Garmin, Inc.) for triangulation. The triangulation software program LOCATE III (Pacer Computing, Tatamagouche, NS) was used with the Maximum Likelihood Estimator (MLE) to determine an accurate location from triangulation data. If the animal was stationary, I located the burrow it was in and recorded UTM coordinates, broad habitat type, presence/absence of Columbian ground squirrels (*Spermophilus columbianus*) within a detectable distance by surveyors (≤ 100 m), and geophysical characteristics. Locations were obtained from early morning throughout the day until dusk. Late night locations in the dark were rarely attempted as the animals were usually active and moving and I did not want to deter or influence their foraging behaviour or movement patterns. During summer field season (May to August) my crew and I attempted to collect a minimum of one location per week per individual, but this frequency shifted to once every two weeks in the fall and winter months when badgers reduced their movements, sometimes entering into a period of inactivity or torpor (see Symes 2013). Attempts were made while radio-tracking badgers to observe and document any road crossings, either above or below grade. Periodic fixed-wing telemetry flights were conducted when an individual was not located for two or more consecutive weeks. Locations of individuals identified during previous DNA sampling sessions also were used to augment radio-telemetry locations of study animals.

A subset of study animals were outfitted with GPS datalogger backpacks to determine detailed movement patterns. To accomplish this, telemetered animals were recaptured > 1 year after implantation using the same capture and handling techniques described above. Animals were fitted with a nylon harness that encircled their neck and chest and was stabilized by two crossing sternum straps that prevented the top-heavy GPS unit from sliding under the animal (Figures 2.2A and 2.2B). The GPS and harness were secured with a quick-release device so that the entire unit could easily be retrieved from the animal after being deployed for 2 – 4 weeks. The attachment harness was pilot-tested on a tame, captive badger prior to deployment on wild animals. The GPS unit paired with a small VHF tracking device (Sirtrack Ltd., NZ) was attached to the top of the harness in order to obtain exposure to satellites in the sky when the animal was moving above ground (Figure 2.3). The GPS unit was programmed to obtain a fix every 15 minutes. If satellites were detected by the unit (animal was above ground), the satellite search would continue for three minutes until a fix was obtained; otherwise, the unit would shut off until the next programmed fix.

Figures 2.2A and 2.2B. Harness system testing on tame, captive badger illustrating sternum strap for stabilization of GPS datalogger backpack (top), and removing the harness system (bottom) at British Columbia Wildlife Park, Kamloops BC, Canada, June 2008.

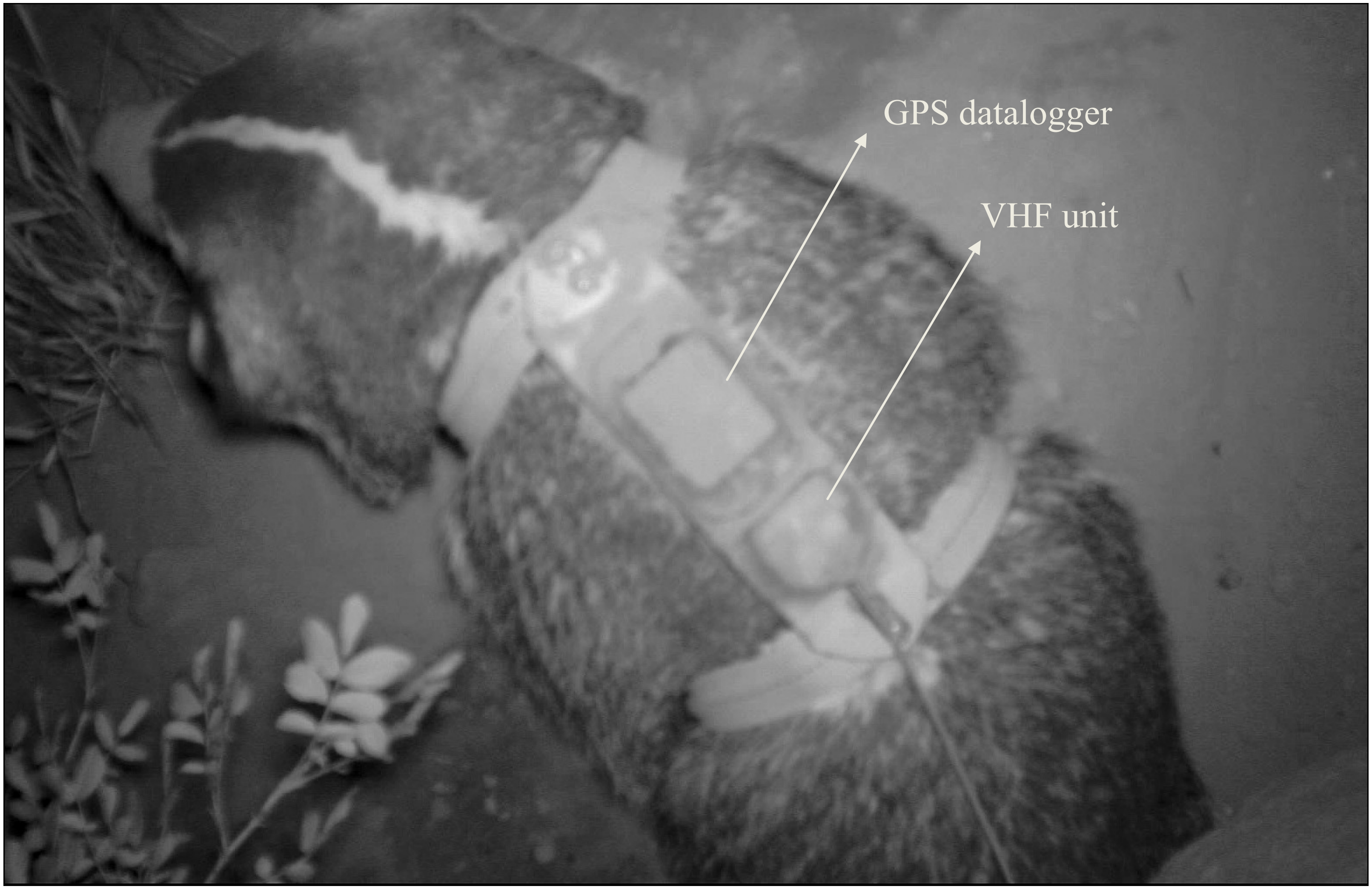

Figure 2.3. Dorsal view of a wild free-ranging male badger outfitted with GPS datalogger nine days after deployment exiting from a burrow near Meadow Lake, BC, 14 August 2009. Photo taken by remote motion camera.

If no satellites were detected (e.g., animal below ground), the unit would continue the satellite search for 30 seconds before shutting down until the next programmed fix. This programming prevented undue drainage on the battery caused by prolonged satellite searches by the unit while the animal was underground.

Home range and movements

To calculate badger home ranges I applied fixed kernel (FK) estimation using least-squares cross validation (Seaman and Powell 1996; Powell 2000; Kernohan et al. 2001). Kernel estimators have a number of features that make them useful for home ranges calculations: they work well with small amounts of data, they are robust to autocorrelation, they are nonparametric, and they allow multiple centers of activity rather than a simple home range outline (Kernohan et al. 2001). I did not use the adaptive kernel method as it tends to perform poorly, often over-estimating home range areas (Seaman and Powell 1996, Powell 2000). I used the program *The Home Ranger* (Hovey 1999) to calculate FK home range estimates followed by post-processing and importing the outputs into Arcview 3.2a (ESRI) for further spatial analysis. Annual home ranges (95% FK) were calculated for individuals with > 30 radio-locations spanning a year of radio monitoring. Due to tracking constraints and the unpredictable road mortality of study animals, seasonal range sizes were sometimes estimated using ≥ 5 radio-locations.

A geographic information system (GIS) was used to display 95% FK, including 100% minimum convex polygons (MCP) using the extension Home Range in ArcView (Rodgers and Carr 1998) for all animals. Displaying 100% MCP in concert with 95% FK is useful for displaying locations with disjunct kernels (concentrated areas of use) derived by the fixed kernel (FK) method with an overall area that an animal may use (MCP).

I divided seasonal home ranges based on four intervals that corresponded to annual life-history phases of badgers. Radio-telemetry locations were then grouped into seasonal categories based on these periods of times: summer for rearing of kits by females and breeding for both sexes (1 June – 31 August), fall for post-breeding recovery and pre-winter fattening for both sexes (1 September – 30 November), winter for reduced activity and dormancy for both sexes (1 December – 28 February), and spring for parturition/rearing for females (1 March – 31 May). Where sufficient samples sizes were collected, comparisons of adult male and female annual and seasonal home range sizes were conducted using Mann-Whitney (U) Rank Sum Tests. Using FK methods, home range core areas (50% utilisation distribution, UD) were delineated to compare distances from the edge of core areas to the nearest highway.

Movement data acquired from GPS datalogger units were analysed for animals that collected data for > 24 hr period in order to be considered independent after harnesses were initially outfitted. Movement rates were divided into 2 categories: (1) an **active period** that included movements collected for every programmed 15 minute fix up to 2 hours to account for short term underground forays, presumably foraging for fossorial rodents, and (2) an **inactive** period that spanned periods where badgers made minimal movements for extended periods of time (i.e., > 2 hrs).

The systematic collection of hair from badgers to identify individuals using DNA fingerprinting began in 2003 to 2006 by government biologists (Hoodicoff and Packham 2006), and concluded with my data collection for this thesis from 2007 to 2009. This system provided both distribution and abundance data in the region. A similar approach has been used successfully with other mustelid species including American marten (*Martes americana*), fishers (*Pekania pennanti*), wolverines (*Gulo gulo*), and European badgers (*Meles meles*) (Belant 2003, Zielinski et al. 2006, Mulders et al. 2007, Scheppers et al. 2007). Data collected using this method provided me with additional information for tracking individual movements, identifying road mortality individuals, and kit dispersal patterns.

Whenever possible, a combination of DNA samples, telemetry, dispersal locations and known fates of individual badgers were determined to provide insight into movement patterns. Several hundred DNA samples (n = 618) collected across the regional study area from 2004-2006 prior to my radio-telemetry study provided baseline demographic data. During this period, 51 badgers (23 ♀, 28 ♂) including two litters, were identified in the region (Hoodicoff and Packham 2007). This DNA hair-snagging program was continued during my live-trapping program in 2007 – 2009. As juvenile badgers have been known to remain on their mother's territory for one year before dispersal, dispersal distances were defined by the distance from the known natal den to the furthest point of detection (e.g., radio-telemetry, DNA, road mortality) from the den within 24 months. Documenting these dispersals allowed me to compare dispersal distances between male and female juveniles (t-tests).

Reproduction

Monitoring of telemetered adult females was conducted more frequently in March to determine the time and location that natal burrows were excavated and/or used. If a female remained at a single burrow for more than two consecutive weeks during late March, a remote motion camera was placed near the den entrance to document the activity pattern of the female, number of kits, and time of kit emergence from the natal den (Figure 2.4). This method also documented the time when natal dens were abandoned and new maternal dens were established. Kits were individually recognized by their unique facial pelage patterns, allowing me to distinguish individual kits and thereby calculate litter size (at least at time of emergence). Facial pattern recognition also allowed me to identify other adult badgers that visited the burrow complex during camera deployment. Observations of copulation by telemetered badgers (both females and males) allowed me to confirm the timing of breeding.

Mortality

Telemetry allowed me to determine mortality factors and location, particularly during the summer (high traffic) season. I also solicited sightings of badgers killed on roads from the public through local newspaper releases, radio interviews, and by placing information posters on community billboards (Appendix C). Reports of dead badgers were verified as soon as possible and biological samples, UTM coordinates, occupancy of ground squirrels in vicinity, and associated roadside habitat types were collected at confirmed mortality sites. Previous badger road mortality sites and archived DNA samples collected from 2003 – 2006 by government biologists also were used in the analysis.

Known badger road mortalities were spatially defined using fixed kernel (FK) methods that highlighted areas of concentrated road mortality sites or ‘hotspots’. These road mortality hotspots were delineated using the 70% utilisation distribution (UD) kernel to identify segments of highway where badger road mortality most commonly occurred. Roadside habitats were then determined at road mortality sites in the study area from Predictive Ecosystem Mapping (PEM) conducted for the Cariboo region (2008).

Figure 2.4. Remote infrared motion camera housed in security box attached to stand deployed at badger burrow.

Kaplan-Meier survival curves (LogRank test) were used to assess the survival probability for radio-tagged males and females over the duration of the study.

Finally, home range core areas (defined by 50% UD) of tagged badgers were delineated and distances from highways to the edge of core areas were compared to assess distance from roads and survival rates in relation to road mortality events for both sexes.

Distribution and abundance

Tracking individuals using DNA

We deployed hair-snagging devices throughout the regional study area where badgers were known to occur, at burrows that had been documented either through direct observations, radio-telemetry, and reports submitted from the public, or from previous burrow surveys conducted by government biologists. In order to maintain some form of systematic consistency, hair-snags were deployed during the same seasons and in areas that were previously sampled from year to year across the regional study area.

Over the course of the study, different material was used to snag hair, ranging from barbed wire to Velcro® pads to pinned knaplock (i.e., carpet edging material) attached to a metal band. In all cases, two opposing snagging plates (approximately 2.5 cm × 4 cm) were riveted to curved metal strapping that had snagging material affixed to it. These devices were anchored to the roof of a burrow using two metal ardox (spiral) nails that prevented slippage out of the soil roof, or by attaching a small gauge wire to the device and then feeding it up through a hole to the surface above the burrow, where it was fastened to a wooden peg anchor (Figures 2.5 & 2.6). This non-invasive method did not deter badgers from entering or exiting the burrow, allowing for the assumption of equal catchability to be met.

Live-capture samples, snagged hair, and road mortality tissue samples were air dried, stored in paper envelopes, and sent to Wildlife Genetics International (Nelson, BC) for DNA extraction and analysis. Over the course of collecting and analysing DNA for this study there were no changes to the DNA extraction protocol or to the convention used of recording data during extraction (QIAGEN DNeasy tissue extraction kit: QIAGEN Inc., Valencia, California). Samples were pre-screened with a single marker to identify species so that only

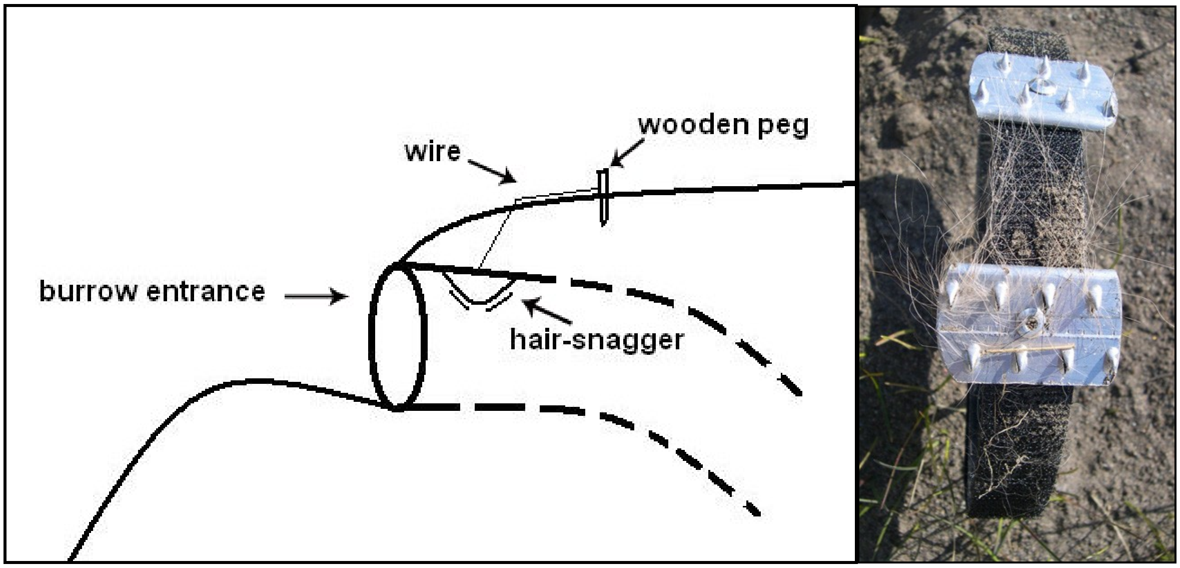

Figure 2.5. Schematic diagram (l) of hair-snagging device deployed in badger burrow and close up photo of hair-snagger (r) with suitable hair sample for DNA analysis. Each of the two snagging pinned knaplock segments were approximately 2.5 cm x 4 cm in dimension.

Figure 2.6. Hair-snagger deployed in active badger burrow revealing suitable hair sample for DNA analysis. Photo taken near 100 Mile House, BC by P. Verkerk.

badger samples were brought forward for further genetic analysis (Paetkau pers. comm. 2010). A standard set of 7 microsatellite markers was used to generate a complete 7-locus genotype with minimal clean-up procedures. Error-checking was done using a protocol that virtually eliminates the possibility of recognizing false individuals through genotyping error (Kendall et al. 2009). We used the markers ZFX/ZFY/SRY that produced a high-confidence gender analysis (Paetkau pers. comm. 2010).

Population modeling

Survival, capture, and recovery

Three modeling methods were used to determine (1) demographic parameters, (2) population size and (3) population growth. The program MARK (version 6.1) was unable to calculate weighted averages for some demographic parameters (i.e., survival, recapture) using one method alone. In addition to the Burnham (Both) model to estimate demographic parameters, models POPAN and Pradel-λ generated estimates of population size (N), and growth (λ) through program MARK (White and Burnham 1999, Cooch and White 2000).

I used a multi-model selection procedure to estimate demographic parameters for the regional badger population, based on the recovery of marked individuals. More specifically, the information-theoretic approach described by Burnham and Anderson (1998) was used to evaluate the relative support of multiple models describing relationships between population parameter variables, such as survival, capture probabilities, and recovery probabilities. Population parameters can be determined by using various complementary sources of data (e.g., recoveries, recaptures, and telemetry), thereby allowing estimates of parameters to be calculated when they would not otherwise be available. This approach improves the precision of parameter estimates, and provides “flexibility” in accommodating encounter data that are collected “opportunistically” throughout the year (Cooch and White 2000). For example, the assumption of permanent or random emigration in a study based on live recaptures can be relaxed if live re-sightings or dead recoveries are included in the analysis.

There were four main steps in the estimation of demographic parameters for badgers in the regional study area. Firstly (1), I constructed encounter histories for marked individuals, then (2) I used the Burnham (Both) model to estimate survival (S), recapture (p), and recovery (r) probabilities, followed by (3) determining how well the resulting general model fit the data by comparing the deviance of the general model using the bootstrap method and correcting for poor fit, which then (4) allowed me to use a maximum-likelihood method to determine the reduced model that best represented the data.

Burnham (1993) developed an approach for combining dead recovery and live encounter data into a single analysis, and I followed this approach using program MARK. I first constructed encounter histories for each individual badger from both live-recapture data, and live and dead encounters (Cooch and White 2000). Individual badgers were initially identified through live-capture and/or DNA sampling protocols. Following this method, a badger was recorded as "recaptured" in the annual summer field season if it was detected through any of the various methods being used, or as "not captured" if it was undetected during that time period. Once a badger was detected, subsequent recaptures in that same season were not considered in the analysis. DNA 'captures' were removed if they originated outside of the season or beyond the geographic extent of the study area. Badgers were analyzed separately according to gender.

Using the encounter histories constructed for individual badgers, I determined estimates of survival (S), recapture (p), recovery (r), and fidelity (F) using the Burnham (Both) model for live and dead encounters for open populations (Burnham 1993). For the joint analysis of live encounter and dead recovery data, MARK uses the Seber ('S and r') parameterization primarily to take advantage of increased flexibility (Cooch and White 2000). Based on the assumption that recoveries of dead marked animals and recaptures will occur in the same sampling area, fidelity (F) for the marked sample is fixed at '1' (Cooch and White 2000).

A general (global) model with all the population parameters mentioned above, dependent on group (i.e., male or female) and time, was fit to the Burnham (Both) model, followed by deriving models with reduced parameters to determine the best representation of the data. The fit of the general model was determined by comparing its deviance to the mean deviance of 1000 bootstrap-replicated models. I found this general model deviated significantly from the mean bootstrap deviance ($P = 0.045$), indicating poor fit. Accordingly, model selection was then based on a quasi-likelihood corrected version of Akaike's Information Criterion (QAICc)(Cooch and White 2000).

In order to determine the model that best represented the data, model selection was conducted using maximum-likelihood methods (Burnham and Anderson 2001). The corrected Akaike Information Criterion (AICc) was used to determine the model that was the most parsimonious (Burnham and Anderson 2004). To account for any overdispersion in the data (goodness of fit test), the model deviance of the AICc ($\hat{c}$=1) was adjusted to the deviance of the general model ($\hat{c}$=1.174), as calculated by the median $\hat{c}$ test in MARK. The adjusted $\hat{c}$ required that model selection be conducted using the quasi-likelihood estimator, QAICc (Burnham and Anderson 1998). Population parameter probabilities were then estimated using weighted averages from the QAICc model weights. In order to reduce errors deriving from invalid estimates of some parameters and standard errors during the model-averaging process, all models with less than one percent support from the QAICc were dropped from consideration (Cooch and White 2000). Weighted parameter estimates then were obtained from the reduced model list.

Population size

Given that data collection spanned several years, permanent additions or deletions to the population were present, so I used the open population model POPAN to estimate population size (N). This is a Jolly-Seber model derivative that uses mark-recapture rates to derive estimates of abundance and related parameters (Schwarz and Arnason 1996). This process varies from the Burnham (Both) model in that it estimates population size in addition to survival (*S*) and capture (*p*) probabilities. However, this model was not used to determine *S* and *p* simply because Program MARK is unable to calculate weighted averages for the POPAN models, where it will do so for the Burnham (Both) Jolly-Seber models. Final selection was based on the three most parsimonious models from the Burnham (Both) Jolly-Seber model (i.e., models with over 10% support from the QAICc). Constructed models were compared using the AICc to determine the most parsimonious model, which was then used to estimate population size for badgers in the region from 2003-2008.

Population growth

Population growth (λ) was estimated using the Pradel-λ formulation of the Jolly-Seber model, which also provides an estimate of survival (S), similar to the parameters survival (Φ), and recapture (*p)* (Pradel 1996). Similar to the POPAN formulation model, the

Pradel-λ model does not allow calculation of weighted averages for Φ and *p,* and therefore it could not provide estimated values for them. Models were therefore constructed using the three most parsimonious models from the Burnham (Both) Jolly-Seber analysis. Thus, λ was allowed to vary with time or it was held constant to determine which reduced model best fit the data. Model selection was achieved using AICc to determine the most parsimonious model from which the population growth estimate could be obtained. The Pradel-λ estimator requires that at least three sampling periods be carried out in order to calculate variables (Pollock et al. 1990). Unfortunately for this analysis, DNA identification cannot determine age class and all of the badgers had to be treated as a single group for the calculation of λ.

Highway structures influencing movements and mortality

Previous projects reported that existing underpass structures (i.e., culverts) may be used by badgers to cross under major transportation corridors (Newhouse and Kinley 2001). I therefore collected data on 114 potential underpass structures that existed within the local study area where badgers were known to occur, as determined by radio-tagged animals, road mortality sites, and burrows in the vicinity. This was done to determine the degree to which suitable and unsuitable crossing structures were present at badger road mortality sites. I recorded these structures as being **suitable** if a badger could easily traverse the structure unimpeded and **unsuitable** for a crossing if they showed blockages (e.g., crushed culvert ends, infilled or blocked openings, etc.), or if they had been originally installed with a hanging end (i.e. culverts protruding from the highway bank ≥ 45 cm above ground), or if water or mud ≥ 5 cm in depth was present in the actual structure.

Of the 114 structures that I investigated, 101 were corrugated metal culverts ranging in size from 400 mm to 1300 mm diameter, 12 were corrugated metal and concrete box livestock underpasses (2000 mm – 4000 mm diameter), and there was a single corrugated metal pipe installed for a stream crossing (4800 mm). Two open spans (i.e., bridges) were encountered during culvert surveys but were not assessed as they contained running water across their entire width.

To document the frequency and ratio of above and below grade road crossings by badgers, remote motion cameras were placed at entrances to underpass structures. This permitted a comparison of GPS movement data with camera data. Over the course of three field seasons, I monitored 41 potential underpass structures using remote motion cameras (Reconyx Inc., RC55) within radio-tagged badger home ranges. In order to simultaneously sample as many concurrent underpass structures as possible within a badger's home range, a single camera was placed at one opening of an existing structure and each motion event triggered three successive photos with no time delay between events. Successful crossings by animals were then determined by examining the sequential images from the cameras to determine if crossings were successful or not. Underpass structures ranging in size from 400 mm to 4000 mm were in the sample (37 corrugated metal culverts + 4 concrete box underpasses). Culverts ranging in size from 500 – 700 mm were most common along highway segments accounting for 80% of the sample surveyed. I selected three highway segments for this intensive monitoring where both radio-tagged badgers and road mortality occurred: (1) 3.2 km of Highway 24 in eastern portion, (2) 17.6 km of Highway 97 in central portion, and (3) 7.2 km of Highway 97 in northern portion of study area. These sites were spread across the study area ranging from two- to four-lanes in width.

To determine if the frequency of existing suitable crossing structures affected badger road mortality rates, I compared the number of suitable and non-suitable crossing structures between two segments of Highway 97 where known badger road mortalities frequently occurred. These segments had comparable traffic volumes, habitat types, soils, and landscape characteristics. In addition, small mammal surveys were conducted during August 2009 along highway right-of-way at these sites to determine the presence and distribution of common prey species. The north segment was 8.9 km and south segment was 10.1 km in length and were separated by 35 km. Using the Fisher's exact test, I compared the two segments for suitable versus unsuitable underpass crossing structures (i.e., culverts) and differences in mortality among those highway segments.

RESULTS

Despite the ongoing loss of study animals to road mortality, I was able to collect sufficient data to portray the ecology of badgers in this region, and the factors contributing to road mortality. A total of 84 badgers (42 ♂, 38 ♀, 4 unknown) were detected in the region during the course of this study. Of this sample, 16 animals (5 ♂, 11 ♀) were captured in the local study area, radio-tagged, and tracked from 2007 – 2009. A subset of 5 study animals (3

♂, 2 ♀) were equipped with a GPS datalogger backpack system for short-term intensive monitoring, this being to my knowledge the first such use of this technology on the species.

Live-capture and radio-telemetry

From 2007 to 2009 I captured more than twice as many females than males (5 ♂, 11 ♀); this sample may reflect the sex ratio of the population given the propensity for males to suffer mortality on roads (see below). Attempts to capture an equal number of badgers in close proximity to (≤ 1 km), and distant (≥ 4 km) from highways, resulted in seven and nine captures respectively. I collected 1,057 independent radio-locations spanning 914 days (July 31, 2007 – January 31, 2010). Individuals were located at least once a week from May – August ($\bar{x}$ = 4.2 days, SD = 0.81) and two to three times a month during spring, fall, and winter ($\bar{x}$ = 8.52 days. SD = 1.32).

Home range

The average annual home range size for both sexes was 70.1 km^2 (SD = 91.2, n = 11, Table 2.1). Across all seasons, adult male home ranges were considerably larger those for adult females (overall, t = -27.8, n = 9, 2, P = 0.001). Although five males were tagged, three were struck and killed on the highway within three months of tagging, providing limited spring and summer data on habitat use. Due to these constraints, the data from these animals were not included in the annual home range analysis, although seasonal home ranges were calculated using the radio-telemetry data collected during the summer and spring field seasons. The average home range for the two males that provided sufficient numbers of locations (415 and 716 days, see individuals BM01 and BM02, Table 2.1) was 253.1 km^2 (SD = 9.8, n = 2) while average for females were 29.4 km^2 (SD = 12.2, n = 9).

Important differences were noted in the size and shape of home ranges for male versus female badgers, and how they were orientated in relation to highways. In general, all badgers had some type(s) of road within their home ranges, with 12 home ranges containing a major highway, three having at least one paved secondary road, and one having a few two-lane gravel roads. Home ranges for males were generally linear in nature following the corridors of suitable habitat (Figure 2.7). Male animals north of the town of 100 Mile House generally inhabited the valley bottom, resulting in Highway 97 bisecting the majority of their

Table 2.1. Annual and seasonal* 95% fixed kernel home ranges (95% FK) for all study animals, July 30, 2007 - January 31, 2010. Sample sizes for each seasonal estimate are provided in the 5 rightmost columns. Seasons are defined as follows: Spring (March-May), Summer (June-August), Fall (September- November), and Winter (December-February).

		Fixed Kernel 95% (km^2)					**Number of radio-locations**				
Gender	Identity	ANNUAL	SPRING	SUMMER	FALL	WINTER	AN	SP	SU	FA	WI
♀	BF01	27.3	18.2	15.2	4.4	1.6	119	26	41	29	23
	BF02	32.0	23.5	19.4	9.5	2.0	91	11	47	24	9
	BF03	32.5	12.0	18.8	7.6	1.6	118	22	48	25	23
	BF04	19.6	11.0	13.7	8.1	2.1	68	14	24	20	10
	BF05	22.2	10.6	17.7	5.0	1.1	118	12	52	30	24
	BF06†	-	12.4	-	7.6	2.7	42	13	4	14	11
	BF07	12.6	8.6	9.0	6.2	-	50	12	12	15	11
	BF08	46.7	-	53.2	7.9	-	43	2	30	8	3
	BF09†	-	-	15.5	5.3	-	35	1	24	8	2
	BF10	49.4	-	47.8	21.8	-	33	2	20	9	2
	BF11	22.6	-	21.3	13.8	5.9	32	0	21	6	5
	MEAN ♀ (SD)	29.4 (12.2)	13.8 (5.2)	23.2 (14.9)	8.8 (5.0)	2.2 (1.6)					
♂	BM01	246.1	114.2	270.2	72.2	35.2	147	33	59	32	23
	BM02	260.0	65.0	235.0	42.4	18.0	85	11	58	11	5
	BM03	-	22.9	103.1	-	-	31	6	25	0	0
	BM04	-	26.7	61.8	-	-	23	7	16	0	0
	BM05	-	-	147.1	-	-	22	0	22	0	0
	MEAN ♂ (SD)	253.1 (9.8)	57.2 (42.5)	163.4 (87.7)	57.3 (21.1)	26.6 (12.2)					
	POP. MEAN (SD)	70.1 (91.2)	29.5(32.2)	69.9 (83.8)	16.3 (19.7)	7.8 (11.6)					

† Individual assumed to be less than one year old

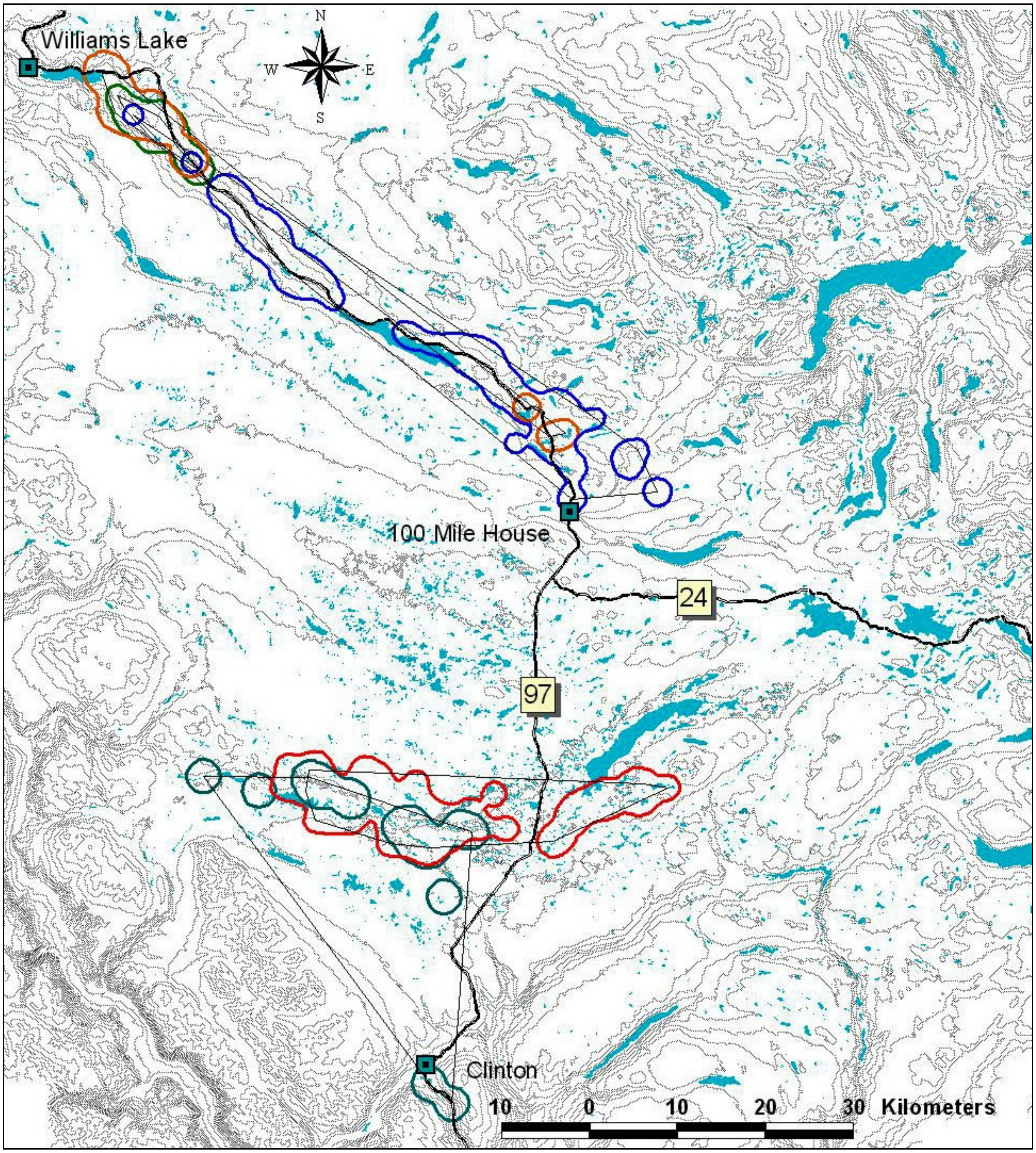

Figure 2.7. Adult male badger fixed kernel (FK 95%) polygons and 100 minimum convex polygons (100% MCP, straight lines) home ranges (n=5) in south-central BC, Canada, 2007 – 2010.

linear home ranges. Changes in topography south of 100 Mile House resulted in a mosaic of pothole lakes and wetlands, where badger habitat was linked to glacio-lacustrine features, such as drumlins and eskers. These areas were characterised by a mosaic of wetlands, pocket grasslands and aspen copses, timber harvested sites, and dry open forests of lodgepole pine. These habitats were linked in a more west-east orientation where Highway 97 intersects this smaller area, resulting in less road mortality risk.

Female home ranges were generally less linear in nature, and due to their smaller size were spread across the region in areas of suitable high-quality habitats (i.e., high quality native grasslands, Figure 2.8). Many of these habitats were in close proximity to both Highway 97 and 24 surrounding the 100 Mile House area. Only four of 11 female home ranges did not include highways bisecting their core home ranges (50% UD), with the edge of the core area an average distance of 12.0 km (SD = 4.4, n = 4)) from highways as compared to other females (n = 7) that had core areas < 500 m from highways ($\bar{x}$ = 71 m, SD = 18, P = 0.012).

Movements

Over the course of this study I collected 503 radio-locations during summer, 231 during fall, 151 during winter, and 172 during spring for an average of 6.3 days/location (SD = 1.7). Badgers moved much more in summer than all other seasons (Table 2.2). Average seasonal movement rates estimated from radio monitoring for all badgers were 840 m/day (SD = 847) in summer, 287 m/day (SD = 155) in fall, 105 m/day (SD = 100) in winter, and 356 m/day (SD = 483) in spring. Males had higher movement rates than females for all seasons but were significantly higher during summer and spring (P < 0.05). Reproductive females (n = 6) had significantly lower movement rates in spring than females that did not have litters (n = 5) that season (P < 0.05).

Monitoring of tagged badgers showed that 15 of 16 animals had home ranges in close proximity to major paved roads, with 12 of 16 animals known to frequently cross highways, with all five males crossing highways at least twice throughout the summer season. A combination of radio-telemetry and DNA burrow records showed one male traveled a linear distance of 132 km over 14 days (23 June – 09 July, 2008), moving from a ranch in the north to a pasture in the central portion of the study area and back again. Another telemetered male

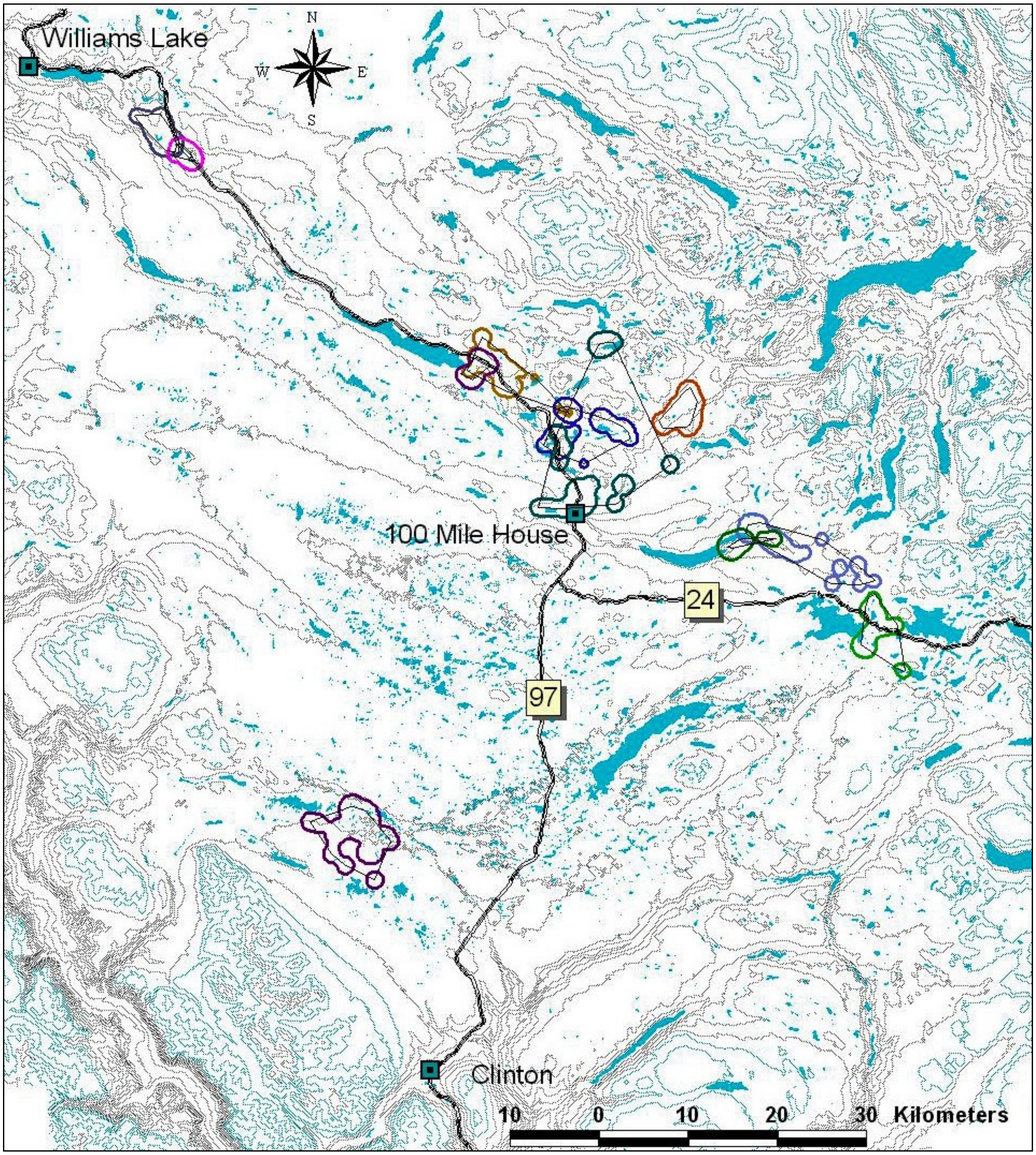

Figure 2.8. Female badger home ranges (n = 11) 95% FK polygons and 100% MCP (straight lines) in south-central BC, Canada, 2007 – 2010.

moved a minimum of 152 linear kilometers along the Highway 97 corridor over 17 days (04 – 21 August 2008) averaging 30.5 km between successive radio-locations. This same male showed consecutive daily movements ranging from 1.9 km to 10.4 km ($n = 7$), with a longest movement recorded of 64.1 km over a duration of 3 days (14 – 17 August, 2008).

Of the 11 adult females radio-tagged, only four were not recorded crossing at least one of the highways. These four females had 50% utilisation distribution core areas ranging from ≥ 6 – 16 linear kilometers away from highways.

GPS backpacks were deployed on five study animals (3♂, 2♀) during the 2008 and 2009 summer seasons, with three animals providing reliable detailed movement data (> 24 hrs – Table 2.3). One GPS datalogger unit was lost when the bonding agent attaching the GPS to the harness failed (animal BM01 – not shown on Table 2.3), while another animal (BM03, Table 2.3) managed to remove his harness within 20 hours of deployment.

For those badgers that provided >24 hrs of GPS data collection ($n = 3$), the average rate of movement recorded was 4,800 m/day ($SD = 1.1$). During the summer period (July and August) these badgers moved more extensively between GPS fixes during the dusk to dawn period (21:00 – 06:00, $\bar{x} = 185$ m, $P < 0.05$) than the diurnal period (06:00 – 21:00, $\bar{x} = 94$ m).

The average rate of movement calculated from GPS fixes for badgers that were active was 188 m ($SD = 19.3$) every 19 min and 48 sec ($SD = 02$ min, 11 sec), providing an estimate of 564 m/hr when actively moving above ground. When badgers were inactive or GPS fix attempts failed, presumably because animals were underground, the average movement rate dropped to 61.3 m ($SD = 54.5$) every 03 hours and 15 min ($SD = 02$ min, 06 sec) resulting in approximately 19 m/hr.

Based on the GPS data, badgers were capable of moving on average 6,800 m over 12 hours when actively traveling and foraging, and < 228 m over 12 hours when inactive. The longest period that a badger was inactive was 48 hours, as demonstrated by an older male (BM02). The longest periods of inactivity for females ($n = 2$) were 20 hr: 50 min (BF05) and 12 hr: 16 min (BF01). The longest distance traveled by a badger between GPS fixes (15 minutes) was 1,014 meters, a travel speed of > 4 km/hr. Within the GPS sample, there were no significant differences ($t = -0.59$, $P = 0.61$) in movements detected between genders.

Table 2.2. Average movement rates (m/day) derived from conventional radio-tagged badger data monitored between 2007 and 2010 for all seasons in south-central BC.

	Season			
Category	Summer	Fall	Winter	Spring
All Badgers (♀,♂)	840 (847)	287 (155)	105 (100)	356 (483)
Male ♂	1640 (1163)*	421 (100)	197 (223)	930 (563)*
Female ♀	476 (261)*	263 (153)	85 (60)	78 (67)*
Reproductive ♀	373 (77)	254 (152)	96 (79)	33 (20)*
Non-reproductive ♀	598 (358)	274 (172)	70 (29)	135 (58)*

* $P < 0.05$

Table 2.3. Summary of GPS datalogging deployment on four badgers in south-central BC, July - August 2008 and 2009.

Animal ID/ sex	Date deployed	Year	Time collecting data (hrs:min:sec)	# of fixes	Total distance traveled (m)	Distance traveled/day (m)
BM03 ♂	22 - 24 Jul	2008	19:35:40	39	5,886	-
BF01 ♀	20 Jul - 07 Aug	2008	73:35:54	104	11,495	3,749.3
BF05 ♀	04 - 17 Aug	2009	217:07:23	277	54,513	6,025.7
BM02 ♂	06 - 22 Aug	2009	298:30:24	399	57,515	4,626.5

The detailed GPS data collected from one female (BF05) with kits indicated that, in at least some cases (e.g. summer), radio-telemetry was significantly underestimating the amount of road-crossings that an individual badger conducted over a given time period. Conventional radio-telemetry of this adult female was conducted while she was outfitted with a GPS datalogger, 04 - 17 August. During this time, five radio-telemetry fixes were collected on the female, all of which were on the south side of the highway suggesting she did not cross the highway during that time period. However, the GPS data revealed that during this time she moved extensively, averaging 251 m/hr (SD = 323), and crossing the highway six times. All of these crossings occurred from late evening until early morning (Figure 2.10). Remote motion camera monitoring of culverts in the vicinity of her crossings did not detect badger underpass use during this period, suggesting all crossings were above the road grade.

Dispersal

DNA samples from individual badgers live-captured, hair-snagged at burrows, or carcasses collected from roads confirmed several matches from previous hair-snagging sessions prior to my research. Dispersal movements detected several young animals (n = 9) crossing highways to occupy new territories, with a minimum estimate of 50% road mortality for dispersing juveniles (Table 2.4). Average detected minimum dispersal distance was 43.2 km (SD = 32.1) for both sexes. Dispersal distances averaged 53.5 km (SD = 36.2, n = 6) for males, while females averaged 30.8 km (SD = 24.3, n = 5; t = 1.18, P = 0.133). One juvenile male (BM04) was documented making an extensive movement over the course of a year, travelling 63 kilometers southwest across Highway 97 during dispersal, then moving 86 kilometers north in less than two months the following summer, once again crossing the highway before being radio-tagged in the northern portion of the study area. The straight line distance from the natal den to his last known location was 83 kilometers.

Reproduction

The 13 natal burrows that I detected provided data on reproductive success of the females, in terms of minimum litter size and successful kit emergence (Appendix A). The average number of kits I detected emerging from the den was 2.4 (SD = 0.76, n = 13). For those natal dens that had a complete history of camera monitoring, the mean date of kit emergence for all years was 16 May (SD = 9.5, n = 8); after the first detected emergence by

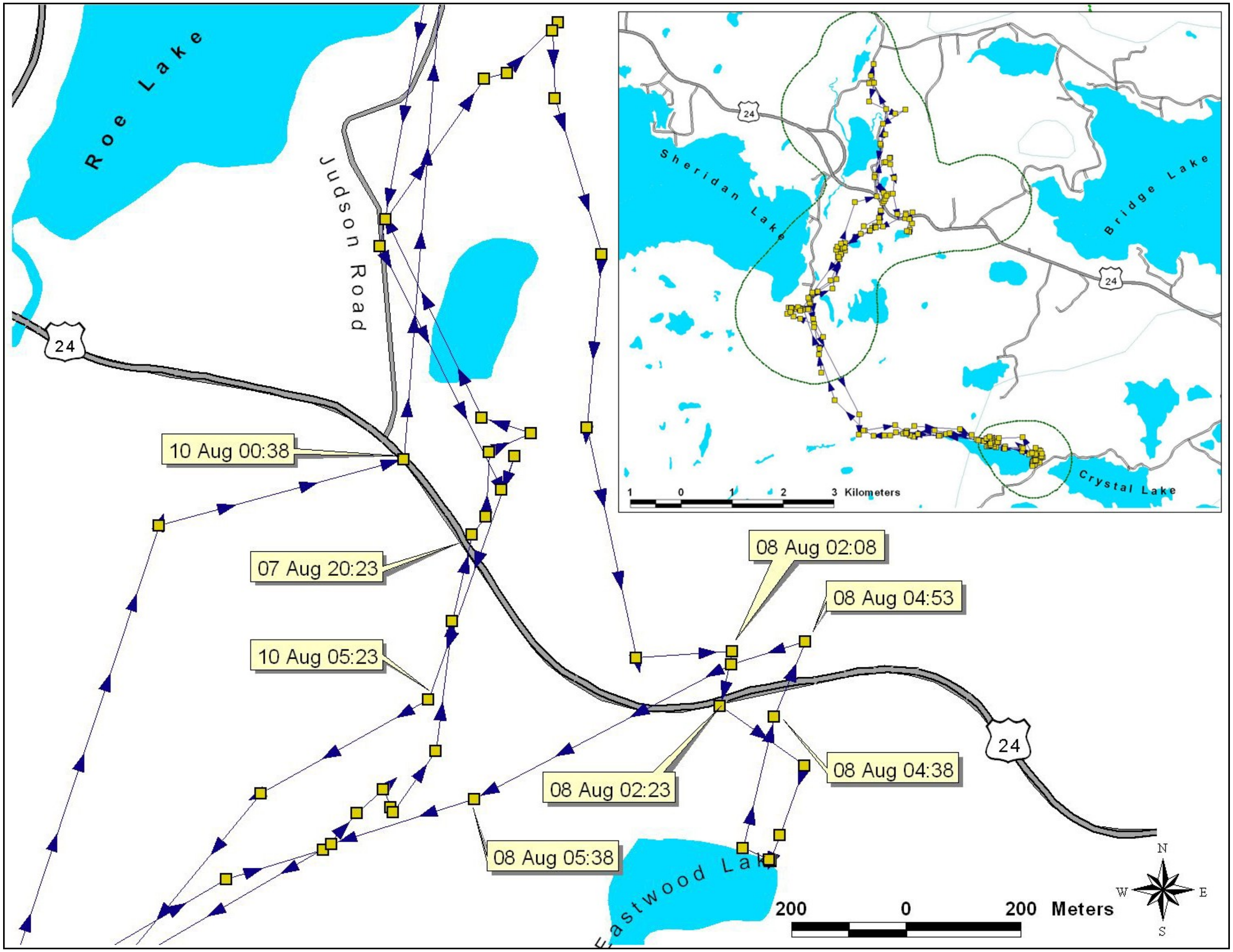

Figure 2.9. Detailed GPS track of adult female badger's (BF05) movements crossing Highway 24 near Bridge Lake, BC, 04 - 17 August 2009. Squares represent sequential GPS locations acquired every 15 minutes. Inset map: Entire GPS track overview and home range outline (95% FK) derived from VHF radio-telemetry.

Table 2.4. Minimum detected dispersal distances of badger kits as determined by DNA or live-capture mark/recapture at burrows. Detection method describes whether the animal was live-captured or DNA hair-snagged at burrow.

Year	Mother ID (DNA)	Kit ID (DNA)	Sex	Study animal ID	Detection method	Known dispersal (km)	Known fate (as of Jan 31, 2010)
2005	F179	-	♀	-	Natal den	-	Unknown
		F316	♀	BF04	Burrow snag	67	Road mortality
		M326	♂	-	Burrow snag	21	Unknown
		M355	♂	-	Burrow snag	68	Road mortality
		F328	♀	BF11	Live capture	1.2	Alive
2006	F507	-	♀	BF03	Natal den	-	Alive
		F534	♀	BF02	Live capture	20	Road mortality
		M520	♂	-	Burrow snag	20	Road mortality
		M513	♂	BM04	Live capture	90	Road mortality
		F533	♀	-	Burrow snag	38	Unknown
2008	F507	-	♀	BF03	Natal den	-	Alive
		F898	♀	BF08	Live capture	28	Alive
		M884	♂	BM06*	Live capture	24	Alive
2008	-	-	♀	-	Maternal den	-	Unknown
		M931	♂	-	Burrow snag	-	Unknown
		M932	♂	-	Burrow snag	98	Road mortality
All			♂,♀			$\bar{x}$ = 43.2	

* Study animal tagged post-2010.

the kits, an average of 22 days (SD = 3.8. n = 8) expired before natal den abandonment occurred.

Interestingly, in spring 2010, one adult female occupying a home range where ground squirrels were absent had a litter of two kits emerge approximately 2 – 3 weeks behind that observed for all other females. Based on occurrence surveys of Columbian ground squirrels during telemetry tracking, 12 of 13 natal dens had ground squirrels ≤ 100 m and the reproductive output (i.e., number of kits emerging from den) of mature females in areas containing colonies of fossorial rodents were notably higher ($\bar{x}$ = 2.67 kits, n = 9) than that for the mature female (BF10) in the area lacking colonial rodents ($\bar{x}$ = 1.0, n = 1). Younger breeding females reproductive output was higher in areas containing ground squirrels than the area lacking this consistent prey base, but lower than mature experienced females ($\bar{x}$ = 1.25, n = 3).

Mortality

No incidents of 'natural' mortality (i.e., predation) or intentional killing by humans were detected through the telemetered cohort (n = 16); rather, all known mortalities to study animals arose from vehicle collisions on paved roads (n = 8). Eight of 16 (4 ♂, 4 ♀) tagged animals were struck and killed on Highway 97, which accounted for 80% of males and 36% of females in my sample. All of the males died in July and August, whereas females were killed over a broader time span (Appendix B). Kaplan-Meier survival curves reveal a significant difference in survival time for radio-tagged badgers between genders (χ^2 = 4.528, P = 0.03) with an average survival time of 728 days for females and 329 days for males (Figure 2.11).

From 2004 to 2010, reports and retrievals of 39 badgers (16 ♂, 18 ♀, 5 unknown) killed on roads were investigated and mapped, with 72% of these deaths occurring on the major highway in the region (Hwy 97), and only 3% occurring on the secondary highway (Hwy 24). The remaining 25% occurred on secondary paved 2-lane roads (≥ 80 km/hr speed limit) throughout the region.

Over the course of the study, females whose core home ranges (50% UD) spanned highways had a 43% survival rate (n = 7) whereas females isolated from highways had 100% survival rate (n = 4; t stat = -5.36, df = 9, P = <0.001). The core areas for all radio-tagged

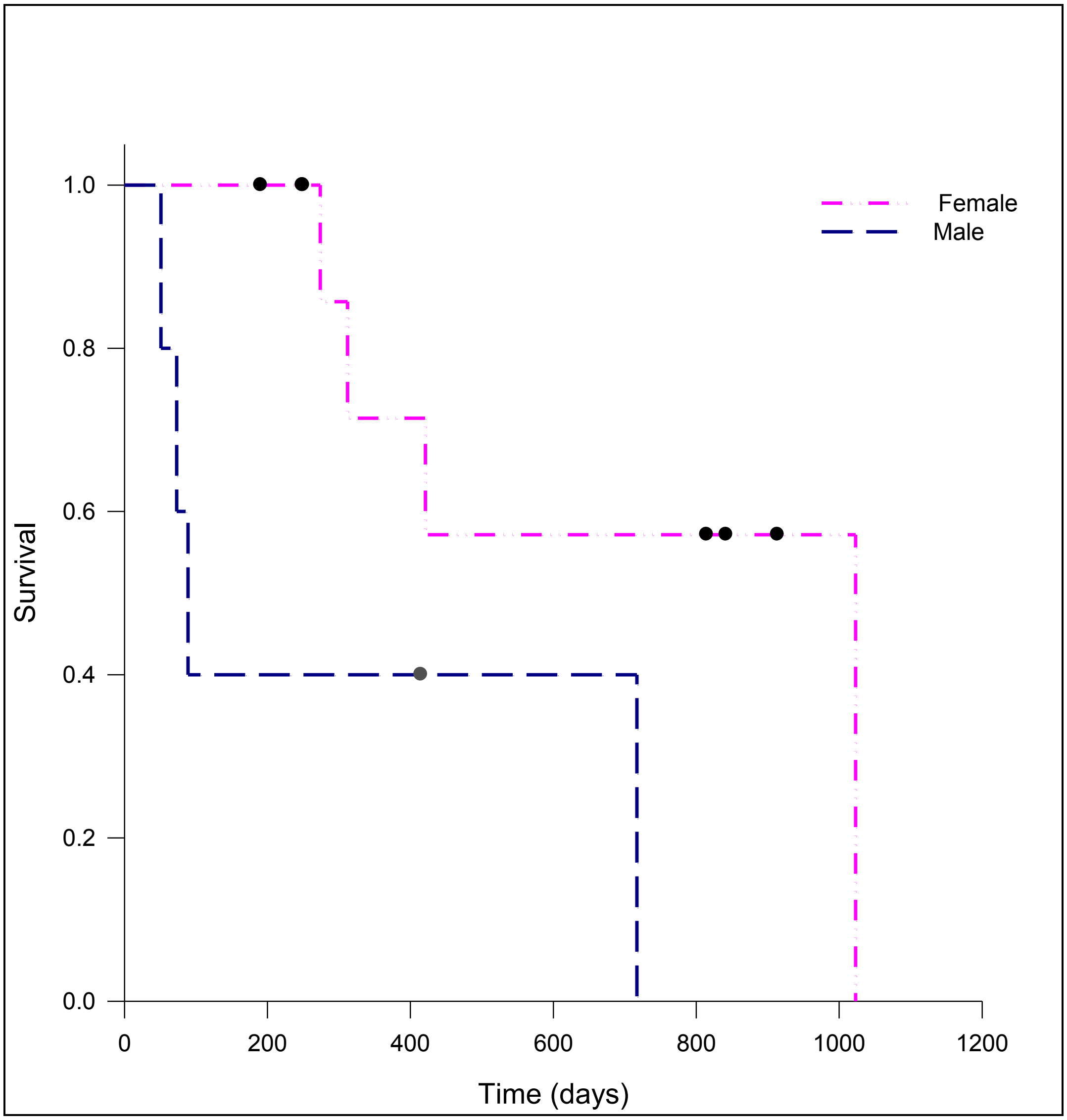

Figure 2.10. Kaplan-Meier survival curves for male and female radio-tagged badgers that died on roadways in south-central BC, 2007-2009.

male badgers were an average distance of 1.82 km (SD = 2.6, n = 5) from highways, with these animals having only a 20% survival rate.

Females and their dependent kits residing near major roadways were also subject to road mortality. After one female (BF07) moved her kits in early summer to a maternal den adjacent to the highway, she was struck and killed, with one kit subsequently being hit 13 days later (the fate of the second kit was unknown). Road mortality was detected for two more juveniles from two separate litters, representing a total of 50% kit mortality from these three litters. One of these juveniles was observed being struck and killed by a vehicle while following their mother across a paved road. Additionally, juveniles are exposed to road mortality during dispersal as family units identified from DNA hair-snagging (see Table 2.4) had 50% road mortality of dispersing juveniles (4 ♂, 2 ♀) from four litters (n = 12).

From 2004 – 2010, badger deaths on Highway 97 most often occurred from May to December with a peak in July (Figure 2.12). Males accounted for 40% of road deaths in July and August, which coincided with a peak in summer traffic volume and the breeding season, while female deaths were spread throughout their active seasons.

Three separate road segments along Highway 97 (approx. 18 km) in the northern portion of the study area (100 Mile House to Williams Lake) contributed to the majority of badger-vehicle collisions, which accounted for 11% of the paved highway through the regional study area (Clinton to Williams Lake, 165 km). The 70% utilisation distribution of badger road mortality highlights three areas that contributed to over half (60%) of all the road mortalities in the region. These include a 4 km radius from 100 Mile House (includes secondary paved roads), an 8 km segment of Highway 97 in the central portion of the study area, and a 6 km segment of Highway 97 in the northern portion of the study area (Figure 2.13). Areas that consisted of non-forest upland with improved pastures were the dominant roadside habitat-type associated with badger road mortalities (n = 19).

Of the eight telemetered animals lost on roads from 2008 - 2010, only three were reported by the public (38%) with the remaining five mortalities confirmed by radio-telemetry monitoring. Conservative estimates of the percentage of the regional population killed by the highway annually range from 7 – 11% based only on the reporting rate of road mortalities and increase to 15 – 25% when adjusted for the corrected reporting rate.

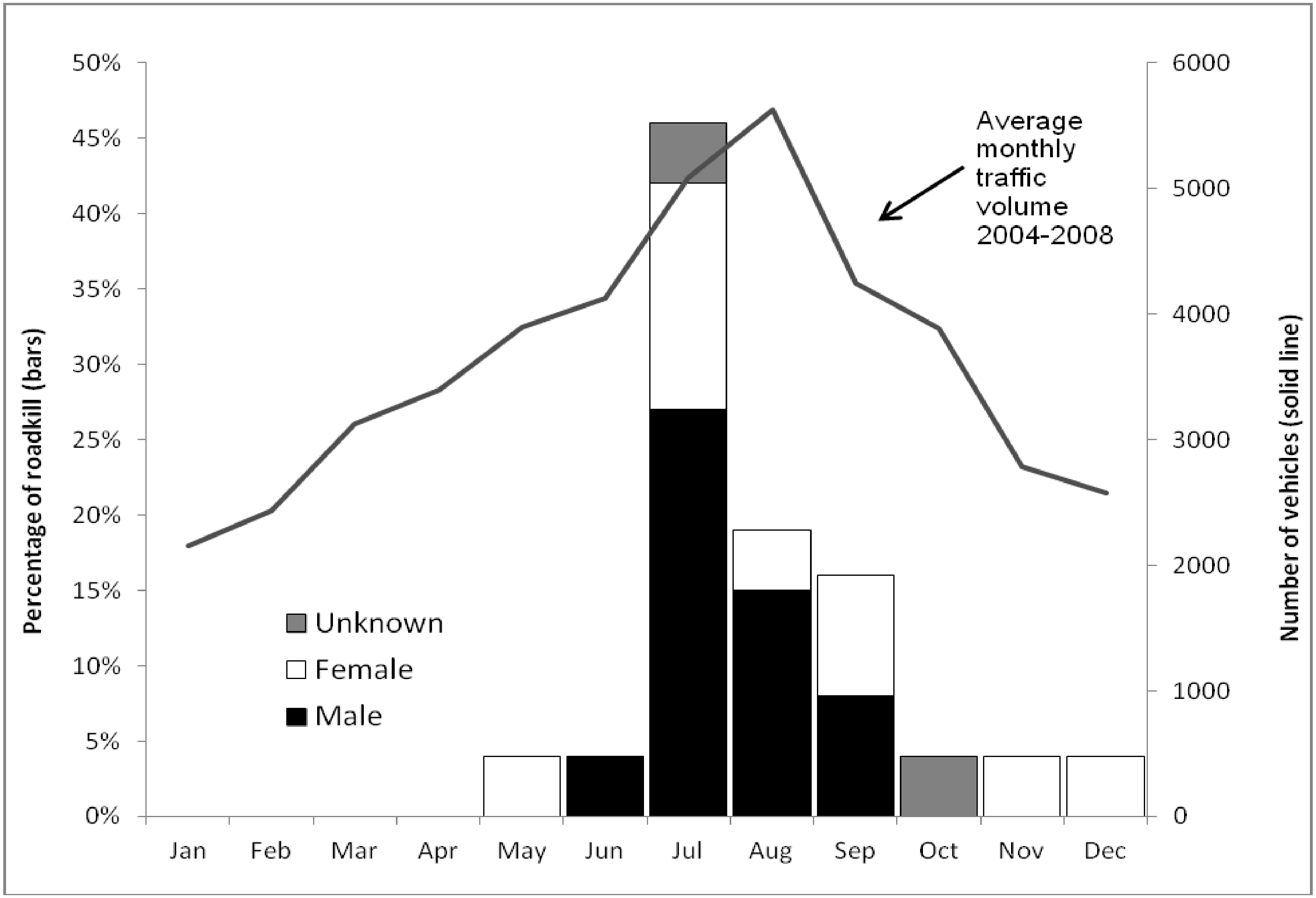

Figure 2.11. Percentage of badger-vehicle collisions in relation to average daily traffic volume (ADT)* by month on Highway 97 in south-central British Columbia, Canada, 2004 – 2010. *Source: Ministry of Transportation and Infrastructure, Traffic Data Program, 2004 – 2008.

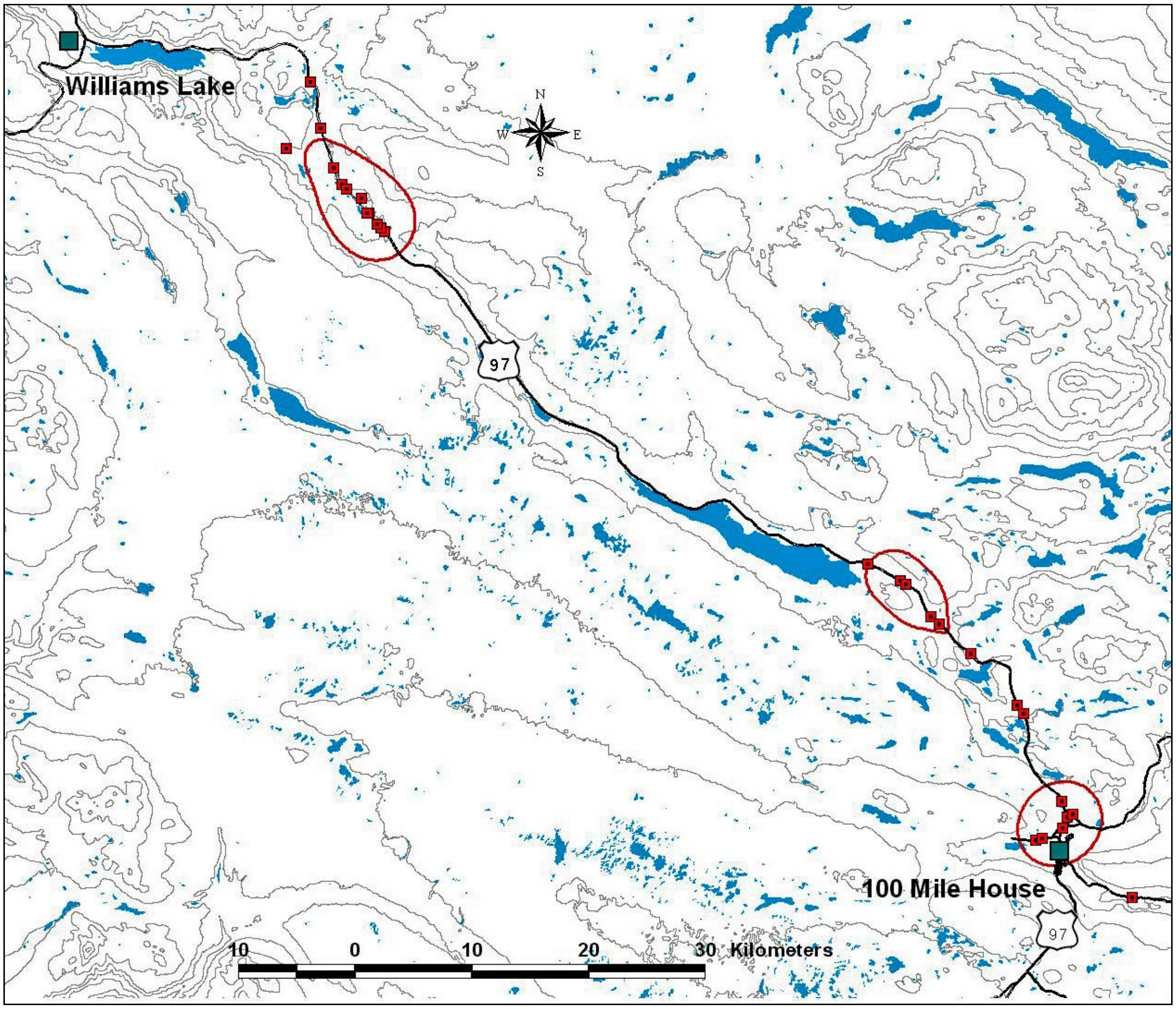

Figure 2.12. Plotted road mortality locations with 70% fixed kernel utilization distribution contours revealing three ‘roadkill hotspots’ in relation to major roads in the northern portion of the study area in south-central BC, 2004 – 2010. Sixty percent of badger road mortality in the region occurred in these three zones along Highway 97 in the study area from 2004 – 2010.

Population modeling

DNA hair-snagging

Over the course of the study, I collected 1,004 samples of hair from different burrows. The average success rate of hair samples having suitable DNA for extraction and thus being individually identified was 49% (SD = 18.8) over six annual sampling sessions (range: 22% - 75%). This approach was therefore successful at first-time identification of individuals as well as providing 're-capture' data.

Population parameters (Survival, recapture, and recovery)

Thirty-nine badgers were recovered dead from roads during the course of the study. Twenty of the dead badgers were included in the live and dead encounter histories for the DNA sampling component of the study, while the remaining 19 were excluded as they were collected post-2008, beyond the years used for analysis.

The general population model generated through MARK was S(t*g)p(t*g)r(t*g)F(t*g) where S = the survival probability as a function of the interaction between year (t) and sex (g), p = capture probability as a function of the interaction between year and sex, r = recovery probability as a function of the interaction between year and sex, and F = fidelity probability as a function of the interaction between year and sex. This model was used to test goodness of fit to the data by summarizing the discrepancy between observed and expected values (P = 0.045). Based on the measure of fit of the model to the data, the variance inflation factor was estimated as $\hat{c}$ = 1.174 (SE=0.161). A suite of candidate models were then generated and ranked according to QAICc (Table 2.5). The most parsimonious model was $S_{(year)}\ p_{(constant)}\ r_{(constant)}\ F_{(constant)}$, where S = survival probability as a function of year with the remaining variables held constant

Sex did not appear to be a major factor in influencing survival from year to year, but the survival probability varied by year for both genders combined (Table 2.6). Survival probabilities ranged from a low of 0.45 (SE = 0.28) in 2008 to 0.78 (SE = 0.10) in 2005. The probability of 'capturing' badgers over the course of the study was 0.75 (SE = 0.06) and the probability of recovering marked dead animals was 0.28 (SE = 0.08).

Table 2.5. Suite of top-ranked candidate models derived by the Reduced Burnham (Both) Jolly-Seber method. These models provides estimates for survival (S), recapture (p), and recovery (r) of marked individuals based on corrected Quasi-Akaike Information Criterion (QAICc) with an adjusted ĉ=1.174. Model names indicate if survival (S) or probability of capture (p), recovery (r), and fidelity (F) were held constant (.), or varied with group (g) or time (t). ΔQAICc is the difference in QAICc values between a model and the most parsimonious model. 'Model weights' indicates the support for a model. Number of parameters specifies the number of variables estimated for a model. QDeviance is the deviance of a model from the full general model.

Model	QAICc	Δ QAICc	Model Weights	Model Likelihood	Number of Parameters	QDeviance
S(t)p(.)r(.)F(.)	256.59	0.00	0.212	1.000	7.00	100
S(.)p(.)r(.)F(.)	256.76	0.17	0.195	0.917	3.00	109
S(t)p(g)r(.)F(.)	256.91	0.33	0.180	0.850	8.00	98
S(g)p(.)r(.)F(.)	258.75	2.16	0.072	0.339	4.00	108
S(g)p(g)r(.)F(.)	259.09	2.50	0.061	0.286	5.00	107
S(t)p(g)r(g)F(g)	259.18	2.59	0.058	0.274	9.00	98
S(t)p(g)r(g)F(.)	259.18	2.59	0.058	0.274	9.00	98
S(.)p(.)r(.)F(t)	259.23	2.64	0.057	0.267	6.00	105
S(.)p(g)r(.)F(.)	259.63	3.04	0.046	0.218	5.00	107
S(.)p(.)r(.)F(g)	261.02	4.44	0.023	0.109	5.00	109
S(t*g)p(.)r(.)F(.)	261.32	4.74	0.020	0.094	12.00	93
S(t*g)p(g)r(.)F(.)	261.55	4.97	0.018	0.083	13.00	91

Table 2.6. Output from program MARK vers. 6.1 for most parsimonious model providing population parameter estimates for survival by year (S), probability of recapture (p), and probability of recovery of dead marked individuals (r) for the regional badger population in south-central BC, Canada, 2003 – 2008.

BADGER DEAD-LIVE RECOVERY

Standard Error and Confidence Intervals Corrected for ĉ = 1.174

Ranked 1st

Real Function Parameters of {S(t)p(.)r(.)F(.)}

				95% Confidence Interval	
Parameter	Year/gender	Estimate	SE	Lower	Upper
1: (S) survival	2003/both sexes	1.00	0.00	1.00	1.00
2: (S) survival	2004/both sexes	0.67	0.13	0.39	0.86
3: (S) survival	2005/both sexes	0.77	0.10	0.52	0.92
4: (S) survival	2006/both sexes	0.62	0.10	0.41	0.79
5: (S) survival	2007/both sexes	0.71	0.11	0.46	0.87
6: (S) survival	2008/both sexes	0.45	0.28	0.08	0.88
7: (p) recapture	All years/both sex	0.75	0.06	0.61	0.85
8: (r) recovery	All years/both sex	0.27	0.08	0.15	0.46
9: (F) fidelity	Fixed (see methods)	1.00	0.00	1.00	1.00

Population size

The POPAN model provided derived estimation of abundance. Based on this, the population size in the regional study area was estimated to have increased over the course of the study (Figure 2.14). The minimum number of badgers detected alive in 2003 was 12 with the overall population estimate increasing to 72 (SE = 3.5, 95% CI = 67-83) by 2008. This provides an estimated density of one badger/100 km^2 across the regional study area.

Population growth

Using the Pradel-λ method, a suite of candidate models were calculated and ranked in order of lowest scores for AICc (Table 2.7). The most parsimonious model for the Pradel-λ population growth model was $\lambda = \Phi\ (_{constant})\ p(_{constant})\ \lambda\ (_{constant})$. The resulting population growth rate (λ) was 1.249 (SE = 0.07). Both the POPAN population estimate and Pradel- λ growth model generated in MARK provide similar trajectories in population growth, suggesting an increasing population of badgers in the regional study area (Table 2.8).

Highway structures influencing movements and mortality

Motion cameras deployed on 41 underpass structures allowed me to document 108 occurrences of badgers crossing underneath highways. Size of structures used by badgers ranged from 500 mm to 2500 mm diameter. The most frequently-used underpass structure was 500 mm corrugated pipe culverts that accounted for 81% of all badger crossings, with livestock underpasses (> 2 m) accounting for only 8% of these crossings (Figure 2.15). Although 500 mm culverts had the more frequent use, they were also the most common culvert size in the sample. Deployment of cameras on underpass structures ranged from 35 – 520 days ($\bar{x}$ = 115 days, SD = 84.6) resulting in the detection of badgers crossing under roads at 37% (SD = 0.48, n = 15) of the structures monitored.

The average number of badger crossings per structure monitored from 2007 – 2009 was 3.58 (SD = 6.74) with a range of 0 – 31 crossings/structure. The average number of camera nights/ badger crossing was 67 (SD = 2, n = 4,525) with July having the highest frequency of crossings. There were 274 badger detections recorded with 108 documented crossings (39%). Non-crossings were detected 166 times (61%) where badgers were recorded near the opening of an underpass but not detected passing through them. These situations included badgers entering the underpass then promptly exiting < 1 minute, investigating

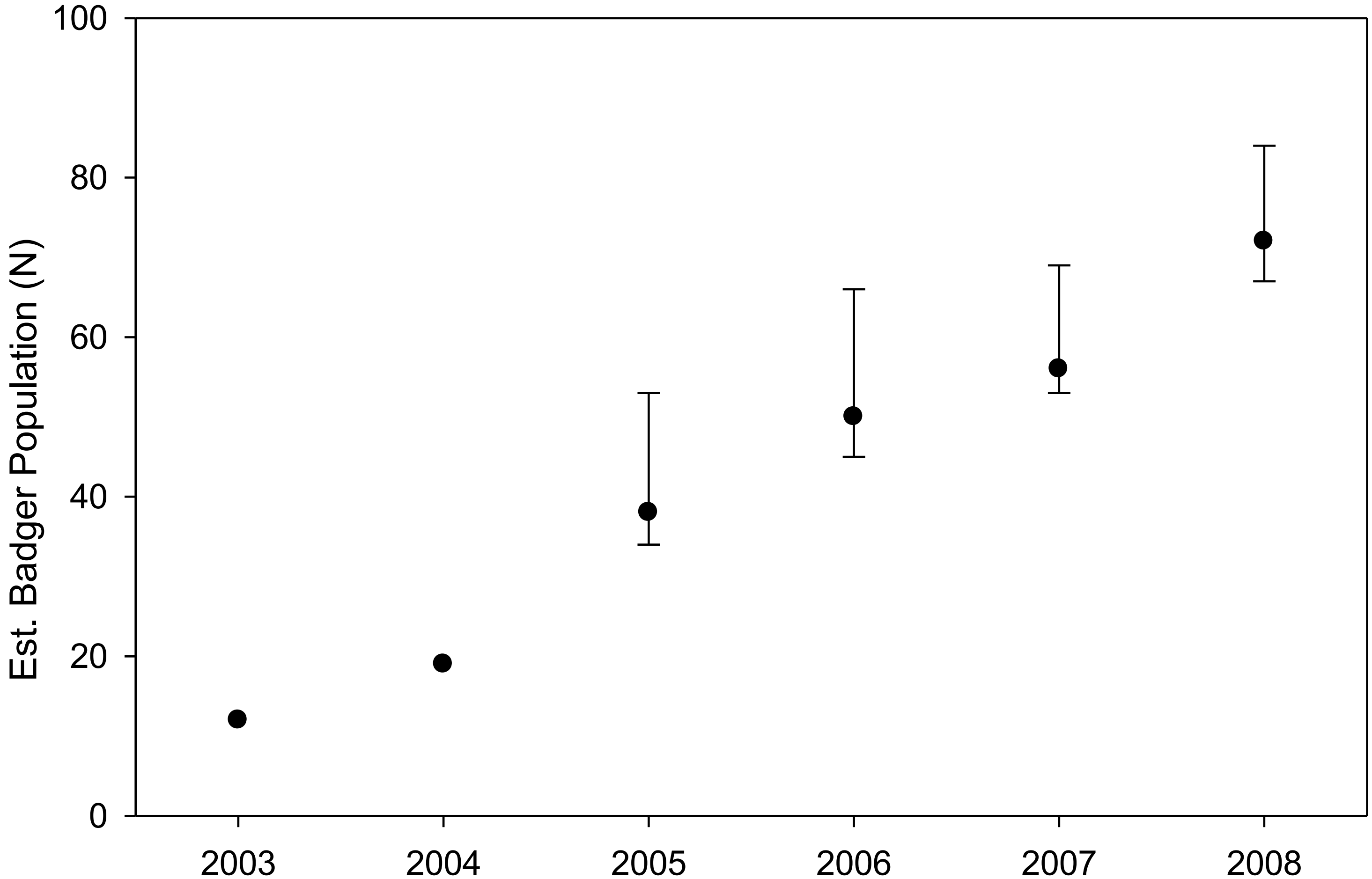

Figure 2.13. POPAN model derived population estimate of badgers across the regional study area in south-central British Columbia, Canada, 2003-2008. The 2003 estimate is based on minimum number of badgers detected alive. Bars represent +/- 1 standard error.

Table 2.7. Pradel-λ badger population model selection based on Akaike Information Criterion (AIC). Model names indicate if population growth (lamda, λ) was held constant (.) or varied by time (t). Model weight indicates the support for a model. Number of parameters specifies the number of variables estimated for a model. Pradel-λ model does not allow calculation of weighted averages for Φ and *p,* and therefore it does not provide estimated values for them.

Model	**AICc**	**Delta AICc**	**AICc Weights**	**Model Likelihood**	**Num. Par**	**Deviance**
Φ(.) p(.) λ(.)	410.07	0.00	0.611	1.000	3	49.24
Φ(t) p(.) λ(.)	411.13	1.06	0.360	0.589	7	41.58
Φ(.) p(.) λ(t)	416.71	6.64	0.022	0.036	7	47.17
Φ(t) p(t) λ(.)	420.10	10.03	0.004	0.007	12	38.85
Φ(t) p(t) λ(t)	421.56	11.49	0.002	0.003	14	35.35
Φ(.) p(t) λ(t)	424.00	13.93	0.001	0.001	11	45.17

Table 2.8. Badger abundance estimates derived from both the POPAN model and estimates of λ derived from Pradels-λ model. A similar trend in population growth of badgers in the regional study area from 2003-2008 is shown using both methods.

Year	**POPAN**	**(SE)**	**Pradels-λ = 1.249**
2003	12	-	-
2004	19	(0)	-
2005	38	(4.2)	38
2006	50	(4.7)	47
2007	56	(3.6)	59
2008	72	(3.5)	74

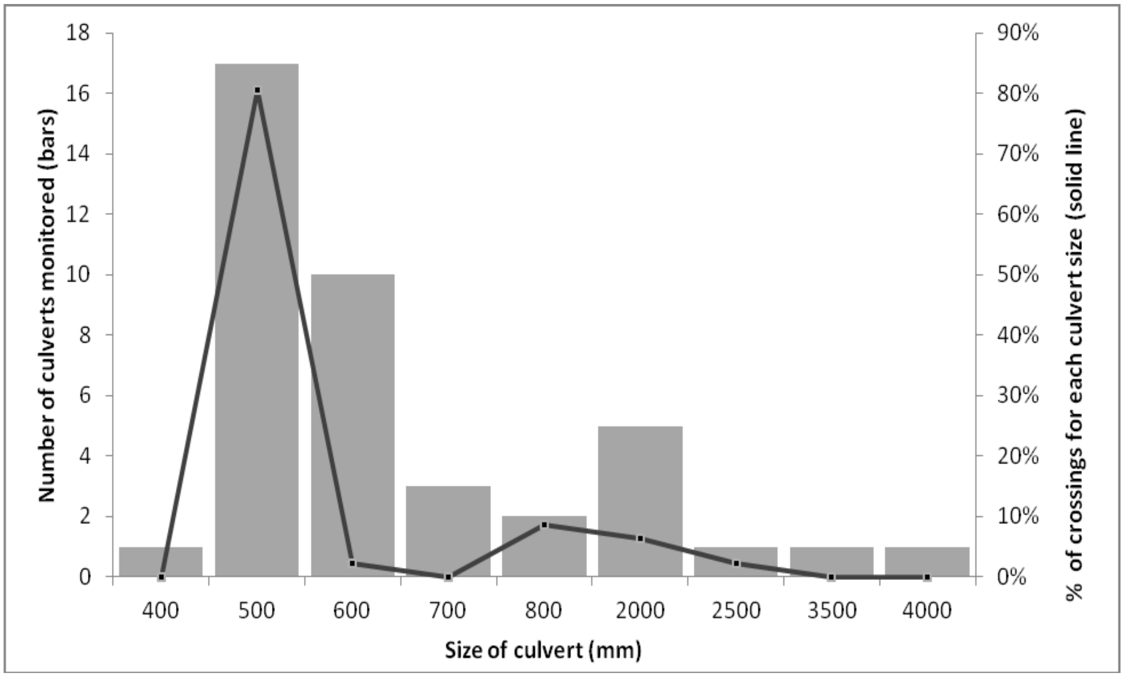

Figure 2.14. Number of underpass crossing structures monitored (n = 41) by size and percentage of use by badgers in south-central BC, 2008 – 2009.

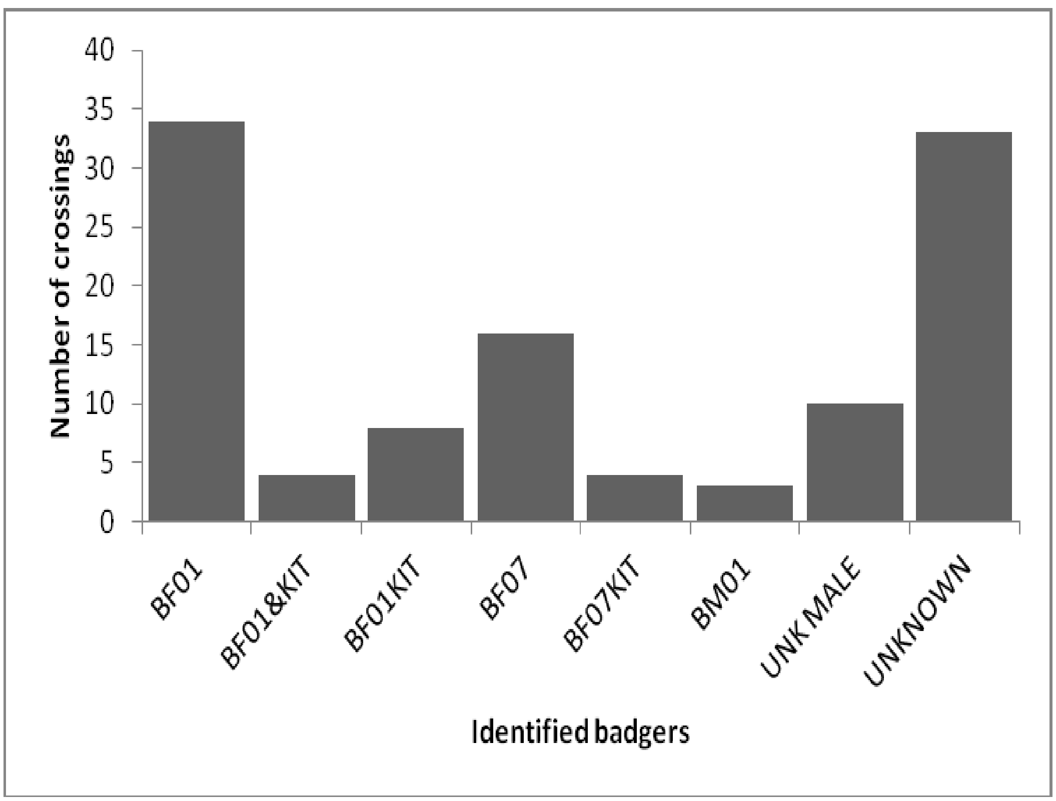

Figure 2.15. Number of underpass crossings documented by identified study animals, known juveniles, and unknown badgers in south-central BC, 2008 – 2009.

around the entrance and leaving, or simply passing by the opening of the structure in the right-of-way.

Study animals accounted for 51% of detected crossings while the other 49% consisted of known juveniles and untagged or unknown badgers. Three badgers were identified as study animals: an adult male (BM01) and two adult females (BF01 & BF07, Figure 2.16). Both of the radio-tagged females were documented traveling through these structures with their kit(s) in late summer (Figure 2.17).

Of the 40% of badgers that were classified as unknown individuals, nine percent were identified as males based on sexual dimorphism features (i.e., head and body structure). Facial-stripe recognition showed that repeated use of the structures was also happening by badgers not in our tagged sample (Figure 2.18).

Surveys of 114 culverts in the study area where badgers were known to occur revealed that 24% of these structures ($n = 27$, $SD = 0.42$) were physically impassable to badgers. Common factors that limited the passage of badgers (and other wildlife) were infilling with soil (37%), physical damage to the culvert (23%), standing water (23%), blockage by debris (13%), and inaccessibility (hanging entrance, 4%).

The two compared segments of Highway 97 where badger road mortality occurred had significantly different number of suitable crossing structures: the north segment had 45% passable structures (9 of 20) while the south segment contained 88% passable structures (22 of 25; Fisher's exact test $p = 0.003$). The north segment had 1.55 passable structures/km whereas the south segment contained 2.62 passable structures/km. Overlaying known badger road mortality sites revealed that a rate of 1.72 badger deaths/km along the north segment were considerably higher than the 0.60 badger deaths/km from the south segment.

Discussion

Why are badgers susceptible to road mortality?

In my study area, a variety of temporal and spatial factors predispose badgers to the risk of road mortality. Road mortality showed seasonal patterns that were consistent with higher mobility periods such as rearing of young (May-July), dispersal (September-November) and breeding season (July-August). In Spain, Grilo et al. (2009) found that the

Figure 2.16. Adult female (BF01) with male kit (right) exiting 500 mm culvert under Highway 97 in south-central BC, 21 July 2009.

Figure 2.17. Facial pattern recognition was used to identify unique individual badgers that passed through underpass structures in south-central BC, 2008 – 2009. Radio-tagged female (left) and unknown male (right).

highest periods of road mortality for fox and marten were when feeding visits increased due to the energetic demands of the litter. There appears to be similar evidence for badgers in my study area, as two females were struck and killed on highways either in pursuit of prey, or delivering prey to waiting kits, thus orphaning several dependent juveniles. Based on remote camera data at natal dens, as juvenile rearing progressed beyond mid-May females traveled extensively to capture and deliver prey to the den, followed by moving kits to a new maternal den by mid-June. This behaviour increased both female and juvenile mortality risk as they crossed major roads during this early summer period.

Juveniles dispersing from their natal territory across the landscape in the fall to establish home ranges may be unfamiliar with the risk of roads. This study revealed that adult females living in close proximity to roads were crossing under highways along with kits. Later, the independent juveniles continued to use the underpass crossings, suggesting that these individuals were learning or incorporating these structures as part of their regular movement patterns, thereby reducing their road mortality risk. Road mortality risk may be elevated for dispersing juveniles originating from a natal territory far from major roads as they may be naïve to the risk of crossing high traffic-volume highways and be more susceptible to vehicle collisions. Road mortality was less frequent in the fall and sex ratios of badgers were equal suggesting that these road mortalities may be dispersing juveniles searching for suitable habitats before the onset of winter.

Male badgers had considerably larger home ranges and traveled greater distance than females, particularly during the breeding season from late June to early September, which resulted in most males (4 of 5) being struck and killed on roads in the region. Males tripled their mean movement rates and distances over females during summer, resulting in at least a fivefold increase in home range size over females. Being a polygynous species, long distance movements made by males likely occur as they are seeking receptive females during the breeding season, suggesting females may be a limited resource, occurring sporadically in patches across the landscape (Clutton-Brock and Harvey 1978, Sandell 1989).

Movement patterns also varied temporally, with animals documented crossing highways from several times a day to once every several days, with most crossings occurring during the summer season. Data from the animals outfitted with GPS dataloggers suggests many of these crossing are not detected using conventional radio-telemetry methods, being most frequent in late evening through to the early morning period. The GPS data from this study indicate that badgers move more extensively during foraging and traveling periods in summer than previously estimated (Hoodicoff 2003, Kinley and Newhouse 2008).

Distinct spatial patterns emerged in the badger road mortality data. Despite live-capturing three of five males > 9 km from a major highway, home ranges for all male badgers in the study eventually spanned major transportation corridors. In contrast, the smaller home ranges of females were often isolated from major roads. Thus, males appeared more susceptible to road mortality across their range in the study area; this may in part be attributed to both searching for receptive females during breeding season and seeking a consistent prey source at specific times of the year, particularly in the fall when badgers are accumulating fat reserves. Over the course of the study, females whose home ranges spanned highways had lower survival rates than those females isolated from highways. The home ranges of females spanning roadways consisted of mostly private land with a matrix of public and private land between core areas [for definition of badger 'core areas' see (Hoodicoff et al. 2009)]. In contrast, female home ranges that were distant from highways were primarily composed of larger tracts of public land, had fewer roads, and consisted of a mixture of native pocket grasslands adjacent to riparian corridors with open forests dominating the uplands.

Other studies documenting carnivore road mortality recorded higher mortality in low and intermediate traffic volume road segments, suggesting avoidance of high traffic volume (Grilo et al. 2009), while others found high traffic volume had significant impacts on a similar species, the Eurasian badger (Clarke et al. 1998). Clarke (1998) surmises that in addition to causing direct mortality, major roads may also reduce dispersal and colonisation movements. Of the two highways that occurred in the study area, the major roadway (Highway 97) contributed to the majority of badger fatalities, while only a small percentage occurred on the secondary roadway (Highway 24). It is unclear if traffic volume, amount of suitable adjacent roadside habitat, or both acting together best explains the discrepancy between badger fatalities along these highways.

I observed strong associations among highway location, home range orientation and badger fatalities. These data highlighted three segments of Highway 97 in the study area where the majority of mortalities occurred. Preferred badger habitat types of non-forested upland with improved pasture/agricultural were consistent at these sites. Annual and summer daily traffic volumes were three times higher on Highway 97 and it appears that this highway bisects more suitable habitat, resulting in a peak of badger-vehicle collisions coinciding with breeding season and high summer traffic volumes.

Is the population significantly impacted by road mortality?

The main ways that roads may affect wildlife populations are by (1) affecting the survival rate through direct mortality, (2) changing population structure through disproportionate road mortality of either sex causing biased sex ratios, and (3) changing movement rates or patterns that ultimately affects population connectivity (Row et al. 2007). Results from this study indicate that the population is stable to increasing despite several animals being lost annually to direct mortality, sex ratios appear stable, and habitat connectivity in the region is a concern with continuing highway improvement and development projects.

In the radio-telemetry component of this study 50% of radio-tagged individuals succumbed to road mortality. Survival rate estimates derived from DNA methods across the region from the Burnham (Both) model suggest a highly variable estimate from year to year for 'captured' badgers ranging from 45% to 78%, with an overall recovery rate of 28% of marked dead individuals over the course of the study. The overall survival estimate of 75% for all years and genders combined suggests that road mortality plays an important factor in the long-term persistence of badgers in the region. Recovery rates for radio-tagged animals and corrections for missed roadside deaths suggest that approximately 25% of the local badger population annually succumbed to road mortality over the course of the study. Other factors likely contribute to the overall mortality rate for badger populations in BC including predation (Newhouse and Kinley 2001, Hoodicoff 2003) and persecution (*jeffersonii* Badger Recovery Team 2008). Despite no study animals dying from either of these factors, there were two reported instances of shooting of untagged badgers in the local study area (one confirmed mortality).

Attempts were made to equally sample badgers living near and distant from major roads, and over half were captured a considerable distance from highways (> 4 km), but due to their long-distance movements they still were exposed to highways in the region. Regionally, areas in the western portion of the larger study area where we deployed hair-snags had a lower density of secondary roads with no highways present and thus survival would be expected to be much higher in those areas. It should be stressed that the increasing population trend is region-wide with the majority of road mortality occurring within the local study area where most of the study animals resided. Although age classes of dead animals were not determined, the possibility of dispersing juveniles may account for the continued but lower rates of road mortality outside of the breeding season. Road mortality can have short-term consequences on population viability and it appears that badgers are most vulnerable to increased traffic volumes during summer on highways that bisect high-quality badger habitats. The reduction of traffic volume on major highways during the remainder of the year provides a respite from direct mortality as badgers have restricted their movements, either in anticipation of rearing young in the spring or preparation for the onset of winter. It is unclear at what threshold that an increase in either road density or traffic volumes through high-quality badger habitats may have on the long-term persistence of badgers in the region but direct mortality will likely continue to exert a strong effect.

Population modeling from this study indicates that the regional population is stable or increasing. The two most important assumptions for modeling population size and growth rate are having a consistent study area size and equal catchability of animals (Cooch and White 2000). While these assumptions were considered met in this study (particularly equal catchability), achieving a consistent sampling area was likely confounded by increasing efficiency and intensity of our DNA hair-snagging methods. Much of the population growth early on in the project may be attributed to badgers being discovered in concert with better sampling methods, thus increasing from a minimum number alive (12) to an estimate of 72 animals. Additionally, many of the recaptures we detected were likely dispersing juveniles that provided population growth projections that would not be attributed to by immigration to the study area. Therefore, areas where females occurred at the edge of the study area may not have been sampled equally over the course of the project and dispersing juveniles from these areas would act as a form of immigration. However, increasing regional badger population estimates were also supported by anecdotal reports of landowners in the study area that the badger population was on the increase during the course of the study from 2005 – 2009.

The effects of road mortality may explain the drastic sex bias in my sample of captured badgers. My goal was to capture equal numbers of both sexes, but I captured twice as many females than males (11 ♀: 5 ♂); this bias may have been attributed to my live-capture attempts being focused in areas with high quality badger habitat in summer resulting in the capture of resident females rather than wide-ranging males. In addition, movement and road mortality data would suggest that males were disproportionately being struck and killed on roads before I could detect them. Despite this gender bias in my local study animals, the data from the DNA hair-snagging sessions from 2003 – 2008 over a larger area of the region suggests a more equal (50:50) sex ratio (48♂:52♀). Sex ratios of documented litters (n = 12 kits) using DNA methods were also close to 50:50 (58♂:42♀). Overall, results from the long-term genetic sampling suggest that the population sex ratio in the region does not appear to be affected by road mortality despite the high mortality rates within the local study area where highways bisected badger habitat.

The apparent increase in badger abundance and distribution in the regional study area could be in part due to a similar lag in population growth following recently improved foraging conditions as seen elsewhere in the province (Kinley and Newhouse 2008). Currently connectivity of badger metapopulations in the Cariboo region could be considered favourable. In recent years, land clearing for agriculture on private lands combined with a recent mountain pine beetle (*Dendroctonus ponderosae*) epidemic has created more open landscapes dominated by graminoids and forbs (which support colonial rodent populations) and improved range conditions favouring an abundant and diverse small mammal community. Additionally, data from GPS-tagged animals reveal that badgers are crossing secondary highways (Hwy 24) during periods of lowest traffic volumes (early morning, night) resulting in less direct mortality thereby allowing movement of individuals across the eastern portion of the study area. Despite suitable habitat conditions in the region and lower road mortality risk along the lower traffic-volume secondary highway (Hwy 24), the ongoing incidences of high road mortality along the Highway 97 corridor continues to be a concern regarding the flow of individuals between metapopulations across the northern portion of the region.

Mitigation and/or compensation

My results provide evidence that underpass structures are a feasible option for reducing direct mortality of badgers from vehicle collisions. Although I identified three segments of highway with high incidences of badger mortality, to predict these sites in other areas without intensive study will be difficult. Instances where there is good habitat near the road but low current road mortality can indicate particularly important locations for mitigation to restore historically depressed populations (Eberhardt et al. 2013). Data from culvert surveys and road mortalities suggests a higher incidence of badger deaths/km of highway when suitable crossing structures were limited, while the camera data indicated frequent use of culverts by badgers, including family units, independent juveniles, and tagged and unknown males. The 500 mm culverts were the most common type along roadways and badgers appeared to use these smaller structures most frequently, while > 2000 mm underpass structures showed some degree of use, suggesting that badgers may use a broad range of underpass structures when available. My ability to effectively monitor sufficient numbers of structures simultaneously were limited by equipment and time constraints, and further monitoring may reveal a wider range of structures used by badgers.

Smaller pipes or culverts are an increasingly common road mitigation tool for small- to medium-sized animals (Lankester et al. 1991, Forman et al. 2003). The recovery of the Eurasian badger and other small animals has been greatly facilitated in parts of Europe through the use of pipes, culverts, and other road underpass systems (Lankester et al. 1991). In the Netherlands alone, over 300 such structures have been installed, contributing to the remarkable recovery of the badger (Bekker and Canters 1997). In my study area, priority should be given to maintenance of existing underpass structures (i.e., culverts) in areas that are not slated for road improvements to optimize cost benefits by providing effective structures currently in place for use by wildlife. Additionally, based on the results of this study provincial government transportation and infrastructure planners are currently incorporating wildlife- and badger-specific underpass crossing structures in highway upgrades, including 4-laning along Highway 97 within known badger range.

Resident females residing on high-quality habitats that were considerable distances [≥ 6 km based on radio-tagged females core home ranges (50%UD)] from highways and major paved roads act as a source element in the population. These areas usually contained older mature females that had a higher reproductive output (based on number of kits emerging from the den) than younger females, or females occupying areas where ground squirrels were absent. In addition to mitigating the direct effects of road mortality, particular attention should also be focused on preserving or conserving the lands occupied by these females. Acquisition of private parcels of land may be a feasible form of compensating for habitat loss and direct mortality of badgers arising from the expansion of highway infrastructure, while habitat enhancement and protection of high quality habitats on public land should continue to be pursued by appropriate government agencies.

Remote motion cameras and GPS backpack methods proved useful for monitoring badgers, albeit with some limitations (e.g., slow trigger speed of cameras missing animals). For example, remote motion cameras successfully detected a GPS outfitted female (BF01) passing through a culvert twice (Figure 2.19). Unfortunately, I could not compare her detailed GPS movements at the time with the underpass camera data as the GPS battery unit failed prematurely. Overall, using these methods in tandem revealed that specific highway features (i.e., existing culverts) were being used by badgers, allowing me to document both underpass crossing use and highway crossing rates that previously were underestimated. Future advances in microGPS technology, in tandem with underpass monitoring (i.e., remote cameras) remains a promising tool in detecting whether badgers utilize badger-specific highway underpass structures or cross above grade in areas where movements are not constrained (e.g., fencing).

Badgers in south-central BC appear to be susceptible to road mortality, but also are exhibiting temporal and spatial variation in local population levels that may be attributed to their existence at the northern periphery of their range. Few researchers have systematically studied variation in population density over the geographic range of a species to determine what environmental variables and population attributes may limit the abundance and distribution of particular local populations (Brown 1984). Symes (2013) found that badgers occurring at their northern range limit in BC were more active in winter than their conspecifics further south, and that constraints imposed by the harsh winter environment may limit the use of torpor as an energy-saving tactic. Rare carnivores living at the peripheral edge of their range also are at greater risk to drastic fluctuation or stochastic events that precipitate a sudden decline in population size (Lesica and Allendorf 1995). A corresponding decline in genetic diversity may in turn impede adaptive responses to climate change. Interestingly, projected climate change and associated effects of the mountain pine beetle across central BC may improve badger habitat in the future by maintaining areas in an open grassland/forest state with an abundant and diverse small mammal community.

Figure 2.18. Adult female badger (BF01) exiting culvert with GPS datalogger backpack in south-central BC, 01 August 2008.

Conversely, these climatic changes may also have an impact on prey species distribution including altering the synchronicity of food sources (timing of ground squirrel hibernation) that may adversely affect foraging strategies for badgers in the region.

Using the “fine-filter” approach of protecting endangered species, subspecies or populations is an important complement to more large-scale efforts (Franklin 1993). Protecting biological diversity in the face of accelerating human-caused perturbations is a major undertaking, and identifying and conserving habitats where badgers can fulfill their life requisites (foraging, natal dens, over-winter sites) must be pursued not only to benefit badgers but a wide range of species that are grassland and dry forest dependent.

Conclusion

Mitigation measures to reduce highway mortality coupled with habitat conservation (to increase carrying capacity), appear key for allowing badgers to persist and perhaps increase within south-central BC. This study represents the first attempt at investigating the complex interaction of roads and their effects on North American badgers. Still, a number of important issues concerning badger ecology and their relationship to roads remain to be examined.

At the present time, the population appears to be stable or increasing with strong recruitment compensating for road mortality losses in the region. Despite the positive trend in population growth, densities are still a staggering low of one badger per 100 km^2. Reported densities further south in the United States indicate that badger populations can range from one badger per 4 km^2 up to one badger per 0.17 km^2 (Warner and Ver Steeg 1995, Quinn et al. 2006). Improvements in our sampling methodology may in part explain this increasing population trend, but anecdotal observations also support that the population was expanding in the region. Further DNA mark-recapture studies used to assess regional or metapopulations should incorporate a rigorous systematic sampling design to reduce the bias associated with the increasing efficiency in hair-snagging methods as developed throughout the course of this study.

As mentioned, improved foraging conditions in tandem with public awareness may have likely contributed to an increasing population that occurred during the course of this study. It is unclear at what threshold increases in traffic volumes and expanding road networks will render the local badger population unsustainable. It is unknown whether the population will stabilize, decline, or follow a pattern of declines linked to direct mortality and then increases associated with habitat conservation/improvements (increasing reproductive output).

In the face of an expanding transportation system, population viability analysis (PVA) for local badger populations should be explored. Road ecology studies similar to this study have revealed through PVA that road mortality can increase extinction probability to dangerous levels over the long-term (Row et al. 2007, Beaudry et al. 2008). Further data collection on road mortality sites to help refine 'hotspots', as well addressing the relationship between road mortality, prey abundance, and vegetation composition along right-of-ways would certainly provide critical insights to assist the development of mitigation plans that can minimize the adverse effects of roads on badgers.

Fencing in concert with under-passages has proven to be a successful method in reducing badger-vehicle collisions in Europe (Broekhuizen and Derckx 1996, Vink et al. 2008). Clarke et al. (1998) and Lankester et al. (1991) conclude that road construction should include fences to deter badgers (*Meles meles*) from crossing roads, and tunnels and underpasses to increase survival. These methods could be employed in North America where fencing trials could be conducted in areas that emerge as road mortality 'hotspots' with the aim of significantly reducing badger deaths at these localized sites. Site-specific plans to address the effects of constructing permanent drift-fencing as well as monitoring a range of underpass structures should be pursued to determine other possible strategies for reductions in badger-vehicle collisions in BC

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CHAPTER 3 – REDUCE MORTALITY AND INCREASE RECRUITMENT; A STRATEGY FOR MAINTAINING BADGERS (*TAXIDEA TAXUS*) IN SOUTH-CENTRAL BRITISH COLUMBIA

INTRODUCTION

In this chapter I present a focused discussion on how an understanding of the ecology of badgers (particularly movements) may be integrated into habitat protection and restoration plans, including mitigation for current and future road infrastructure projects, thereby reducing impacts on this species. A brief overview of these findings followed by management and mitigation recommendations is provided below. The reader may refer to Chapter 2 for a more detailed description on methods and results from my study.

OVERVIEW OF STUDY FINDINGS

The badger is one of British Columbia's (BC) most endangered mammals, with estimates placing the total provincial population at fewer than 340 adults (*jeffersonii* Badger Recovery Team 2008). Previous research projects in the province have isolated two main factors contributing to the continued decline of badgers in BC: (1) a historical and current decline in habitat, and (2) road mortality caused by major transportation corridors running through valley bottoms where badgers exist. Realizing that badger mortality on roads in south-central BC could threaten badgers, as it has elsewhere in the province, the BC Ministry of Transportation and Infrastructure funded this research to study the interaction between badgers and roads in the Cariboo region (see Figure 1.3, Chapter 1). Little to no literature exists, to my knowledge, for research conducted specifically to understanding the effects of roads on badgers in North America (Wright 1965, Case 1978). This study, focused on the basic ecology and movements of the badger population, as a means to understand the factors making these animals vulnerable to road mortality.

Mean home ranges for males were much larger than females, almost an eightfold increase (♂ = 253.1 km^2, ♀ = 29.4 km^2). In addition to their extremely large home ranges, males displayed extensive movements during summer, while reproductive females maintained the smallest home ranges and restricted their movements during the kit rearing period. Movements of adult females with kits were influenced by time of kit emergence from the den, litter size, and period of time before natal den abandonment.

Movement rates were five times greater for GPS outfitted badgers versus conventional radio-telemetry estimates [GPS 4,801 m/day (n = 5): VHF radio 840 m/day (n = 16)].

Both marked and unmarked badgers were recorded using a variety of structures, with the majority of crossings occurring within the 500 mm diameter class. Data revealed that both genders and family groups used culverts and livestock underpasses to pass under roads. Both above- and below-grade road crossings were detected, with frequency varying by individual, time of day, and seasonality.

Surveys of culverts in the study area where badgers occurred near roads revealed that 24% were physically impassable to badgers. Common factors that limited badger passage were physical damage to the culvert, infilling with soil, blockage by debris, standing water, and inaccessibility (overhanging opening).

Animals whose home ranges bisected highways were repeatedly observed crossing highways, with half of the study animals succumbing to collisions with vehicles (8 of 16). Due to their large home ranges, all five males in the study eventually crossed highway corridors with four of five males dying on these major roadways. Sites of badger road mortalities were spatially defined to identify areas of concentrated road mortality sites or ‘hotspots’ on major roadways in the south Cariboo.

Despite the high percentage of road mortality, long-term DNA data collection and population modeling suggests an increasing or stable population of badgers in the regional study area. At the present time, the high incidence of road mortality in this region seems to be negated to some extent by strong recruitment. Increasing efficiency in sampling techniques over the course of the study may have also contributed to the apparent population increase in the region.

Home range and movement rate estimates for badgers in this study are some of the largest reported in BC. Human-induced pressures on badger habitat often conflict with seasonal movement patterns of badgers (i.e., breeding season) leading to habitat fragmentation and direct mortality. The ability to understand these movement patterns and provide mitigation measures (e.g., road underpasses, land conservation) that reduce direct mortality and increase productivity will allow for the continued existence of this species near their range limit in south-central BC.

MANAGEMENT AND MITIGATION

Management strategies for attempting to preserve populations of endangered carnivores generally fluctuate between restoring habitat to allow increased recruitment or reduce risks of mortality to increase survival rates (Ferreras et al. 2001). In this study, protecting and restoring suitable habitat away from roads should result in more territories of breeding females (i.e. increased carrying capacity). In theory, enhancing habitat (increasing prey abundance) might reduce the average territory size, thus increasing the number of breeding territories and reducing large movements during breeding and dispersal. Conversely, knowing the mechanisms that predispose badger to road mortality should make it possible to increase survival by instituting mitigating measures for an expanding transportation sector. Below, I provide recommendations for both increasing recruitment (habitat conservation/restoration) and minimizing direct (road) mortality of badgers in the study area.

Habitat protection / restoration (increase recruitment):

- Radio-tracking adult badgers revealed specific areas that contained important habitat elements (suitable soils, prey) on public lands where suitable badger habitat was limited (i.e., rocky soils). Land use management actions on public lands to improve badger populations include creating Wildlife Habitat Areas (WHAs) that permit limited development provided it does not harm or degrade habitats in specific areas. At the present time, 3,819 hectares of quality habitats has been included for WHAs in the Cariboo region of BC providing some degree of protection for these important habitat features.
- Natal dens of mature female badgers were often located on private lands considered “high quality” habitats in the local study area. Dispersing juveniles from these land parcels provide migrants for vacant territories. Land acquisition, including covenants and easements by conservation organizations (i.e., The Nature Trust of BC) could be a cost-effective mitigative solution for highway improvement projects. These acquired parcels could serve to aid the recovery of badgers and other endangered

wildlife species, and preserve essential habitat connectivity. Habitat enhancement and restoration efforts could be conducted on acquired conservation lands to support adaptation and species resiliency for this peripheral population.

- Radio- and GPS-tracking of badgers revealed the use of timber-harvested sites that were in early seral stages. Specific forest harvesting and silvicultural techniques that enhance habitat, in concert with continued grassland ecosystem restoration efforts that promote an abundance of prey species (e.g., vole spp., ground squirrels) should be pursued in areas where badgers are known to occur. Grassland restoration efforts have been conducted for 2,900 hectares on public land in the Cariboo region of BC from 2004 – 2010.
- Landowners were more receptive to tolerating badgers on their properties when they were made aware that the major prey source for badgers are those rodent species generally considered 'pests' by the agricultural industry (see public brochure - Appendix D). In order to counter the possible extirpation of badgers in the region, stewardship by landowners of high-quality habitats occurring on private land should be attempted. This management action would then continue to provide a source population to fill the vacancies created by road mortality losses. Stewardship activities targeted at educating and promoting badgers on landowner's properties should be continued.

Mortality reduction (highway specific):

This study found evidence revealing that badgers frequently used existing dry culverts to pass under roadways in the Cariboo region of south-central BC. Previous projects reported that existing underpass structures (i.e., culverts) may be used by badgers to cross under major transportation corridors (Newhouse and Kinley 2001). Identifying areas of high road mortality, seasonality of road mortality, adjacent vegetative cover modifications, roadside topography (habitat), and types of crossing structures present all contribute to the knowledge required for managers to implement mitigation measures to counter the effects of road mortality of badgers. Recommendations from this study are occurring through the installation of a variety of wildlife-specific underpass crossing structures, including badger-specific underpasses along Highway 97 (Figure 3.1). Recommendations pertaining to the reduction of badger road mortality in the region include:

- Providing dry culverts as underpasses is a feasible form of mitigation for badgers where road mortality occurs. Over a third of culverts monitored showed badgers (both genders, family units, adults, and juveniles) crossing under highways in the study area. Evidence suggesting that adult females are passing this knowledge on to juveniles was documented by remote motion cameras.
- Badgers crossing under highways were most frequently documented using between 500 – 800 mm corrugated metal pipe culverts with some use of larger structures, up to 2500 mm. It appears badgers will readily use these structures based on availability and providing a range of size in structures will not only benefit badgers but a variety of wildlife species.
- Regularly conducted maintenance of culverts would be a cost-effective way of providing underpass structures for wildlife. Approximately 24% of all culverts surveyed in this study were considered impassable to badgers. These works include repairing crushed ends, removing blockages, ensuring soil is removed from the entrance for proper drainage, and constructing earthen ramps to overhanging culverts to allow access for the short-legged badger.
- A slight grade in the structure would prevent standing water buildup during regular rainfall events. In light of badgers crossing under roads more frequently in the summer, some seasonal flooding or extreme weather events resulting in excess runoff would be acceptable short term impacts.
- Earth substrate bottoms were a common feature for culverts frequently used by badgers (Figure 3.2). There is evidence to suggest that badgers have particularly sensitive feet (to detect burrowing rodents) and foreign metal surfaces may be avoided.

Figure 3.1. Recently installed badger-specific underpass crossing structure along Highway 97 south of 100 Mile House BC, Canada, 2010.

Figure 3.2. Suitable existing underpass structure (500 mm corrugated pipe) with earth substrate bottom used by badgers to pass under Highway 97 north of 100 Mile House BC, Canada, 19 August 2008.

- Attempt to have more than two underpass structures per linear kilometer of highway. Two segments of highway where radio-tagged badgers and badger-vehicle collisions frequently occurred were assessed for suitable existing underpass structures. The south segment had the lowest road mortality rates where 88% of existing culverts were available for badger underpass use. Higher road mortality rates occurred on the north segment where only 45% of existing culverts were available for badger underpass use. A suitable crossing structure may not necessarily be a badger- or wildlife-specific structure but an existing dry culvert.
- Include access roads in wildlife underpass structure planning and design. Monitoring revealed that access road culverts were used by badgers to travel along highway right-of-ways. Access roads were common at road mortality sites suggesting that animals wandered onto the highway roadbed when encountering a blocked passageway under these accessory roads. A common feature at road mortality and above grade crossing sites were raised banks adjacent to the highway. Consider installation of wildlife-specific culverts along stretches where there is a raised bank on one or both sides of right-of-way, especially in areas where pasture/agricultural land is adjacent to the roadway (Figures 3.3A and B). These sites were not considered for drainage purposes so there are minimal existing culverts at these sites.
- Mowing of roadside vegetation during summer months when vegetation exceeds 30 cm should be conducted. Badgers were observed traveling along the shoulder of the highway where tall dense vegetation can be used as cover when threatened by approaching vehicles. By mowing and removing this tall grass-structure two to four meters from the shoulder of the roadbed the animals would then be more exposed and less likely to travel along the edge of the road.
- Alternative vegetation should be explored for re-seeding large areas of right-of-ways by replacing the tall (> 50 cm) herbaceous vegetation with lesser-palatable lower growing species (< 30 cm). This can still achieve the erosion, soil conditioning, and noxious weed reduction objectives of seeding right-of-ways with herbaceous vegetation. Avoid species such as alfalfa (*Medicago* spp.) and clover (*Trifolium* spp.) and other domestic graminoid species. The seed crop from these highly palatable forage species cause an abundant small mammal community to flourish along the

Figures 3.3A and B. Examples of raised banks adjacent to highway corridor. Badger road mortality site (top) where no crossing structures were present nearby (> 250 m) and successful crossing site used repeatedly by badger (below). Both sites along Highway 97 north of 100 Mile House BC, Canada.

right-of-way which attracts badgers to forage along roadsides. An additional benefit would be the reduction in tall dense cover that badgers prefer when traveling along highway right-of-ways during daylight hours, while also reducing the attraction for large herbivores (i.e., deer) to the roadside.

- Pre- and post-monitoring of structures (e.g., cameras, track plates) should be implemented to measure success or failures of wildlife underpass crossing projects. It is often noted that there is a need for additional evidence-based support that wildlife crossing structures contribute to the long-term persistence of wildlife populations and long-term monitoring is recommended (Clevenger and Sawaya 2010).

Future study

Much work is still needed to expand on the understanding of the complex relationship between badgers and roads from this study. As with most exploratory projects, a number of important questions arise to be answered. Recommendations to improve the knowledge of road ecology of badgers are as follows:

- Initiate culvert/underpass studies to expand on the knowledge of preferred structure size, density of suitable structures, and placement on the landscape for not just badgers, but other species that may benefit from increasing permeability across roadways.
- Conduct a comprehensive Population Viability Analysis (PVA) for badgers to determine long-term risk assessment for metapopulations in the region.
- Long-term, consistently-collected road mortality data would aid immensely in refining the spatial and temporal patterns of mortality ‘hotspots’ and should be continued by appropriate government agencies.
- Pursue the development of movement models for badgers incorporating movement data, habitat, soils, and landscape use, which may identify important corridors and aid in resolving current and future roadway conflicts. This should include projected habitat alterations induced by potential climate change effects, an expanding transportation infrastructure, and human development.
- Conduct fencing trials in areas that emerge as road mortality ‘hotspots’ with the aim of significantly reducing badger deaths at these localized sites.

- Vegetation trials along highways should be conducted to determine if amount of cover influences badger attraction/avoidance and species richness/diversity has an effect on prey abundance and distribution.
- Conduct periodic systematic non-invasive DNA capture-recapture sampling of badgers every three to five years to assess local population trends and status.
- Identify ecological factors that contribute to colonial fossorial rodent (i.e., Columbian ground squirrels, yellow-bellied marmots) colonization and distribution in BC. It has been postulated that badger distribution in BC is linked to the distribution of these prey species (*jeffersonii* Badger Recovery Team 2008).

DISCUSSION

My study supports the notion that badger conservation in the region may be best served by a two-pronged approach aimed at reducing mortality coupled with increasing recruitment via habitat protection and restoration. Over the last decade, natural resource managers and transportation agencies have become increasingly aware of the effects of roads on wildlife and remedial measures to counter these effects are an emerging science (Ruediger 1998, Clevenger and Sawaya 2010). Wildlife crossing structures are increasingly used by transportation agencies to meet the need to allow animals to cross roads with reduced hazards to both motorists and wildlife (Goosem et al. 2001, Mata et al. 2005). Studies have demonstrated that a broad range of species will use wildlife crossing structures (Ng et al. 2004, Mata et al. 2005), which can reduce road-related mortality for some species (Clevenger et al. 2003). Despite reducing direct mortality of carnivores, it has been stressed that the usefulness of preserving areas that act as refugia for source populations will also have a large affect on the population persistence (Ferreras et al. 2001)

Results from population modeling for this study appear somewhat contradictory: direct mortality from collisions with vehicles seems overwhelming, but yet DNA capture-recapture data suggests a stable or increasing population. At the present time, the high incidence of road mortality in the study area seems to be negated to some extent by strong recruitment. It should be stressed that the population trend is region-wide with the majority of road mortality occurring within the local study area. Bias from an increasing efficiency in DNA sampling methods over several years also likely occurred.

In recent years land clearing for cultivation/agriculture on private lands combined with the recent mountain pine beetle epidemic has favoured the expansion of open landscapes across the region dominated by graminoids and forbs that are favourable to colonization of rodents. The apparent increase in badger distribution could be in part due to a similar lag in population growth following recently improved foraging conditions, as seen elsewhere in the province (Kinley and Newhouse 2008). Another factor contributing to this apparent increase may be in part to the social impacts emanating from this study. Fieldwork was frequently carried out on private lands resulting in an elevated awareness and message that badgers occurring on these lands were providing beneficial ecosystem services (i.e., rodent control) resulting in less human persecution. Certainly, efforts should be maintained to keep the public aware of ecosystem benefits of badgers residing on both private and public lands.

Badgers appear to be a favourable candidate in the wake of possible climate change as peripheral populations often occur in atypical habitats where adaptation and resiliency to this change may be reflected along the northern limits of their range (Root and Schneider 2006). Due to badgers existing at the northern periphery of their range, sudden stochastic events, possibly due to the effects of climate change [e.g., prey collapse, extreme weather (Walther et al. 2002, Thomas et al. 2004)], coupled with increased mortality due to an expanding transportation sector may lead to a drastic decline in the local population eventually leading to extirpation as observed in the early 90's in the south-east corner of the province (Newhouse and Kinley 2001). Despite the apparent population increase of badgers in the region, little is known on the distribution and abundance of prey species. Many landowners noted that populations of colonial rodent populations in the early part of the 2000s were at an all-time high, having declined dramatically since the recent influx of badgers. Therefore, the best way to assure the survival of badgers is to continue to provide refuge habitats with high carrying capacity coupled with the reduction of direct (road) mortality so that populations can adapt to changes in the environment.

A multi-scale approach to mitigation planning, including land acquisitions that extend beyond the local study area, can ensure that mitigation optimally adds to regional ecological plans (Thorne et al. 2009). The wide range of underpass use by a number of species indicate that species-specific considerations in tandem with broader ecosystem planning may facilitate several different underpass types at varying frequencies to be incorporated into transportation projects (Mata et al. 2005), thus reducing mortality and increasing connectivity for not just badgers but a suite of wildlife species. Infrastructure agencies are not necessarily able to meet all the conservation goals for a region through their mitigation obligations, and conservation planners should consider the opportunities of partnering with these groups as society strives to achieve regional sustainability (Thorne et al. 2009).

The data collected in this study provide an initial understanding of badger road ecology in the Cariboo region of south-central BC, in particular how roads interact with and shape the animal's movements, distribution, and demographics. It is unclear at what threshold that an increase in either road density or traffic volumes through high-quality badger habitats may have on the long-term persistence of badgers in the region but direct mortality will likely continue to exert a strong effect. My goal is that these findings, in tandem with habitat conservation and restoration efforts provide guidance for managers, biologists, and engineers to implement effective management plans for this unique carnivore. I believe that such efforts will increase this species' resilience and allow adaptation in the face of environmental change. The continued existence of this ecologically important mesocarnivore will allow people the opportunity to discover these fascinating creatures that are contributing to healthy ecosystems across southern BC.

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APPENDIX A. Reproductive parameters for female badger natal dens monitored during the study in south-central BC, Canada 2008-2010.

Badger ID ♀	Year	# of kits	Kit emergence	Leave natal den	# of days
BF05	2008	2	14/05/2008	11/06/2008	28
BF03	2008	2	20/05/2008	07/06/2008	18
BF11	2009	2	28/05/2009	14/06/2009	17
BF07	2009	2	01/06/2009	24/06/2009	23
BF05	2009	3	23/05/2009	03/06/2009	11
BF03	2009	4	23/05/2009	29/05/2009	6
BF02	2009	3	25/05/2009	30/05/2009	5
BF01	2009	1	25/05/2009	31/05/2009	6
BF10	2010	2	01/06/2010	01/06/2010	0
BF11	2010	3	08/05/2010	29/05/2010	21
BF09	2010	2	09/05/2010	29/05/2010	20
BF08	2010	2	06/05/2010	01/06/2010	26
BF03	2010	3	14/05/2010	05/06/2010	22

APPENDIX B. Fates of radio-tagged badger study animals, capture dates, known mortality dates, fate, and number of days radio-monitored as of June 2010.

Badger ID	Sex	Capt. date	Mort. date	Fate	Days monitored
BF01	♀	2007-07-29	?	unknown	842
BF02	♀	2007-07-29	2010-05-17	roadkill	1023
BF03	♀	2007-08-02	-	alive	914
BF04	♀	2007-08-05	2008-09-29	roadkill	421
BM01	♂	2007-08-05	2009-07-22	roadkill	717
BF05	♀	2007-08-15	-	alive	815
BM02	♂	2008-05-19	-	alive	415
BM03	♂	2008-05-21	2008-08-18	roadkill	89
BM04	♂	2008-05-23	2008-07-13	roadkill	51
BM05	♂	2008-06-18	2008-08-30	roadkill	73
BF06	♀	2008-08-22	2009-05-23	roadkill	274
BF07	♀	2008-08-24	2009-07-02	roadkill	312
BF08	♀	2009-05-25	-	alive	191
BF09	♀	2009-05-25	-	alive	191
BF10	♀	2009-05-27	-	alive	250
BF11	♀	2009-05-28	-	alive	249

APPENDIX C. Poster for solicitations for badger sightings from the public.

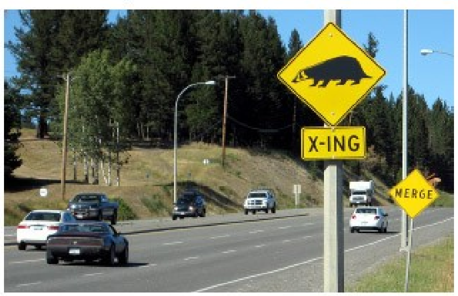
APPENDIX D. Public brochure handout (front and back) distributed in the south Cariboo region, 2007-2010.

Current Research

In 2007, the Cariboo Badger Project partnered with Ministry of Transportation to investigate the relationship between badgers and roads. Roadkill has been identified as a leading cause of mortality for badgers in BC. Research will focus on tracking badgers detailed movements to determine where and when badgers cross roads.

A badger uses an existing culvert to underpass Highway 97 near 108 Mile in the Cariboo.

This information will be used in designing new highways and upgrading existing ones. Options include; installing dry culverts, drift fences, permeable concrete roadside barriers, and signage. This is the first intensive radio-telemetry study to address road mortality ever conducted in Canada.



Badger crossing sign near 100 Mile House.

You can help!

We depend on sightings of badgers to identify areas where the species still occurs. Also, road-killed badgers provide vital information, so we need to retrieve dead badgers as soon as possible after they have been struck.

If you have recently seen a badger, fresh burrows, or a dead badger, please call:

Ministry of Environment 250-395-7853
or
Richard Klafki 250-344-1002

1-888-223-4376 toll-free elsewhere in BC

E-mail: info@badgers.bc.ca

For more information on badgers,
please visit:

www.badgers.bc.ca

Project partners include:
Thompson Rivers University
Ministry of Transportation
Ministry of Environment
Habitat Conservation Trust Foundation
Forest Science Program
British Columbia Conservation Corps

Habitat Conservation Trust Foundation
British Columbia The Best Place on Earth
FIA Forest Investment Account Forest Science Program
Thompson Rivers University

Cariboo Badger Project

In 2003, the Cariboo Badger Project was initiated to learn more about these elusive and endangered animals in the Cariboo Region of BC.

Badger facts

APPEARANCE

Badgers are among the largest members of the weasel family. Flattened body, black and white face, white stripe on top of head, long front claws, coarse gray-yellow fur. Lower legs are black.

FOOD SOURCE

Primarily Columbian ground squirrels (gophers) and marmots - other items include small rodents, birds, fish, insects and some berries. Many landowners consider badgers beneficial by reducing rodent populations, such as ground squirrels.

Yellow-bellied marmots are important food items for badgers in the Cariboo.

HABITAT PREFERENCE

Grasslands and dry open forests associated with suitable soils for digging burrows are ideal. Badgers are often seen near roads, ranches or in recent cutblocks. Badgers can dig up to a **meter per minute** in pursuit of prey or escaping predators!

WHAT DO BURROWS LOOK LIKE?

Badger burrows are oval in shape and about 30 cm in diameter with a large fan of excavated dirt at the entrance. Fox and coyote dens are taller than they are wide, while marmot and ground squirrel burrows are smaller & more round. The amount of dirt excavated is variable and is not a good indicator of which species dug the burrow. Claw marks may be parallel to the ground.

How the research is done

Badgers are live trapped and implanted with a radio-transmitter. The badger is then returned to its burrow. It can then be tracked using a radio-telemetry receiver. This can be done from an aircraft or on the ground directly to their burrow. Information about movement patterns, home range size, habitat type, birth rates and causes of death can be documented.

Previous DNA hair-snagging techniques in the Cariboo have determined that home ranges for females averaged 32 km^2 while males averaged 161 km^2— **that's 3-100 times larger** than in other studies in the USA.

Loss of habitat and prey, declining populations, and high mortality from roadkill and human persecution are the causes for their **endangered** status in BC.

What we have learned

- To date, 13 badgers have been killed on roads in the Cariboo region since 2003.
- The largest home range documented by DNA finger-printing was a male who ranges over 1280 km^2.
- Since 2007, 9 badgers—5 females and 4 males, have been radio-tagged and are continuing to be monitored in the region.
- In search for food and mates, badgers can use hundreds of burrows within their home range. Many burrows are **re-used**.
- Badgers use a variety of habitats, including grasslands, agricultural areas, wetland edges, and forested habitats.
- Using DNA methods, 31 badgers were estimated to be alive in 2007 (Cariboo).
- Badgers are often found on private land and the continued stewardship of landowners is essential to the continued existence of badgers in the Cariboo and throughout BC.
- There are **less than 340** badgers estimated to be alive in British Columbia today.
- Studies have estimated that badgers eat an average of 2.3 ground squirrels a day.
- Badgers can swim quite well.